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Integrating Health and Energy Efficiency in Healthcare Facilities

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Integrating Health and Energy Efficiency in Healthcare Facilities

The U.S. Department of Energy's Federal Energy Management Program (FEMP), in partnership with the General Services Administration, is exploring how traditional building energy efficiency measures can impact the health of occupants in the federal sector through the Healthy Buildings Toolkit.

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Background

The Healthy Buildings Toolkit investigates the intersection of energy efficiency and occupant health and wellbeing. Healthy buildings is a developing field that looks at impacts of the built environment on the health and wellbeing of building occupants. It encompasses a wide range of applications that promote human health, such as lighting, thermal comfort, and indoor air quality, and human outcomes such as improved individual and organizational performance, reduced absenteeism and presenteeism in the workplace, and lowered healthcare costs.

The Healthy Buildings Toolkit currently only includes office buildings in its methodology and application. In this report, PNNL presents a review of literature and current best practices along the intersection of energy efficiency and occupant health at U.S. healthcare facilities, including federally owned buildings. This report includes a review of building standards and certification systems for healthcare indoor environmental quality (IEQ) and research on building measures that optimize occupant health and energy efficiency. The healthcare industry includes a wide variety of services and thus facility types. This case study focuses primarily on inpatient facilities, such as hospitals.

HEALTHY BUILDINGS TOOLKIT OFFICE BUILDING METHODOLOGY

The Healthy Buildings Toolkit utilizes a framework to evaluate a building's improvement potential regarding occupant health in commercial and government office buildings. This research may be expanded to include healthcare buildings in subsequent editions. As shown in Figure 1, the current framework is comprised of the following three key modules:

1. The ***Performance Baseline Module*** collects baseline IEQ data by measuring parameters such as carbon dioxide, temperature, humidity, and light levels, and administering an occupant survey.
2. The ***Improvement Opportunities Module*** uses the baseline IEQ data to guide the collection of additional building characteristics, operation, and asset information needed to understand the reasons for any IEQ issues and identify specific improvement actions to help achieve the IEQ targets.
3. The ***Productivity Financial Gains Module*** uses the data collected in Module 1 to estimate the potential productivity improvement for a building. PNNL developed a series of correlations between IEQ metrics and occupant productivity from a meta-analysis of 51 peer reviewed academic studies. The potential productivity gains between the baseline IEQ values and the target IEQ values are converted to financial gains using the personnel cost of employees in the building.

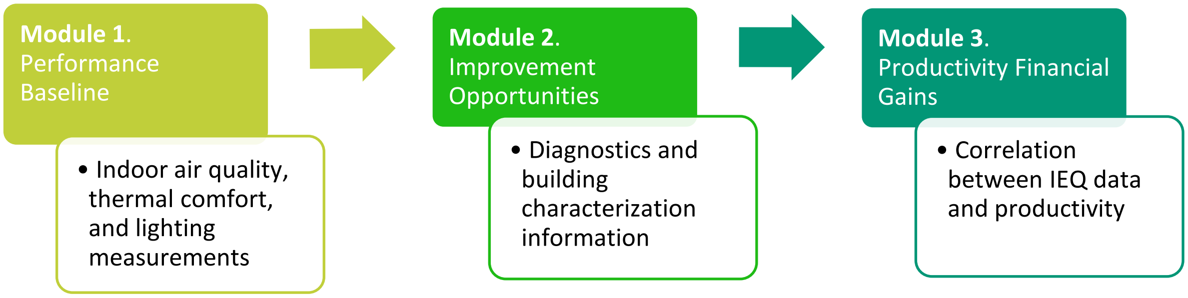

Figure 1. Healthy Buildings Toolkit diagram of major components for office buildings.

Healthcare Facilities: Opportunity Space

U.S. healthcare facilities comprise approximately 4 billion square feet or 5% of total commercial floorspace, accounting for about 10% of total commercial building energy consumption (EIA 2012). Hospitals and other inpatient facilities comprise about half of the healthcare facilities floorspace and nearly three-fourths of all energy consumed by healthcare facilities (EIA 2012). Hospitals tend to have a high energy use intensity (EUI) compared to other building types, nearly three times the average commercial building (Della Barba 2014). They are currently the second most energy-intensive building type in the U.S., with heating, cooling, and ventilation (HVAC) comprising 52% of their energy use (Taylor and Arch 2016). The healthcare sector also has high operating expenditures, with a combined budget of about $1 trillion (AHA 2020).

