

# **2016 Human Physiological Responses to Light Meeting Report**

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Washington, D.C.

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|                  |   |
|------------------|---|
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| George Brainard  | Thomas Jefferson University                     |
| Mariana Figueiro | Lighting Research Center                        |
| Gena Glickman    | University of California San Diego              |
| John Hanifin     | Thomas Jefferson University                     |
| Michael Herf     | F.Lux Software LLC                              |
| James Ibbetson   | Cree  |
| Steven Lockley   | Brigham and Women's Hospital                    |
| Fred Maxik       | Lighting Science Group                          |
| Naomi Miller     | Pacific Northwest National Laboratory           |
| Maria Northup    | NEMA  |
| Jeff Quinlan     | Acuity Brands Lighting, Inc.                    |
| Luc Schlangen    | Philips Lighting Research                       |
| David Sliney     | Johns Hopkins Bloomberg School of Public Health |
| Richard Stevens  | University of Connecticut                       |
| Kenneth Wright   | University of Colorado Boulder                  |
| Jamie Zeitzer    | Stanford University School of Medicine          |

### DOE SSL Program Attendees

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|-----------------|--|
| James Brodrick  | U.S. Department of Energy - Building Technologies Office |
| Joel Chaddock   | National Energy Technology Laboratory                    |
| Morgan Pattison | SSLS, Inc.   |
| Victor Taylor   | Navigant   |
| Mary Yamada     | Navigant   |

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## Introduction

On July 19<sup>th</sup>, 2016, 17 experts in the fields of human physiological responses to light and SSL technology gathered with the DOE Solid-State Lighting (SSL) Program team members for a discussion of common research themes, research challenges, and paths forward to better understand human physiological responses to light. The meeting, hosted by Navigant in Washington, D.C., commenced with presentations, where each participant was invited to give a short presentation describing their field of expertise and forward-looking research concepts. This was followed by a general discussion of research and development opportunities for SSL that will further understanding into and minimize impacts of light on human physiology.

This report is a summary of the input provided by these experts in the field of human physiological impacts of lighting at this meeting and the subsequent discussions.

## 1. Key Conclusions

Human physiological responses to light represent a complex interaction that requires dedicated research efforts. At the same time, the advent of solid state lighting has enabled new levels of control of our every day lighting that can be guided by better understanding of healthful, and even therapeutic, lighting. The experts' discussions in the meeting were focused around four research themes: photoreceptive inputs and their responses, methods of circadian and neurophysiological regulation, human medical responses to light, and product application hurdles. Each of these themes resulted in general consensus among experts on how to most effectively address healthy human light. They concluded that **the researched effects of light on the human body are useful in understanding what inputs could be used to produce different non-visual effects, but more research is needed to fully grasp the relationships**. Additionally, **with the proper understanding of the specific effects of light on alertness and sleepiness, light could potentially act as a non-pharmaceutical tool to adjust the circadian clock**. Existing research has addressed the fear of optical damage from LED light, assuring that short periods of direct LED light exposure would not harm the eye, however, additional work is needed to determine if prolonged exposure to LED light can cause problems. Finally, the experts concluded that **better metrics, improved data collection tools and processes, and a definition for a healthy lighting dosage are needed to create marketable, healthy LED lighting and minimize risk factors as LED adoption increases**. This would allow for more coordinated studies that would help clarify what happens when photoreceptors receive different inputs, and how light could best be applied to help control circadian and neurophysiological regulation and reduce the frequency of light-related circadian disorders, depression, obesity, eye damage, and cancer. Potential research topics could include:

- **Applied Research** – Carrying forward results from controlled research in laboratory settings on physiological responses to light to lighting scenarios typically encountered in daily life. This would include research on: cancer tumor development under different light spectra and light-dark cycles; light duration and the effect on melatonin suppression; daytime light intensity and

melatonin suppression at night; different light spectra and intensities with the time of day to pinpoint specific responses to controlled doses of light; light dosage and circadian resetting.

