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LIGHT SPECTRUM & WELLNESS

Best practices to create an immersive lighting design experience for

Education, Workplace, Healthcare and Retail environments

Version 1.5

CONTENTS

1. Abstract

Stimulus perceived from the surrounding environment are translated into chemical reactions in our brain: attention, perception, focus, learning, language, thought, and intelligence are some of the factors that are influenced by these changes.

Behaviour towards day-to-day activities is affected by natural and artificial light. In fact, circadian rhythm evolves following the conditions of the sun, which explains the oscillations of the cognitive processes. Colours are also seen to impact the way our Brains perceive the interior space, which in turn can affect our Mood and Well-being.

Optimal environmental conditions, which include lighting, sound, and temperature, improve the basic and high complexity cognitive processes and better regulating circadian rhythm.

In the following paper, we are going to explore how good lighting design practices applied in the educational, workplace, healthcare and retail facilities can help improve productivity, motivation, performance, boost sales, enhance personal health and well-being as well as the different executive cognitive functions. We will also explore various lighting design recommendations with respect to the workplace, education,healthcare and retail planning layouts.

In the educational setting, the research studies and data show consistent results. The results demonstrate that a tunable LED system is beneficial to the different activities and learning processes inside the Classroom. Most studies conducted used four different lighting Settings. These are used to target specific actions that vary from general processes, reading, activities requiring focus, testing, presentations involving audiovisual components, and calm and soothing activities. As the Classroom is a Dynamic Environment, the Lighting systems should support different levels of activities to enhance the behavioural response of the Students. Research suggests students with special needs such as Autism, ADHD, SPD (Sensory Processing disorder),and developmental delays are strongly affected by environmental conditions with lighting conditions required to be specifically designed for optimal wellness. To get more information on this topic, The Whitepaper focused on the Education environments discusses the critical role of lighting in creating a comfortable environment for special students with sensory sensitivities.

Likewise, in the Workplace Environment, an effective and changeable Lighting Design can influence the well-being of employees. Exposure to more intense light may boost employees' feelings of alertness and vitality during the daytime and at night. Studies have shown that light intensity and spectrum may influence individuals' ability to sustain attention and cognitive performance. The Light patterns that

employees experience during the daytime may affect their sleep during the subsequent night while exposure to light during night shifts can reduce melatonin secretion and affect the timing of sleep.

The healthcare sector has to fulfil special care as inhabitants with a range of concerns to cater for from being sick or chronically ill to being disabled or have age-related problems. The health care sector has to take into account the daily activities of its patrons who have visual problems, frailty, movement disorders, sleep disturbances or memory and thinking problems. Light can play a very prominent role in improving the quality of life for these individuals, as has been shown with studies involving daylight. Majority of artificial lighting studies in the healthcare sector focus on energy-efficient light solutions and lack interdisciplinary working models which involve the effects light has on the human body; thus other journals and studies are required to be used.

Light is widely recognised for its healing qualities, with more medical journals focusing on the benefits of light therapy. Studies show how the healing effect of light replicates and restores cells. 24-hour light-dark exposure becomes very important for the repair and regeneration of cells. This is due to the regeneration cycle depending on strong signals from the body clock, whose activity is influenced by light quality, intensity and timing. Therefore, the installation of personalised dynamic light settings for each room in hospitals and care homes should be considered.

The Retail industry is continually changing and to remain competitive retailers are continually developing new ways to drive their business. The current challenges of competing with Online Shopping has pushed the retail sector's need to not only provide excellent products and customer service but to create unique in-store shopping experiences, enhanced product displays and develop a strong brand identity.

Innovative Lighting Solutions are at the forefront of this development - Lighting Design has become a necessary part of delivering the optimal experience for shoppers. It has become a vital element of saving costs as well as building a strong brand. Increasing evidence shows that if you invest in showcasing your merchandise or enhancing the purity of your food products, you can improve sales and make a real effect on the bottom line.

In any environment, the lighting intensity and colour inside the space can affect the feelings and emotions of the user. Blue light improves a number of cognitive processes (e.g., attention, working memory and sleep) known to influence our creative abilities. Blue light exposure results in significantly improving convergent thinking ability and further studies back that up by reporting low dopamine levels promotes convergent thinking. Divergent thinking has been associated with elevated dopamine level, which is beneficial in the working and learning environment. (University of Liege,2014) Key studies show that emotions affect the cognitive process; such an example is light intensity affecting a person’s creative insight. Bright lighting promotes convergent thinking, while dim lighting sparks creativity.

(Azeemi & Raza, 2005) Light is responsible for turning on the brain and body. Light triggers the Hypothalamus which regulates our body's biological clock. Light affects our Hormones, and in turn, Hormones affect more than just mood. These vital chemicals like Serotonin, Dopamine, Melatonin, and Cortisol enable daily bodily functions, movement and more.

- **Serotonin** is an important chemical and neurotransmitter in the human body. It is believed to help regulate mood, social behaviour, appetite and digestion, sleep, memory, sexual desire, and other bodily functions. Serotonin is produced during exposure to daylight.
- **Dopamine** is a chemical in your brain that plays a role in the regulation of cognition, memory, motivation, mood, attention, and learning. Dopamine Levels are increased when there is a High Exposure to bright lights..
- **Melatonin** is a hormone that's made by the pineal gland in the brain. Melatonin helps control your daily sleep-wake cycles. Melatonin Levels and Production are affected by light and are reduced when exposed to blue light.
- **Cortisol** is a hormone produced by the adrenal gland. Cortisol is a steroid hormone that regulates a wide range of processes throughout the body, including metabolism and the immune response. It also has a very important role in helping the body respond to stress. An enhancement of Cortisol Awareness Response in humans by morning light exposure may be important to "stimulate" the body when it is time for it to be active.

Further new studies and articles pertaining to artificial blue light have been gaining traction recently, due to its detrimental effects to sleep and circadian rhythm. These studies show further evidence that blue light boosts alertness, helps memory and cognitive function, and also elevates mood if appropriately applied which would be perfect for use in stimulating cognitive processes in a Learning and Working Environment.

Reducing glare is also an integral part of effective lighting design. It is recommended to have adequate background lighting in environments which are prone to glare with a high UGR. This can be achieved by having indirect illumination from ceilings (skyglow), and walls (backlight). Most commonly indirect illumination is achieved by lights that can provide diffused light to ceilings as well as wall washing.

Coloured RGB LED lighting shows promise in affecting mood. Colour is an influential tool in evoking emotions and current studies into coloured lighting are encouraging lighting designers to explore further into this field. Each colour has its own effect. Blue light increases blood flow and mood, which is great for focused tasks and convergent thinking. Red coloured lighting slowed reaction times and made it easier to fall asleep, making it an excellent choice for evening lighting. Green lighting promotes calm and soothing feelings while also enhancing learning and concentration. Studies and tests have been done in the medical field on the effects of green light managing chronic pain as it is promoted as a Healing Color to treat migraine. Yellow and orange, warm colours which sparks and trigger increased mental activity. These are just a few examples of the significance of using coloured lighting to enhance the learning environment and promote positive and desirable reactions. However, coloured lighting studies and research are mostly applied to home environments, and most studies are focused on general applications. It will be beneficial for the education, corporate, and healthcare industry together with lighting designers to delve into studies pertaining to RGB LED lighting. There is a gap in this market, which further tests and studies should be conducted.

With these findings, it is important to underline the need for a more dynamic and circadian friendly lighting system in the following environments:

- Educational: to further improve the performance and learning capabilities of students as well as assisting teachers in creating an engaging learning experience.
- Workplace: to boost employee productivity and efficiency together with promoting comfort and a sense of well being.
- Healthcare: to develop a healing atmosphere and enhance the perceived well being of the patients, reduce the use of painkillers and reduce staff error rates.
- Retail: to promote better Customer Engagement and Shopping Experience, which will then increase sales and improve the health and wellbeing of the Consumer and the Employees.

2. Research Findings & Statistics

EDUCATION

1. Research done by:
Pacific Northwest National Library for US Department of Energy, 2017
Case Study in Carrollton-Farmers Branch Independent School District in Carrollton Texas
Three Classrooms:
1) Fifth Grade Math and Science Classroom (49 students) from Dale B. Davis Elementary School,
2) Fourth Grade Reading and Language Arts Classroom from Sheffield Elementary School, and;
3) Eight Grade science laboratory (Different groups of students came into the room) from Charles M. Blalack Middle School (BMS).

Light Output Controls Used:

Behavioral Outcomes:

- Scene 1 used for 70% of the Class Time
- Scene 2 used for 25% of the Class Time
- Scene 3 - not used
- Scene 4 used for 5% of the Class Time
- SPD Setting General = 90% (used for most class activities)
- SPD Setting Reading = used on occasion (Reading) and for breathing times.
- SPD Setting Testing = used on occasion (Testing)
- SPD Setting Energy = several times in the Morning, but found to be uncomfortable

2. Research done by:

Dr Hyeon-Jeong Suk - Korea Advanced Institute of Science & Technology

The Study involved two classrooms, where 54 fourth grade students were taking a math test.

Light Output Control used:

6500K

Behavioural Outcomes:

Students were more alert and scored higher on their test.

3. Research done by:

Sigma Luminous - a 2006 study looked at the effect of colour temperature on visual acuity in schoolchildren. Optometrists conducted vision and reading tests for children under 3 different scenarios.

Light Output used:

5000K

4000K

3000K

Behavioural Outcomes:

5000K = used for High Level of Focus and Concentration

4000K = used for Discussion and Group Activities

3000K = used to Calm students down after lunch and recess

LIGHT OUTPUT CONTROL BUTTONS	
LABEL	**DESCRIPTION**
SCENE 1	FULL – All luminaires on at 100% setting
SCENE 2	AV MODE – Luminaire row A turned off; other rows dimmed to 40% setting
SCENE 3	PRESENTATION MODE – Luminaire Row A on at 100% setting; other rows dimmed to 50% setting
SCENE 4	DIM – All luminaires on at 10% setting
ON	All luminaires powered on at their previous setting
OFF	All luminaires powered off
UP ARROW	Light output of all luminaires increased by 5%
DOWN ARROW	Light output of all luminaires decreased by 5%
SPD CONTROL BUTTONS	
GENERAL	All luminaires set to 4200 K setting
READING	All luminaires set to 3000 K setting
TESTING	All luminaires set to 3500 K setting
ENERGY	All luminaires set to 5000 K setting

4. Research done by:

Mott et al - a Study with 84 pupils (grade 3, age 7 to 8) was done to determine Oral Reading Fluency for two kinds of light conditions.

Light Output used:

500lx illuminance and 3500K (warm white)

1,000lx illuminance and 6500K (cold white)

Behavioural Outcomes:

Higher illumination level and Higher CCT leads to improved oral reading fluency by 36%

5. Research done by:

Sleegers et al. - Three Dutch Studies were performed to measure the effects of lighting on Focus Task: Study 1 comprises of 98 pupils = 52 pupils from control school (21 pupils in Grade 4 and 25 pupils in Grade 6) and 46 pupils from the experimental school (21 pupils in Grade 4 and 25 pupils in Grade 6). 39 Pupils were boys, and 59 Pupils were girls. The average age was 10 years.

Study 2 comprises of 44 pupils = 23 boys, 21 girls; average age = 10 years) 22 pupils from the control classroom and 22 pupils from the experimental classroom.

Study 3, designed as an experimental post-test control group design. For this study, the dynamic lighting system was installed in a windowless lecture room designed for 28 students at the University of Twente in the Netherlands.

Light Output used:

For Focus Task = (1st Study) 1,000lx illuminance and 6500 (cold white)

For Study Controls = (2nd Study) 600lx and 4000K, (3rd Study) 380lx and 3000K, (4th Study) 300lx and 3000K to 4000K

Behavioural Outcomes:

Higher illumination level and higher CCT leads to increased concentration

6. Research done by:

Lighting for People Lighting Europe & A.T. Kearney, A study on the Quantified Benefits of Human Centric Lighting includes 1,000 Students in Primary (6-12 yrs) and High School (12-18 yrs) as well as Teachers.

Light Output used:

No information available

Behavioural Outcomes:

4.5% Increase in Productivity

1% Decrease in Errors

1% Decrease in Absences

7. Research done by:

Abdullah et al., 2016 - Based on the Data from 21 participants (13 males , 8 females) from a study that lasted 10 days.

Light Output used:

Blue Light

Behavioural Outcomes:

24.3% Increase in convergent thinking

8. Research done by:

Bermudez (2018) - No sample size available

Light Output used:

Task Lighting

Behavioural Outcomes:

16% Increase in Task Performance

WORKPLACE

1. Research done by:

Phipps-Nelson, Redman, Dijk & Rajaratman, 2003 - No Sample Size available

Light Output used:

>1000 lx during daytime (compared to dim light - <10lx)

Behavioural Outcomes:

Induce alertness during daytime

2. Research done by:

Field study by Partonen and Lönnqvist (2000) - among office workers after four weeks of exposure to bright light. No sample size available.

Light Output used:

2500 lx at eye level, 6500K

Behavioural Outcomes:

Improved feelings of vitality and reduced depressive symptoms among office workers after four weeks of exposure - for at least one hour per workday during the dark winter months in Finland.

3. Research done by:

Smolders et al., 2012; Smolders & de Kort, 2014, Smolders, de Kort & van den Berg, 2013
- No sample size available

Light Output used:

1000lx at the eye

Behavioural Outcomes:

Can induce alertness and vitality during regular office hours, even in the absence of sleep and light.

4. *Research done by:*
Münch et. al - No sample size available
Light Output used:
1000lx at the eye, daylight sometimes combined with artificial lighting
Behavioural Outcomes:
Bright light exposure in the afternoon may affect alertness and performance in the early and late evening.

5. *Research done by:*
Hoffman et. al - Laboratory study, No sample size available
Light Output used:
500 - 1800lx at 6000K in the morning and early afternoon
Behavioural Outcomes:
Showed subtle improvements in subjective vitality and fatigue under exposure to a variable lighting regime with gradual changes in illuminance level in the morning and early afternoon as compared to constant office lighting at 500lx with a lower CCT (4000K) during daytime office work.

6. *Research done by:*
Dr. Marcella Ucci (Head of the MSc in Health, Wellbeing and Sustainable Buildings at the University College of London), No sample size available.
Light Output used:
The lighting in the room is linked to an astronomical clock - cool blue in the morning, brilliant white in the afternoon, and super warm as the day winds down.
Behavioural Outcomes:
The pilot study to measure impact on employees in a detailed post-occupancy study shows that productivity was boosted by up to 20%, Additionally employees were 38% calmer and 10% more focused than their colleagues in the rest of the office.

7. *Research done by:*
Eindhoven University of Technology - The study is part of a project called Personalised Intelligent Lighting Control Systems (PILCS) led by Professor Yvonne de Kort, No sample size available
Light Output used:
The office workers were first exposed to a randomly selected lighting regime for three weeks and then a new test regime for the following weeks. The workers in a control group received standard office lighting of an average illuminance of 500 lux on their desks in a neutral white light while those in the test group got a dynamic light with varying colour temperature and intensity. The light was customised to the test person's age and whether he or she is a morning lark or a night owl.

Behavioural Outcomes:

The researchers discovered that the workers with personalisation showed a higher illuminance level in the early morning. The colour temperature level at the desk and close to the eye was also higher in the personalised, dynamic scenario, regardless of the time. Those employees in the personalised lighting group received better-tuned lighting exposure, in spite of the fact that they were mobile and that daylight contributions were allowed in all conditions. The subjects reported having slept 26 minutes longer on average in the personalised scenario.

HEALTHCARE

1. Research done by:

Schlangen et al - randomised trials under controlled conditions in people with Seasonal Affective Disorder (SAD) and unipolar depression. No sample size available

Light Output used:

6000lx and more

1700lx - 3500lx

600lx

Behavioural Outcomes:

6000lx and more = more effective

1700lx - 3500lc = less effective

600lx = not effective

2. Research done by:

Martiny, Lunde et al. 2005; Sondergaard, Jarden et al. 2006. - No sample size available

Light Output used:

10000lx - Bright Light Therapy

4000 lx - Medium

50 lx - Dim Light

Behavioural Outcomes:

Bright Light Therapy, in comparison to medium or dim light, applied in the morning as an adjunct treatment, increases the anti-depressant effects of SSRIs such as sertraline and citalopram in patients treated for depression.

3. Research done by:

Buchanan, Barker, Gibson, Jiang, & Pearson, 1991 - Study to examine the effect of different illumination levels on Pharmacist prescription-dispensing error rate. - No sample size available

Light Output used:

450lx

1100lx

1500lx

Behavioural Outcomes:

1500lx = Medication-dispensing error rates were lower by 2.6%

450lx = error rates are at 3.8%

4. Research done by:

Beauchemin & Hays, 1996 - Study to examine the impact of Artificial Bright Light on reducing depression. - No sample size available

Light Output used:

2500lx to 10000lx

Behavioural Outcomes:

Exposure to natural bright light is effective in reducing depression.

5. Research done by:

Walch et al., 2005 - assess the amount of Sunlight in a Hospital Room modifies a patient's psychosocial health, quantity of analgesic medication used, and pain medication cost. - No sample size available

Light Output used:

46% Higher Intensity Sunlight on average

Behavioural Outcomes:

Patients exposed to an increased intensity of sunlight experienced less perceived stress, marginally less pain, took 22% less analgesic medication per hour, and had 21% less pain medication costs.

RETAIL

1. Research done by:

Andre Wiggerich, M.Sc together with Oktalite and Edeka Store in Lower Saxony, Germany conducted a case study at two Edeka Store over a total period of ten months in 2016. A control group study was conducted in several phases. Both groups of persons were surveyed at the same time to examine the interaction between customers and employees. A total of 39 employees and 329 customers took part in the study. Overall significantly more females (85%) than male (15%) employees worked in the two stores. On average, the employees were 43.38 years old. In the reference store, the employees had an average age of 47.11 and were thus somewhat older than in the HCL store, where the average age was 40.17.

Light Output Controls Used:

In the morning, the Lighting is characterized by neutral white colour temperature (4,000 K) as well as a reduced horizontal illuminance (700 lx). At midday and in the afternoon the colour temperature rises to 5,000 K (cold white) and the illuminance to 1,000 lx horizontally. Towards evening the horizontal illuminance drops to 600 lx.The colour temperature becomes warmer and drops to 3,000 K

Behavioural Outcomes:

- Time customers spend in the store is significantly longer by 21%

- Employee sickness-related day of absence reduce by 35%
- 35% of customers decided in favour of shopping at the HCL store because of the 'special atmosphere.'
- 23% Good Service observed by Customers
- 25% better sleep quality in the transition months March and October
- Customer assessed the Lighting to be 33% more natural
- Boosted Sales per section: +26% Fruit & Veg, +23% Wine & Spirits, + 28% Confectionery, +19% Dairy Products, +19% Drugstore, +23% Pre-packaged meat, +17% Frozen Products, +19% Meat Counter.

2. Research done by:

Philips Lighting produced the study in conjunction with major German grocer Globus, No sample size available.

Light Output Control used:

Three settings were tested including the store's uniform overhead lighting, regular spotlights and a combination of spotlights with pastel-coloured uplights.

Behavioural Outcomes:

Customer Visits to the revamped section are increased by 15% compared to an area lit with standard store lighting. Basket values were increased by 6%

3. Research done by:

Dutch supermarket giant PLUS partnered with Philips in a two-year pilot which measured the effect of ambient Lighting on shopper behaviour.

Light Output used:

The customized solution included general Lighting, indirect LED cove lighting and dynamic light 'recipes' in which variances of white light combined with selective colour tones.

Behavioural Outcomes:

- Customers spend 8% longer in-store to explore more and take different routes
- Basket Value has increased by 5.5%

4. Research done by:

E. Leclerc retail store in Langon, Southwestern France, a total of 771 people used the E.Leclerc app that gave them access to the Internet of Things (IoT) lighting system at the 75,000 sq.ft outlets. They wirelessly connected their smartphones to Bluetooth-equipped ceiling lights delivering discounts and information. The Supplier of the connected lighting system is Zumtobel.

Light Output used:

The 800 LED Luminaires are equipped with Bluetooth beacons for Indoor positioning to transmit information such as product offers and location to customers phones.

Behavioural Outcomes:
Revenue rose from 34% for the high turnover customers more than in the previous year. Another group of typically less-frequent buyers spent 42% more.

5. Research done by:
A study in California (Heschong, 2003) measured sales over 34 months in 73 different stores. No sample size available.
Light Output used:
One-third of the shops had diffuse skylights fitted which let in natural daylight; the other two-thirds did not.
Behavioural Outcomes:
Researchers concluded that daylight uplifted sales by between 1% and 6%. Critically, the additional sales represented a much larger financial benefit to retailers than the energy savings from using natural light. The increased profits were, in fact, between 19 and 100 times higher than the reduced energy bills.

RESIDENTIAL

1. Research done by:
The Farnsworth Group together with the 2017 MFE Concept Community conducted a survey examining usage and perceptions regarding next-gen building performance. The survey received online responses from 159 multifamily builders, developers and architects. Apartment units featuring next-gen products help bring in higher rents. Almost two-thirds of multifamily builders, developers and architects say they expect using next-gen products to increase the average return on investment.
Light Output used:
Lighting Fixtures (as part of the next-generation products) garner the top ROI.
Behavioural Outcomes:
8.8% of respondents rank Lighting fixtures as a top product to bring ROI.

2. Research done by:
T3 Sixty undertook a survey to determine the state of smart home adoption among residential real estate professionals. The survey was sent to U.S residential real estate brokers and agents and yielded 3,027 responses.
Light Output used:
Smart Home Lighting Technology as a marketing tool for Real Estate Professionals
Behavioural Outcomes:

- 23.55% Always use Smart Home Technology when marketing Real Estate
- 27.01% Very Often use Smart Home Technology when marketing Real Estate
- 40.69% Sometimes use Smart Home Technology when marketing Real Estate

- 30.42% Always respondents use Smart Home Technology
- 8.92% Very Often respondents use Smart Home Technology
- 13.28% Sometimes respondents use Smart Home Technology
- 78.8% of respondents said that buyers are willing to pay more for Smart Homes.

3. Circadian Rhythm and How it affects well-being, cognitive and mental processes.

Rattner (2017) indicates that central to any discussion of light is the circadian rhythm. A mashup of the Latin words for “approximately” (circa) and “day” (Diem), the term refers to the roughly 24-hour period it takes the earth to revolve once around its axis. Many aspects of human physiology are biologically pegged to this period, most noticeably the internal clock that controls our sleep-wake cycle. For example, the release of the hormone melatonin, which prepares us for sleep, is triggered by the onset of darkness, whereas the cool light of morning suppresses its production, enabling us to fully awaken and become energized before the cycle repeats itself again. Other hormones ebb and flow to regulate bodily functions throughout the cycle as well. Regardless of the myth of the depressed, debauched, and destitute artist, the truth is that being at your best creatively means being at your best physiologically and psychologically. Attuning your sleep-wake cycle to the circadian rhythm is an important step in that quest.

The challenge is that we are far removed from the purely natural environments of our caveman ancestors, for whom the sun was the sole source of light and who did not spend around 90 percent of their waking hours indoors, as we do. Absence of daylight can wreak on mind and body; the researchers found that people who work in windowless environments on average get 46 minutes less sleep on work nights, experiencing lower-quality rest. They are less physically active during the workday than colleagues who are afforded adequate exposure. Artificial illumination can thoroughly disrupt our circadian rhythms by exposing us to blue light at all hours of the day and not just from light bulbs. Our computer screens, mobile devices, televisions, and assorted electronic doodads all emit light in the blue spectrum.