Most hospitals in the U.S. are community hospitals (nonfederal, short-term general, and other special hospitals), with almost half of these being not-for-profit (AHA 2020). Federal government hospitals make up only 4% of U.S. hospitals (AHA 2020). Federal healthcare facilities include the U.S. Department of Defense's (DoD) Military Health System (which provides healthcare to active duty, Reserve component, and retired U.S. military personnel and their dependents), the Veterans Affairs (VA) hospitals (which serve military veterans), and the Indian Health Service (IHS, an agency within the Department of Health and Human Services (HHS) that is responsible for providing federal health services to Native Americans).

Even with robust infection control and hygiene practices, patients can still contract hospital-acquired infections (HAIs)[1] which threaten their health and survival (Taylor and Arch 2016). A number of studies (Deloach 2004; Craig et al. 2003; Hoskins 2003) show a direct relationship between certain concentrations of air pollutants with internal health problems, such as allergies, asthma, bronchitis, pneumonia, and lung cancer. Studies have also documented correlations between ventilation and the transmission of infectious diseases such as measles, tuberculosis, chickenpox, influenza, and severe acute respiratory syndrome (SARS) (Li et al. 2007, Mendell et al. 2002; Yu et al. 2004). HVAC systems that are poorly designed or poorly maintained (i.e., conducive to contamination) are common in hospitals and contribute to poor indoor air quality (Hellgren and Reijula 2006). This may lead to Sick Building Syndrome, various occupational hazards, and HAIs (Reijula et al. 2013). HAIs, in turn, are associated with increased mortality, length of hospital stay and costs.

Health and Energy Efficiency Intersection

Core aspects of healthy buildings revolve around areas such as lighting, indoor air quality, thermal comfort, acoustics, access to nature, access to healthy foods, and opportunities for movement. With healthcare facilities, some of these aspects are also linked to improved hygiene and infection control. Healthcare building design is guided by rigorous research that links hospitals' physical environments to health outcomes, building on

[1] In a year, about 2 million patients suffer from HAIs in the United States. Of these cases, nearly 90,000 patients are expected to die. HAI is ranked the fifth leading cause of death in U.S. acute-care hospitals. The total direct cost of HAIs to hospitals is from $28 billion to $45 billion.

strategies that help to inform organizations that create building standards such as the Facilities Guidelines Institute (Hamilton 2003; Ulrich et al. 2008).

The occupants in healthcare facilities are diverse compared to office buildings and include workers/staff, patients, and visitors. This report provides an overview of the current literature on occupant health-related issues concerning healthcare facilities in the context of energy efficiency. Specifically, it looks at linkages between healthy building concerns and practices related to HVAC (e.g., ventilation rate and humidity control to reduce pathogen loads and thermal comfort) and lighting (e.g., lighting spectrum for night-shift workers, lighting illuminance for precision tasks, and daylighting for patient recovery and to reduce stress and improve sleep of healthcare providers).

Ventilation

Much of the effort to address occupant health in the healthcare industry has centered around ventilation, which refers to the amount of outdoor air delivered to interior spaces. Ventilation rates at healthcare facilities have long represented a delicate balance between reducing pathogen loads and addressing the sector's high energy use (English 2016). The high EUI in hospitals is mostly attributed to the HVAC systems, primarily in supply air heating to meet ventilation requirements (English 2016). Ventilation rate, which can be expressed as air changes per hour (ACH), cubic feet of air per second per person, or in other similar units, is an important parameter for controlling indoor air quality (Ulrich et al. 2008).

ASHRAE Standard 170, *Ventilation of Health Care Facilities* serves as the main roadmap for designers and health facility operators across the nation (ASHRAE 2017; English 2016). Table 1 shows sample ventilation specifications, as well as relative humidity ranges, for inpatient spaces. Standard 170 brought together several ventilation standards used throughout North America into one document and is referenced almost exclusively in building codes for ventilation requirements in hospitals and other healthcare facilities (Emmerich et al. 2017). The standard is also included in its entirety in the Facility Guidelines Institute's (FGI) Guidelines for Design and Construction of Hospitals, Outpatient Facilities, and Residential Health, Care, and Support Facilities, respectively[2], which has been adopted by 42 states (ASHRAE 2019). Many outpatient facilities (e.g., doctor's offices) are classified as B-occupancy (Business) and may be instead applicable to ASHRAE Standard 90.1 (Energy Standard for Buildings Except Low-Rise Residential Buildings) and ASHRAE 62.1 (Ventilation for Acceptable Indoor Air Quality) (ASHRAE 2019).