- **Technology Demonstration** – Demonstration of productivity and/or health benefits as a result of the biological and behavioral effects of light.

In addition to research needs, it was also emphasized that the facilitation and collaborative presence of the DOE SSL Program within these research groups is helpful. It was suggested that DOE help to endorse standardization of meaningful metrics and measurements of circadian lighting, coordinate testing methods, and sponsor controlled research and field studies to improve the understanding of the impact of light on humans.

The following sections summarize attendee presentations and input regarding the critical challenges and suggested research needs for photoreceptive inputs to light (section 2), circadian and neurophysiological regulation (section 3), and human medical research (section 4). Additionally, a group of LED manufacturers and experts provided an overview of the technology, the status of performance metrics, and considerations when applying physiological effects to lighting (section 5).

## 2. Photoreceptive Inputs

### Discussion

Intensity, time, duration, distribution, and spectrum have proven to be the key inputs on human physiological responses to light. Short-wave lighting of about 460 – 480 nm is maximally effective at suppressing melatonin secretion in humans as well as animals. Wavelengths across the entire visible spectrum, however, can play a role in melatonin regulation at sufficient intensities. Research shows that it is possible to use light to affect the body in a few different ways, but more studies and research are needed to fully understand what inputs produce the different non-visual effects, and how to properly control them. Studies on different exposure times, from instantaneous flashes to a full day of constant light, on spectrum exposure, and on light intensity are needed to disassociate the inputs and match them with specific health effects. Success in this research could lead to LED lighting that can match the task, application, and safety requirements of the space with that of the human physiological needs.

### Participant Presentations

**George “Bud” Brainard from Thomas Jefferson University** presented his research on light regulation of biology and behavior in humans. Brainard presented the findings of several recent studies which connect the efficacy of circadian, neuroendocrine, and neurobehavioral light dose to four key parameters – irradiance, wavelength, duration, and time. A study by West et al. was conducted in 2011 with a polychromatic, narrowband blue LED exposure system. At different levels of irradiance, melatonin levels were measured and a sigmoidal relationship between melanopic lux and melatonin suppression was found. Brainard also presented the results of newly unpublished work which enabled the development of a melatonin suppression influence response curve using a broad bandwidth white LED panel with 6,500K correlated color temperature (CCT). Lastly, he showed that the narrow bandwidth blue LED light array produced over three times more calculated melanopic lux than the 6,500K white LED array.

In conclusion, Brainard emphasized that short wavelength enrichment increases potency of light and both unpublished and recent published results indicate that monochromatic data does not completely predict the performance of polychromatic light. He recommended that DOE sponsor research into efficacy of solid state lighting for regulating human circadian and neurobehavioral systems. He also encouraged DOE to foster evidence-based lighting in the development and distribution of technologies intended to improve human health and performance.

**Mariana Figueiro of the Lighting Research Center (LRC)** spoke about the key areas of research at the LRC, which include specifying and measuring circadian light, as well as applying their knowledge in the field in the form of tailored lighting interventions that promote circadian entrainment and acute alertness. Figueiro emphasized that these areas of research could have a tremendous impact on Alzheimer’s disease patients, shift workers, submariners, office workers, healthy older adults with sleep problems, and adolescents. In order to diagnose and prescribe lighting treatments for each of the patient groups, Figueiro stated that we have to be able to match up the visual and non-visual systems, which are separate and are influenced by a human’s culture, experience, and expectations.

Referencing three of her past studies on acute melatonin suppression by light at night, Figueiro and colleagues published a mathematical model of human circadian phototransduction based on published data on acute melatonin suppression by light. The model can be used to compare the effectiveness of multiple light sources in activating the circadian system, as measured by acute melatonin suppression. The model utilizes spectral power distribution and light levels to predict acute melatonin suppression, but it is not a complete metric because it does not take into account timing, duration, and photic history. For example, in order to accurately predict circadian phase shifting response, it is essential that light exposure is monitored and recorded throughout the day – this would require the continued development of wearable calibrated instrument to measure circadian light exposure.