Level of Illumination - That’s what psychologists Anna Steidel and Lioba Werth discovered when they assessed the effects of light intensity on creative insight. According to their findings, on average people exhibit a greater aptitude for solving creative problems working under relatively dim light (150 lux) than in a typical office (500 lux) or highly illuminated setting, like a television studio (1,500 lux). Darker is better for out-of-the-box thinking, Steidel theorizes that bright lights give people the impression they’re under surveillance, which in turn makes them feel less free to take risks for fear of criticism. Low-light conditions also discourage the eye from narrowly focusing on the details of our surroundings, leaving us free to engage in the abstract, big-picture style of mental processing associated with creative thinking.

(Abdullah et al., 2016) The effect of light on us is diverse and complex. In particular, when it comes to our circadian systems, light is often the most important environmental factor. Light modulate our neural and physiological processes depending on the wavelength, time, duration and intensity of exposure. These non- visual effects of light include improving mood and long-term memory.

It should be noted that these biological processes (e.g., mood and attention) reflect circadian rhythms. In general, a variable and adaptable lighting system could help ensure circadian stability. For example, it has been shown that circadian instability in shift-workers can be minimized by the appropriate use of light. Jet lag, another form of circadian disruption, could also potentially be reduced by light exposure. We believe there is a potential opportunity for developing circadian aware technology — systems that play to our biological strengths (and weaknesses).

Moreover, a system that focuses on stimulating our creative ability by providing appropriate support, depending on the task, along with taking individualized circadian rhythms into consideration. Lighting for People (2016) created an Infographic on how Human Centric Lighting affects Human Health and Well-being, which illustrated the need for the right light for our activities. They have noted and highlighted that Human Centric Lighting increases vision and performance of people with +4.5% increase in Productivity, -1% decrease in errors and absences.

4. Color, Brain and the Effects of Light

a. Endocrine system and lighting

(Leproult et al., 2001) The only well-documented effect of light exposure on endocrine function is the suppression of nocturnal melatonin. Bright light exposure has behavioural effects, including the alleviation of sleepiness during nocturnal sleep deprivation. The present study examines the effects of bright light on the profiles of hormones known to be affected by sleep deprivation (TSH) or involved in behavioural activation (cortisol).

The early morning transition from dim to bright light suppresses melatonin secretion, induced an immediate, greater than 50% elevation of cortisol levels, and limited the deterioration of alertness normally associated with overnight sleep deprivation. No effect was detected on TSH profiles. Afternoon exposure to bright light did not have any effect on either hormonal or behavioural parameters. The data unambiguously demonstrate an effect of light on the corticotropic axis that is dependent on time of day.

(Figuerio & Rea, C2012) Short-wavelength light enhances cortisol awakening response in sleep-restricted(sic) adolescents. Levels of cortisol, a hormone produced by the adrenal gland, follow a daily, 24hour rhythm with concentrations reaching a minimum in the evening and a peak near rising time. In addition, cortisol levels exhibit a sharp peak in concentration within the first hour after waking; this is known as the cortisol awakening response (CAR). It is now well accepted that the circadian system is maximally sensitive to short wavelength (blue) light (peak sensitivity close to 460 nm) as measured by Acute melatonin suppression or phase shifting of the dim light melatonin onset (DLMO).Short wavelength light has also been shown to increase heart rate and alertness at night and to induce an increase in clock gene PER2 expression in the evening.

The present results are the first to show that 40 lux of short wavelength (blue) light enhances CAR in adolescents who were restricted from sleep for one night (with 4.5 hours allowed in bed). An enhancement of CAR in humans by morning light exposure, especially in adolescents who tend to be sleep deprived, may be important to “stimulate” the body when it is time for it to be active and, thus, prepare adolescents for any environmental stress they might experience. In addition, the data presented here tentatively suggest that reduced evening light exposures may also influence CAR. Further studies should be performed to confirm these findings.

b. A critical analysis of chromotherapy and its scientific evolution

(Azeemi & Raza, 2005) Chromotherapy is a method of treatment that uses the visible spectrum (colours) of electromagnetic radiation to cure diseases. It is a centuries-old concept used successfully over the years to cure various diseases.

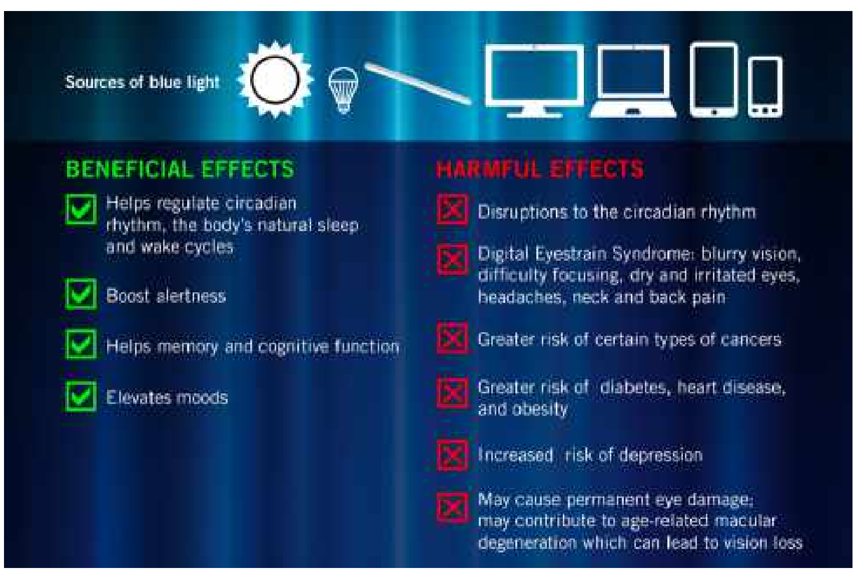
Chromotherapy is a narrow band in the cosmic electromagnetic energy spectrum, known to humankind as the visible colour spectrum. It is composed of reds, greens, blues and their combined derivatives, producing the perceivable colours with their unique wavelength and oscillations, when combined with a light source and selectively applied to impaired organs or life systems, provide the necessary healing energy required by the body. Light affects both the physical and etheric bodies. Colours generate electrical impulses and magnetic currents or fields of energy that are prime activators of the biochemical and hormonal processes in the human body, stimulants or sedatives necessary to balance the entire system and its organs.

Chromotherapy provides colours to the electromagnetic body or the aura (energy field) around the body, which in turn transfers energy to the physical body. This makes chromotherapy the most effective among various therapies. Understanding of these effects has come about only as a result of research into the hormones melatonin and serotonin, both of which are produced by the pineal gland in the brain. Melatonin is known to be the crucial chemical pathway by which animals respond to light and synchronize their bodily functioning with diurnal and seasonal variations. Serotonin, a stimulant is produced during daylight, whereas the output of melatonin, which is linked with sleep, increases when it is dark and has a generally depressive effect. This is reversed when it is light and the production of melatonin drops.

Light is responsible for turning on the brain and the body. Light enters the body through the eyes and skin. When even a single photon of light enters the eye, it lights up the entire brain. This light triggers the hypothalamus, which regulates all life sustaining bodily functions, the autonomic nervous system, endocrine system, and the pituitary (the body's master gland). The hypothalamus is also responsible for our body's biological clock. It also sends a message, by way of light, to the pineal organ, which is responsible for releasing one of our most important hormones, melatonin. The release of melatonin is directly related to light, darkness, colours, and the Earth's electromagnetic field. This necessary hormone affects every cell in the body. It turns on each cell's internal activities, allowing them to harmonize with each other and nature. The pineal gland is believed to be responsible for our feeling of oneness with the universe and sets the stage for the relationship between our inner being and the environment. If that relationship is harmonious, we are healthy, happy, and feel a sense of well-being. The Pineal is our "light meter".

c. The effects of blue light

(Blue Light Exposed 2018) Blue light is actually everywhere. When outside, light from the sun travels through the atmosphere. The shorter, high energy blue wavelengths collide with air molecules causing the blue light to scatter. This is what makes the sky look blue. In its natural form, your body uses blue light from the sun to regulate your natural sleep and wake cycles. This is known as your circadian rhythm. Blue light also helps boost alertness, heighten reaction times, elevates moods and increases the feeling of well being. Artificial sources of blue light include electronic devices such as cell phones, laptop computers as well as energy-efficient fluorescent bulbs and LED lights.



Blue wavelengths, which are beneficial during daylight hours because they boost attention, reaction times, and mood, are inversely most disruptive at night. The proliferation of electronics with screens, as well as energy-efficient lighting, is increasing our exposure to blue wavelengths, especially after sundown.

i. Bluelight and creative Thinking

(Abdullah et al., 2016) Given the importance of creativity for both personal and societal achievements, there have been consistent efforts to stimulate creative ability. But an important environmental factor, blue (i.e., short wavelength) light, has been relatively unexplored to date. Blue light improves a number of cognitive processes (e.g., attention, working memory and sleep) known to influence our creative abilities.

Blue light exposure resulted in significantly improving convergent thinking ability. The average increase in the convergent thinking score during light exposure days was around 24.3% compared to control days. However, it did not have any significant impact on divergent thinking.

Divergent and Convergent thinking - involve distinctly different neurophysiological processes with contrasting attentional focus requirements. While convergent thinking ability benefits from focused attention, divergent thinking requires defocused attention corresponding to a longer attention span. As such, the intervention requirements for stimulating these two opposing cognitive processes are very different, as evident from our findings. Walking in outside environments results in defocused attention, which helps to improve divergent thinking. On the other hand, blue light exposure, which is known to increase attention and focus, has an immediate positive effect on convergent thinking.

Our findings here about the efficacy of light exposure in significantly improving convergent thinking further reinforces the importance of dynamic light systems that are adaptable to the varying needs of the situation and the individual. Such a dynamic system would be particularly helpful in enabling individuals to shift between phases of divergent and convergent thinking modes and optimizing the creative process, as mentioned above. Beyond creativity, these systems could also be used to tune productivity and mood. A dynamic lighting system, as a result, has the potential of being indispensable in a workplace environment, in particular for the educational and scientific research domains.

ii. Effects of Blue Light on the circadian system and eye physiology

(Tosini et al., 2016) Although the light emitted by most LEDs appears white, LEDs have peak emission in the blue light range (400–490 nm). The accumulating experimental evidence has indicated that exposure to blue light can affect many physiologic functions, and it can be used to treat circadian and sleep dysfunctions. However, blue light can also induce photoreceptor damage. Thus, it is important to consider the spectral output of LED based light sources to minimize the danger that may be associated with blue light exposure.

(Harvard Health Publishing, 2012) Not all colours of light have the same effect. Blue wavelengths, which are beneficial during daylight hours because they boost attention, reaction times, and mood, are the most disruptive at night. And the proliferation of electronics with screens, as well as energy-efficient lighting, is increasing our exposure to blue wavelengths, especially after sundown. While light of any kind can suppress the secretion of melatonin, blue light at night does so more powerfully. Harvard researchers and their colleagues conducted an experiment comparing the effects of 6.5 hours of exposure to blue light to exposure to green light of comparable brightness. The blue light suppresses melatonin for about twice as long as the green light and shifted circadian rhythms by twice as much (3 hours vs 1.5 hours).

(Bradford, 2016) "In terms of light and our brains, there is a spectrum of wavelengths that impacts the human circadian system," said David Earnest, a professor and circadian rhythms expert at the Texas A&M Health Science Center College of Medicine. "Blue light is the most sensitive side of the spectrum."

A study by the University of Toronto found that those who wore glasses that blocked blue light wavelengths produced more melatonin than those who didn't during night shifts. Other studies have found that blue wavelengths suppress delta brainwaves, which induce sleep and boost alpha wavelengths, which create alertness.

iii. The unique health effects of blue light

(Holzman, 2010) Researchers are finding increasingly that an out-of-phase circadian rhythm is a health hazard. "Maintaining synchronized circadian rhythms is important to health and well being," says Dieter Kunz, director of the Sleep Research and Clinical Chronobiology Research Group at Charité–Universitätsmedizin Berlin. "A growing body of evidence suggests that a desynchronization of circadian rhythms may play a role in various tumoral diseases, diabetes, obesity, and depression."

Shift workers, whom Kunz calls "a model for internal desynchronization," are known to experience increased morbidity and mortality for a number of diseases, including cardiovascular disorders and cancer. In fact, in 2007, the World Health Organization decreed that shift work is a risk factor for breast cancer, and on that basis, in 2009, the Danish government began compensating some female shift workers with breast cancer. At the same time, researchers have repeatedly shown that bright white light has the power to mitigate depression and other maladies of mood. Emergent recent literature suggests that blue light may be particularly potent for such applications.

Researchers have shown in humans that light influences hormone secretion, heart rate, alertness, sleep propensity, body temperature, and gene expression. Moreover, in such studies, blue wavelengths have been found to exert more powerful effects than green wavelengths. In experiments published in the September 2003 issue of The Journal of Clinical Endocrinology and Metabolism, Brainard, Czeisler, and Steven Lockley, an assistant professor of medicine at Harvard Medical School, compared suppression of melatonin in humans during 6.5 hours of nighttime exposure by monochromatic light at 460 nm, the peak sensitivity of melanopsin cells, with 555 nm, the peak sensitivity of the visual system. The blue wavelength suppressed melatonin for about twice as long as the green.

In other experiments, blue also proved more powerful in elevating body temperature and heart rate and in reducing sleepiness, according to Gilles Vandewalle, of the Center for the Study of Sleep and Biological Rhythms at the University of Montréal. "Performance improves acutely after the onset of light exposure, both at night and during the day," Vandewalle and colleagues wrote in a review in the October 2009 issue of Trends in Cognitive Neuroscience. Electroencephalography has shown that light exposure reduces alpha, theta, and low-frequency activity, which are correlates of sleepiness. And Vandewalle showed that blue light proved superior to other wavelengths in enhancing responses in the left frontal and parietal cortices during a working memory task.

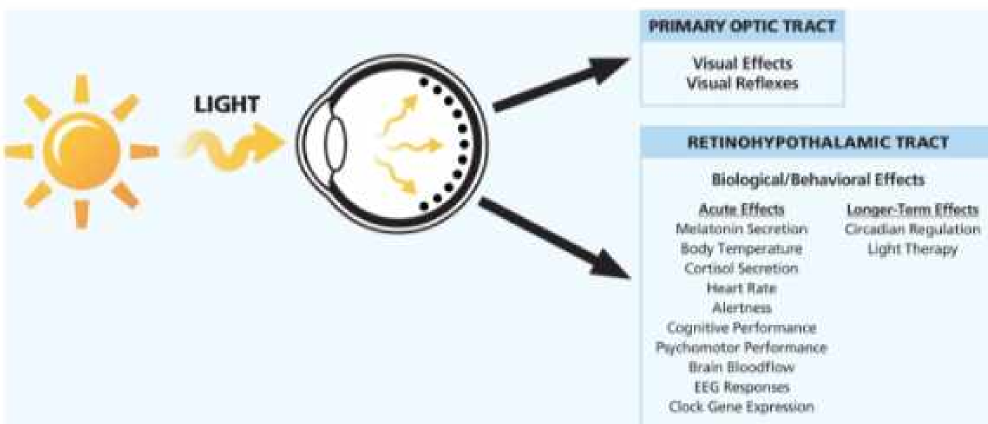
Daniel Kripke, an emeritus professor of psychiatry at the University of California, San Diego, thinks bright light, particularly blue wavelengths, may also prove useful for treating premenstrual depression and bulimia, and he says there is preliminary evidence it might be useful for anxiety. And researchers at Case Western Reserve University, led by Patricia Higgins, an associate professor of nursing, are testing bright blue lights in a long term care facility for patients with dementia. Very preliminary results "show promise in raising activity levels during daytime hours and increasing sleep at nighttime," she says.

Kunz believes rapidly increasing knowledge concerning the circadian timing system and the coordination of physiologic and psychologic processes on the one hand as well as the increasing understanding of the mechanisms of circadian entrainment will induce a substantial change in our daily living. "The major aim will have to be to strengthen the circadian timing system which can be achieved by increasing the blue portion in artificial light during daytime and by reducing the same blue portion of artificial light during the night and evening hours," he says. "Increasing the blue portion of artificial light may improve health in patients staying at nursing homes or hospitals." On the other hand, he adds, a reduction of the blue portion in artificial light during nighttime hours could protect shift workers against disorders such as cancer and cardiovascular disorders as well as reduce sleep disturbances and their consequences among the general population.

The irony of blue as an environmental agent is that before the industrial age, it was merely a colour. The unnatural lighting conditions we created turned it into both a potential hazard and a treatment for the ailments it brought about. In addition to the traditional architectural values of visual comfort, aesthetics, and energy efficiency, Brainard says architectural lighting must be redesigned to account for its biological and behavioural impact on humans. “Ultimately that should improve people’s health and well being in the built environment,” he says.

“Some people consider the progress in the field of light and health over the last couple of years as the most important light-induced innovation since the invention of the light bulb,” says Kunz. “Fascinating times are ahead of light industry, clinical chronobiologists, and architects, to mention just a few. By optimizing lighting regimes, we will be able to improve health, save energy, and improve learning and performance.”

The 1998 discovery of a new photoreceptor in the eye - which later turned out to be especially sensitive to Blue Light, revolutionized the way we think about how circadian rhythm is entrained. Today we understand that Blue Light has many unique physiological effects.



Light: An Influential Environmental Agent

Light acts on the body by two pathways: the primary optic tract governs visual perception and responses whereas the retinohypothalamic tract governs circadian, endocrine, and neurobehavioral functions. The retinohypothalamic tract is most sensitive to blue light stimulation—energy in the wavelength of roughly 459–485 nm.

Source: Benjamin Warfield and George Brainard/Thomas Jefferson University. Adapted by Matthew Ray/EHP.

Blue light both in subtle and dramatic forms surrounds us, its special properties serving many purposes. When it comes to light perception, glare and brightness are both functions of wavelength; the short wavelength of blue light appears relatively bright to human eyes, making this among the most energy efficient colours of light to produce. The bright bluish light emitted by high intensity discharge headlamps thus increases visibility while using less energy than halogen headlamps, but that brightness also can heighten glare for oncoming drivers, particularly elderly drivers, who may already have trouble seeing at night. Now ubiquitous compact fluorescent lamps (CFLs) similarly produce more light with less energy compared with incandescent lamps, and the bluer the CFL (“daylight” bulbs have the bluest colour balance), the more energy-efficient. More dramatic blue light is found in dental offices, where blue curing lights are used to harden amalgam material (orange goggles and filters provide eye protection against the intense light). The specific wavelength and intensity of the curing light stimulate a photoinitiator in the amalgam to decompose and initiate polymerization of the compound. But don’t think blue light is all work and no play.

Blue light-emitting goggles, panels, and other devices are used to treat problems such as sleep disorders, jet lag, seasonal affective disorder, and premenstrual syndrome. But blue light doesn’t work solely through ocular stimulation; the shorter wavelengths can penetrate the skin—this is how blue light is used to treat neonatal jaundice, in which the infant’s liver is unable to clear the normal hemolysis byproduct bilirubin. Bilirubin builds up in the blood and enters body tissues, making the eyes and skin appear yellow. Blue light penetrates the skin and converts bilirubin into forms that can dissolve into the blood and be excreted in urine. The process repeats as untreated bilirubin continues to deposit into tissues from the blood until most or all the bilirubin is converted.

iv. Melanopic Lighting

1. Melatonin and Melanopsin

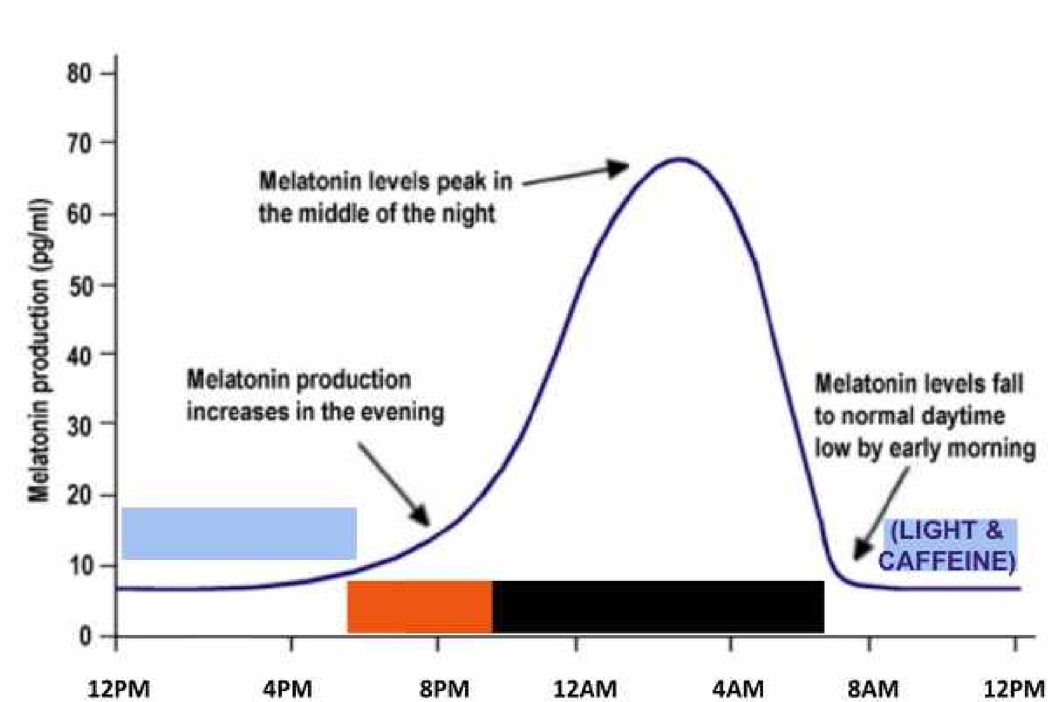
Melanopic Lighting originates from the name of the hormone Melatonin which regulates our circadian rhythm and controls our sleep-wake cycles. Bullock (2016) states that it is a lighting that’s tuned to both our visual and non-visual responses to light. Melanopic vision acknowledges that there is more going on than purely visual perception, there is also the biological impact of light.

Melanopsin on the other hand is defined as a (En.wikipedia.org, 2019) type of photopigment belonging to a larger family of light-sensitive retinal proteins called opsins and encoded by the gene Opn4. In humans, melanopsin is found in intrinsically photosensitive retinal ganglion cells (ipRGCs). ipRGCs are photoreceptor cells which are particularly sensitive to the absorption of short-wavelength (blue) visible light and communicate information directly to the area of the brain called the suprachiasmatic nucleus (SCN), also known as the central "body clock", in mammals. Melanopsin plays an important non-image-forming role in the setting of circadian rhythms as well as other functions.

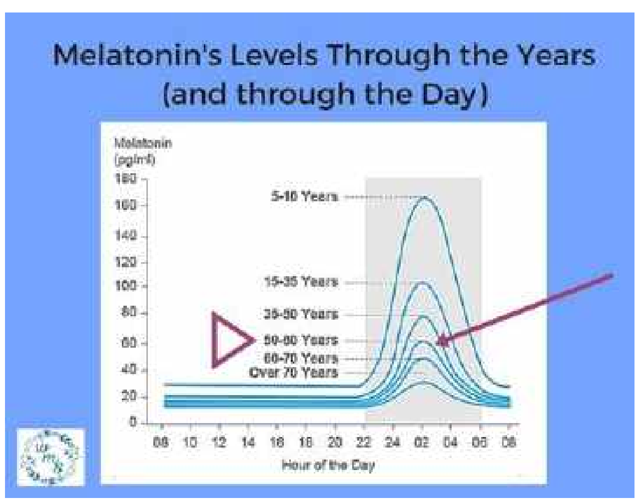
Through ipRGCs, lights of high frequency and intensity promote alertness, while the lack of this stimulus signals the body to reduce energy expenditure and prepare for rest.