Both the VA and the IHS instruct designers and engineers to use ASHRAE 170 for medical spaces (IHS 2019; VA 2020). DoD's 2019 Unified Facilities Criteria for Military Medical Facilities (DoD 2019) cites ASHRAE 62.1 for ventilation requirements. Leadership in Energy and Environmental Design (LEED) v4.1, a green building certification system, has a healthcare specific framework for new and existing buildings. LEED v4.1 has differing energy credits for healthcare buildings compared to other use types, and for IEQ specifically related to ventilation, the certification program adopts requirements from ASHRAE 170.

WELL, created by the International WELL Building Institute (IWBI), was the first building certification system to focus exclusively on health and well-being and is open to all building typologies including inpatient and outpatient healthcare, although it does not have specific callouts for these building types. WELL requires conforming with ASHRAE 62.1 ventilation rates as a pre-requisite for basic certification (WELL 2020 A06). For advanced certification levels, WELL offers points for achieving 30% and 60% above ASHRAE 62.1. Adventist and MetroHealth are examples of healthcare systems that have pursued WELL. IWBI is in the process of standing up the WELL Advisory on Healthcare.

Natural ventilation, an effective strategy to decrease energy consumption and provide outdoor air to buildings, has not been fully studied in healthcare facilities. The main concern is that natural ventilation compromises

[2] See relevant FGI guidelines at: https://fgiguidelines.org/guidelines/2018-fgi-guidelines

building envelope integrity by allowing in non-filtered air with outdoor air contaminants such as fungal spores (Bartley, Olmsted, and Haas 2010). Natural ventilation can be supplemented with mechanical ventilation (known as mixed-mode ventilation) when natural ventilation rates are too low or when outdoor temperatures are not amenable for natural ventilation.

Table 1. ASHRAE 170 ventilation design parameters for inpatient spaces. Source: ASHRAE 170-2017.

Function of Space	Pressure Relationship to Adjacent Areas[3]	Minimum Outdoor ACH	Minimum Total ACH	Design Relative Humidity (%)
Cesarean delivery room	Positive	4	20	20-60
Critical care patient care station	No requirement	2	6	30-60
Operating room	Positive	4	20	20-60
Procedure room	Positive	3	15	20-60
Treatment room	No requirement	2	6	20-60
Endoscope cleaning	Negative	2	10	No requirement
Physical therapy	Negative	2	6	Max 65
Laboratory work area, pathology	Negative	2	6	No requirement

Ultraviolet germicidal irradiation (UVGI), using UV-C lighting (a short-wave UV light) in heating, ventilation, and air conditioning (HVAC) systems and upward-facing UV light fixtures in patient rooms, has been used in some hospitals to disinfect the air of both bacteria and viruses (Memarzadeh et al. 2010). Other stand-alone units can be placed inside the bathrooms of patients above the door to clean on a cyclical basis. It is important to note that even the most robust HVAC system may not achieve enough air mixing in interior spaces to kill off microbes where the mode of transmission is droplets that do not remain suspended in the air for long periods of time. This is the case for infectious agents such as influenza and SARS-CoV; Memarzadeh et al. (2010) suggest that droplets fall out within a 2-meter radius from a coughing/sneezing person and the particles may never reach the upper-room UV zone.

Recent experimental data on SARS-CoV-2 (i.e., the virus that causes COVID-19) (Klompas et al. 2020; van Doremalen et al. 2020) support that the virus can be transmitted by aerosols which can remain airborne long enough for mitigation strategies like better air distribution, filtration, and upper room UVGI to be effective. Escombe et al. (2009) tested the use of upward-facing UV light fixtures in the ceilings of a negative-pressure tuberculosis isolation ward. The researchers concluded that an upper-room UVGI fixture can be an effective, low-cost intervention for use in tuberculosis infection control in high-risk clinical settings, provided there is adequate mixing of room air. According to a 2010 review by Memarzadeh et al. (2010) of this technology, practitioners should view UVGI as a supplemental strategy rather than an alternative to adequate ventilation levels. Additionally, the safety of UV devices when used in proximity to building occupants needs further study.[4]

A recent study by Morawska et al. (2020) underscores the importance of good filtration at healthcare facilities as a design solution. The investigators suggest that the building should try to maximize the outdoor-air level

[3] A positive pressure room (protective environment) allows staff to reduce exposure of vulnerable patients to infections and disease. They can maintain a higher pressure inside the treated area than that of the surrounding area, preventing air in potentially contaminated rooms from entering treated rooms. Conversely, a negative-pressure room isolates patients with infectious conditions and protects people outside that room from exposure.

