Healthcare Lighting Series White Paper: #HC010

The Science Behind Properly Lighting an Operating Room

Improving Visual Acuity Using Light Levels and Color

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The Science Behind Properly Lighting an Operating Room

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Operating rooms are integrating a variety of technological advances which require proper lighting to be fully utilized. This paper describes these challenges, reviews the historical solutions, and provides insight into how LED technology can more effectively reduce eyestrain, improve visual acuity and create an ***operating advantage*** for the OR team.

Hybrid Operating Room

Advances in medicine have come from a variety of sources ranging from basic research to public policy. Such research is generally designed to give us better insight into the processes that are occurring at a molecular level so that targeted interventions or therapies can, in turn, be developed. At a slightly higher level, the entire field of medical imaging (CT, fluoroscopy, MRI, nuclear medicine, etc.) was developed out of a need to see the structure and/or metabolic processes occurring within the body, diagnose the underlying condition, and provide accurate treatments while reducing the need for invasive surgeries.

Surgery and Imaging Partnership

Historically, imaging was typically used in a clinical setting pre-operatively to target the procedure and post-operatively to assess its effectiveness. In recent years, this capability has been brought directly into the OR to allow physicians to perform more complex procedures by providing them with real-time or near real-time feedback on the effectiveness of their actions. This creates a single episode of care model where both the imaging and the intervention can be combined in the same setting. Another important advancement in the field of surgery was the development of minimally invasive or endoscopic techniques which have greatly reduced procedure cost, infection rates and recovery time while improving patient outcomes.

While substantially different in complexity and cost, the equipment used in both of these environments consists of a range of monitors/flat panel displays positioned at various distances around the physician and the rest of the OR staff. These monitors allow for selection of individual angles/views for display and viewing by the entire OR team. In many cases, they are suspended directly within the surgical field on the same booms as the surgical lights. In other cases, they may be placed outside the surgical field (e.g. on the wall opposite where the physician normally stands) to remove visual clutter from within the surgical field.

The use of monitors has been expanded for non-imaging purposes where they display vital sign information, charts, room controls, etc. Thus, virtually every type of OR incorporates monitors to some degree. Therefore, ensuring that they are properly placed around the room and illuminated is a topic of interest to all.

An Interesting Challenge

Normally, the OR is brightly lit to facilitate better task performance, however, this can have the unintended side effect (in this particular set of applications) of making it very difficult for the OR team to see the monitors due to reflections, glare, and poor contrast.

Brightly Lit OR Room

The earliest response to this dilemma was to simply turn off the overhead lights to create an effect similar to that in a movie theater. While this did improve the OR team's ability to view the monitors, it created an entirely new set of challenges related to performing simple tasks that they had previously took for granted such as moving about the room, viewing/writing information, and handling equipment.

Another alternative to simply shutting the lights off is to dim them to levels that provide enough illumination for the secondary tasks identified above while improving contrast between the room and the monitors that are critical to the display of information in these environments. Unfortunately, at that time, most OR's had switches, but rarely dimmers due to limitations with their ballast. Therefore, this option was ruled out and yet another option was considered. The fixture was rewired in such a way that only about 10% of the lamps throughout the room were utilized in this particular configuration. Furthermore, a green filter was placed over these lamps to not only reduce their output, but to also maximize the photopic response of the light in the environment thereby creating better contrast with the monitors while providing sufficient light through the entire OR. This adjusted the overall light levels to ~ 86 lux- roughly equivalent to twilight or street nightlights.

What is the "Right" Amount of Light for the OR?

To understand the reasoning behind this choice and why it was so effective, one must understand how the eye works under different light conditions. In Figure 1 below, the eye is broken down into some of its basic components. The lens focuses light onto the retina where photosensitive pigment on the rods and cones convert it into electrical impulses that are conducted to the brain via the optic nerve.

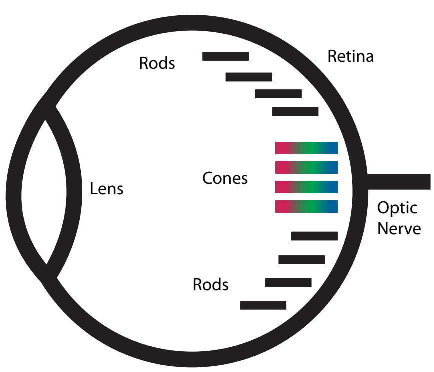


***Figure 1:** Basic components of the human eye highlighting the difference in location and function of the primary receptors, rods and cones.*

Under normal daylight or "bright" light conditions (> 100 lux), light reception is determined primarily by receptors called cones which are sensitive to both the intensity and color of light. This level of illumination is referred to as the "photopic" region. The visual system is optimized for contrast in this region and uses any "excess" light to create sharp, fine detail in images.