(Jonelis, 2019) IpRGCs are exquisitely sensitive to the blue-green portion of the visible light spectrum because the intensity of blue-green light changes the most as the sun moves in the sky, with little blue-green light at sunrise/sunset, lots of blue-green light at noon. The "master clock" in our brain uses the signal from our eyes to regulate the release of hormones into our blood. The levels of these hormones oscillate over the course of 24 hours to let the organs inside our body know the time of day.

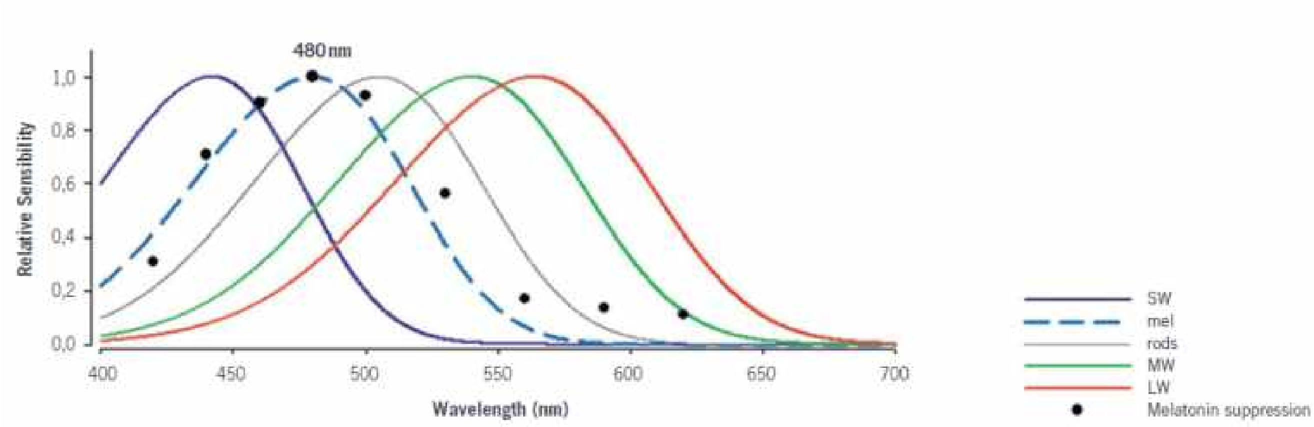
Activation of the ipRGC's by blue-green light suppresses the release of melatonin into the blood. Once the sun goes down and our eyes no longer detect blue-green light, melatonin levels in the blood start to rise. Our ideal bedtime is when melatonin blood levels are maximally rising, which usually occurs several hours after sunset. Melatonin levels continue to rise until around the midpoint of sleep, then decline again as we approach the morning. Melatonin remains in our system until our eyes again detect blue-green light and our master clock actively suppresses its release.



Leggett (2018) points out that Melatonin levels decrease as we age like all of our other hormones as shown on the graph below.



(Bullock, 2019) At the core of circadian lighting is the phenomenon that we call “the melanopic response”. This comes from the research that’s been going on into the non-visual effects of lighting. It relates to the way that blue frequencies in daylight restrict the production of melatonin in the body’s system until after dusk, after which time melatonin washes through the system – and it’s time for bed.



The frequency at which the melanopic response is most efficient is 480nm (or 490nm according to others). All LED lighting systems have a peak around this wavelength, the idea being that energy can be saved by concentrating the spectral distribution of the LED at those frequencies where there is a known physiological reaction.

2. Equivalent Melanopic Lux

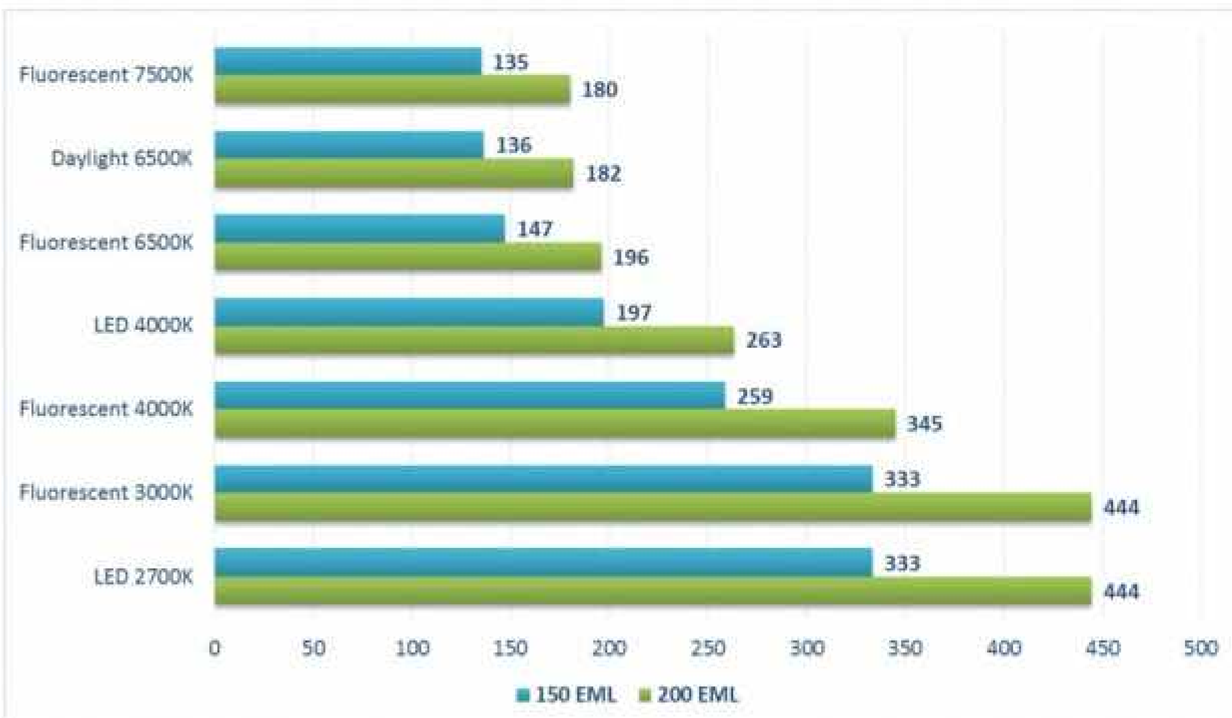
(En.wikipedia.org, 2019) Historically light was measured in the units of luminous intensity (candelas), luminance (candelas/m2) and illuminance (lumen/m2). After the discovery of ipRGCs in 2002 additional units of light measurement have been researched in order to better estimate the impact of different inputs of the spectrum of light on various photoreceptors. However, due to the variability in sensitivity between rods, cones and ipRGCs and variability between the different ipRGC types a singular unit does not perfectly reflect the effects of light on the human body.

The accepted current unit is Equivalent Melanopic Lux which is a calculated ratio multiplied by the unit lux. The melanopic ratio is determined taking into account the source type of light and the melanopic illuminance values for the eye's photopigments. The source of light, the unit used to measure illuminance and the value of illuminance informs the spectral power distribution. This is used to calculate the Photopic illuminance and the melanopic lux for the five photopigments of the human eye, which is weighted based on the optical density of each photopigment.

(Ticleanu, 2018) The WELL Building Standard Is the first standard to focus exclusively on the health and wellbeing of building occupants, aiming to improve their nutrition, fitness, mood, sleep, comfort and performance. Feature 54 promotes luminous environments that minimise disruption to the human circadian system.

Standard recommendations include at least 200 EML (Equivalent Melanopic Lux) – which may incorporate daylight – measured vertically at 1.2m above floor level at 75 percent of more workplaces for at least the hours between 9am and 1pm every day of the year. Alternatively, electric lighting alone should provide at least 150 EML.

The diagram below shows the equivalent visual lux levels for typical light sources and colour temperatures.



These are vertical illuminances; horizontal illuminances may typically be double these values.

These values may be very difficult or even impossible to achieve in most internal spaces using common artificial lighting practice. Lighting standards and codes generally recommend lower values of vertical illuminance to see visual tasks and avoid glare. The adjusted illuminance levels shown in the diagram are significantly higher and may be difficult to achieve from electric lighting alone. On the other hand, lower EML values from electric lighting would be beneficial in the evening to reduce unwanted health effects linked to melatonin suppression from bright light at the wrong time. The WELL standard does not explicitly recommend this, a potential weakness.

(Brennan and Collins, 2018) Successful outcomes in design practice requires simulation of vertical illuminance from all sources of light, including electric, daylight and reflected light incident at the eye of the viewer, and consideration of the spectrum of each source, energy code, glare and cost. In WELL projects, circadian light systems are spot checked after occupancy in the field with spectrometer measurements taken at any desk at an unknown time of year. Therefore, designers must account for spectral power distributions (SPD) for glazing, materials, daylight, and electric sources, as well as accounting of the variable illuminance from daylight, daylight dimming, and shade deployment.

(Healthfullighting.org, 2018) Equivalent Melanopic Lux (EML) can be calculated by multiplying the visual lux (L) designed for or measured in a building by a Melanopic Ratio (R) based on the light source:

EML = L x R

For instance, incandescent lights provide 200 lux of vertical illuminance in a space, Equivalent Melanopic Lux is calculated as 108.

EML = 200 x 0.54 = 108

If daylight is modeled to provide the same vertical illuminance of 200 lux, it will also provide 220 Equivalent Melanopic Lux.

EML = 200 x 1.10 = 220

Melanopic Ratio by Light Source

CCT (K)	Light Source	Ratio
2700	LED	0.45
3000	Fluorescent	0.45
2800	Incandescent	0.54
4000	Fluorescent	0.58
4000	LED	0.76
5450	CIE E (Equal Energy)	1.00
6500	Fluorescent	1.02
6500	Daylight	1.10
7500	Fluorescent	1.11

** Source: WELL Building Standard*

Melanopic Ratio (R) depends on the light spectrum, and it is obtained by multiplying the wavelength by the Melanopic curve provided by WELL Building Standard.

d. The subconscious and non-visual effects of colored lighting

(Varkevisser et al., 2011) Illuminance level and ambient colours appear to have differing effects on perception and to some degree on physiological parameters. In the present study, LED lighting was used in a mock-up office to expose 37 participants to two levels of illuminance, being 45 lx and 195 lx on the eye, and four ambient colour combinations, being Red-Green, Red-Blue, Green-Blue, Red-Green-Blue. Overall, the results showed interactions between lighting condition and illuminance levels on the currently investigated subjective and objective parameters.The expected arousing impact of colour combinations with a blue component was only partially observed in the current study. The results may have implications for future office design in which coloured lighting takes a central role.

Most evidence emerges from chronobiological studies, which have explored the direct effects of colour lighting typically during the nighttime period, and showing the arousing quality of blue light as compared to other light conditions (Cajochen et al., 2004; Gordijn et al. (2005). These effects can be attributed to a recently discovered photoreceptor that is particularly sensitive to the blue regions and primarily projects information to non- sensory brain areas, such as the suprachiasmatic nucleus where the biological clock is situated (Berson et al, 2002; Brainard et al., 2001).

Nonvisual Effects of Led Coloured Ambient Lighting 165

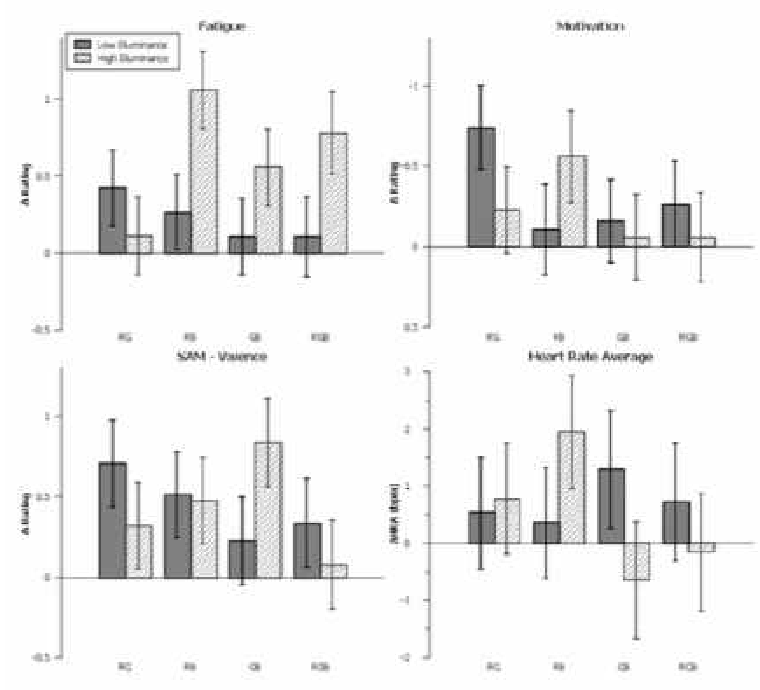


Fig. 2. Estimated Marginal Means ± SEM of Fatigue, Motivation, Mood Valence, and Heart Rate Average. Note that the axis for Motivation is inverted: a higher negative score denotes less motivation

The present study explored the impact of ambient LED colour light and illuminance level on momentary wellbeing, and cardiac reactivity after relatively short, repeated periods of mental stress. Overall, the results showed the most robust effects in momentary wellbeing. Most significant effects were due to the influence of colour light in interaction with illuminance level. In particular, magenta (RB) and yellow (RG) elicited relatively strong negative effects across these measures.

With respect to momentary wellbeing, the RG and RB colours in the present study elicited strong reactions on fatigue. Yet, this was also dependent on illuminance condition. In the low illuminance condition, the RG colour elicited a stronger negative effect on fatigue, whereas in the high illuminance condition this was true for the RB colour. Although the strength of the blue light component might not have been sufficient to increase arousal (Berson et al., 2002; Brainard et al., 2001; Mills et al., 2007), it does not explain the increase in for instance fatigue. The participants indicated annoyance –a more perceptual/visual quality compared to the other well- being parameters– in the RG and RB conditions. Thus, it might have been more tiresome/straining to work in the RG and RB light conditions leading to decreased feelings of wellbeing.

(Philips Lighting Blog 2015) The colour is frequently used in the lighting industry to bring a bright, vibrant feel to an environment. Now that the lighting industry is beginning to understand these effects, coloured light is helping people all over the world. Listed below are the effects of coloured lighting.

- Blue - Blue lighting has a special effect on the body in a variety of ways. Many findings show that the human eye has photoreceptors that are sensitive to blue light, which has an effect on circadian rhythm. Because of this, blue light is good when waking up in the morning and helping a person readjust his circadian rhythm when travelling and suffering from jetlag. Blue LED lighting can also be used to increase blood flow, as the skin is also sensitive to the colour blue, and can ultimately remove pain in the body and promote healing.
- Green - a calming colour, conveying hope, soothing and healing. The colour green is the most visible and sensitive colour to the human eye. Green lighting was introduced into operating rooms in 1914 by Dr Harry Shermanwho found the colour green reduces glare and complements haemoglobin red, the colour of blood, to create a more visible environment for surgeons. Green light can also enhance learning and concentration, which is why it is sometimes used in classrooms.
- Yellow - a warm colour, which can evoke feelings of happiness or joy, as well as spark muscle energy and mental activity. The colour yellow catches attention, which is why it is used often on taxicabs or school buses. In hospitals, warm tones of yellow lighting are used to create a relaxed and cosy atmosphere, which can help patients get to sleep at night.
- Orange - a welcoming colour, creating a friendly atmosphere. Some of the meanings behind the colour orange are friendship, endurance, enthusiasm, and creativity. Orange lighting is perfect for bringing home a newborn baby, making them feel at home, welcome, and comfortable, considering red, orange, and yellow are some of the first colours a baby can see. It can also stimulate appetite in young people, which is why orange is associated with healthy foods. The colour orange can also increase oxygen to the brain, therefore triggering increased mental activity.
- Purple - Light purple generates feelings of wisdom, inspiration, and magic. Dark purple can deter people because it can be associated with sadness or frustration. In hospitals, a purple, or violet

light, called “HINS-light”has been found to kill “superbugs” like MRSA and C. difficile. According to researchers at the University of Strathclyde in Glasgow, Scotland, better sterilization and disinfection methods in hospitals are considered urgent needs, making this an important finding within the field

- Red - has a lesser effect on circadian rhythms, making it an excellent choice for evening lighting.

5. WELL Building Standards for Lighting

a. Overview

Developed by Delos, the WELL Building Standard is the result of 7 years of meticulous research in collaboration with chief scientists, physicians, and industry professionals. WELL is administered and managed by a public benefit corporation named IWBI (International WELL Building Institute). The motive of WELL is to boost human health & wellbeing through the built environment. International WELL Building Institute has joined forces with GBCI (Green Business Certification Inc.), the same firm that manages LEED certification, to offer third-party certification for different rating systems relating to the built environment.

WELL v2 consolidates previous iterations and pilots into one WELL for all project types. The system is designed to grow in specificity and specialty over time, adapting to accommodate diverse project types and geographies and in response to new evidence and ever-evolving public health imperatives. A Dynamic WELL Scorecard guides project teams through the development of a unique scorecard. This digital platform recommends a selection of features based on project-specific parameters that can be further defined and refined by the project team. There are ten concepts in WELL v2: Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind and Community. Each concept consists of features with distinct health intents. Features are either preconditions or optimizations.

Projects must achieve all preconditions, as well as a certain number of points to earn different levels of certification:

- WELL Certification Silver: 50 points.
- WELL Certification Gold: 60 points.
- WELL Certification Platinum: 80 points.

Projects must earn a minimum of two points per concept. Projects may earn no more than 12 points per concept.

WELL Core projects must achieve all preconditions as well as a certain number of points to earn different levels of certification:

- WELL Core Bronze Certification: 40 points.
- WELL Core Silver Certification: 50 points.
- WELL Core Gold Certification: 60 points.
- WELL Core Platinum Certification: 80 points.

For WELL Core Certification, projects must earn a minimum of one point per concept. Projects may earn no more than 12 points per concept

Innovation features promote the continuous evolution of the WELL Building Standard by encouraging projects to go above and beyond existing WELL feature requirements or to propose a new intervention that addresses health and well-being in a novel way. Projects can submit proposals and may receive up to 10 points in Innovation.

To know more about the WELL Building Standard you can visit their Website and review the WELL V2 version or download the WELL V2 PDF Standards.

b. IALD + LIRC Guidelines For Well Rating Systems

These recommendations help lighting manufacturers create standardized information to help lighting designers determine if their designs will meet the WELL Building Standard criteria. The IALD + LIRC offers four recommendations for the sections with required documentation that provide guidelines for best practices for lighting manufacturers. Through these guidelines, lighting designers working on WELL projects will be able to easily identify the relevant data from manufacturers and make comparisons based on standardized formatting. This will allow lighting designers to more easily determine if their designs will meet the WELL Building Standard criteria.

HOW TO USE THIS GUIDE

Manufacturers should refer to two types of guidelines, required and recommended, to be included in manufacturer documentation. These guidelines define a general format for communicating specifications on manufacturers' specification documents, data sheets or "cut sheets" as well as the supporting documentation required to validate the published values.

REQUIRED: Minimum required manufacturer documentation which must be included in specifications or supplementary technical documentation for each product.

RECOMMENDED: Recommended practice may include additional documentation or information that will assist lighting designers to demonstrate compliance with the WELL Building Standard v2 pilot.

FIRST RECOMMENDATION: MELANOPIC RATIO GUIDELINES
WELL CONCEPT / LIGHT / FEATURE L03 - CIRCADIAN LIGHTING DESIGN
FOR all spaces - 3 pt. Maximum

The WELL feature L03 Circadian Lighting Design requires projects to provide users with appropriate exposure to light for maintaining circadian health and aligning the circadian rhythm with the day - night cycle.

<u>REQUIREMENTS FOR THIS FEATURE:</u>
Electric lighting is used to achieve light levels shown in the table below as measured on the vertical plane at eye level of the occupant. The light levels are achieved at least between the hours of 9 A.M. and 1 P.M. and may be lowered after 8 P.M.

The project meets the following requirements in regularly occupied spaces:

ELECTRIC LIGHT ONLY		ELECTRIC LIGHT AND DAYLIGHT	PTS
At least 150 EML [136 melanopic equivalent daylight D65]	or	The project achieves at least 120 EML [109 melanopic equivalent daylight D65] with electric light and at least 2 points in Feature L05: Enhanced Daylight Access.	1
At least 240 EML [218 melanopic equivalent daylight D65]	or	The project achieves at least 180 EML [163 melanopic equivalent daylight D65] with electric light and at least 2 points in Feature L05: Enhanced Daylight Access.	3

EML stands for Equivalent Melanopic Lux, and is defined by the photopic lux multiplied by a melanopic ratio, EML = LxR.

MINIMUM REQUIRED MANUFACTURER DOCUMENTATION:

For each unique light spectrum (CCT, CRI, LED source, etc.), manufacturers must provide a value for the melanopic ratio using the IWBI Melanopic Ratio or equivalent tool.

Example:

	2700K		3000K		3500K		4000K	
	80+	90+	80+	90+	80+	90+	80+	90+
Luminous Flux Multiplier	0.85	0.75	0.90	0.80	0.95	0.85	1.00	0.90
Melanopic Ratio	0.362	0.476	0.411	0.593	0.532	0.602	0.705	0.775

RECOMMENDED PRACTICE:

Provide Spectral Power Distribution (SPD) for each unique light spectrum (CCT, CRI, LED source, etc.) with the following characteristics:

- Radiant power values for wavelengths between 380nm-730nm in 5nm increments
- File type should be .csv or similar to allow simple copy/paste into the calculation tool

SECOND RECOMMENDATION: GLARE GUIDELINES
WELL CONCEPT / LIGHT / FEATURE L04 - GLARE CONTROL
FOR all spaces - 3 pt. Maximum

The WELL feature L04 Glare Control requires projects to manage glare by using a combination of strategies such as calculating of glare, choosing appropriate light fixtures for the space and using shading techniques. Space planning and lighting design can minimize the amount of glare experienced by individuals in the space. For electric lighting, the light source, type of luminaires used and lighting layout can lead to reduced glare.

REQUIREMENTS FOR THIS FEATURE:
Each luminaire meets one of the following requirements for regularly occupied spaces. Wall wash fixtures properly aimed at walls, as specified by manufacturer's data, as well as decorative fixtures may be excluded from meeting these requirements:

• 100% of light is emitted above the horizontal plane
• Unified Glare Rating (UGR) values are met as per the below conditions:

1. Luminaires installed at a height of 5 m [16 ft] or lower meet UGR of 19 or lower
2. Luminaires installed at a height greater than 5 m [16 ft] meet UGR of 22 or lower

• Shielding angles are as described in the below table:

LUMINANCE	SHIELDING ANGLE, α (α = 90 - CUTOFF ANGLE)
< 20,000 cd/m² (Include reflected sources)	No shielding required
20,000 cd/m² to 50,000 cd/m²	15°
50,000 cd/m² to 500,000 cd/m²	20°
> 500,000 cd/m²	30°

• Fixtures have a luminance of less than 10,000 cd/m2 between 45 and 90 degrees from nadir, and/or an intensity of less than 1,000 candela between 45 and 90 degrees from nadir

MINIMUM REQUIRED MANUFACTURER DOCUMENTATION:

For each luminaire type, manufacturers must provide a statement of compliance for one of the four methods or exclusion from the standard, plus supporting values as defined in the compliance category.