[4] The U.S. Environmental Protection Agency recently issued a compliance advisory for UV lights (https://www.epa.gov/sites/production/files/2020-10/documents/uvlight-complianceadvisory.pdf). UV lights are regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as pesticide devices when sold or distributed with claims to kill or be otherwise effective against viruses and/or bacteria. EPA has not conducted a human health risk assessment to determine the safety of UV light devices.

and "apply filtering or ultraviolet germicidal irradiation to remove or deactivate potential viral contamination from the recirculated air" (Morawska et al. 2020, p. 3).

A popular HVAC solution for achieving ventilation targets while minimizing energy use is adaptive variable air volume (VAV) systems. Often, regular VAV systems installed in hospital isolation rooms run at constant air volume, which leads to higher fan energy use (Kim and Augenbroe 2009). Adaptive VAV control systems—a feedback control system that adjusts its characteristics in a changing environment—have the benefit of consuming significantly less energy while not showing a significant difference in the potential spread of contaminants and thermal comfort (Reijula et al. 2013). Another ventilation solution is demand-controlled ventilation (DCV), a ventilation rate control practice that provides the amount of outdoor air to each space based on the real-time demand (Jeong, Choi, and No 2010). DCV systems can utilize occupant scheduling (for buildings with predictable occupancy patterns), infrared sensors to sense human activity, or CO_2 sensors to estimate the ventilation demand.

Humidity

There is a lack of industry consensus on acceptable and optimal indoor relative humidity levels. For instance, there is evidence that airborne viruses are sensitive to ambient humidity, but the precise mechanisms underlying the relationship remain largely unverified (Yang and Marr 2012). Some studies indicate that a relative humidity of 40-60% is optimal for human health in indoor places (Ahlawat et al. 2020; Taylor and Arch 2016), and EPA and ASHRAE 170-2017 now recommend maintaining humidity levels between 30% and 60% (EPA, n.d.). For example, in a recent overview study of the role of relative humidity in airborne transmission of SARS-CoV-2, Ahlawat et al. (2020) explained that in dry indoor places (i.e., where there is less humidity), the rate of airborne transmission of SARS-CoV-2 is higher than that of humid places (i.e., where relative humidity is greater than 90%). The proposed mechanism is that, when the indoor relative humidity is lower than 40%, there are less water particle obstacles in the air, which provides an optimal route for the long-distance transmission of small infectious aerosols. Ahlawat et al. clarified that "these viral airborne particles will further travel, become inhaled by other residents, or finally settle on surfaces where they can survive for many days. The infectivity of many viruses, including SARS-CoV-2 are actually enhanced due to low [relative humidity] levels" (p. 1,858). Moreover, according to Moriyama, Hugentobler, and Iwasaki (2020) and Taylor (2020), dry air also results in a significant impact on our respiratory immunity. When inhaling air when relative humidity is low, the mucus in our nose and throat becomes dry and more viscous, which diminish the cilia's[5] capability to expel viral aerosols. The low relative humidity compromises our bodies' first-line defense against foreign microorganisms.

Nevertheless, the relationship between humidity and the transmission of airborne viruses is not as straightforward. Other factors can influence the transmission of viruses. For example, Yang and Marr (2012) hypothesize that for airborne viruses, the changes in the pH within the aerosol that are induced by evaporation may compromise the ability of the virus to establish an infection and may explain observed differing responses of some viruses to humidity. Other pathogens require different relative humidity guidelines. To prevent mold growth in indoor spaces, for example, general guidance from ASHRAE calls for keeping indoor relative humidity below 65% (CDC 2015).