In conclusion, to achieve more accurate modeling of human response, Figueiro indicated that it is essential that stimulus is specified, difference between species accounted for, and total light exposure throughout the day is considered. This would enable the development of personalized tracking and monitoring systems that can offer recommendations for when a person should receive or avoid light. Figueiro also emphasized the importance of transitioning lighting design to focus on the best human health practices.

**Gena Glickman of the Center for Circadian Biology at the University of California San Diego** spoke on her research in modulating light sensitivity for photobiological response in humans, and also reviewed other pathways for mediating the effects of light. She began by discussing how the characteristics of the light source (e.g. wavelength, intensity) and human variables (e.g. pupillary response, light sampling behaviors) may directly change the magnitude of human physiological responses but then further focused on how circadian phase may be indirectly altered via naturally occurring changes in the duration of light within a day/photoperiod. Starting from previous photoperiod research, in 2012 Glickman concluded shorter days elicited a 40-fold increase in sensitivity to light in hamsters that experienced bright flashes of light. The study also found that the expression of pERK, PER1, and cFOS, proteins that underlie the biochemical events associated with physiological response to light, mimicked the pattern found for phase shifting under long and short days. However, a lack of difference in melatonin suppression response under long and short days suggests this modulation of light sensitivity by photoperiod is occurring downstream of the photoreceptor level. Together, this work demonstrates the potent effects of photoperiod history on subsequent response to light and begins to pinpoint the mechanism responsible for those effects, which may ultimately provide novel pharmacological targets for enhancing circadian response to light.

Glickman concluded that the effects of differing photoperiods on hamsters would likely produce a similar effect on humans, but further exploration is needed. This would help fine tune light response and find solutions that address one response issue without causing a negative impact in another.

**Jamie Zeitzer of the Department of Psychiatry and Behavior Sciences at Stanford University** discussed his research on the brain's perception of light, and how it can be tricked. Zeitzer focused on integrated intrinsically photosensitive retinal ganglion cell (ipRGC) outputs, the output from the retina that is received in the brain. IpRGC fire rapidly when lights are turned on and can continue for several minutes after the lights are turned back off. This can be used to create circadian illusions in which the

effectiveness of the light far exceeds the exposure time. In his research, human circadian timing and melatonin levels were measured when exposed to light flashes of different frequency and pattern. The results indicated that flashes were able to shift the circadian timing by as much as two hours, which was three times greater than continuous light of the same intensity, despite that melatonin suppression did not occur consistently.

Zeitler noted that this knowledge could potentially be applied a number of ways to quickly correct circadian timing, but the full effects of the extrinsic inputs (rods and cones) must first be understood more completely. More research is needed to fully understand how ipRGC systems feed into the different physiological outputs of interest.

### 3. Circadian and Neurophysiological Regulation

#### Discussion

Circadian rhythms are inherently tied to the natural daylight cycle – light enhances wakefulness and darkness promotes sleep. In the natural environment, humans would rise in the morning when the sun comes up and gives off high intensity, blue-enriched light. Humans then begin to get tired in the evening when the light has less blue wavelengths, and go to sleep after the sun sets. With the advent of artificial lighting, circadian clocks have shifted to match this artificial system, but not necessarily for the better. Exposure to light late into the evening suppresses nocturnal melatonin and can shift or lengthen the circadian cycle, sometimes leading to medical issues. The circadian clock is resilient, however, and bounces back to a natural cycle quickly when the correct lighting scenarios are introduced. With the proper understanding of the physiological effects of light on the alertness and sleepiness, light can be turned into a useful, non-pharmaceutical tool to adjust the circadian clock for increased alertness and better sleep.