Example of all options:

L04 GLARE CONTROL CRITERIA	COMPLIANT	VALUE
a. Indirect (100% emission above horizontal)	✓	100%
b. Unified Glare Rating (UGR)	✓	15 @ 16ft 17 @ 20ft
c. Shielding Angle	✓	17° @ 35,000 cd/m²
d. Max. Luminance / Max. Intensity (45°–90°)	✓	1500 cd/m²
e. Not Applicable	✓	Decorative

Example Luminaire A

L04 GLARE CONTROL CRITERIA	COMPLIANT	VALUE
a. Indirect (100% emission above horizontal)	✓	100%
b. Unified Glare Rating (UGR)		
c. Shielding Angle		
d. Max. Luminance / Max. Intensity (45°–90°)		
e. Not Applicable		

Example Luminaire B

L04 GLARE CONTROL CRITERIA	COMPLIANT	VALUE
a. Indirect (100% emission above horizontal)		
b. Unified Glare Rating (UGR)		
c. Shielding Angle		
d. Max. Luminance / Max. Intensity (45°–90°)		
e. Not Applicable	✓	Decorative

THIRD RECOMMENDATION: COLOR RENDERING GUIDELINES
WELL CONCEPT / LIGHT / FEATURE L07 - ELECTRIC LIGHT QUALITY PART 1
ENSURE COLOR RENDERING QUALITY
FOR all spaces except circulation areas - 1 pt. Maximum

The WELL feature L07 Electric Light Quality requires projects to consider characteristics of electric light used in the space such as color rendering, color quality and flicker. Humans have evolved to depend on the sun as the main and ideal source of light and are tuned to the color rendering provided by daylight and recognize colors in association with daylight. Color can impact peoples' cognition and behavior. Using electric light with high color rendering can improve people's perception of a space, while low color rendering can impact the ability to differentiate between objects and perceive the surroundings accurately.

REQUIREMENTS FOR THIS FEATURE - PART 1
Electric lighting meets at least one of the following color rendering requirements. (Decorative fixtures, emergency lights and other special-purpose lighting may be excluded from these requirements.)

METRIC	THRESHOLD
CRI	CRI > 90
CRI, R9	CRI > 80 with R9 > 50
IES TM-30-18	IES $R_f \geq 78$, IES $R_g \geq 100$, $-1\% \leq$ IES $R_{cs,h1} \leq 15\%$

Note: CRI = Ra

! MINIMUM REQUIRED MANUFACTURER DOCUMENTATION:

For each unique light spectrum (CCT, CRI, LED source, etc.), manufacturers must provide a statement of compliance plus supporting values, including R9 where the second criterion is applicable.

Example:

L07 ELECTRIC LIGHT QUALITY PART 1 ENSURE COLOR RENDERING QUALITY	COMPLIANT	VALUE
CRI > 90		
CRI > 80 with R9 > 50	✓	CRI = 84 R9 = 60
IES Rf ≥ 78, IES Rg ≥ 100, -1% ≤ IES Rcs, h1 ≤ 15%		
Not Applicable (decorative, emergency, other)		

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FOURTH RECOMMENDATION: FLICKER GUIDELINES
WELL CONCEPT / LIGHT / FEATURE L07 - ELECTRIC LIGHT QUALITY PART 2
MANAGE FLICKER
FOR all spaces- 1 pt. Maximum

The WELL feature L07 Electric Light Quality requires projects to consider characteristics of electric light used in the space such as color rendering, color quality and flicker. Electric lighting used indoors can have low frequencies of flicker that are not present in daylight. Flicker has been associated with eye strain, headaches, migraines and epileptic seizures. Identifying and utilizing lighting fixtures that emit a high quality of light and do not display signs of flicker contributes to a comfortable and healthy space.

<u>REQUIREMENT FOR THIS FEATURE - PART 2:</u>

All electric lights (except decorative lights, emergency lights and other special-purpose lighting) used in regularly occupied spaces meet at least one of the following requirements for flicker:

• A minimum frequency of 90 Hz at all 10% light output intervals from 10% to 100% light output.
• LED products with a “low risk” level of flicker (light modulation) of less than 5%, especially below 90 Hz operation as defined by IEEE standard 1789-2015 LED.

MINIMUM REQUIRED MANUFACTURER DOCUMENTATION:

Non-LED Luminaires

For each ballast/light source combination available, manufacturers must provide a statement of compliance plus a supporting value for minimum frequency in the output range of 10%-100% full light output.

Example:

L07 ELECTRIC LIGHT QUALITY PART 2 MANAGE FLICKER	COMPLIANT	VALUE
Minimum frequency of 90 Hz within the range of 10% to 100% light output	✓	400 Hz

LED Luminaires

For each driver/light source combination available, manufacturers must provide a statement of compliance with IEEE Standard 1789-2015 with supporting values for full light output. At a minimum, this includes publishing the numerical values.

Example:

L07 ELECTRIC LIGHT QUALITY PART 2 MANAGE FLICKER	COMPLIANT	VALUE
Meets IEEE 1789-2015 Standard Recommended Practice	✓	Modulation = 1% Frequency = 80 Hz

RECOMMENDED PRACTICE:

It is strongly recommended that manufacturers provide the supporting data using the Modulation (%) vs Frequency (Hz) chart that is included in the IEEE standard (Figure 20 – Recommended Practice).

Example: Modulation vs Frequency from Section 8.1 of IEEE 1789-2015*

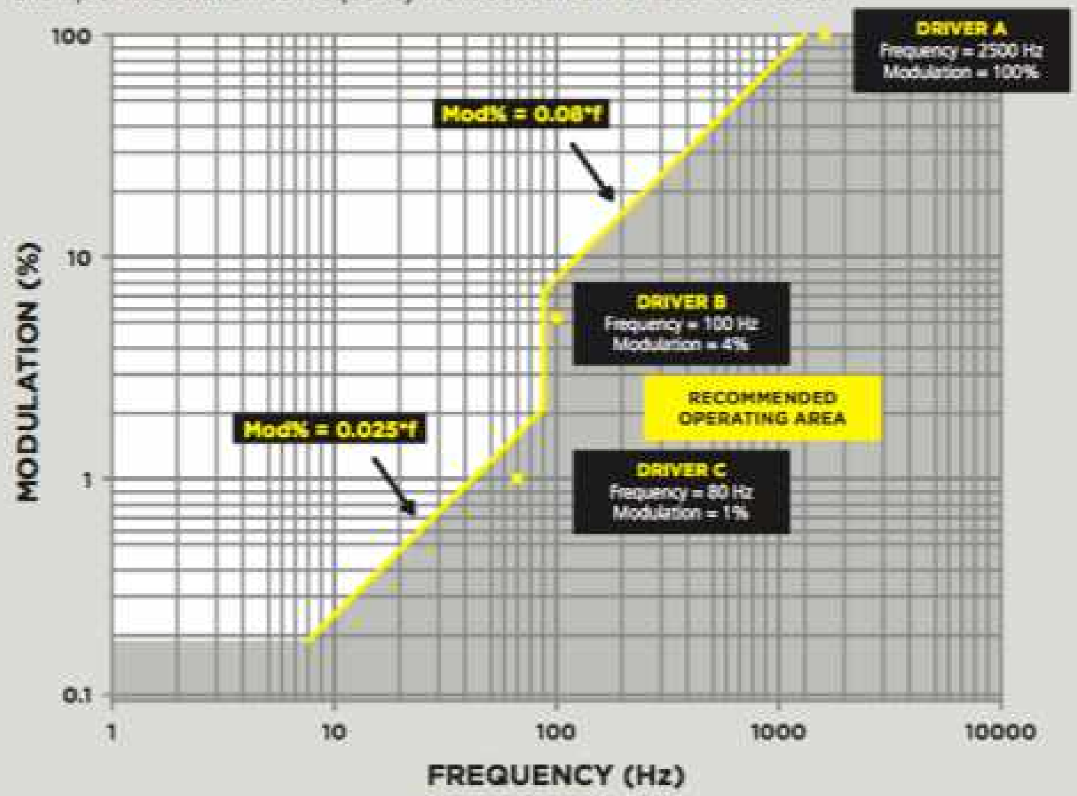


Figure 20—Recommended practices summary

Limitations:

- Values provided are for 100% light output
- Values provided are for static white operation at a single CCT

Optional:
Manufacturers may provide modulation vs frequency values for dynamic driver/light source combinations (for example, CCT tuning, dimming levels, etc.)

RECOMMENDED PRACTICE:

- Publish modulation % vs frequency for dimming levels
- Publish Flicker Index: provides a familiar metric for comparison of traditional and LED sources
- Publish Flicker Percentage: simple to calculate and provides an indication of flicker behavior

6. Light Spectrum and its effects on wellness and learning in Education Environment.

a. Creative Thinking: Convergent Thinking vs Divergent Thinking

(Martin 2015) States that when it comes to problem-solving and idea generation, two ways are commonly cited, namely divergent and convergent thinking strategies. The convergent style of thinking was rapidly equated with typical intelligence, while divergent thinking was equated with creativity. There has been an increasing acceptance of the fact that real creative production needs both divergent thinking and convergent thinking. (Chermahini & Hommel 2011) Growing evidence suggests that emotions affect cognitive processes, and recent approaches have also considered the opposite, that cognitive processes might affect people's mood. Research indicates that convergent and divergent thinking affect mood in converse ways. With convergent thinking triggered a negative mood, and divergent thinking triggered a positive mood.

b. Human Centric Lighting: The Future of Education Lighting Design

(Kluizenaar et al. 2016) The recommendations detailed below are based on the guidance provided by stakeholders during interviews and literature reviews, complemented by feedback received from experts, cities and SMEs. This effort led to two application recommendations:

Application recommendation 1:

Similar application recommendations included for the workplace are proposed for educational settings. The two distinct sectors share similar needs in terms of lighting supporting alertness and productivity, while contributing to a good sleep at night (important for memory consolidation and recovery), whilst incorporating a desired level of flexibility to adapt to individual characteristics and/or needs, time of day and activity.

- Provide lighting solutions with software-driven dynamic changes in lighting spectral composition and intensity;
- Provide lighting to pupils with a relatively high 'blue' content along with natural daylight during the day time to support alertness;

- Provide dynamic lighting, depending on the time of the day, with higher light intensity along with higher blue content, using cooler tones of light and higher colour temperatures during morning hours.
- Solutions where the light is not too focused and illuminating larger areas, to enhance comfort.

Application recommendation 2:

Lighting systems to support the improvement of the learning experience by providing more structure to classes during school days (e.g. with predefined settings) and making clear to students what kind of activity is expected at a certain moment in time. Lighting solutions to support different levels of concentration in order to perform tasks with a variable degree of complexity, as well as relaxation during breaks.

This may include the following practical recommendations:

- Presets for different activities for example ‘concentrated working’ (providing higher light intensity, together with higher blue content in the spectral composition, and using higher colour temperatures);
- Presets for ‘relaxed working’ / supporting relaxation (providing lower light intensity, together with warmer light tones in the spectral composition).

c. Effects of Lighting to enhance focus, reduce glare and provide correct lux levels

i. Case Studies

Numerous studies and experiments have been conducted on LED lighting systems in a classroom setting. An example of this was done at Carrollton-Farmers Branch Independent School District in Carrollton, Texas. (Pacific Northwest National Library for US Department of Energy, 2017) The lighting control system installed provided the ability to vary the spectral power distribution (SPD) of the lighting across four preset conditions, associated with nominal CCTs of 3000K, 3500K, 4200 K, and 5000K. The controls also provided for preset scene controls to vary the on/off status and dimming level of different luminaire zones within the room, to better support classroom functions such as AV presentations and student speeches

LIGHT OUTPUT CONTROL BUTTONS	
LABEL	**DESCRIPTION**
SCENE 1	FULL – All luminaires on at 100% setting
SCENE 2	AV MODE – Luminaire row A turned off; other rows dimmed to 40% setting
SCENE 3	PRESENTATION MODE – Luminaire Row A on at 100% setting; other rows dimmed to 50% setting
SCENE 4	DIM – All luminaires on at 10% setting
ON	All luminaires powered on at their previous setting
OFF	All luminaires powered off
UP ARROW	Light output of all luminaires increased by 5%
DOWN ARROW	Light output of all luminaires decreased by 5%
SPD CONTROL BUTTONS	
GENERAL	All luminaires set to 4200 K setting
READING	All luminaires set to 3000 K setting
TESTING	All luminaires set to 3500 K setting
ENERGY	All luminaires set to 5000 K setting

Table 1. Descriptions for the control buttons installed in each classroom. The control configuration used is shown in Figure.

The four SPD settings are shown in clockwise order, beginning with the upper left photo: 3000 K (Reading), 3500 K (Testing), 4200K (General), and 5000K (Energy). The Scene 1 setting was used during the photographs, so all luminaires were on at full light output. (Photos courtesy of ABL.)

The Scenario - Fifth Grade Math and Science Teacher at DES

During the majority of the time with students, this teacher used Scene 1 (all luminaires on at the 100% control setting). She used Scene 2 (AV mode with the front row of luminaires off and other room luminaires dimmed to the 40% output setting) occasionally for presentations but felt that this scene was sometimes too dark overall. Whenever this teacher wanted to introduce a “breathing” period - she would set the lighting controls to Scene 4 (all luminaires dimmed to the 10% output setting). As a rough estimate, this teacher used Scene 1 for 70% of the class time, Scene 2 for 25%, and Scene 4 for 5%. Scene 3 (presentation mode with the front row of luminaires on at 100% setting; other rows dimmed to 50% setting) was not used. For the SPD settings, the General setting (4200 K) was used for most class activities. The Reading setting (3000 K) was used on occasion for the breathing times and also was used whenever students were working on digital notebooks (iPads or Chromebooks). The Testing setting (3500 K) was used consistently during the standardised state tests. The teacher used the Energy setting (5000 K) several times in the mornings, but she personally found that setting to be visually uncomfortable and stopped using it.

Conclusion & Key Highlights:

- The reduction in input power for the tunable-white LED lighting system used in the three classrooms was estimated to be 58% relative to the incumbent fluorescent system.
  This reduction in luminaire power is attributable to the higher efficacy of the LED luminaires and a reduction in illuminances, which previously exceeded IES-recommended levels.
- The dimming incorporated into the scene controls and separate up and down dimming controls furthered the energy savings in each classroom. While the individual teacher’s usage of the controls varied widely, in each case the lighting consistently operated with all or some of the luminaires turned off or dimmed for portions of the school day.
- The LED lighting systems were installed and commissioned with very few difficulties, and any issues with initial performance were quickly resolved.
- The three teachers involved used the scene controls regularly during the school day, but used the SPD controls infrequently.
- Illuminance levels in the classrooms at maximum output met or exceeded IES recommendations for the typical visual tasks, with both the new LED and the incumbent fluorescent systems.
- Color consistency for the tunable white LED luminaires used in the classrooms was very good among luminaries and very good over the dimming range, with minor variations in CCT and D_{uv}.
- The two teachers interviewed by DOE appreciated the ability to tailor the lighting to different classroom needs, and felt that the lighting and controls allowed the students to be engaged in

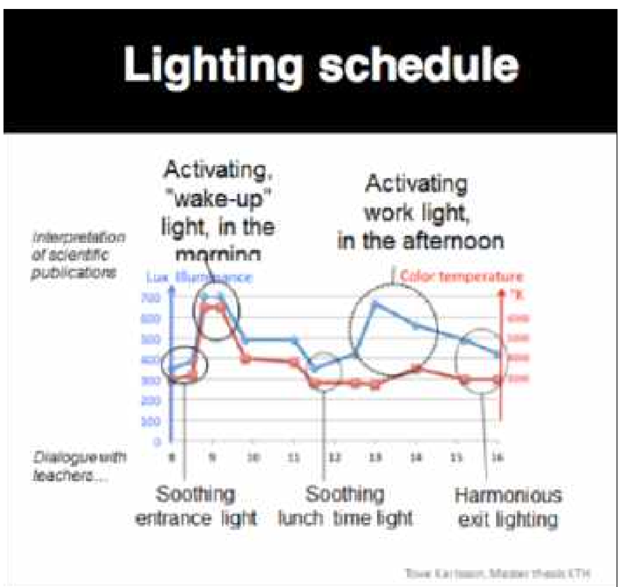
choosing the settings for various classroom activities. Both teachers stated that the lighting system improved the overall learning environment.

Another case study was done in Malmo School - Lighting or People (2016) The City of Malmo governors and engineers soon realised that top-class education would be crucial to the success of the city. A review of lighting in the existing schools showed it to be old and inefficient. New lighting was needed, and it was decided to make a trial of human centric lighting, HCL, to make the classrooms more attractive and more conducive to learning.

The solution:

- Tuneable white 60X60, 2700 – 6500 K, 3800 lm, Dali 2, from Candelux
- Crestron 5"- panel for switching scenarios
- Dali and Crestnet protocol
- Lighting schedule from LTH
- Colour temperature between 2700 K – 5800K

Lighting Schedule implemented in the Malmo School Case Study



Lighting schedule

Time	Intensity	CT
08:00	70 %	2700
08:40	100 %	6500
09:00	100 %	5000
11:00	70 %	4000
11:30	70 %	3000
12:00	70 %	2700
12:20	80 %	4000
13:00	90 %	5000
13:20	70 %	4000
14:00	70 %	3500
14:20	70 %	3500
14:50	70 %	3500
15:20	60 %	2700

ii. Lighting Design Techniques

(Branz Ltd for Ministry of Education, 2007) - For classrooms, suitable illumination levels are between 300 to 500 lux at the working plane. Good illumination is most important at desktop height. Illumination levels for most school spaces are assessed at a working plane about 800 mm above floor (700 mm for desks and 850 mm for benches – Figure 1).

FIGURE 1 Light is measured at the appropriate plane

Lighting requirements for schools: Table 4 quantifies the factors discussed above and is adapted from AS 1680.2.3: 1994.

TABLE 4: SPECIFIC RECOMMENDATIONS FOR TEACHING SPACES

Type of space	Maintenance illumination lux	Lamp appearance group	Lamp colour rendering group	Maximum glare index	Comments
Multi-purpose halls					
• general use	160	warm or intermediate	1B or 2	19	
• social use	80	warm or intermediate	1B or 2	19	
• examinations	240	warm or intermediate	1B or 2	19	
• theatre use					special requirements
General classrooms	240	warm or intermediate	1B or 2	19	
Workshops	240				with task lighting
Art rooms	400 to 800	warm or intermediate	1A	16	see *Specialist Teaching Spaces*
Laboratories	320	warm or intermediate	1A or 1B	19	
Music rooms	320	warm or intermediate	1B or 2	19	
Textile craft rooms	320	warm or intermediate	1B or 2	19	task lighting
Gyms	320	warm or intermediate	1B or 2	19	see *Specialist Teaching Spaces*
Libraries	240	warm or intermediate	1B or 2	19	see *Specialist Teaching Spaces*

(Lang et al., 2014) Besides the short-term effects of light on different academic tasks, also a long-term effect is measurable that shows how blue-enriched light during the morning hours in school improves different academic requirements. In a study with 58 High school students, the difference of standard lighting (control) versus blue enriched lighting (test group) was measured for short and long-term effects.

Vertical illuminance levels were measured for the control with 300 lx and 3000K / 3500K colour temperature and for the test group with 300 lx and 5500K colour temperature. The study design consisted of a pre/post measurements with an intervention phase in-between the measurements with standard or blue-enriched lighting.

Speed of cognitive processing, concentration performance, and inaccuracy has been measured. Pre-test took place for all groups under standard lighting. Post-test was under standard or acute blue-enriched lighting, respectively, for the intervention phase with standard or blue-enriched lighting period.

The outcome of this study was that long-term and acute blue-enriched lighting showed significant differences in speed of cognitive performance compared to standard and acute blue-enriched lighting.
In respect to concentration performance, the following has shown significant differences compared to standard lighting:

- Acute blue enriched lighting after long-term standard lighting,
- Long-term blue enriched lighting,
- Standard and acute blue enriched lighting.

Memory effects have not been measured, but it has to be assumed that due to higher concentration levels, there might be a positive effect on memory. Nevertheless, this study has shown that there are already beneficial long-term effects due to improved lighting solutions.

(Howard 2016) a research study found that students were more alert and scored higher on their tests when they were in a classroom with 6500K lighting. “The preliminary study and the field experiment fully supported a positive effect of 6500K lighting on academic performance and 3500K lighting on encouraging recess activities,” said the study’s first author, Kyungah Choi, a PhD candidate at the institute.

Bermudez (2018) mentioned that Task lighting is an important component of any study area. Task lighting is lighting that focuses on a specific area, making it easier to complete tasks such as reading, writing, or viewing a computer screen. Good task lighting reduces eye strain and mental fatigue and can increase task performance by 16 percent.

iii. Colour Temperature Lighting for Schools

(Sigma Luminous, 2018) Lights in the 5000K range are optimal for tasks that involve high levels of focus and concentration, Change it to a slightly warmer 4000K for classroom discussions and group activities, and tune it to 3000K to calm the students down after lunch and recess.

(Howard, 2016) The researchers found that students were more alert and scored higher on their tests when they were in a classroom with 6500K lighting.

"The preliminary study and the field experiment fully supported a positive effect of 6500K lighting on academic performance and 3500K lighting on encouraging recess activities," said the study's first author, Kyungah Choi, a PhD candidate at the institute.

The researchers concluded that the 3500K warm lighting may(sic) provide a relaxing environment to support recess activities, whereas the 5000 K "standard" lighting may be applied for reading activities, and 6500K dynamic lighting supports students' performance during intensive academic activities

iv. Case Studies to measure Lighting effects on Oral Reading Fluency and Concentration.

Two studies were done to determine oral reading fluency and focus task to measure concentration:

1) (Mott et al, 2012) First was a Study with 84 pupils (grade 3, age 7 to 8) was done to determine oral reading fluency for two kinds of light conditions:

Standard Lighting = 500lx illuminance level and 3,500K (warm white) CCT
Lighting optimized for Focus Tasks = 1,000lx illuminance level and 6,500K (cold white) CCT.

Based on this research, the authors conducted the current study utilizing a lighting system and intended to create a "teaching tool" to positively influence school performance. Children in the experimental group, with the optimized lighting, started with a lower score (assessed before the intervention) and ended with a significantly higher score (assessed after the intervention).
Increasing the quality of artificial light positively affected students' ORF (Oral Reading Frequency) performance, a key component of reading comprehension. Light qualities of illumination and Colour temperature were found to influence student gains in reading, and there is a positive upward trend for motivation under the optimized lighting, while the trend for motivation under standard lighting declined during the school year.

Conclusion: Higher illumination level and higher CCT leads to improved oral reading fluency by 36%

2) (Sleegers et al., 2012) Three Dutch Studies were performed to measure the effects of lighting on Focus Task.

All three studies used the same light system for their experimental groups, which consisted of:

Lighting optimized for Focus Tasks = (1st Study) 1,000lx illuminance level and 6,500K (cold white) CCT
For study controls = (2nd Study) 600lx and 4,000K / (3rd study) 380lx and 3,000K / (4th Study) 300lx and 3,000K to 4,000K The second and third study report better performance in concentration or at least a positive trend for concentration and fewer errors. Findings of the first study report better performance in the concentration test of the Control Group - also reports an increased performance growth in the Experimental group. The results of the field studies offer support for the positive influence of classroom lighting conditions (lux and K) on concentration. Although all pupils performed better at the concentration test at the consecutive measurement points, it appeared that the performance of the pupils in the experimental groups improved more than the performance of their peers in the control groups.