To avoid high humidity levels, a double heat pipe heat exchanger system has been recommended (over conventional heat exchangers) to decrease fungus growth and energy consumption in hospitals located in hot and humid areas (Yau 2008; Yau and Ng 2011). This system also has a lower initial cost, lower maintenance cost, and lowering operating cost. However, to date, only a few studies have investigated the use of double-pipe heat exchangers in air conditioning applications (Ghani et al. 2018). Furthermore, greater energy efficiency can be achieved using energy recovery ventilators (ERVs) to recover and maintain humidity levels

[5] The cilia are hairlike structures lining the mucous membranes in our nose.

in dry climates or solid desiccant systems to remove humidity in wet climates, which are both innovative methods of managing humidity in pre-condition supply air.

Traditionally, humidity control in buildings has been primarily focused on reducing humidity to eliminate condensation and mold growth, rather than on preventing low humidity levels. Solutions for humidity control should depend on the climate zone and moisture category the building is located. If the site is located in a humid area (moisture category A or C according to ASHRAE climate zone categorization[6]) and high humidity levels are measured indoors (e.g., greater than 60-65%), removing humidity from supply air should be the design intent. Conversely, if the location is in an arid region (moisture category B) and low humidity levels are recorded indoors (e.g., less than 30-40%), then the solution should be focused on humidifying supply air and maintaining humidity levels. Regions that are considered mixed-humid climate zones according to ASHRAE (climate zones 3A and 4A), like the U.S. east coast, often experience dry air during cold weather but moist air during warm weather, and therefore the solution for humidity control can be seasonally dependent.

Thermal Comfort

Thermal comfort in the healthcare setting is a less explored topic compared to air quality (Derks et al. 2018; Verheyen et al. 2011), but of the studies to date, a few have found linkages with health outcomes. One study of hospital operating rooms found that thermal comfort affects the working conditions, wellbeing, safety, and health of the medical personnel (Balaras, Dascalaki, and Gaglia 2007). While ASHRAE 170 states that the desirable indoor air temperature is from 20 to 24°C (68 to 75°F) and desirable relative humidity is from 30 to 60%, Balaras et al. (2017) clarify that the use of lower or higher temperatures can be justified when patient comfort and/or medical conditions require those conditions. For example, for pediatric surgeries, practitioners commonly set a higher indoor air temperature (sometimes as high as 27°C [80.6°F]) because children tend to be more sensitive to lower temperatures (Balaras, Dascalaki, and Gaglia 2007; Nastase et al. 2016).

Thermal sensation greatly varies from person to person, especially between patients and medical personnel. In a study of nursing staff in hospital wards, one study found that the thermal condition was reported to be "slightly warm" and negatively impacted self-reported work performance (Derks et al. 2018). Optimal thermal sensation for nurses (i.e., to suit thermal comfort requirements and work performance), the study found, would be closer to "slightly cool" than neutral. Derks et al. (2018) recommend a design approach of dividing the hospital ward into separate thermal zones, with different setpoints for respective patients' and care-professionals' comfort, which they posit would not only contribute positively to the work environment but also provide opportunities to conserve energy.

ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy) specifies the combination of environmental factors (temperature, thermal radiation, humidity, and air speed) and personal factors (activity level and clothing) that will produce thermal conditions acceptable to most occupants. However, there exist scenarios and spaces within healthcare facilities where the standard is not applicable or where deviations from Standard 55 are required (Addendum H to ASHRAE 170-2017). Section 2.7 of Standard 170 states that this standard does not ensure compliance with ASHRAE Standard 55. ASHRAE 170 Addendum H also clarifies that the standard provides HVAC design temperature and humidity ranges that, while potentially affecting occupant comfort, are also provided to address therapeutic patient outcomes, aseptic practices, and worker protection.

Multi-parameter HVAC Solutions

In terms of solutions, rapidly advancing building automation system (BAS) technology has the control capabilities to measure and optimize multiple IEQ parameters such as air temperature, carbon dioxide (CO_2) concentration, humidity, and ventilation rate and adjust to satisfy medical staff, patients and visitors, while also minimizing energy use (Reijula et al. 2013). However, most HVAC systems only respond to a single

[6] Map of ASHRAE climate zones: http://www.iaqsource.com/article.php/ashrae-climate-zone-map/?id=194

environmental parameter (e.g., air temperature or ventilation rate) due to lack of advanced sensors and HVAC optimization techniques. Some HVAC solutions required system and control upgrades, such as DOAS, which requires separated outdoor air and temperature-regulated air supply systems so that ventilation rate and air temperature do not need to compete against each other (Reijula et al. 2013). Without the ability to balance multiple parameters, the building is either consuming excessive energy or not achieving desired indoor air quality (Reijula et al. 2013). Another prevalent problem for HVAC performance is due to faults in the system, which underscores the need for regular maintenance and performance checks. Modern adaptive and user-centric technologies and control solutions are particularly important in healthcare facilities where occupant needs can vary greatly from one space to another.