At night (< 0.1 lux), the vision system employs a different set of photoreceptors known as rods to detect light. They are very sensitive to the intensity of light but do not provide color information. Their sensitivity, however, is wavelength dependent. This level of illumination is referred to as the "scotopic" region. The visual system is optimized for overall light level detection in this region and trades off image detail for sensitivity. This increased sensitivity causes the rods to become overstimulated and rendered temporarily inoperable (i.e. blinded) at photopic light levels (~100 lux) due to depletion of the corresponding photopigment. After this stimulus is removed (e.g. turning the lights in a room off), the photopigment rebuilds and the scotopic system returns to normal. This explains why there is a period of visual adjustment in these situations.

Light levels between these two points are processed using a combination of both systems. This is referred to as the "mesopic" region. Visual performance at these light levels is dominated by whether objects lie in the line of sight or in the peripheral vision. Referring to Figure 1, objects which lie in the line of sight will be viewed by the cones and will thus have relatively good visual acuity and color vision while those objects in the peripheral vision will be viewed by the rods and will therefore have relatively poor visual acuity, loss of color vision, and a slight blue shift in spectral sensitivity as shown in Figure 2.

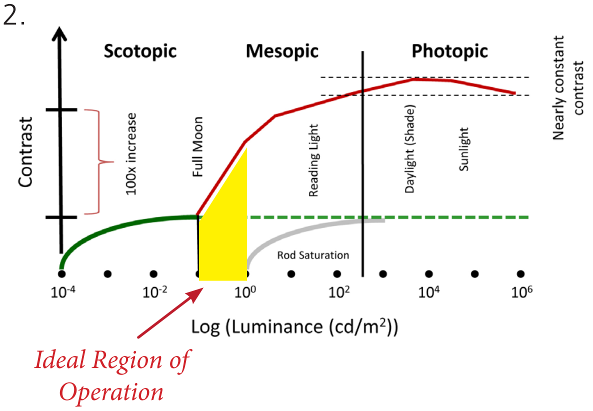


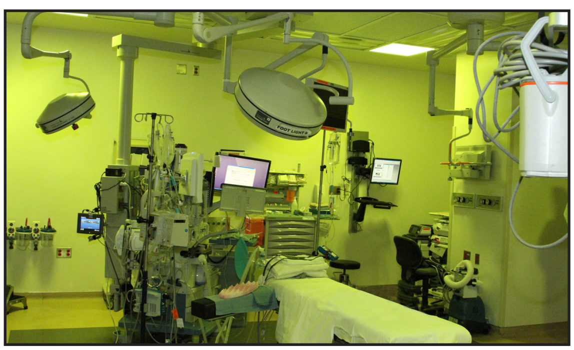
***Figure 2:** Performance of the human vision system under various lighting conditions. Note the optimal level of illumination which provides for color vision and contrast while preserving night vision capability.*

Armed with this information, one can see that the choice of 86 lux places the illumination near the top end of the Mesopic region thereby preserving the use of both the rod and cone systems. This is important as it allows one to see both within the surgical field and near the edges of the room where there may be more or less illumination depending upon how the overhead lights are arranged.

This decision also highlights the fact that the choice of illumination level is a balancing act of sorts. On one hand, having the light level as low as possible (i.e. off) eliminates glare due to reflections from the monitor face and improves contrast with them. On the other hand, having a bright light makes it easy to perform tasks such as reading labels, choosing instruments, and moving about the room. Thus, the optimal light level is one that balances these two considerations for an OR team. This can be best achieved by using lighting with some type of dimming such that the illumination level can fall down into the Mesopic region if desired.

Why Green? (Or Which Green is Best?)
Having established an illuminance level, one must also consider the effect that the illumination's hue has upon the OR team's visual capabilities.

Green-Yellow



Blue-Green

Early "night vision" systems used red light as this significantly reduced the impairment to the scotopic system thereby allowing the user to see and function better with or without the light active. The reason for this is the relatively low sensitivity of the rods to red light as highlighted in Figure 3 below.

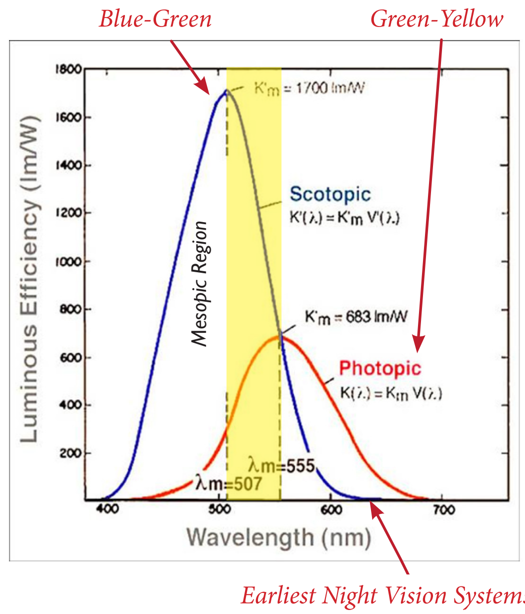


Figure 3: Spectral sensitivity of the receptors in the human eye. Optimizing the performance for the Mesopic region suggests a color choice between 507nm and 555nm (~ 525-530 nm).