Conclusion: Higher illumination level and higher CCT leads to increased concentration.
Another research shows for the first time tangible results on the positive impact of light on children that enhances the learning process in the classroom. (Voermans, 2007) This lighting system which allows both the intensity and the colour temperature of the light to be adjusted to suit the activity in the classroom. Using a control panel, the teachers can tailor the lighting in the classroom to suit what they are doing at the time.
Normal: Standard brightness and color tone sets the scene for the day's lesson.
Focus: Highest light intensity and a cool color tone helps the kids concentrate during tests.
Energy: This setting produces high intensity light with a very cool color tone to help students stay alert early in the morning and after lunch.
Calm: Standard intensity level with a warm color tone can calm down a class that has grown hyperactive.

v. How to reduce Glare for Comfortable Lighting Levels

(Brightgreen, 2015) Glare affects everyone. It is a visual sensation, which is best described as an excessively bright light spill, which is exposed to the line of sight of an individual, causing discomfort and/or disability to the person experiencing it. Despite glare being a truly detrimental visual pollutant, with many deleterious effects on people, there are several ways to reduce or even neutralize it, through better luminaire/fixture design as well as lighting design of spaces.

Glare can be greatly reduced by having a well-lit environment with indirect lighting. As identified by (Holladay et al. 1925, p.244) pupillary dilatation is a factor of the surrounding brightness, and the larger the pupil diameter, the higher the glare dazzling, hence a brighter background will cause pupil constriction and lower glare perception. Following the fact above, it is safe to recommend adequate background lighting in environments which are prone to glare with a high UGR. This can be achieved by having indirect illumination from ceilings (skyglow) and walls (backlight), most commonly achieved by lights that can provide diffused light to ceilings as well as wall washing.

In the instance of luminaire/fixture design, using the IESNA guideline for luminaire shielding, it is possible to reduce the UGR of spaces dramatically. Additionally, through good lighting design, it is possible to greatly reduce the UGR by specifying better lights, background lighting, skyglow lighting, and sound distribution of light sources in spaces.

7. Light Spectrum and its effects on wellness and productivity in the workplace.

a. Human Centric Lighting: The Future of Workplace Lighting Design

(Kluizenaar et al., 2016) Lighting companies in the market for offices seek to offer tailor-made lighting solutions that create comfortable and well-lit workspaces, while at the same time reducing energy use and lowering maintenance costs. Moreover, controls and connectivity mean that lighting can be personalised at an individual level.

If anything else, scientists seem to agree that there are considerable individual differences in light level preferences in offices [e.g. Begemann, van den Beld and Tenner (1997), Boyce, Eklund and Simpson (2000), Logadóttir and Christoffersen (2008), Newsham, Aries, Mancini and & Faye (2008) and Smolders (2013)). In particular, a series of studies (e.g. Veitch, Donnelly, Galasiu, Newsham, Sander and Arsenault (2010), Veitch, Newsham, Mancini and Arsenault (2011), Veitch JA, Stokkermans MGM, Newsham GR (2013) and Dickel, Veitch, Burns and Mancini (2015)] find that when people are able to work in conditions that broadly match their personal preferences, they judge the lighting to be of higher quality and the office to be more attractive. These people tend to be in a more positive mood, to be more focused on their work, and to show better wellbeing at the end of the workday. These field investigations found that being in lighting one judges as better also may lead to fewer health problems and greater job satisfaction and organisational commitment. Thus, by enhancing light quality and comfort, and by giving workers more control over their environment, HCL may act as a “virtuous cycle”, where employee satisfaction and HCL enhanced productivity work in a feedback loop to reinforce each other. The fulfilment of the employees’ needs is at the core of efficiency and productivity. Employers and employees share this concern for the existence of optimal working conditions. Working in good-quality lighting is good for individuals but also for their employers: it benefits organisational productivity both by facilitating work focus and by reducing costs for such things as time off and employee turnover. The concerns of the employers are related to the provision of optimal working conditions at limited overall costs while meeting the security and safety requirements, preserving a good company 'image' (for commercial reasons) and being perceived as an attractive employer (in order to attract the best personnel).

The recommendations detailed below are based on the guidance provided by stakeholders during interviews and literature reviews, complemented by feedback received from experts, cities and SMEs. This effort led to 2 application recommendations.

Application recommendation 1:

Application one has the aim to support alertness and productivity, adaptable to individual characteristics and/or needs, time of day and activity. It encourages the use of light in support of the circadian rhythm, i.e. helps to awaken in the morning, prevent 'after lunch dip' and contribute to good sleep at night.

- Combination of LEDs (which are available for a variety of well-defined colour-spectrum ranges) with ICT to develop dynamic lighting solutions for buildings, enabling flexible adjustment of spectral composition and intensity of the light throughout the workday;

- It is recommended to provide light during the day with sufficient light intensity, and with a relatively high 'blue' content (and resort to natural light as much as possible), while avoiding blue-rich light and cool tones of white light (high color temperatures) in the evening and night time (with the exception of workplaces where the employees must stay highly alert during those times, to avoid mistakes or accidents, such as, e.g. surgery rooms) (see also SSL-erate literature review "Lighting for health and wellbeing")

- Specialised software driving the dynamic changes in the spectral composition and intensity of light, allowing a high degree of customisation, to allow implementation of new scientific insights coming available in time (such as knowledge on how to optimise lighting for individual needs which may differ based on subjects, time of year, type of task, etc.);

- Increased light intensities are recommended for people who spend limited time outdoors during the day;

- Solutions where the light is not too focused and illuminating larger areas are recommended to increase the comfort for people;

- The importance of keeping solutions individually adjustable was noted frequently and should be taken account of.

Application recommendation 2:

Smart lighting with sensors incorporated in a future proof design allows lighting to adapt to individual needs (depending on the individual presence, time of day, and activity). Paving the way for personalised lighting solutions, taking into account (physiological) differences between people and personal preferences. Desirable features that were mentioned by stakeholders include a structure that allows changes and improvement, flexibility to change, and the possibility to add new features over time.

Improving Productivity and Wellness is at the forefront of Office Lighting Design today. In fact, (Lux Magazine, 2019) Circadian Lighting can boost productivity by 20% as studied by Dr Marcella Ucci - Head of the MSc in Health, Wellbeing and Sustainable Buildings at the University College of London. She says her pilot study to measure the impact on employees in a detailed post-occupancy study shows that productivity was boosted by up to 20 per cent. Additionally, employees were 38 per cent calmer, and 10 per cent more focused than their colleagues in the rest of the office.

The study was conducted on a 'Biophiliac' Office on the Twelfth Floor of London's Shard Skyscraper.
The Living Lab – part of the headquarters of energy services consultancy and outsourcing giant Mitie – is an experimental workplace which provides short-term rest and meditation functions for company employees. Space features colour- and intensity-tuning circadian lighting which aims to match the occupants' sleep-wake cycles. Designed by DaeWha Kang Design, it's designed to boost worker wellness and productivity. This project comprises two spaces, an immersive work environment with natural materials and two 'Regeneration Pods; that provide a space for meditation and reflection. The Living Lab has bamboo screens that wrap onto the ceiling above. The floor, desks, and task lights are also formed from different shades and textures of bamboo. The lighting in the room is linked to an astronomical clock—cool blue in the morning, brilliant white in the afternoon, and super warm as the day winds down.

Mitie employees work at these desks for four weeks at a time, answering daily surveys about their comfort, satisfaction, and emotional response. They then spend four weeks working in a control area on the same floor with similar environmental conditions but without biophilic design, and their responses will be compared between the two spaces.

Sleep can also be improved by HCL by 26 minutes. (Lux Magazine, 2018). The improved sleep duration was reported by workers who had, in general, cooler and brighter lighting with a degree of personal control over the intensity and colour temperature. The study – by Eindhoven University of Technology – provides for the first time a qualitative measure of the importance of personalisation in improving wellbeing.

The office workers were first exposed to a randomly selected lighting regime for three weeks and then a new test regime for the following weeks. The workers in a control group received standard office lighting of an average illuminance of 500 lux on their desks in a neutral white light while those in the test group got a dynamic light with varying colour temperature and intensity. This light was customised to the test person's age and whether he or she is a morning lark or a night owl.

Measuring the light close to the eye, the researchers discovered that the workers with personalisation showed a higher illuminance level in the early morning. The colour temperature level at the desk and close to the eye was also higher in the personalised, dynamic scenario, regardless of the time. Those employees in the personalised lighting group received better-tuned lighting exposure, in spite of the fact that they were mobile and that daylight contributions were allowed in all conditions. The subjects reported to have slept 26 minutes longer on average in the personalised scenario.

b. Best Practices for Office Lighting Design

i. Office Lighting Design Recommendations

Up to 80% of the information is processed visually. This leads to the fact that the choice of illumination has a more and more significant impact on the adequate processing of information. At the workplace, the illumination is mainly a part of ergonomic guidelines. Besides the fact that light does influence personal well-being and health, it also has a positive impact on motivation and performance. Lighting at the workplace is based on ergonomic principles and has to meet safety requirements within the meaning of occupational health and safety. Light has different functions that have to be taken into consideration for a comprehensive assessment of a lighting concept in a room. Illumination does not only support the visual perception and therefore, the information brokerage, but it is also signified by psychic-emotional and psychic-biological effects.

The visual perception in a room is initially achieved by illumination. Therefore, ceiling fixtures have to be chosen individually according to the room condition. In addition, table lights and floor lamps can intensify the lighting effect. They are also able to zoom in on information processing and mental stimulation at the same time.

The appropriate use of daylight and artificial light can have a strong impact on the psychic-emotional factors of lighting. Other factors that are influenced by light are health and performance. Ergonomically designed lighting can be very supporting(sic), and as studies have proved, a good illumination at the working place has also(sic) an impact on motivation.

The right light level at the workplace avoids tiredness and lack of concentration. This can be regulated by the illuminance, which is measured in Lux (lx). A minimum of 500 Lux is stated for the brightness at computer workstations. Generally speaking, an increase in illuminance boosts the(sic) visual performance and positively influences the detailed and fast visual information processing. An illuminance between 500 and 1000 Lux can also be seen as stress-free.

The more complex the visual task is, the higher the illuminance requested. Additionally, person variables like age are crucial for a final and overall evaluation of the chosen lighting concept. An illuminance between 750 and 1.000 Lux is said to sustainably enhance the working performance of older workers(sic). Mood lighting is often achieved by the illumination parameter light colour. In this regard, the rendering index (CRI) is used as an orientation. Indices from 90 Ra can be seen as natural values and are used, for example, in connection with LED lights and fluorescent lamps. For further characterisation of illuminants and light sources, the light colour of fluorescent lamps is compared to the light colour and illuminance of light bulbs. This leads to the following classification of light colours: warm white, neutral white and bright white.

Also, the effects of light and shadows decide on the lighting quality. To achieve a balance between natural and artificial light and to avoid shadows and glare, it is recommendable to place lights parallel to the window and the working place. This coherence was already pointed out by one of the first studies of the Ergonomic Institute (1997). If the visual comfort is directly compromised by light sources with a very high illuminance in the visual field, lighting experts refer to glare as a parameter of illumination. Reflection is the second phenomenon that negatively influences the lighting quality.

(Cafeculture+Insitu, 2018) Many office work environments still fail to recognise the difference lighting can make to their work areas. While there is no ‘one size fits all’ in office lighting, there are best practice guidelines to determine which lighting fixtures work best in conjunction with specific layouts and workspace use. There are four main categories of office lighting that provide office, workspace and specific task illumination. Each can work in conjunction with vertical illumination to provide natural lighting, enhance productivity and create scenes and moods for different zones within the office.

<u>DIRECT CEILING PENDANTS</u> - Perhaps the most common type of workspace lighting, ceiling pendants, provide light directly from the ceiling to the workspace and are usually fixed into the ceiling. They are best used in large, organised workspaces, working in conjunction with natural light to reduce glare and maintain a consistent mood throughout the day. Warmer or cooler lamps can be fitted depending on the scene required.

PROS:

- Provide light to the entire room,
- Suitable for office spaces large and small,

- Simple, flexible and easy to deploy.

CONS:

- Don't provide task specific light,
- Not ideal for defining zones or structure.

INDIRECT AND DIRECT CEILING LUMINAIRES - Suspended from the ceiling as pendants, these lights provide Omni-directional lighting. Indirect/direct lighting can help provide more natural tones in deeper office spaces or specific work zones. Indirect lighting also helps provide structure to open-plan office spaces and helps orientate staff and visitors.

PROS:

- Good for a variety of specialised zones from conference rooms to breakout and rec areas,
- Can provide warmer light than direct ceiling luminaires,
- Useful for structure and defining zones.

CONS:

- Requires highly accurate planning and knowledge,
- Can be expensive to deploy,
- Less flexible than simple direct/indirect lighting,
- Overhead space required.

CONTROLLED TASK LIGHTING - Suspended, multi-directional lighting with controllers for dimming and brightness. Useful for high concentration work or areas with highly variable natural light. Individual lamps can be fitted with different moods to provide a diverse set of scenes throughout the day (and evening).

PROS:

- Perfect for high concentration task areas like CAD,
- Multi-directional controls offer ultimate flexibility,
- Help define zones and areas.

CONS:

- Can be expensive to implement,
- Requires positional layout knowledge before installation.

STANDING AND DESKTOP LUMINAIRES - Providing greater control over the task and workspace, standing lights provide indirect illumination while desk/table lamps highlight work specific surfaces. Glare, sunlight and office depth should all be considered when planning office space lighting. To better aid overall productivity and well-being, there are several vertical surface illuminations to consider.

PROS:

- Individual control and flexibility,
- Easy to scale and move

CONS:

- Occupy desk and floor space,
- Not suitable for highly structured and efficient layouts like call centers.

VERTICAL SURFACE ILLUMINATION - Vertical surface illumination lights up walls, cabinets, bookshelves and walkways to help better define the overall office space. This type of lighting should be used in conjunction with office space lighting, as it often won't provide enough nuance on its own for a perfectly lit office.

SPOTLIGHTS - These lights provide flexible illumination to highlight specific zones, wall mountings, artworks, portals etc. Some spotlights can swivel and be repositioned, enhancing their flexibility. Spotlights are ideal for creating separate scenes within an office that help staff move through different moods, aiding in the relaxation and general productivity.

PROS:

- Highly flexible, work well in conjunction with many layouts,
- Cost effective,
- Can aid with zone and structure definition and room orientation,
- Can help create feelings of warmth and space for relaxation,
- Great for vertical visual information like cabinets and bookshelves.

CONS:

- Specific uses don't offer much adaptability to change,
- Should not be used to completely light an office, computer screens or horizontal surfaces (desks).

WALL WASHERS - Similar to spotlights, wall washers provide a broader, softer illumination for vertical surfaces. Ideal for recreation and break rooms, they provide a softer, more relaxed atmosphere.

PROS:

- Great for defining specific areas and orientation (corridors and paths etc),
- Suitable for relaxing atmosphere of reading areas, recreation and breakout rooms.

CONS:

- Not suitable for illuminating horizontal surfaces like desks, or visual surfaces like computers.

WALL LUMINAIRES - Like their ceiling suspended counterparts, wall luminaires provide vertical light up and down, and are commonly used to orientate and define spaces, walkways and thoroughfares. Break areas and recreational zones benefit from warmer lamps, while conference and meeting areas can use cooler lamps to highlight interior design and draw attention to objects and presentations.

PROS:

- Ideal for spatial definition, defining thoroughfares and walkways,
- Coordinate with direct ceiling luminaires to create defined spaces that feel bigger than they are.

CONS:

- Not suitable for workplace or task area illumination.

DOWNLIGHTS - Similar to spotlights but with less flexibility, downlights provide illumination straight down into specific work ones and portals.

PROS:

- Best used to illuminate specific task areas, particularly shared areas like printing stations,
- Suitable also for kitchens, reception areas and conference rooms,
- Great for defining space within open plan offices.

CONS:

- Lighting task areas can be tricky. Consider dimmable options.

ii. Lighting design techniques to enhance focus, increase productivity and reduce glare

The combination of different light sources contributes to a lighting concept that can be adapted to different light requirements. The use of direct and indirect lighting in addition to a balance of daylight and artificial light is very important. On the one hand, in offices and at computer workstations a very high level of indirect lighting is recommended to minimise glare. On the other hand, direct lighting provides the(sic) essential shadiness for good illumination. That is the reason why combining both illumination techniques is vital.

(Cafeculture+Insitu, 2018) For those of us that work predominantly inside of offices, a lack of natural lighting can negatively impact mood, lead to fatigue and poor productivity. Making sure desks are positioned appropriately in regards to windows will help reduce glare. However, levels of sunlight change throughout the day, meaning natural lighting needs to be supplemented to ensure continued productivity and staff comfort. To design an effective lighting plan for your office, it helps to consider office lighting over three stages; start broadly with lighting the room, then define specific task areas, then light surfaces to create individual spaces within the office environment. This not only improves productivity but creates sensible moods that reflect what is actually happening within zones around the office. For example, a boardroom will generally have bright lighting, whereas a quiet-zone might suit more subtle lighting.

If you're installing lighting into a brand new office where the layout of the room remains unknown, lighting choices can be more general and flexible. Consider direct lighting from ceiling luminaires and direct or indirect lighting from pendant luminaires. Task area lighting fills the gap between the work surface and room lighting. It's useful for rooms with several specific work areas and can help define separate workspaces when designed in tandem with interior design and layout. Work Surface lighting provides more attention(sic) to detail for the illumination of specific work surfaces within task areas. Because it's comprised mostly of portable table lamps and floor lights, work surface office lighting is quite flexible and gives greater control to the individual when determining how to illuminate surfaces and work areas. This can help reduce glare-induced fatigue and provide better engagement with work materials over longer time periods. Suspended, adjustable lighting is also used to light work surfaces, though it is less common as it is generally more expensive. Controlled task lighting can usually be controlled from the desk or via software. To design an effective lighting plan for your office, it helps to consider office lighting over three stages; start broadly with lighting the room, then define specific task areas, then light surfaces to create individual spaces within the office environment. This not only improves productivity but creates sensible moods that reflect what is actually happening within zones around the office. For example, a boardroom will generally have bright lighting, whereas a quiet-zone might suit more subtle lighting. Considering each of these needs(sic), different lighting should be implemented throughout the office to stimulate productivity, keep us engaged during meetings and help us relax when we're taking a break. This is best achieved when lighting is tailored to the layout of the individual office.

The Open Plan Office - The primary consideration for lighting an open plan office is the avoidance of direct and indirect glare. When light reflects off screens or surfaces, be it from the sun or from lamps and luminaires within the office, it contributes greatly to fatigue and can adversely affect the health and performance. Open-plan offices are particularly susceptible as their highly structured and coordinated layout leaves little room for flexibility. To increase performance and productivity(sic), the use of long rows of windows, deep offices and light-dependent luminaire regulation should all be considered. Orientation can be aided with bright perimeter zones lit with wall washers, while conference rooms and reception areas benefit from diverse work and task level lighting to provide structure and suit the flexible needs of the zones.

The Cellular Offices - The cellular office is a traditionally private space that suits up to half a dozen staff who need to either work in constant close collaboration, privacy, silence or with clients.
While they might not be as efficient as open-plan or combi offices, the cellular office provides a high degree of flexibility for the inhabitants. This extends to the lighting policy, which should take into account the variation of tasks performed across all three layers of lighting. Louvred and recessed luminaires are common for use in small rooms, while downlights for cabinets, printing areas and other task-specific zones can provide structure. Table lamps may be suitable for individual work tasks, as they provide flexibility for the diverse range of tasks performed in cellular offices.

The Combi Office - In response to the changing nature of office work, the combi office is an architectural reimagining of the office space as a marketplace of collaboration with individual production zones where personal productivity can take place. As communication and collaboration take precedence in many offices, individuals spend more of their time as members of many cross-functional teams. The combi office supplies the platform for this co-working space, with a focus on an atmosphere that is agreeably lit with an indirect pendant or standard luminaires.Dimmable luminaires and desktop lamps create flexible working areas in individual production zones, while downlights help define zones within the combi office 'marketplace'.

The Group Office - You'll need to look back to the late 1970s and early 80s to find the first examples of the group office. As computers became more prevalent in the workplace, the more structured divisions of the open-plan office gave way to clustered workspace arrangements that encourage team collaboration among groups. When it comes to lighting group offices, the flexible nature of the layout should direct equally flexible lighting plans. Because group offices are zonal, lighting should be used to help highlight these zones. For example, fax and printing areas can be lit with downlights or indirect wall luminaires depending on their locations. Meeting spaces will benefit from direct and indirect luminaires that provide more natural modelling on work surfaces, while break rooms should feel warm, with an overall indirect trunking system supported by table lamps for recreational tasks like reading.
The flexible design of the group office structure is still a popular layout in many modern offices, providing the conditions for direct communication and effective teamwork.

The Executive Office - The interior design of executive offices can vary widely depending on the company and the people who occupy it. When it comes to lighting, however, there are several common features. There are three key areas within the prestige office, each with their own function and mood:

1. *Workplace zone* - There are many choices for the workplace zone, including ceiling and desktop luminaries and controlled lighting. Most importantly, lighting around the workspace should work in harmony with other zones to prevent eye strain and fatigue.
2. *Small conference zone* - Warm, low key light helps keep attention on the persons present. Suspended direct/indirect lights with warm lamps are a good choice.
3. *Presentation zone* - Highlighting of relevant areas can be achieved using wall washers, spots and downlights.

The CAD Office - Computer-Aided Design represents a significant challenge to office design, both in terms of interior layout and lighting. Visual accuracy is highly important, but lighting that is too bright can cause eye strain and fatigue. Many CAD workers also work with paper, and in collaboration with other team members, meaning there's a need to find a balance in lighting throughout the day to ensure scenes are coordinated for the best productivity.

Ensure desks are at right angles to windows to reduce glare. Similarly, ceiling luminaires work best running parallel to the windows. For maximum glare reduction, adjustable external louvres can be installed on the windows that can be opened and closed to let in and reduce natural light from the window when needed. Controlled task lighting should also be considered, so individuals within the office have better control over their lighting needs. If this is not an option, then desk lamps are an alternative.
Like all office layouts, CAD offices should also consider vertical lighting for cabinets, and zonal lighting for meeting areas and printer stations. All lighting should endeavour to work in conjunction with available daylight and the overall atmosphere of the office.

ii. Lighting for health and well-being in workplaces

(Schlangen et al., 2014) Workplace lighting can, in addition to providing sufficient light to conduct work-related visual tasks, affect employees' alertness, mood, cognition, sleep-wake pattern and health. The timing, duration and spectral composition of the light exposure all play important roles in these non-image forming effects. Moreover, research has shown that these effects may depend on the environmental context, type of activity, personal characteristics and employees' momentary level of fatigue.

Where do current solutions fall short? What consequences can this have?

To date, lighting conditions in workplaces are often designed to optimally support visual performance and minimise visual discomfort(sic). The non-image forming effects of light are generally not considered nor implemented in current workplace lighting solutions. Optimal lighting solutions may, therefore, require different light settings. This can have the consequence that current lighting systems render lighting conditions that are suboptimal to support non-image forming functions, e.g.., they do not optimally accommodate employees' ability to concentrate and engage in cognitive and mentally demanding tasks during the workday.