Lighting

Circadian Lighting at Night

Over one-third of the components of our genome are clock-controlled (controlled by circadian rhythms), and over half of all drug-response pathways are also clock-controlled (Wolverton 2013). A growing body of research indicates that chronic circadian disruption may lead to a higher risk of diseases ranging from diabetes and obesity to cardiovascular disease and cancer (IES 2016). According to Marks (2013), electrical lighting codes and standards with an emphasis on energy efficiency usually supply insufficient illuminance (measured in lux or footcandles) during the day and too much illuminance at night to maintain a normal circadian function.

A survey conducted in 2004 (Rogers et al. 2004) revealed that hospital staff workers usually worked longer than scheduled with approximately 40 percent of study participants logging in greater than twelve-hour shifts. Long shifts, particularly when it involves rotating and overnight shifts, are associated with increased risks for developing cancer and other diseases (Figueiro et al. 2007; Figueiro et al. 2009; Figueiro et al. 2016; IES 2016; Plitnick et al. 2010). Research in this area has primarily focused on circadian disruption and exposure to light at night. Nurses and doctors who work irregular shifts and patients who are exposed to bright light while sleeping are challenged to entrain their 24-hour natural circadian cycle (Schernhammer et al. 2001).

Therefore, providing the appropriate lighting levels and spectral characteristics is important for night-shift staff and sleeping patients. Lighting does not just affect visual acuity, but also the non-visual systems emanating from the retina which modulate alertness and regulate circadian rhythms (Rea and Figueiro 2016).[7] A few key parameters to consider for developing lighting design for circadian impact include illuminance level, the duration of exposure to light, and the time of day of the exposure (WELL 2020 L03). For night lighting at healthcare facilities, studies (Figueiro et al. 2016; Rea and Figueiro 2013; Rea and Figueiro 2016; Plitnik et al. 2010) have found that exposure to lower illuminance (below 300 lux/30 footcandles) 640-nm red light does not significantly suppress melatonin levels (a hormone produced in response to darkness to cause sleepiness) but can still provide adequate light for achromatic visual tasks (e.g., reading black font on a white paper). Research has found that even more modest light levels (no more than 60 lux/6 footcandles) on horizontal surfaces using warm white light (2700 K) is enough for minor visual tasks without circadian disruption but may not provide enough illuminance for alertness in workers (IES 2016). The Illuminating Engineering Society (IES) RP-29-16 recommends that patient room night lighting employs even lower levels (less than 5 lux or 0.5 footcandles) from warm (2700 K) light sources. This suggests that very low illuminance (5-60 lux), warm lighting is ideal for night-time conditions in patient rooms so that medical staff can perform brief visual tasks and the circadian rhythms of sleeping patients are not disrupted, and that moderate illuminance (60-300 lux) with high intensity in the red spectrum is ideal for non-patient areas at night so that night shift workers feel alert but their circadian rhythms are not interrupted.

[7] Circadian rhythms are kept in sync with light (in addition to other cues) via the intrinsically photosensitive retinal ganglion cells (ipRGCs), the non-image- forming photoreceptors of the eyes (WELL 2020).

Circadian Lighting and Daylighting

Daylighting, where practical, can also be leveraged to regulate circadian rhythms. Studies (Beauchemin and Hayes 1998; Benedetti et al. 2001; Oren et al. 2002; Sumaya et al. 2001; Joarder et al. 2009; Walch et al. 2005) have demonstrated that patients located in rooms with greater exposure to daylight are likely to recover more quickly and require less medication. For example, in a study of patients undergoing elective cervical and lumbar spinal surgery, Walch et al. (2005) found that patients in brighter rooms exposed to natural sunlight used 22 percent less pain medication which reduced medication costs by 21 percent.