In a surgical environment, however, the choice of red is sub-optimal as it impairs visualization of red objects (tissues, veins, wounds, etc.), creates greater eyestrain (both physical and psychological), and consumes more electrical power as compared to shorter wavelengths. Outside of the medical environment, these same night vision systems were used in aviation with some success, however, the users were challenged to read the magenta markings on their maps due to poor contrast under such illumination. Replacing the red with green provided a solution to these issues as the photopic response peaks at 555 nm thereby maximizing the optical benefit of those photons while creating contrast with the monitor/ displays in the room.

Finally, choosing the "right" color of green will help to maximize the contrast when viewing a monitor. This can be explained with the help of the 1931 CIE diagram shown in Figure 4. Here, the length of the line between the Planckian locus (white light) and a particular hue of green demonstrates the relative contrast between them. Thus, one can see that blue-green hues (~520nm) provide greater contrast than green-yellow hues (~555 nm).

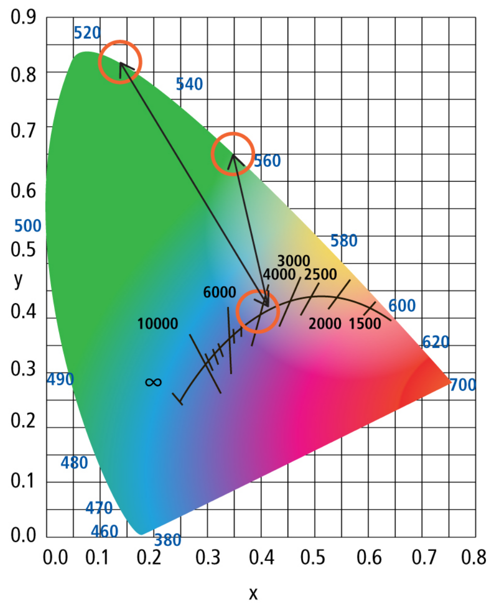
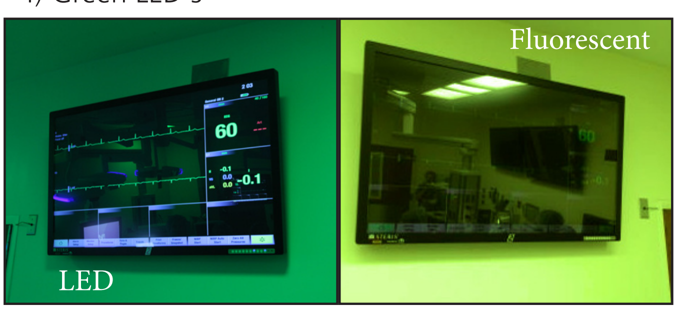


Figure 4: 1931 CIE Chromaticity Diagram with vectors showing the contrast between a white monitor and various green hues. Note that blue-green hues (~520nm) provide more contrast than yellow-green hues (~555nm) as evidenced by the length of the appropite vector.

Technology Solutions

Manufacturers use 4 different methods to produce green light in this environment:

1) White fluorescent tubes with green filters
2) Green fluorescent tubes
3) White LED's with green filters
4) Green LED's



Blue-Green LED: 525nm | *Green-Yellow Fluorescent: 555nm*

***Figure 5:** Superior visual acuity created by blue-green LED's as compared to green fluorescent technology.*

While each of these options has their own advantages, the use of Green LED technology provides the user with an application optimized spectrum that has no transmission loss due to filters, a more saturated green hue, and superior maintenance benefits.

Bringing It All Together

The key learning objectives of this paper can be summarized in the following points:

1) All types of operating rooms are incorporating various displays and monitors which can benefit from low-levels of ambient illumination
2) This level of ambient illumination should be adjustable across a range that is low enough to provide good contrast with the displays and monitors in the room and yet be high enough to allow the OR team to:
   a. See with high visual acuity within the surgical field
   b. View monitors, perform tasks, and move about the room as required
   c. Shift one's view between different levels of illumination (monitors, inside the surgical field, outside the surgical field) with minimal impact
3) The hue of this illumination should be greenish-blue (525 nm) to:
   a. Maximize its optical benefit
   b. Maximize contrast with monitors in the room
   c. Minimize its impact to the OR team's low-light vision
   d. Provide the ability to distinguish between different shades of red
4) Green LED's provide a more efficient, reliable method of producing light which meets these requirements as compared to fluorescent tubes and/or white LED's.

About Kenall Manufacturing

Founded in 1963 by Ken Hawkins, Kenall Manufacturing carved a niche within the lighting industry by creating the first impact and vandal-resistant lighting products. Kenall produces and supports high quality and durable lighting solutions for the most challeng-ing environments; providing sealed enclosures for food processing, containment, and specialized healthcare applications and high-abuse/rough service lighting for transportation applications and security lighting for detention facilities. Most Kenall products comply with the Buy American Act: manufactured in the United States with more than 50% of the component cost of US origin. For additional information, visit www.kenall.com.