#### Participant Presentations

**Kenneth Wright of the Department of Integrative Physiology at the University of Colorado** presented his research on the effects of light on human physiology and cognition, and specifically the effect of light cycles on melatonin production throughout the day. In his study, Wright took subjects camping and measured their light exposure using wrist light-loggers. He compared this with the light exposure humans traditionally experience in modern society, concluding that humans get much less light in modern society than in nature. In addition, he found that the human circadian clock readily readjusts to a natural rhythm during the camping. Wright also discussed his research where subjects were exposed to bright and dim light for a set duration, finding that higher body temperature is correlated with brighter light and that children are more sensitive to ambient light than adults.

Wright stated that patient recovery and well-being could be improved by enhancing the lighting conditions for patients in intensive care units (ICUs), such as increasing the lighting during the day and decreasing the light at night to reflect a natural rhythm. Shifting sleep times to be in sync with the natural daylight cycle could help reduce obesity, sleep deprivations, and diabetes.

**Steven Lockley of the Brigham and Women's Hospital and Harvard Medical School** presented his review of the short wavelength sensitivity for phase resetting and melatonin suppression by bright light over longer duration light exposures. In an experiment, Lockley tested the effects of varying light intensities and exposure times, finding that the response curves change dramatically depending on the exposure time. Lockley explained that this result indicates the action spectra are not consistent depending on duration and intensity. More recently, Lockley studied the effect of light as an input for acute alerting effects, finding that at night, alertness is increased when given a dose of photons.

With this knowledge, Lockley noted that programmable and non-programmable lighting systems are useful in different spaces depending on the desired task. He noted that NASA recognizes the use of light as a tool and has invested in lighting systems that can produce wavelengths for high circadian wakefulness and alertness, and for sleep. Lockley concluded that while some recognize the usefulness of

light, most do not understand how lighting impacts their biology. New metrics and tools for measuring these impacts are necessary in order to communicate this importance to the public.

## 4. Human Medical Research

### Discussion

While the proper lighting dosage can help to regulate the circadian system and provide physiological benefits, the wrong dosage can cause chronic health issues and be a catalyst for disease. It is common knowledge that staring into the sun can harm the retina, but the fear of the “blue-light hazard” has risen more recently with the introduction of blue-intensive LEDs. Current research into this concern show minimal likelihood of eye damage due to short periods of direct light exposure, but prolonged exposure problems are still unknown, and need to be researched. Also, various links have been found to light-influenced medical issues like seasonal affective disorder (SAD), depression, obesity, diabetes, sleep disorders, and cancer. Additional studies into the effects of different color temperature lighting on cancer growth in laboratory rodents could benefit cancer patients by increasing the effectiveness of certain cancer drugs and slowing the spread.

### Participant Presentation

**David Sliney of the Department of Environmental Health Sciences, Johns Hopkins Bloomberg School of Public Health**, spoke broadly on retinal phototoxicity, and more directly toward the “blue-light hazard.” He explained that phototoxicity occurs when individual photons alter biologically critical molecules in the retina. Photomaculopathy is blue-light retinal phototoxicity that results from a person staring at an intense light source for a long time. Sliney claims that it is difficult to receive this type of injury from LEDs because the eye has a natural aversion and involuntary eye movement to harsh light. However, more research is needed to determine whether there are issues related to chronic exposure to blue light.

**Richard Stevens of the University of the Connecticut School of Medicine** discussed the potential harm from excessive exposure to high CCT light during night hours. In the short term, night time exposure to light emitted from electronics like computers, E-books, and LED televisions can create a delay in melatonin production. Stevens indicated that this delay can affect sleep quality and have negative impacts on morning alertness. Although research into long term effects is underway, there is currently no data on the chronic effects of evening light.

Stevens expressed concerns that increasing the CCT of street lights from 4000K to 5000K could potentially cause physiological harm, and that the industry should assess the physiological impact of the currently marketed “white” LED products. Analytical predictive models are needed to assess the effects of high CCT light. However, in order to develop such a tool, more research and data are necessary. Stevens concluded that specifiers, lighter designers and installers need to consider human health impacts in conjunction with the demands of the lighting application, cost savings, and energy efficiency.