Moreover, daylighting has a positive psychological impact. Studies have demonstrated that abundant daylight is correlated to a shortened length of stay of psychiatric patients, as well as improved overall mood and accelerated recovery from depression. Beauchemin and Hayes (1998) found that women in east-facing rooms recovered faster than woman in west-facing rooms. In a study by Benedetti et al. (2001), direct sunlight in the morning reduced hospital stays by 3.67 days. In another study (Sumaya et al. 2000), 50 percent of participants exposed to 10,000 lux (or 1,000 footcandles) in the morning, no longer diagnosed as depressed, while the control group showed no change. Similarly, a study by Oren et al. (2002) found mean depression ratings improved by 49 percent with no adverse effects in a 3-week study of patients exposed to bright light in the morning. There are also studies suggesting that daylighting leads to job satisfaction among healthcare staff (IES 2016). For example, Alimoglu and Donmez (2005) found that exposure to three hours of daylight per day lowered stress among nurses in a University Hospital and increased job satisfaction responses.

Quality views may be a confounding factor in daylighting studies, and the two variables are often inextricably present. In a study by Ulrich (1984) that looked at records on recovery after cholecystectomy, 23 surgical patients

CIRCADIAN LIGHTING PRACTICES IN NEONATAL INTENSIVE CARE UNITS

There is a trend in healthcare facility design to incorporate more holistic and user-centric healthy buildings practices. One example is the SSM Health St. Mary's Hospital Neonatal Intensive Care Unit (NICU) project (Dunwoody 2017). NICUs are the hospital units where newborn babies who need intensive medical care are treated and cared for. We do not fully understand the effects of lighting on premature babies (Morag and Ohlsson 2016). There are some indications that too much exposure and brightness can be extremely damaging to a newborn's development (IES 2016). Thus, it is important for medical administrators to closely monitor the amount and types of light in a NICU environment. However, there is a need to further study the potential benefits and harms of differing light in neonatal units (Morag and Ohlsson 2016).

The SSM Health St. Mary's Hospital NICU utilizes daylight in one section and circadian lighting in the other to bring a natural diurnal cycle of light to the infants which can be blocked out by curtains if too bright. In addition, window coverings on the windows are helping to control the amount of daylight received by the babies. The NICU has also created separate zones within the room for the babies and their families which allow the babies to sleep in more controlled light while families are able to still enjoy natural light.

This example follows similar cases that suggest that these lighting practices may help increase sleep in the babies (patients) which is critical for their brain development, as well as result in less stress in staff and comfortable conditions for their parents (visitors). In a similar case at an NICU in Bath, England, healthy building measures such as controlled lighting and exposure to more natural lighting resulted in babies sleeping for 20% longer (Maddox 2014). In addition, compared to an older unit without these measures, parents visited an average of 30 minutes longer a day and staff reported feeling less cramped and less stressed. Moreover, 90% of babies were breastfed in the unit, compared with 64% of babies observed in the old unit.

assigned to rooms with windows looking out on a natural scene had shorter postoperative hospital stays, received fewer negative evaluative comments in nurses' notes, and took fewer potent analgesics compared to 23 matched patients in similar rooms with windows facing a brick building wall.

Daylighting design should incorporate window treatment, such as low-E film, to control glare and excessive solar heat gain. Fiber optic daylighting is difficult to implement in existing building but can bring sunlight into a building via fiber optic cables. This technology could be useful in healthcare facilities where exterior glazing may not be desirable or practical (Werring 2009). It also has the benefits of being more energy efficient than conventional electric lighting systems. However, fiber optic daylighting systems should be compared to other readily available technologies such as light-emitting diodes (LEDs), which can be used to achieve the same lighting quality and is easier to install.

There is evidence to assist designers, architects, and engineers in selecting adequate quantity and quality of light for different healthcare settings (Marks 2013). For example, we know that cool (bluish white) color temperature light has the effect of suppressing melatonin and increasing alertness in humans. Thus, this type of lighting should not be prescribed for use above a hospital patient's bed at night yet could be beneficial during the daytime for patients and staff (Holzman 2010). There are ways to balance the lighting needs among different staff, patients and visitors and at different times of the day (see the sidebar on page 8 for an example of this in a Neonatal Intensive Care Unit).