<u>INTENSITY</u> - Good visibility is often a prerequisite to engage in many work-related tasks. In addition to providing sufficient light to conduct work-related visual tasks, the light intensity can also affect employees' appraisals of the lighting and atmosphere perception of the workplace. Research has shown that the atmosphere of a space with a higher intensity level may be perceived as more lively, less tense, more formal (Vogels & Bronkers, 2009) and more pleasant (David & Ginther, 1990). Results by Smolders and colleagues (2012; 2014) suggested that persons may evaluate commonly experienced intensity levels in indoor workplaces as more pleasant as compared to bright light settings (provided by artificial lighting only) after one hour of exposure during the daytime. In addition to measuring individuals' appraisals of the lighting, multiple studies have investigated individuals' preferences for artificial light settings during the daytime. These preference studies have revealed substantial inter- and intra-personal differences in preferred illuminance levels (e.g., Begemann, van den Beld & Tenner, 1997; Boyce, Eklund & Simpson,

2000; Butler & Biner, 1987; Logadóttir & Christoffersen, 2008; Newsham, Aries, Mancini & Faye, 2008; Smolders, 2013), suggesting that whether a certain intensity level is experienced as pleasant or attractive may vary as a function of person characteristics, time and/or context.

Insights in the non-image forming effects of light have shown that the effect of light on a person's affective, cognitive and physiological functioning is dependent on the intensity level. Multiple studies have demonstrated acute activating effects of exposure to brighter light at night on subjective and objective indicators of alertness and arousal. For instance, the results showed that exposure to more intense light during the biological night can(sic) counteract subjective feelings of sleepiness, result in faster responses on attention tasks, suppress melatonin secretion, increase heart rate and core body temperature, and modulate brain activity (e.g., Badia, Myers, Boecker, & Culpepper, 1991; Boyce, Beck-stead, Eklund, Strobel & Rea, 1997; Cajochen, Zeitzer, Czeisler & Dijk, 2000; Campbell & Dawson, 1990; Daurat et al., 1993; Figueiro, Bullough, Bierman, Fay & Rea, 2007; Lewy, Wehr, Goodwin, Newsome & Markey, 1980; McIntyre, Norman, Burrows & Armstrong, 1989; Myers & Badia, 1993; Rüger, Gordijn, Beersma, De Vries & Daan, 2006; Yokio, Aoki, Shiomuar, Iwanaga, & Katsuura, 2003; Zeitzer et al., 2000).

Exposure to light at night may, in addition to its acute effects on melatonin secretion, also shift the timing of melatonin onset after the light exposure, which can be accompanied by changes in the timing of sleep and wakefulness during the next day. Research has shown that the intensity of the light exposure at night affects the magnitude of the phase-shift in individuals' circadian rhythm induced by the lighting (e.g., Zeitzer et al., 2000). (Zeitzer and colleagues 2000) showed a larger phase delay in melatonin rhythm after exposure to more intense light during the subjective early night.

A major output of the biological clock system is the production of the hormone melatonin. This production in the pineal gland shows systematic variations with time of day and is under the control of the biological clock. Melatonin is secreted at night and has minimal levels during the daytime, even if persons during one day are not exposed to light. A larger melatonin suppression during the light exposure often coincides with increased feelings of alertness and higher sustained attention. However, there are also indications that melatonin suppression at night can have adverse health effects in the long term (Blask, 2009; Davis, Mirick, & Stevens, 2001; Haus, & Smolensky, 2013; Schernhammer, & Hankinson, 2005; Schernhammer, & Schulmeister, 2004; Stevens, Brainard, Blask, Lockley, & Motta, 2013; Stevens, 2009; Stevens, & Davis, 1996; Straif et al., 2007). It is thus important to not only consider the effects of the intensity of workplace lighting on employees' state of alertness and performance at night(sic), but also its potential disturbing effect on their sleep-wake cycle and long term health.

As discussed above, acute alerting effects and phase-shifts of light are larger with increasing illuminance level at night. Several studies have shown that these relationships can be best described by a logistic function (Boivin, Duffy, Kronauer, & Czeisler, 1996; Cajochen et al., 2000; Zeitzer et al., 2000). These latter studies also suggested that, at least under very controlled conditions, relatively low illuminance levels

(~150 lx at the eye) are sufficient to induce alertness and shift a free-running circadian rhythm. The acute as well as phase-shifting effects shown at night(sic) are particularly relevant for night shift workers.

Although most studies to the acute alerting effects of light intensity among healthy persons are performed at night, several studies have provided indications that light can also induce alertness during daytime. For example, a few laboratory studies have shown alertness-enhancing effects of exposure to a high illuminance level (>1000 lx at the eye) as compared to dim light (<10 lx) during daytime under high sleep pressure due to sleep loss (Phipps-Nelson, Redman, Dijk & Rajaratman, 2003) or after prior exposure to very low intensity levels (Rüger et al., 2006; Vandewalle et al., 2006). Complementary to these results in the laboratory, a field study by Partonen and Lönnqvist (2000) revealed improved feelings of vitality and reduced depressive symptoms among office workers after four weeks of exposure to bright light (2500 lx at eye level, 6500 K) for at least one hour per workday during the dark winter months in Finland. In addition, two very recent laboratory studies revealed that daytime exposure to bright light (1000 lx at the eye) can also induce alertness and vitality during regular office hours, even in the absence of the deprivation of sleep and light (Smolders et al., 2012; Smolders & de Kort, 2014) and when compared to an illuminance level which is commonly experienced in indoor work environments during daytime (i.e., 200 lx at the eye; Smolders, de Kort & van den Berg, 2013). Extending these results under controlled conditions in the laboratory to everyday situations(sic), a recent field study confirmed a significant relationship between experienced light intensity and feelings of vitality during daytime in everyday life (Smolders et al., 2013). Their results suggested that when persons are exposed to more light, they feel more energetic immediately afterwards. Together, these studies suggest that exposure to a higher intensity level can also benefit employees working during daytime. It should be noted, however, that the daytime effects of illuminance levels were most consistent for the subjective measures of alertness and vitality as compared to objective indicators for performance and physiological arousal. This suggests that among office employees, bright light exposure during the daytime may particularly support mental well-being.

In addition to the acute effects of exposure to more intense light on human daytime functioning, a few studies have provided indications that the light intensity experienced during daytime office hours may also affect employees' alertness, performance and sleep later in the evening or at night. Hubalek et al. (2010), for example, showed that office employees reported better sleep quality when they had experienced more light during the day. (Figueiro and colleagues 2013) Revealed some improvements in performance in the early morning after extended wakefulness when participants were exposed to daylight as compared to the darkness between 7 am and 5 pm. In addition, results by (Münch and colleagues 2012) suggest that bright light exposure (~1000 lx at the eye; daylight, sometimes combined with artificial lighting) in the afternoon may affect alertness and performance in the early and late evening.

TIMING - The development of artificial lighting has enabled us to provide sufficient light to engage in visual work-related tasks at any moment during the 24-hour day. However, as discussed in the previous sections, artificial lighting not only enables vision but may also affect employees' feelings, cognition and physiology throughout the 24-hour day. Several studies have shown that the non-image forming effects of light are influenced by time of day. For instance, research has shown that the size and direction of the phase-shifting effect of light on the human circadian rhythm are dependent on the timing of the light exposure. Phase-response curves have demonstrated that light exposure in the evening and early night (before core body temperature minimum) can result in a phase delay, while exposure to light in the early morning (after core body temperature minimum) can phase advance the circadian rhythm (e.g., Czeisler et al., 1989; Jewett et al., 2005; Khalsa, Jewett, Cajochen & Czeisler, 2003; Minors, Waterhouse & Wirz-Justice, 1991; Rüger et al., 2013).

Rüger and colleagues (2006) investigated the effects of bright light exposure on persons' state of alertness and physiological arousal both during daytime and at night. While acute effects of bright light exposure on subjective alertness, fatigue and vitality were independent on time of day (daytime: noon – 4 pm vs. nighttime: midnight – 4 am), results revealed only a significant increase in heart rate and core body temperature under bright light exposure at night and not in the afternoon. In addition, a few studies provided indications that the effects of light intensity during daytime office hours also depend on the timing of the light exposure. Results by Smolders and colleagues (2012) showed that the effect of bright light exposure on sustained attention were(sic) only significant in the morning, and not in the afternoon. Moreover, recent results provided indications for a more pronounced relationship between the amount of light experienced and feelings of vitality in the morning than in the afternoon (Smolders et al., 2013). Together, these studies show that it is also important to take into account the time at which employees will be present in the workplace (e.g., day vs night shift) when designing lighting scenarios to support well-being and performance at work.

In addition to potential time-dependent effects of light on employees' feelings of alertness, performance and physiology, a few studies have shown that preferred light settings may vary with time of day. Begemann et al. (1997) and Newsham et al. (2008) revealed time-dependent variations in-office employees' preferences for light settings (a combination of natural and artificial light exposure). Results showed that employees did not prefer constant light settings in terms of intensity and CCT during the workday. In these studies, artificial lighting was generally added to the daylight levels throughout the day, resulting in – on average - higher intensity and CCT levels around noon than in the early morning and late afternoon. A field study by Juslén et al. (2005) also showed variations in light preferences over time among employees working in an industrial work environment without daylight contribution. However, their results suggested that employees preferred a higher illuminance level, especially in the morning, at the start of their working day. Although current insights on time-dependent variations in individuals' preferred light setting are still inconclusive, these studies provide indications that light preferences can differ over time.

DURATION - Research performed in the evening and at night has shown that phase responses to bright light are dependent on the duration of the light exposure, with larger phase-shifts with increasing exposure durations (Chang et al., 2012; Dewan, Benloucif, Reid, Wolfe, & Zee, 2011). Recent insights demonstrated that short durations of bright light exposure can also induce phase-shifts in individuals' circadian rhythm, and may result in even larger shifts than longer pulses when expressed per minute of exposure (Chang et al., 2012; St Hilaire et al., 2012). Moreover, research has shown that (repeated) exposure to intermittent bright light at night or in the early morning can induce phase-shifts (delay and advance, respectively) in human circadian rhythms of a similar magnitude as consolidated exposure to bright light (Gronfier et al., 2004; Rimmer et al., 2000). In fact, results by St Hilaire et al. (2012) and Rimmer et al. (2000) revealed a non-linear relationship between the duration of exposure to bright light and the size of the phase-shift, suggesting that persons are particularly sensitive to light in the first part of the light exposure.

Several studies have provided indications that the acute effects of light are moderated by the duration of exposure. Instead of employing various durations, these studies have mainly studied the onset of such effects during the light exposure. Results revealed that the onset of lighting effects on alertness and arousal vary depending on the type of indicator (e.g. Cajochen et al., 2005; Smolders et al., 2012; Smolders & de Kort, 2014). For instance, Smolders and colleagues (2012; 2014) showed that effects of bright light on subjective alertness and vitality were not dependent on the duration of exposure, while effects on participants' response times on a sustained attention task occurred with a delay (i.e., after about 20-30 minutes of exposure). In addition, Cajochen and colleagues (2005) showed quite direct effects of blue light on melatonin secretion and subjective alertness, but more delayed effects on core body temperature and heart rate. Moreover, an overview paper by Vandewalle, Maquet and Dijk (2009) reported duration-dependent dynamics in brain activity by light, with initial activation in subcortical structures related to the regulation of alertness and emotion within several minutes and modulations in activity in various cortical areas after about 20 minutes of exposure. This activation process takes about 20 minutes to establish, and the activation is only maintained for a time period of 20 minutes after the end of light exposure. This suggests that continuous or repeated exposure is required when activation is its intention.

EXPOSURE PATTERN - A few studies have investigated the effect of dynamic light exposure patterns on individuals' affective and cognitive functioning. Results of a laboratory study by Hoffman and colleagues (2008) revealed some subtle improvements in subjective vitality and fatigue under exposure to a variable lighting regime with gradual changes in illuminance level (500-1800 lx at 6000 K) in the morning and early afternoon as compared to constant office lighting at 500 lx with a lower CCT (4000 K) during daytime office work. Results showed, however, no significant activating effects of the dynamic light exposure on performance or physiological arousal (Hoffmann, Griesmacher, Bartenbach & Schobersberger. 2010). Iskra-Golec and Smith (2008) revealed some trends for beneficial effects of intermittent exposure to bright light pulses (4000 lx) during the day on cognitive performance and feelings of vitality as compared to constant exposure to 300 lx. However, their results also suggested that the bright light pulses were experienced as less pleasant. A field study by de Kort and Smolders (2010) revealed no activating effects of exposure to artificial lighting with gradual variations in illuminance level (500 lx - 700 lx) and CCT (3000 K - 4700 K) in the morning and early afternoon for several weeks on individuals mental well-being, health and performance during the winter period. However, employees were more satisfied with the dynamic lighting scenario providing subtle changes over time as compared to the constant lighting condition (500 lx and 3000 K). Thus, insights in the potential beneficial effects of temporal modulations in the artificial light settings on employees' experiences, task performance and physiology are still inconclusive.

In addition to temporal changes in the lighting settings during working hours, several studies have investigated the effect of gradual increasing intensity levels in the early morning. Results of these studies showed that exposure to artificial dawn simulation light as compared to darkness prior to awakening may reduce sleep inertia and improve a person's well-being and cognitive functioning during the day. A laboratory study by Van de Werken et al. (2010) showed that exposure to artificial dawn light can(sic) reduce experienced sleepiness and increase vitality after awakening among persons experiencing difficulties to wake up early in the morning. Similar results were found in the field (Gimenez et al., 2010). In addition, results by Gabel and colleagues (2013) suggested some improvements in subjective well-being, mood and cognitive performance under dim light exposure during the waking period after prior exposure to artificial dawn simulation light (0-250 lx) vs dim light (<8 lx) during waking up among persons with mild sleep deprivation.

Research has also provided indications that employees' experienced light patterns prior to their office hours may affect their sensitivity to lighting conditions at work. Several laboratory studies have shown that individuals' responses to light in terms of melatonin suppression (Jasser, Hanifin, Rollag & Brainard, 2006; Smith, Schoen & Czeisler, 2004) and phase-shifts in the circadian rhythm (Chang, Scheer & Czeisler, 2011) are dependent on their light history. Moreover, a very recent laboratory study by Chellappa and colleagues (2014) showed more pronounced modulations in executive brain functions during daytime exposure to green light with gradual changes in intensity over time after prior exposure to dim orange as compared to dim blue light, suggesting that the effect of light on executive functioning may depend on the spectral composition of a person's prior light exposure. In addition to these results obtained under well-controlled conditions in the laboratory, results in the field also suggested that exposure to more intense light during the day may result in less pronounced effects of light on melatonin secretion at night (Hébert, Martin, Lee & Eastman, 2002; Owen & Arendt, 1992). Hébert and colleagues (2002) showed that exposure to bright light for several hours during the waking period for one week during participants' daily routine as compared to no bright light during the day resulted in reduced melatonin suppression by relatively bright light (500 lx) for three hours at night at the end of the week. These results suggest that exposure to bright light during the daytime may protect the biological system from distortion by moderate light levels in the night. Results by Owen and Arendt (1992) also showed some differences in individuals' responses to light at night in terms of melatonin suppression during the summer period as compared to the dark winter months in Antarctica. In addition to these potential moderations by prior light history in the effect of light on melatonin suppression at night, results of a field study by Smolders et al. (2013) showed that person's' light exposure was only significantly related to their feelings of vitality during the darker months of the year, providing some first indications that prior light history may also play a role in the effect of light intensity on vitality during daytime.

INTRA AND INTER-INDIVIDUAL VARIATIONS IN SENSITIVITY TO LIGHT EXPOSURE

Responses to light can vary between individuals as well as within individuals. The current literature has shown that the effects of light may depend on a person's momentary state and type of activity as well as individuals' characteristics (e.g., chronotype and level of chronic fatigue).

Type of activity. Several studies have provided indications that the effect of light on performance depends on the type of task employed (Chellappa et al., 2011; Boyce et al., 1997; Kretschmer, Schmidt, & Griefahn, 2012; Rüger et al., 2005; Smolders et al., 2012; Smolders & de Kort, 2014). For instance, studies have shown increments in performance on cognitive performance tasks but not on sustained attention tasks when exposed to bright light during daytime after hours of exposure to dim light (Rüger et al., 2005) or at night (Boyce et al., 1997; Kretschmer, Schmidt, & Griefahn, 2012). In contrast, exposure to a higher CCT in the evening enhanced speed on auditory sustained(sic) attention and visual response inhibition tasks, while it did not significantly affect performance on a visual executive functioning task (Chellappa et al., 2011). In addition, Smolders and de Kort (2014) reported faster responses on a sustained attention task under bright light, but also some performance-undermining effects of exposure to more intense white light during the daytime on tasks requiring inhibitory control and working memory. Together, these studies suggest that some tasks may benefit more from bright or blue-enriched light exposure than others. Yet, more research is necessary to determine the optimal light settings for different types of activities.

Mental state. Most studies investigating non-image forming effects of light on human functioning have been performed at night and/or after sleep deprivation, suggesting that light can benefit persons under conditions of relatively high fatigue and sleep pressure. Although circadian and homeostatic sleep pressure are(sic) often relatively low during the subjective day, workers may also experience increased feelings of sleepiness, a lack of energy, and decrements in motivation and task performance during daytime office hours due to mental or physical exertion. Recent research has provided some indications that a person's responses to the ambient light settings during daytime are dependent on their momentary level of fatigue, with more pronounced effects when persons suffer from mental fatigue and experience a lack of energy. A laboratory study by Smolders and de Kort (2014) revealed that the effect of bright light exposure on subjective sleepiness was only significant when persons suffered from fatigue due to mental exertion, and not when they felt more rested and had mainly engaged in relaxing activities prior to the light treatment. In addition, their findings suggested that persons' appraisals concerning the lighting may also depend on their momentary level of fatigue. Participants evaluated the bright light condition as less pleasant and less adequate when rested, but had a more positive attitude towards working in a comparable environment under 1000 lx when fatigued. In contrast, the effects of daytime bright light exposure on the indicators for task performance and physiology were not moderated by participants' prior mental state. Moreover, the high illuminance condition was experienced as brighter and more activating regardless of individuals' mental state (Smolders & de Kort, 2014). In line with the results on subjective alertness in the laboratory, Smolders and colleagues (2013) showed that the relationship between light intensity and feelings of vitality in everyday situations was most pronounced when participants' felt relatively less energetic during the previous hour.

Chronic fatigue. When persons do not sufficiently recuperate from work-related fatigue and the effort spent during the workday on a regular basis (e.g., due to too high work demands, limited time to relax and sleep debt), this may eventually lead to a more chronic level of fatigue. In addition to potential intra-individual variations in light exposure patterns and sensitivity to light as a function of a person's momentary state, there are some indications that persons who experience relatively high general levels of fatigue are exposed to lower light levels during the day (Martin et al., 2012; Smolders et al., 2013) and feel less energetic throughout the day than people with a low level of chronic fatigue (Smolders et al., 2014).

Chronotype. As discussed in section 3.3, research has shown that the effects of light intensity on subjective vitality, sustained attention, and physiological arousal may depend on the timing of light exposure. Recent research has provided evidence that individuals' light exposure patterns as well as their sensitivity to acute alerting effects of light(sic) may not only depend on local time (i.e., clock time), but also on a person's internal time (Chellappa et al., 2012; Martin et al., 2012; Smolders et al., 2014; Vandewalle et al, 2011). Field studies by Martin et al. (2012) and Smolders et al. (2014) demonstrated differences in light exposure patterns throughout the day between persons as a function of chronotype. Chronotype is based on an individual's timing of sleep and wakefulness and quantifies an individual's phase of entrainment (Roenneberg et al., 2003).

Controlled laboratory studies demonstrated inter-individual differences in responsiveness to acute effects of blue or blue-enriched light exposure on alertness as a function of individuals' clock gene polymorphisms (Chellappa et al., 2012; Vandewalle et al., 2011). An MRI study by Vandewalle et all. (2011) Showed that the effect of exposure to 1 minute of blue vs green light on brain activity in the early morning was moderated by a person's clock gene polymorphism and level of sleep pressure. In the morning, after a 7.5-hour sleep episode, modulations in brain areas associated with alertness and executive functioning due to brief exposure to blue light as compared to green light were only significant in PER34/4 individuals. In contrast, only PER35/5 individuals showed significant increments in brain activity under short exposure to blue vs green light in the morning after sleep deprivation. Note that

PER35/5 has been related to increased morning preference (Archer et al., 2003), suggest- ing that morning types showed more pronounced brain modulation after exposure to blue light in the morning after sleep restriction, while late types showed responses to blue light in the morning after a night of sleep. Vandewalle et al. (2011) reported no significant effects of 1-minute light exposure to monochromatic blue vs green light on brain functioning in the evening in either genotype. Employing a longer exposure duration, Chellappa and colleagues (2012) demonstrated stronger acute effects of exposure to relatively dim light with a high vs. low correlated color temperature (CCT) on subjective alertness, EEG power in the theta range and melatonin suppression in the late evening among PER 35/5 individuals as compared to PER34/4 individuals, independent of differences in circadian phase and homeostatic sleep pressure.

These results suggest that persons with increased morning preference are more sensitive to the acute activating effects of blue-enriched light in the evening as compared to persons with increased evening preference.

Complementing these results under controlled conditions in the early morning and late evening(sic), a recent study by Smolders et al. (2014) showed that the relationship between light exposure and feelings of vitality during daytime (between 8 am and 8 pm) was moderated by chronotype. Their results showed that late chronotypes felt more energetic when they were exposed to more light during the previous hour during their daily routine, while light intensity was not significantly related to subjective vitality in early chronotypes.

8. Light Spectrum and its effects on wellness healing and care in health environments.

a. Human Centric Lighting : The Future of Healthcare Lighting Design

How can Human Centric Lighting help? Schlangen et al. (2014) Dynamic light can include a dawn simulation, a cool light colour temperature that fluctuates with warmer colour temperature over the course of the day, and absence of cool colour temperature in the evening. Furthermore, in a hospital a patient should be allowed to adjust light levels in the room by shading daylight to darkness, dimming ceiling light from cool to warm colour temperature and have spotlights for reading or getting up at night. All switches need to be accessible from the bed, therefore a remote console, well labelled for visual impaired and with buttons, which light up when it is dark (e.g. at night).

Research has shown that bright light installations in community rooms of nursing homes do not promote improvement in neuropsychiatric behaviours and sleep as expected. However, fewer studies using natural daylight have documented improvements for these behaviours in the hospital environment and care homes. Therefore, the best strategy for a successful application is to 1) make use of daylight, 2) simulate daylight quality (intensity and spectral composition) as much as possible, and 3) target the most sensible times during which humans are most sensitive to light – the morning and the evening. The hospital and nursing home environment, with inpatients and residents, is ideal to model(sic) dynamic lighting, according to the natural time course of outdoor light – e.g. use a 14:10 hour light-dark cycle, starting dawn simulation from 6:00 o'clock for 20 min.

Nowadays, we spend little of our lives exposed to natural light. We use artificial light to extend our period of wakefulness and activity into the evening hours, and a short sleep schedule which consolidates sleep efficiently at night. A study in New England found that older people (mean age 66 years) spent on average 38% of their waking day in light levels above 100 lux and 15% in light levels above 1000 lux (likely to be outdoor levels of light), whereas young subjects (mean age 24 years) spent only 27% of their waking day in light exceeding 100 lux and only 9% in light levels above 1000 lux (Scheuermaier, Laffan et al. 2010). The older people also woke up and went to bed an hour earlier than younger people, and it is important to note that habitual patterns of light exposure could mask underlying circadian phases or affect entrainment of the body clock directly. The greatest sensitivity to light occurs during the habitual night time when there is typically little light exposure (Chang, Santhi et al. 2012; St Hilaire, Gooley et al. 2012).