**David Blask of Tulane University** discussed the light-induced circadian/melatonin modulation of cancer risk and responsiveness to therapy. His research has focused on how nighttime light exposure affects timing and specifically melatonin suppression, as well as how this translates to human fatty acid and sugar concentration. Blask found that animals became hyperglycemic when exposed to dim nighttime light, resulting in faster tumor growth. Using this initial research as a foundation, Blask tested the

effectiveness of cancer treatments in melatonin suppressed animals. Blask found that the drug had no impact on tumor size in the melatonin suppressed animals, but the tumors vanished in animals that experienced a natural light-dark cycle with associated melatonin levels.

Blask stated that the relationship between the circadian system and nocturnal melatonin on cancer still needs research. Since melatonin helps to fight-off cancer cells, it may be possible to suppress tumor growth with light designed to work with cancer treatments.

**John Hanifin of the Department of Neurology at Thomas Jefferson University** presented his studies on wavelength effects of light exposure on growth and metabolism of human prostate cancer xenographs in nude rats. Hanifin looked at how bright polychromatic light during the night affects blood melatonin levels, prostate tumor growth, signal transduction, and metabolism using samples taken from healthy human male volunteers under four different lighting conditions. He found that tumor growth increased with short wavelength exposure, and is also correlated to the melatonin levels present under the different lighting conditions.

## 5. Application Perspective

### Discussion

LEDs already represent about 6 percent of all lighting installations. As adoption of LED lighting increases it is important that these products are designed with human physiological impacts in mind. LEDs are a long life technology and therefore now is the time to conduct research and prescribe recommendations for lighting with positive human impacts. Designing LEDs to be color changeable, spectrum tunable, controllable, and efficient is now technically feasible. To include the physiological beneficial lighting as a marketable and attractive characteristic, these effects need to be quantified through standardized metrics. In order to create marketable healthy LED lighting, a definition of a healthy lighting dosage is needed. Better metrics, along with simpler processes and tools for collecting and aggregating the data, will help to produce LEDs with minimized risk factors in the later phases of adoption.

### Participant Presentations

**James Ibbetson of Cree** explained how better defined and relatable metrics are necessary in order to demonstrate the value of human impacts of LED lighting. The initial excitement around LED lighting in 2005 was possible because efficacy and lumen metrics were easy to relate to the customer. Human physiological impacts are harder to sell because the benefit for the added cost is not currently measureable, and explaining the physiological experience of better lighting to the customer is a challenge.

Ibbetson explained that the previous push in LED technology has given industry the ability to tune lighting to a wide range of spectral power distribution, color quality, and light intensity distribution, but that we currently don't know what to recommend. The lighting industry needs a standardized metric that can be used to explain the physiological benefits of good lighting. DOE assistance in the first push for LED lighting was very beneficial, and support for understanding human physiological impacts of lighting research would help to continue the drive for LED adoption.

**Jeff Quinlan of Acuity Brands** focused on the necessity of the LED community to take full advantage of the capabilities of LED lighting, stressing that healthy lighting is needed now due to the long lifetimes of LEDs. As an industry, Quinlan noted that LED technology has achieved high efficiency, but direction is needed to make them healthy and beneficial to human biology.

He indicated that questions such as, what is natural white light, does flicker have human health impacts, and how to properly measure color quality need answers. Additionally, glare and mesopic modeling, uniformity impacts, and color perception need additional research into how to define and measure them. Quinlan highlighted that the health and circadian rhythm impacts of lighting are paramount to this stage of LED lighting research. This research will enable the industry to positively impact productivity, sleep preparedness, and many other physiological responses.