Electric Lighting for Visual Comfort

Recently introduced codes and standards for lighting are more prominently incorporating guidelines related to occupant health. IES RP-29-16 Lighting for Hospitals and Healthcare Facilities, published in 2016, is the leading reference for lighting design in healthcare facilities in the U.S. Regulations set out by the DoD and the VA for healthcare facilities follow this standard (DoD 2019; VA 2015). The 2016 version of the standard (the previous one was published in 2006) saw several changes, in large part as a result of massive changes in lighting technologies over the previous decade, such as the rapid adoption of LEDs. It also emphasizes the patient experience and evidence-based design practices. Some of the recommendations include:

- Glare-free lighting to improve visual acuity, reduce eye strain, and enhance the ambience
- Proper illumination levels and uniformity to maximize speed and accuracy of task performance
- Proper illumination to enhance safety and limit slips and falls
- Wayfinding to assist patients and visitors
- Flexibility (for example, in patient areas where recommended illumination levels are below 400 lux/ 40 footcandles, IES RP-29-16 recommends that the designer consider using supplemental illumination for cleaning to promote proper hygiene)

Table 2 provides example recommended maintained illuminance targets (lux) for various healthcare spaces.

Table 2. Example illuminance values for healthcare facilities in IES RP-29-16. Targets shown apply to groups of visual observers where at least half are between the ages of 25 and 65 years.

Space Type	Horizontal Targets (lux)	Vertical Targets (lux)
Patient room corridors: Inpatient (Day)	100	50
Patient room corridors: Inpatient (Night)	50	20
Special Patient Care (Critical Care), Patient room: General	100	20
Special Patient Care (Critical Care), Patient room: Night observation	100	6
Patient Room, Night Observation	30	6
Neonatal Intensive Care, General (Day)	500	100
Neonatal Intensive Care, General (Day)	100	20
Nursery, General	100	30

Space Type	Horizontal Targets (lux)	Vertical Targets (lux)
Nursery, Observation	300	50
Dental suite: Examination, hygiene, treatment	1000	300

Using the proper type and quantity of light can prevent errors such as misreading charts and medication labels or a patient's vital signs (Marks 2013). A large-scale study examining the effects of different illumination levels on pharmacists' prescription-dispensing errors suggested that the frequency of such errors was lowered when work-surface light levels were at an illuminance level (brightness) of 1,500 lux (2.6% error rate) compared to 450 lux (3.8% error rate) (Buchanan et al. 1991). Booker and Roseman (1995) who studied the seasonal pattern of hospital medication errors in Alaska found correlations between increases in medication errors and the season; they observed increases in errors two months after the onset of seasonal darkness.

LED technology has dramatically changed what is possible with electric lighting. It is not only responsible for increases in the lighting efficiency of buildings (and improvements in their color properties), but also in creating a lit environment that provides comfort for occupants by optimizing the light-source spectrum and color rendition (Soltic and Chalmers 2019). Researchers are also exploring the use of diode lasers, although this technology is not ready for commercial application (Cao et al. 2006).

Conclusions

While improving the patient experience has always been recognized as a fundamental building design principal in the healthcare sector, efficiency and delivery of healthcare services are traditionally the focus. Over the past decade, however, the healthcare sector has been undergoing several changes to this landscape. Surgical treatments that used to be performed in a hospital are shifting to an outpatient setting (King et al. 2017; Kos and Quadi 2010). With the interplay of technological innovation, economic market forces, rising healthcare costs, patient and staff safety, and evolving government regulations, there is a move toward patient-centered care which is resulting in the purposeful provision of healthy building measures that improve air quality and lighting. This is reflected in the latest version of lighting requirements in healthcare facilities by IES RP-28–16 which was completely revamped from the previous version and has a whole section dedicated to occupant health. Hospitals can now get reimbursed based on patient ratings, which is a large driver for patient-centered care.[8] Aligned with this new way of operating hospitals and other healthcare facilities are several healthy building initiative outcomes, such as faster recovery of patients, less risk of hospital-acquired infections, the ability to attract and retain staff, a more productive and effective workforce, and an improved visitor experience (Cartledge 2019). This new push toward holistic sustainable design which encompasses both energy efficiency and occupant-centric practices, alongside the construction boom in the healthcare sector, provides an opportunity for incorporating improved occupant health measures.

[8] Ratings are based on the Hospital Consumer, Assessment of Healthcare Providers and Systems (HCAHPS) survey, which is the first national, standardized, publicly reported survey of patients' perspectives of hospital care. Source: https://hcahpsonline.org/globalassets/hcahps/facts/hcahps_fact_sheet_october_2019.pdf.

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