Indirect evidence of the effect of the level and timing of light on mood comes from randomised trials under controlled conditions in people with Seasonal Affective Disorder (SAD) and unipolar depression. The diagnosis of SAD is based on the patient having episodes of depression which have occurred at least two years running during months of short photoperiod (winter) and with no symptoms during long photoperiod (summer). While mood changes are similar to those of non-seasonal depression, SAD is atypical in that symptoms are more likely to include craving sweet things, increased appetite, weight gain, and increased sleepiness. Reports show a dose-response relationship for morning light in SAD patients for typical but not atypical symptoms, with strong light (6000 lux and more) being more effective than medium light (1700-3500 lux) or dim light (600 lux and less) (Lee and Chan 1999). Time of day evaluation of bright light therapy for non-seasonal depression showed that morning exposure was more effective than at any other time of day, and this was equal between groups with and without concomitant drug therapy (Tuunainen, Kripke et al. 2004). This indicates that light intensity applied in the morning has different therapeutic effects on typical mood symptoms. Bright light therapy (10000 lux) in comparison to medium (4000 lux) or dim light (50 lux), applied in the morning as adjunct treatment, increases the antidepressant effects of SSRIs such as sertraline and citalopram in patients treated for depression (Martiny, Lunde et al. 2005; Sondergaard, Jarden et al. 2006). Light therapy in the form of a dawn simulation in non-seasonal depression showed similar effect sizes, but here, no dose-response relationship was carried out (Golden, Gaynes et al. 2005). The effect sizes for light therapy are equivalent to those in antidepressant pharmacotherapy trials.

Kluizenaar et al. (2016) The recommendations detailed below are based on the guidance provided by stakeholders during interviews and literature reviews, complemented by feedback received from experts, cities and SMEs. This effort led to over three application recommendations:

Application recommendation 1

Personalised lighting solutions, taking into account (physiological) differences between people, e.g. lighting solutions supporting visual acuity for elderly. - Provide lighting solutions with software-driven dynamic changes in lighting spectral composition and intensity.

- There is a clear need to provide solutions that are individually adjustable depending on personal needs and preferences.
- ‘Older age’ lighting solutions, providing elevated light levels but homogeneous light distribution and lower brightness contrasts, in order to support aged users to remain engaged in more demanding visual tasks, e.g. reading, needlework for prolonged periods without (visual) fatigue. Note: This recommendation is also applicable in(sic) the domestic environment.

Application recommendation 2

Dynamic lighting solutions to support mental well-being, to treat and/or prevent depressive symptoms.

- Target times during which humans are more sensitive to light, with specific attention to the morning and evening times.
- Mind that use of high intensity (and blue-rich) lighting in the 2 hours prior to bedtime delays sleep onset and is disruptive for sleep.
- Increased light intensities are recommended for people who spend limited time outdoors during the day.
- The SSL-erate literature review “Lighting for health and well-being” notes that two forms of artificial light treatment regimens (for depressive symptoms) exist (either of them applied in the morning).
- White light of strong intensity (>= 6000 lux) for the elderly or white light of 3000 lux for the middle-aged (when selecting intensities, exposure duration is a relevant parameter).
- Dawn simulation.

Application recommendation 3

Dynamic lighting solutions(sic) simulating natural daylight quality as much as possible, in terms of intensity and spectral composition, for application in health care facilities where people reside long term (e.g. nursing or elderly homes). This includes:

- Dawn simulation.
- Daylight exposure of sufficient intensity during the day.

- Provide light with a relatively high ‘blue’ content (and natural daylight as much as possible) during the day time.
- Avoid high light intensities and blue-rich light (dim the lights and use warm tones of light, such as reddish light or low color temperatures) during the evening and night time.
- The intensity of day- and evening light should be individually adjustable, while the change in spectral composition may occur automatically.

The importance of no (or limited) light and noise during the night (darkness and quietness) to support sleep quality was stressed. This may be particularly important for vulnerable patients in e.g intensive care units.

b. Best Practices for Healthcare Lighting Design

i. Lighting for health and well-being in Healthcare and Nursing Homes

Schlangen et al. (2014) The healing properties of sunlight have been(was) known thousands of years ago, the ancient Egyptians had sun-gardens, but with the invention of electrical(sic) light and the industrial revolution, the predominant focus became sufficient illumination for vision. Electrical light replaced daylight and allowed to increase windowless indoor space. That the quality of artificial light sources, its intensity and spectral composition, could matter for well-being beyond visual comfort was not known until very recently, although experiments using bright white light boxes to treat depression has been tested since the 1980s (Terman & Terman 1989 Neuropsychopharmacol). Research has discovered that the eye, just like the ear, is a dual sense organ that not only links light and vision(sic) but also light and non-image forming functions, notably alertness, emotions and biological timing. By doing so, light contributes to the regulation of body functions as diverse as appetite, sleep and body temperature. Current artificial light sources in hospitals and care homes do not live up to the growing responsibilities incumbent on the European public healthcare sector. However, research provides accumulated evidence that there is great potential for engineering and architecture to develop non-image, forming lighting solutions for future application in healthcare.

Important insights:

- Patients and elderly people have higher demands on the quality and quantity of light as their body has to cope with immobility, injuries, pathologies and age-related degeneration of tissue.

- Daylight exposure of sufficient intensity during the day acts as an antidepressant in inpatients on hospital wards and enhances adaptation of circadian rhythms to the natural day-night cycle in the elderly..

- Energy-efficient innovative glass material exists, waiting to be used in the architecture of hospitals and care home facilities to increase the areas of natural daylight to come in.

- Interior lighting designs for hospitals and long-term care facilities has(sic) to fulfil two roles: providing optimal illumination for image and non-image forming functions using dynamic approaches for spectral content, intensity, duration and time of day.

- Two forms of artificial light treatment regimes exist, namely white light of strong intensity (6000 lux and above for old age, 3000 lux for depressive symptoms of middle-age, moreover, when selecting intensities, exposure duration also is a relevant parameter) and dawn simulation, either of them applied in the morning, is most effective in abolishing symptoms of depression.

- Enhanced fluorescent indoor light intensity in care homes has shown very limited evidence of improving neuropsychiatric behaviours such as agitation, aggression, irritability, apathy, or nigh-time sleep quality in people with various dementias.

To date, the designs of lighting systems in hospitals and nursing homes are primarily made to support visual acuity for staff and secondly to minimise hazards such as staircases. However, to obtain proper visual sharpness and better contrast, people of older age requires heightened light levels due to age-related failing vision. Furthermore, the hospital and nursing home environments are often purpose-made for hygiene, cleanliness and safety and ignore that light sources produce substantial glare due to shiny floors/surfaces and inappropriate light at night disrupts not only sleep but also the timing of the body clock, with negative consequences for cognition and emotions. Properties of current lighting systems are inflexible and not designed to take non-image forming effects of light into account for patients or older people's well-being in hospitals or nursing homes.

Following are some spaces in a healthcare facility where the use of LED lighting can enhance the spaces while still reducing energy consumption (LED Lighting in Healthcare Facilities, 2013).

1. Harmonious lighting atmosphere in the entrance halls makes people less apprehensive, inspires confidence and makes the surroundings appear friendlier.
2. For a hospital, corridors and circulation areas are the arteries of the building. Diffused homogeneous lighting avoiding sharp contrasts should be considered. It is also important to ensure that a high level of brightness is avoided so patients are not uncomfortable when they are wheeled along on gurneys.

3. In waiting rooms, dimmable wall lighting and table luminaires will radiate a relaxing, domestic ambience.
4. Exam rooms with optimal light color and high quality color rendering assist in examination and diagnosis.
5. In imaging rooms, a calming environment that can include colored lighting using LEDs, video projections and animations selected by the patient during examination and diagnosis can help them to feel more at ease and create a welcome distraction.
6. In patient rooms, use of recessed or surface mounted luminaires, with the addition of spots to create accent lighting provides a pleasant atmosphere and can be controlled by patients. Added cove lighting provides a variety of scenes and more flexibility in scene setting.
7. Nurse's station with task lighting, down lighting and accent lighting on the back wall creates a pleasant working atmosphere.

ii. Impact of light on outcomes in Healthcare Settings

Joseph (2006) states that light impacts human health and performance by enabling the performance of visual tasks, controlling the body's circadian system, affecting mood and perception, and by enabling critical chemical reactions in the body. Studies show that higher light levels are linked with better performance of complex visual tasks, and light requirements increase with age. By controlling the body's circadian system, light impacts outcomes in healthcare settings by reducing depression among patients, decreasing the length of stay in hospitals, improving sleep and circadian rhythm, lessening agitation among dementia patients, easing pain, and improving adjustment to night-shift work among staff. The presence of windows in the workplace and access to daylight have been linked with increased satisfaction with the work environment. Further, exposure to light is critical for vitamin D metabolism in the human body. Light exposure also is used as a treatment for neonatal hyperbilirubinemia.

Adequate and appropriate exposure to light is critical for the health and well-being of patients as well as staff in healthcare settings. A combination of daylight and electric light can meet these needs. Natural light should be incorporated into lighting design in healthcare settings, not only because it is beneficial to patients and staff, but also because it is light delivered at no cost and in a form that most people prefer.

Light impacts human health and performance by four main mechanisms:

- Enabling performance of visual tasks
- Controlling the body's circadian system
- Affecting mood and perception
- Facilitating direct absorption for critical chemical reactions within the body (Boyce, Hunter, & Howlett, 2003; Veitch & McColl, 1993).

The most obvious effect of light on humans is in enabling the vision and performance of visual tasks. According to Boyce and colleagues (2003), the nature of the task—as well as the amount, spectrum, and distribution of the light—determines the level of performance that is achieved. Performance on visual tasks gets better as light levels increase (Boyce, Hunter, & Howlett, 2003). The work environment for nurses and physicians in hospitals is stressful. They are required to perform a range of complex tasks—charting, filling prescriptions, administering medication, and performing other critical patient-care tasks. Inadequate lighting and a chaotic environment are likely to compound the burden of stress and lead to errors. However, very few studies have focused specifically on the impact of different types of lighting conditions on staff work performance in hospitals.

One study examined the effect of different illumination levels on pharmacists' prescription-dispensing error rate (Buchanan, Barker, Gibson, Jiang, & Pearson, 1991). They found that error rates were reduced when work-surface light levels were relatively high (Buchanan et al., 1991). In this study, three different illumination levels were evaluated (450 lux; 1,100 lux; 1,500 lux). Medication-dispensing error rates were significantly lower (2.6%) at an illumination level of 1,500 lux (highest level), compared to an error rate of 3.8% at 450 lux. This is consistent with findings from other settings that show that task performance improves with increased light levels (Boyce, Hunter, & Howlett, 2003). No studies have looked at the impact of different lighting conditions at the nurses' station on task performance or error rate. More research is needed to understand the optimal lighting requirements for supporting the complex tasks performed by nurses and physicians, especially in the context of the changing demographics (in terms of age) of the workforce.

Reducing Depression & Dementia - At least 11 strong studies suggest that bright light is effective in reducing depression among patients with biponight-shift work among staff. A majority of the studies have examined the impact of artificial bright light on reducing depression. Artificial light treatments usually range between 2,500 lux and 10,000 lux (Beauchemin & Hays, 1996). The treatment is believed to be effective by suppressing the onset of melatonin. Two studies have shown that exposure to natural bright light is similarly effective in reducing depression (Beauchemin & Hays, 1996; Benedetti, Colombo, Barbini, Campori, & Smeraldi, 2001). Benedetti and colleagues (2001) found that bipolar depressed inpatients in east-facing rooms (exposed to bright light in the morning) stayed an average of 3.67 days less in the hospital compared with similar patients who stayed in west-facing rooms. There is strong evidence that exposure to bright light in the morning is more effective than exposure to bright light in the evening in reducing depression. (Beauchemin & Hays, 1996; Benedetti et al., 2001; Eastman, Young, Fogg, Liu, & Meaden, 1998; Lewy et al., 1998; Oren, Wisner, Spinelli, & Epperson, 2002; Sumaya, Rienzi, Deegan, & Moss, 2001; J. S. Terman, Terman, Lo, & Cooper, 2001; M. Terman, Terman, & Ross, 1998; Wallace-Guy et al., 2002). An experimental study that compared the effect of morning and evening light on patients with winter depression found that morning light was twice as effective as evening light in treating SAD (Lewy et al., 1998).

Improving Sleep and Circadian Rhythm - Three studies show that providing cycled lighting (reduced light levels in the night) in neonatal intensive-care units results in improved sleep and weight gain among preterm infants (Blackburn & Patteson, 1991; Mann, Haddow, Stokes, Goodley, & Rutter, 1986; Miller, White, Whitman, O'Callaghan, & Maxwell, 1995). In one study, 41 preterm infants in structurally identical critical-care units were provided either cycled or non cycled lighting (constant light levels during the day and night) during a lengthy hospital stay. Compared to infants in the non cycled lighting condition, infants assigned to the cycled lighting condition had a greater rate of weight gain, were able to be fed orally sooner, spent fewer days on the ventilator and on phototherapy, and displayed enhanced motor coordination (Miller et al, 1995).

Easing Pain - A recent randomised prospective study assessed whether the amount of sunlight in a hospital room modifies a patient's psychosocial health, quantity of analgesic medication used, and pain medication cost (Walch et al, 2005) Patients undergoing elective cervical and lumbar spinal surgeries were admitted to the bright or the dim side of the same hospital unit postoperatively. The outcomes measured included the standard morphine equivalent of all opioid medication used postoperatively by patients and their subsequent pharmacy cost. Patients staying on the bright side of the hospital unit were exposed to 46% higher-intensity sunlight on average. This study found that patients exposed to an increased intensity of sunlight experienced less perceived stress, marginally less pain, took 22% less analgesic medication per hour, and had 21% less pain medication costs (Walch et al., 2005).

Improving adjustment to night-shift work among nurses - There are approximately 8 million workers in the United States who regularly work at night, and, for many of these individuals (e.g., nurses and physicians, airline pilots), peak functioning is critical at all times (Horowitz, Cade, Wolfe, & Czeisler, 2001). Night-shift workers not only experience loss of sleep and misalignment of circadian phase, but they also suffer a greater risk of gastric and duodenal ulcers and cardiovascular diseases (Horowitz et al., 2001). Their decreased alertness, performance, and patients on the unit's vigilance may be responsible for more errors on the job (Smith-Coggins, Rosekind, Buccino, Dinges, & Moser, 1997). The timing of the sleep-wake schedule and work schedule of night-shift nurses remains permanently out of phase with the natural light/dark cycle, and this causes health problems. Several studies show that exposure to intermittent bright light during the night shift is effective in adapting circadian rhythms of night-shift workers (Baehr, Fogg,& Eastman, 1999; Boivin & James, 2002; Crowley, Lee, Tseng, Fogg, & Eastman, 2003; Horowitz et al., 2001; Iwata, Ichii, & Egashira, 1997; Leppamaki, Partonen, Piiroinen, Haukka, & Lonnqvist, 2003). Exposure to bright light during the night shift may also improve mood and sleep. In one study, 87 female nurses were exposed to brief periods (4 x 20 minutes) of bright (5,000 lux) light during scheduled times every night during a 2-week night shift. The treatment alleviated the nurses' subjective distress associated with night-shift work (Leppamaki et al., 2003). In addition to bright-light exposure during the night, studies have shown that additional measures such as using dark sunglasses during the commute home and a regular early daytime sleep schedule ensure complete circadian adaptation to night-shift work (Boivin & James, 2002; Crowley et al., 2003; Horowitz et al., 2001).

Facilitating direct absorption for critical chemical reactions in the body - Light radiation is absorbed directly by the body through the skin, and this stimulates chemical reactions in the blood and other tissues. There are two implications of this on health outcomes in healthcare settings. It supports Vitamin D metabolism and prevents jaundice. One of the well-known beneficial photochemical processes that occur this way in the body is the metabolism of vitamin D. Research shows that most of the vitamin D in the blood can only be derived by exposure to light (McColl & Veitch, 2001). The ultraviolet (UV) radiation in the daylight is considered to be important for this process to occur. Most people are able to metabolise vitamin D by exposure to light. However, some people, such as chronically ill institutionalised individuals, elderly, shift workers, and those living in extreme polar latitudes, may not be able to obtain that necessary sunlight exposure. McColl and Veitch cite a couple of studies that suggest that full-spectrum fluorescent lighting might be able to support this important bodily function but conclude that there is insufficient evidence for the use of such lighting for vitamin D metabolism (McColl & Veitch, 2001).

Preventing neonatal hyperbilirubinaemia - Studies suggest that exposure to light is an effective treatment for neonatal hyperbilirubinemia (neonatal jaundice) (Giunta & Rath, 1969). This disorder is common to premature infants who lack the ability to metabolise bilirubin, a product of the decomposition of haemoglobin in dead red blood cells (McColl & Veitch, 2001). Exposure to light bleaches the bilirubin into a form that can be excreted from the body. In a controlled study of 96 preterm infants, 47 unclothed (except for diapers) babies were exposed to bright light (90 footcandles) and 49 fully clothed babies to dim light (10 footcandles). The group of infants exposed to light showed lower serum bilirubin as compared to the infants who were not exposed to the light (Giunta & Rath, 1969). One potential negative outcome that might occur as a result of overexposure to light in healthcare settings is retinal damage in preterm infants, and a few studies suggest that reducing ambient lighting conditions in hospital nurseries might improve outcomes (Ackerman, Sherwonit, & Fisk, 1989; Mann et al., 1986). Neonatal infants have thinner eyelids and usually have not developed the ability to constrict their pupils in response to light exposure. The high intensity of illumination in their environment makes them susceptible to retinal damage. However, studies that have examined the impact of reduced ambient lighting conditions on the development of retinopathy among premature infants have failed to detect a causal link (Kennedy et al., 2001; Reynolds, Hardy, Kennedy, & Spencer, 1998; Seiberth, Linderkamp, Knorz, & Liesenhoff, 1994).

Clearly, an important goal for facility designers should be to fulfill human needs for light and provide a high-quality lighted(sic) environment. Building interiors are lit by a combination of daylight and electric lighting. There is clearly a strong preference for daylight over electric light. Daylight entering through windows can be extremely beneficial to patients, provided there is no glare and it is possible to control light levels. However, in addition to natural light, electric light is needed in all parts of the hospital, though the need for artificial lighting can be reduced by efficient utilization of sunlight wherever possible.

While making decisions regarding lighting, economic factors (first costs, energy consumption, and maintenance) must also be taken into consideration (Veitch, 1993). Proponents of full-spectrum fluorescent lighting argue that this lighting source is superior to other artificial light sources (e.g., cool white lamps) because it provides a full-spectral wavelength similar to natural light and has the advantages of natural light for health and performance. However, there is inadequate evidence to support this claim except in special situations (e.g., for tasks requiring fine colour discrimination) (Veitch & McColl, 1993). Further, Veitch (1993) suggests that full-spectrum fluorescent lighting is not feasible from an economic standpoint. Compared to cool white lamps, full-spectrum fluorescent lights are about six times more expensive and provide less light per unit of electrical energy (Veitch, 1993).

To maintain current recommended light levels(sic), full-spectrum lights would result in higher electricity costs than other lamp types. Also, lamp life for full-spectrum fluorescent light in some installations may be less than other lamp types (Veitch, 1993).

Where good colour rendering and bright, changing visual environments are desirable, energy-efficient natural light is ideal. Wherever possible in healthcare settings, natural light should be incorporated into lighting design not only because it is beneficial to patients and staff, but also because it is light delivered at no cost and in a form that is preferable to most people.

iii. Lighting Pattern for Healthy Buildings

(Lighting Research Center, 2019) Lighting for healthcare presents unique challenges for accommodating the diverse populations who occupy this environment. Because visual acuity is a particularly important requirement for nursing environments and strict illuminance guidelines are in place, as recommended by the Illuminating Engineering Society (IES), these two factors are still crucial considerations for healthcare lighting design.

Lighting design for healthcare does not begin and end with visual performance and illuminance on the workplane, however. To meet the ongoing needs of the patients in their care, hospitals must operate at all times of the day, every day of the year, which puts tremendous strain on healthcare staff and, by extension, the patients and families who use their services. Healthcare support workers have the highest work absence rates of any occupation, and healthcare practitioners and technicians have the highest work absence rates of any professional occupation (according to the most recent [2016] data available from the U.S. Bureau of Labor Statistics). While OSHA-recordable illnesses and injuries are declining across all U.S. industries, moreover, the rates for hospital workers have remained nearly twice as high as all private industry combined, and injuries among healthcare professionals occur at almost three times the rate of other professional and business services

Research has shown that disruption of the circadian system stemming from rotating shift work poses numerous health risks. While much is still unknown about the optimum lighting needs of healthcare workers, especially those who work at night, it is nonetheless possible to provide some useful guidelines based on current knowledge.

The following information covers three distinct lighting and healthcare environments, as well as the needs of their respective end-users. It includes detailed lighting information from a Base Case to a Redesign Scenario, providing data on lighting for circadian health and alertness as well as lighting for visual task performance. The charts provide recommended illuminance levels for specific environments and spaces, based on the average age of the users. The specifications listed are based on recommendations provided by the IES Lighting Handbook and recommended practices outlined in the IES's Lighting for Hospitals and Healthcare Facilities. All recommended illuminance specifications provided in this web resource are based on those required for users between the ages of 25 and 65.

PATIENT ROOM - Lighting for patient rooms should be designed to promote circadian entrainment, providing high CS during the day and low CS in the evening, in order to increase patients' sleep times and improve their sleep quality. Nighttime lighting should be conducive to patient sleep, while also accommodating visiting families and allowing nurses to perform their tasks.

SINGLE PATIENT ROOM - The single patient room, 14'-10" x 19'-2", has room for 1 patient and 1 guest. It has 1 adjustable bed, 1 cabinet, and 1 chair.

BASE CASE - Lighting Plan

2x4 Troffers

3500 K

Wall Mounted Luminaires

3500 K

All Day

CS: 0.3

> Overhead 2x4 troffers on at 100% output
- 3500 K CCT

> Wall-mounted luminaires on at 100% output
- 3500 K CCT

BASE CASE - Lighting Fixtures & Performance

Troffers

A recessed troffer houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid. Troffers are the most common source of illumination in commercial applications. They are relatively inexpensive and can provide high, uniform illuminance levels throughout a room. Troffers usually house linear fluorescent lamps, but more recently LED troffers are available for replacement of fluorescent troffers. Also, LED "tubes" are promoted as fluorescent lamp replacements.

Wall Mounted Luminaire

Wall mounted luminaire lighting is mounted above patient beds and provide both task and ambient illumination. They may have integrated LED sources or contain linear fluorescents.

Single Occupancy Average Circadian Stimulus- Base Case

2x4 Troffers

3500 K

Wall Mounted Luminaires

3500 K

Bed- Looking at Ceiling

All Day

CS: 0.3

E_H: 260 lux

E_V: 275 lux

LPD: 0.64 Watts/ ft^2

Bed- 45 degree tilt

All Day

CS: 0.3

E_H: 260 lux

E_V: 220 lux

LPD: 0.64 Watts/ ft^2

REDESIGN - Static CCT Lighting Plan

2x4 Troffers

4000 K — OFF

Wall Mounted Luminaires

4000 K — OFF

7:00 AM - 10:00 AM

CS: 0.3

> Overhead 2x4 troffers on at 100% output
  - 4000 K CCT

> Wall-mounted luminaires on at 25% output
  - 4000 K CCT

10:00 AM - 4:00 PM

CS: 0.2

> Overhead 2x4 troffers on at 100% output
  - 4000 K CCT

> Wall-mounted luminaires on at 10% output
  - 4000 K CCT, decreasing the output provides lower levels of circadian stimulation in the afternoon.