**Fred Maxik of the Lighting Science Group** spoke about the importance in considering all possible outcomes when introducing new physiological effects to the public, and also the tradeoffs to adjusting light to appeal to humans. He stressed that all aspects of a space need to be considered prior to making

drastic lighting changes. LED lighting manufacturers have the ability to modify CCT and spectrum independently and this could help address human health without sacrificing customer preferences.

Maxik concluded that, as an industry, it is necessary to identify the specific light characteristics that need to be enhanced or eliminated. It is important to consider designing light that has minimal negative impacts to human health. The DOE can help further this research by funding work that will greater the understanding of healthy lighting and how it can be implemented in the real world.

**Luc Schlangen of Philips Lighting** presented his research on the effects of light beyond vision focusing on the response of hospitalized patients. In hospital patient rooms dynamic lighting was installed with the goal of improving mood and strengthening circadian rhythm. Although there was no change in length of stay, the amount of nighttime sleep increased by 6 minutes per hospitalization day with dynamic lighting instead of standard lighting. In a separate study, participants were exposed to three different constant lighting conditions during 40 hours of wakefulness. This resulted in very little melatonin suppression in older participants. In younger participants melatonin suppression was more pronounced in the first half of the night. Other research found that increased light during the day increased nocturnal melatonin secretion and decreased the melatonin suppression by light at night.

Schlengen indicated that more research into new quantities for photoreceptor weighted lighting intensities are needed. Currently the CIE is working to prepare a light intensity standard which defines lighting dose for several non-visual light responses and provides guidance for what daytime and night time light exposures promote health and well-being.

**Michael Herf of F.Lux Software LLC** was inspired by the problem of computer screen light exposure leading him to create a mathematical model that would automatically adjust the CCT and intensity based on the time of day. Since then, Herf has developed the beta for the f.luxometer app which measures user light exposure and provides recommendations to promote health and wellbeing. The phone app measures light through the camera which can only capture a limited range of the users light exposure – this requires a significant amount of assumptions and while they are able to collect a significant amount of data more is needed.

Herf's goal is to continue to accumulate lighting exposure data so that it can be used to help link the lighting exposure data to specific user impacts. Herf hopes to further his model, focusing on how lighting schedules can be optimized for groups rather than the individual.

## 6. Closing and Next Steps

Based on the presentations from the attendees and the subsequent discussion, there was general agreement that short wavelengths (around 460-480 nm) are most effective at suppressing melatonin and can affect the circadian system if received in the evening. Different quantities and spectra of light are needed throughout the day, so applying the same light in the morning and at night is not aligned with our biological systems. The participants agreed that modern dwellings and workplaces are often not adequately lit, and humans require exposure to brighter light during the day and that nighttime short wavelength light exposure can impact the circadian system. More research is needed, however, to discover proper dosages, and current efforts for collecting data should be organized and leveraged to make large bounds in our knowledge base. Standardized research approaches and uniform metrics can also be applied to maximize useful, comparable discoveries. The attendees agree that better metrics other than CCT are needed.

The conversation surrounding human physiological response to light is in its early stages, and several next steps were proposed to help the energy saving we are seeing to continue, while maximizing the benefits of healthy lighting for humans. The U.S. DOE SSL Program received the following next step suggestions for moving forward from the meeting participants. It was recommended that DOE should consider:

- Coordinating lighting education, research programs, test methods and standards, as well as demonstration projects to improve understanding of how lighting impacts humans.
- Supporting a standardized set of metrics and measurement tools for testing the physiological benefits of light in order to continue collecting meaningful data. This needs to be done before LEDs are fully adopted.
- Supporting more studies, both controlled and in the field, and assist in creating a database of all of the studies to date in order to reach a more solid conclusion as to the nature of human physiological responses to light.

DOE would like to thank all attendees for their participation and for their valuable insights into what needs to be done to help the human physiological responses to light field overcome the challenges it faces, as well as how the DOE SSL Program can facilitate that process. It is active participation from members of these communities, and collaborative efforts, including those initiated between research groups as a result of this meeting, that will continue to drive LED technology forward.