4:00 PM - 7:00 PM

CS: 0.1

> Overhead 2x4 troffers on at 50% output
  - 4000 K CCT

> Wall-mounted luminaires are off

REDESIGN - Static CCT Fixtures & Performance

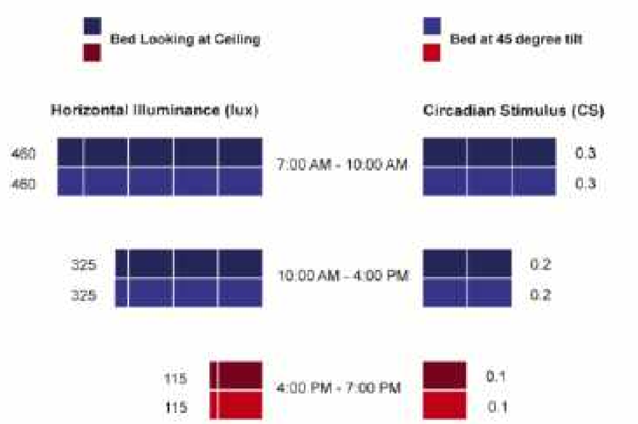
Troffers

A recessed troffer houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid. Troffers are the most common source of illumination in commercial applications. They are relatively inexpensive and can provide high, uniform illuminance levels throughout a room. Troffers usually house linear fluorescent lamps, but more recently LED troffers are available for replacement of fluorescent troffers. Also, LED "tubes" are promoted as fluorescent lamp replacements.

Wall Mounted Luminaire

Wall mounted luminaire lighting is mounted above patient beds and provide both task and ambient illumination. They may have integrated LED sources or contain linear fluorescents.

Single Occupancy Average Circadian Stimulus- Redesign 1



2x4 Troffers

4000 K

Wall Mounted Luminaires

4000 K

Bed- Looking at Ceiling

7:00AM - 10:00AM	10:00AM - 4:00PM	4:00PM - 7:00PM
CS: 0.3	CS: 0.2	CS: 0.1
E_H: 460 lux	E_H: 325 lux	E_H: 115 lux
E_V: 500 lux	E_V: 300 lux	E_V: 85 lux
LPD: 0.45 Watts/ ft ^{2}	LPD: 0.36 Watts/ ft ^{2}	LPD: 0.15 Watts/ ft ^{2}

Bed- 45 degree tilt

7:00AM - 10:00AM	10:00AM - 4:00PM	4:00PM - 7:00PM
CS: 0.3	CS: 0.2	CS: 0.1
E_H: 460 lux	E_H: 325 lux	E_H: 115 luxlux
E_V: 360 lux	E_V: 265 lux	E_V: 100 lux
LPD: 0.45 Watts/ ft ^{2}	LPD: 0.36 Watts/ ft ^{2}	LPD: 0.15 Watts/ ft ^{2}

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REDESIGN - Tunable CCT Lighting Plan

Recessed Linear

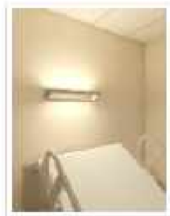
A recessed linear fixture houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid or another hard surface material. Designed to provide uniform illuminance levels throughout a room, they are often specified when a clean, continuous look is preferred. Recessed linear fixtures can house either linear fluorescent lamps or have a dedicated LED source.

Linear Wall Washer

Linear wall washers are mounted along the perimeter of the room. They provide ambient illumination. They may have integrated LED sources or contain linear fluorescents.

Recessed Downlight with Integrated LED Source

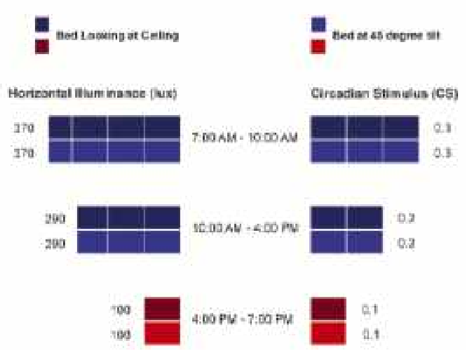
Recessed downlights, sometimes called "cans," are mounted above the ceiling surface and provide task lighting for the area directly below or provide ambient illumination when installed at regular spacing. Downlights may have integrated LED sources or contain CFLs or LED replacement lamps.



Wall Mounted Luminaire

Wall mounted luminaire lighting is mounted above patient beds and provide both task and ambient illumination. They may have integrated LED sources or contain linear fluorescents.

Single Occupancy Average Circadian Stimulus- Redesign 2



Wall Mounted Luminaires

5000 K	4000 K	3500 K

Linear Luminaires

5000 K	4000 K	3500 K

Wall Washers

5000 K	4000 K	3500 K

Downlights

5000 K	4000 K	3500 K

Bed- Looking at Ceiling

7:00AM - 10:00AM	10:00AM - 4:00PM	4:00PM - 7:00PM
CS: 0.3	CS: 0.2	CS: 0.1
E_H: 370 lux	E_H: 290 lux	E_H: 100 lux
E_V: 330 lux	E_V: 250 lux	E_V: 85 lux
LPD: 0.82 Watts/ ft^2	LPD: 0.68 Watts/ ft^2	LPD: 0.27 Watts/ ft^2

Bed- 45 degree tilt

7:00AM - 10:00AM	10:00AM - 4:00PM	4:00PM - 7:00PM
CS: 0.3	CS: 0.2	CS: 0.1
E_H: 370 lux	E_H: 290 lux	E_H: 100 lux
E_V: 350 lux	E_V: 270 lux	E_V: 95 lux
LPD: 0.82 Watts/ ft^2	LPD: 0.68 Watts/ ft^2	LPD: 0.27 Watts/ ft^2

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DOUBLE PATIENT ROOM -The double patient room, 14'-10" x 28'-9", has room for 2 patients and 2 guests. It has 2 adjustable beds, 2 cabinets, and 2 chairs.

BASE CASE - Lighting Plan

2x4 Troffers

3500 K

Wall Mounted Luminaires

3500 K

All Day

CS: 0.3

> Overhead 2x4 troffers on at 100% output
- 3500 K CCT

> Wall-mounted luminaires on at 100% output
- 3500 K CCT

BASE CASE - Lighting Fixtures & Performance

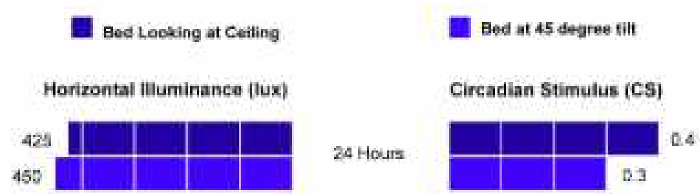
Troffers

A recessed troffer houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid. Troffers are the most common source of illumination in commercial applications. They are relatively inexpensive and can provide high, uniform illuminance levels throughout a room. Troffers usually house linear fluorescent lamps, but more recently LED troffers are available for replacement of fluorescent troffers. Also, LED "tubes" are promoted as fluorescent lamp replacements.

Wall Mounted Luminaire

Wall mounted luminaire lighting is mounted above patient beds and provide both task and ambient illumination. They may have integrated LED sources or contain linear fluorescents.

Double Occupancy Average Circadian Stimulus- Base Case



2x4 Troffers

3500 K

Wall Mounted Luminaires

3500 K

Bed- Looking at Ceiling

All Day

CS: 0.3

E_H: 260 lux

E_V: 275 lux

LPD: 0.74 Watts/ ft ^{2}

Bed- 45 degree tilt

All Day

CS: 0.3

E_H: 260 lux

E_V: 250 lux

LPD: 0.74 Watts/ ft ^{2}

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REDESIGN - Static CCT Lighting Plan

2x4 Troffers

4000 K

Wall Mounted Luminaires

4000 K OFF

7:00 AM - 10:00 AM	10:00 AM - 4:00 PM	4:00 PM - 7:00 PM
CS: 0.3	CS: 0.2	CS: 0.1
> Overhead 2x4 troffers on at 100% output - 4000 K CCT	> Overhead 2x4 troffers on at 100% output - 4000 K CCT	> Overhead 2x4 troffers on at 50% output - 4000 K CCT
> Wall-mounted luminaires on at 25% output - 4000 K CCT	> Wall-mounted luminaires on at 10% output - 4000 K CCT. Lower output decreases circadian stimulation in the afternoon.	> Wall mounted luminaires are off

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REDESIGN - Static CCT Lighting Plan

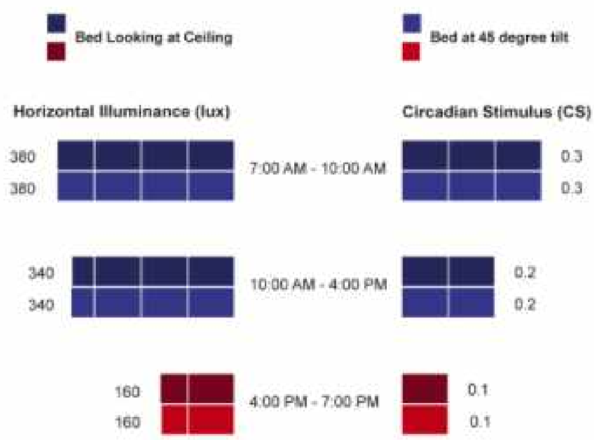
Troffers

A recessed troffer houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid. Troffers are the most common source of illumination in commercial applications. They are relatively inexpensive and can provide high, uniform illuminance levels throughout a room. Troffers usually house linear fluorescent lamps, but more recently LED troffers are available for replacement of fluorescent troffers. Also, LED "tubes" are promoted as fluorescent lamp replacements.

Wall Mounted Luminaire

Wall mounted luminaire lighting is mounted above patient beds and provide both task and ambient illumination. They may have integrated LED sources or contain linear fluorescents.

Double Occupancy Average Circadian Stimulus- Redesign 1



2x4 Troffers

4000 K

Wall Mounted Luminaires

4000 K

Bed- Looking at Ceiling

7:00AM - 10:00AM	10:00AM - 4:00PM	4:00PM - 7:00PM
CS: 0.3	CS: 0.2	CS: 0.1
E_H: 380 lux	E_H: 340 lux	E_H: 160 lux
E_V: 540 lux	E_V: 320 lux	E_V: 85 lux
LPD: 0.52 Watts/ ft^2	LPD: 0.42 Watts/ ft^2	LPD: 0.18 Watts/ ft^2

Bed- 45 degree tilt

7:00AM - 10:00AM	10:00AM - 4:00PM	4:00PM - 7:00PM
CS: 0.3	CS: 0.2	CS: 0.1
E_H: 380 lux	E_H: 340 lux	E_H: 160 luxlux
E_V: 455 lux	E_V: 300 lux	E_V: 100 lux
LPD: 0.52 Watts/ ft^2	LPD: 0.42 Watts/ ft^2	LPD: 0.18 Watts/ ft^2

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REDESIGN - Tunable CCT Lighting Plan

Wall Mounted Luminaires

5000 K — 4000 K — 3500 K

Linear Luminaires

5000 K — 4000 K — 3500 K

Wall Washers

5000 K — 4000 K — 3500 K

Downlights

5000 K — 4000 K — 3500 K

7:00 AM - 10:00 AM

CS: 0.3

> Wall-mounted luminaires on at 100% output
  - 5000 K CCT

> Linear luminaires on at 100% output
  - 5000 K CCT

> Wall washers on at 100% output
  - 5000 K CCT

> Downlights on at 100% output
  - 5000 K CCT

10:00 AM - 4:00 PM

CS: 0.2

> Wall-mounted luminaires on at 75% output
  - Shifts to 4000 K CCT; lower output and warmer CCT decrease circadian stimulation in the afternoon.

> Linear luminaires on at 75% output
  - Shifts to 4000 K CCT; lower output and warmer CCT decrease circadian stimulation in the afternoon.

> Wall Washers on at 75% output
  - Shifts to 4000 K CCT; lower output and warmer CCT decrease circadian stimulation in the afternoon.

> Downlights on at 100% output
  - Shifts to 4000 K CCT; warmer CCT decreases circadian stimulation in the afternoon.

4:00 PM - 7:00 PM

CS: 0.1

> Wall-mounted luminaires on at 25% output
  - Shifts to 3500 K CCT; lower output and warmer CCT decrease circadian stimulation in the afternoon.

> Linear luminaires on at 25% output
  - Shifts to 3500 K CCT; lower output and warmer CCT decrease circadian stimulation in the afternoon.

> Wall Washers on at 25% output
  - Shifts to 3500 K CCT; lower output and warmer CCT decrease circadian stimulation in the afternoon.

> Downlights on at 50% output
  - Shifts to 3500 K CCT; warmer CCT decrease circadian stimulation in the afternoon.

Recessed Linear

A recessed linear fixture houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid or another hard surface material. Designed to provide uniform illuminance levels throughout a room, they are often specified when a clean, continuous look is preferred. Recessed linear fixtures can house either linear fluorescent lamps or have a dedicated LED source.

Recessed Downlight with Integrated LED Source

Recessed downlights, sometimes called "cans," are mounted above the ceiling surface and provide task lighting for the area directly below or provide ambient illumination when installed at regular spacing. Downlights may have integrated LED sources or contain CFLs or LED replacement lamps.

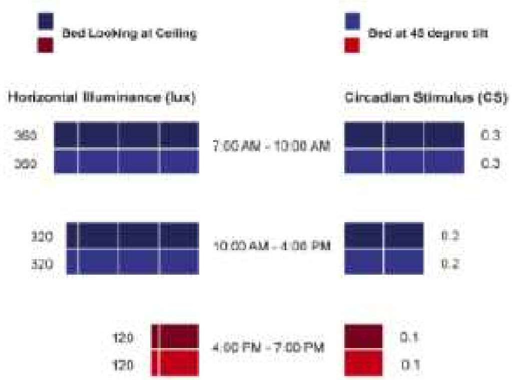
Linear Wall Washer

Linear wall washers are mounted along the perimeter of the room. They provide ambient illumination. They may have integrated LED sources or contain linear fluorescents.

Wall Mounted Luminaire

Wall mounted luminaire lighting is mounted above patient beds and provide both task and ambient illumination. They may have integrated LED sources or contain linear fluorescents.

Double Occupancy Average Circadian Stimulus- Redesign 2



Wall Mounted Luminaires

5000 K — 4000 K — 3500 K

Linear Luminaires

5000 K — 4000 K — 3500 K

Wall Washers

5000 K — 4000 K — 3500 K

Downlights

5000 K — 4000 K — 3500 K

Bed- Looking at Ceiling

7:00AM - 10:00AM	10:00AM - 4:00PM	4:00PM - 7:00PM
CS: 0.3	CS: 0.2	CS: 0.1
E_H: 360 lux	E_H: 320 lux	E_H: 120 lux
E_V: 310 lux	E_V: 240 lux	E_V: 80 lux
LPD: 0.94 Watts/ ft^2	LPD: 0.75 Watts/ ft^2	LPD: 0.27 Watts/ ft^2

Bed- 45 degree tilt

7:00AM - 10:00AM	10:00AM - 4:00PM	4:00PM - 7:00PM
CS: 0.3	CS: 0.2	CS: 0.1
E_H: 360 lux	E_H: 320 lux	E_H: 120 lux
E_V: 310 lux	E_V: 240 lux	E_V: 80 lux
LPD: 0.94 Watts/ ft^2	LPD: 0.75 Watts/ ft^2	LPD: 0.27 Watts/ ft^2

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NEONATAL INTENSIVE CARE UNIT - The NICU 48'-6" x 40'-8", is divided into two zones: nurse's station, and the infants in their incubators. It has 2 redesigns, one with a ceiling grid and one without, both 10' above the floor. The NICU contains incubators and a built-in desk for nurse's.

BASE CASE- Lighting Plan

Infants

2x4 Troffers

3500 K

All Day

CS: 0.4

> Overhead 2x4 troffers on at 100% output
  - 3500 K CCT

Nurse's Station

2x4 Troffers

3500 K

All Day

CS: 0.3

> Overhead 2x4 troffers on at 100% output
  - 3500 K CCT

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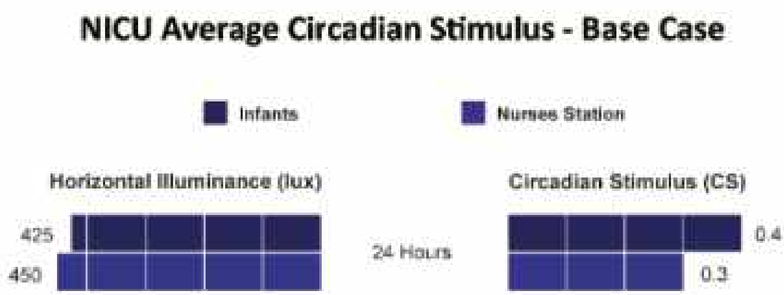
BASE CASE - Lighting Fixtures & Performance

Troffers

A recessed troffer houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid. Troffers are the most common source of illumination in commercial applications. They are relatively inexpensive and can provide high, uniform illuminance levels throughout a room. Troffers usually house linear fluorescent lamps, but more recently LED troffers are available for replacement of fluorescent troffers. Also, LED "tubes" are promoted as fluorescent lamp replacements.



Infants

2x4 Troffers

3500 K

All Day

CS: 0.4

E_H: 425 lux

E_V: 425 lux

Nurse's Station

2x4 Troffers

3500 K

All Day

CS: 0.3

E_H: 450 lux

E_V: 240 lux

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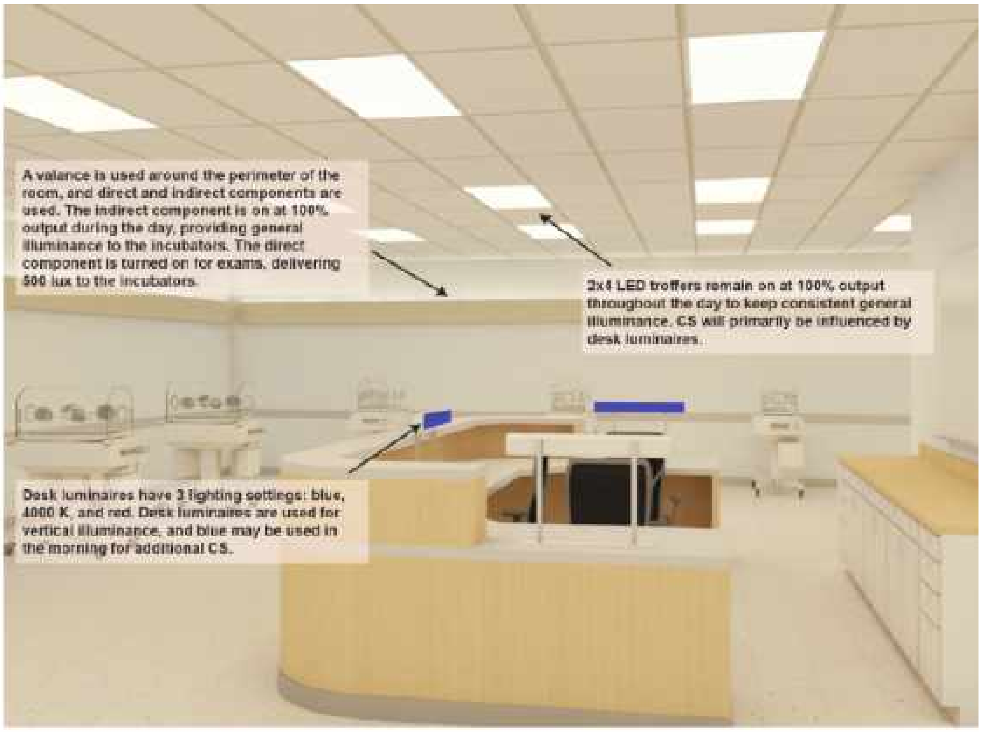
REDESIGN - Static CCT Lighting Plan



Infants

Valance

Indirect Optic- 4000 K

Direct Optic- 4000 K

2x4 Troffers

4000 K

7:00 AM - 2:00 PM

CS: 0.3

> 2x4 troffers on at 100% output
  - 4000 K CCT

> Valance on at 100% output
  - Indirect optic at 4000 K CCT
  - Direct optic remains off unless additional illuminance is needed for exams.

2:00 PM - 7:00 PM

CS: 0.2

> 2x4 troffers on at 100% output
  - 4000 K CCT

> Valance on at 100% output
  - Indirect optic at 4000 K CCT
  - Direct optic remains off unless additional illuminance is needed for exams.

Nurse's Station

2x4 Troffers

4000 K

Desk Luminaires - Option 1

OFF

Desk Luminaires - Option 2

OFF

7:00AM - 2:00PM

CS: 0.5

> 2x4 troffers on at 50% output
  - 4000 K CCT

> Blue desk luminaires on at 100% output
  - Option 1 & 2 saturated blue light provides additional circadian stimulation in the morning

2:00PM - 7:00PM

CS: 0.2

> 2x4 troffers on at 50% output, shifts to 25% output during night hours
  - 4000 K CCT

> Blue desk luminaires on or off
  - Option 1 blue light turns off at 2:00PM.
  - Option 2 blue light stays on until 4:00PM to provide longer circadian stimulation based on the user's preference.

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Troffers

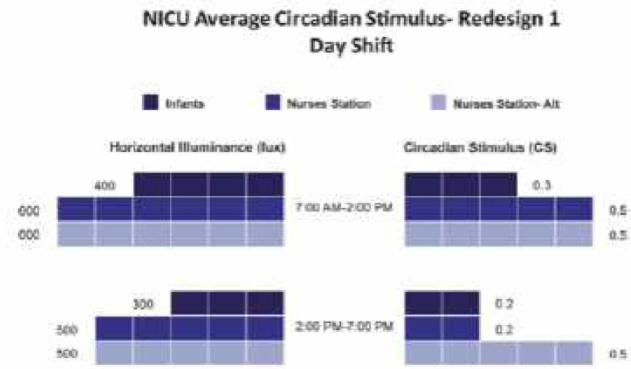
A recessed troffer houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid. Troffers are the most common source of illumination in commercial applications. They are relatively inexpensive and can provide high, uniform illuminance levels throughout a room. Troffers usually house linear fluorescent lamps, but more recently LED troffers are available for replacement of fluorescent troffers. Also, LED "tubes" are promoted as fluorescent lamp replacements.

Valances with Color Tunable LED Lamps

Valances are mounted horizontally on the wall and consist of a shield that hides linear fluorescent or LED light sources from view. Valances direct light up and down, illuminating walls and ceilings to indirectly light a space. They emphasize textures or wall hangings and can provide task lighting when mounted at a lower height.

LED Desk Luminaire

Desk luminaires are placed at eye level where occupants will spend most of their day. They provide task illumination. They have integrated LED sources.



Infants

Valance

Indirect Optic - 4000 K

Direct Optic - 4000 K

2x4 Troffers

4000 K

7:00AM - 2:00PM	2:00PM - 7:00PM
CS: 0.3	CS: 0.2
E_h: 400 lux	E_h: 300 lux
E_v: 440 lux	E_v: 320 lux
LPD: 1.31 Watts/ ft ^{2}	LPD: 0.66 Watts/ ft ^{2}

Note: Nurses can cover incubator and CS would then be less than 0.1, but should allow for a CS level of 0.3 for 2 hours in the morning.

Nurse's Station

2x4 Troffers

4000 K

Desk Luminaires - Option 1

OFF

Desk Luminaires - Option 2

OFF

7:00AM - 2:00PM	2:00PM - 7:00PM		
CS: 0.5	CS: 0.2	OR	CS: 0.5
E_h: 600 lux	E_h: 300 lux		E_h: 300 lux
E_v: 450 lux	E_v: 280 lux		E_v: 330 lux
LPD: 0.57 Watts/ ft ^{2}	LPD: 0.56 Watts/ ft ^{2}		LPD: 0.57 Watts/ ft ^{2}

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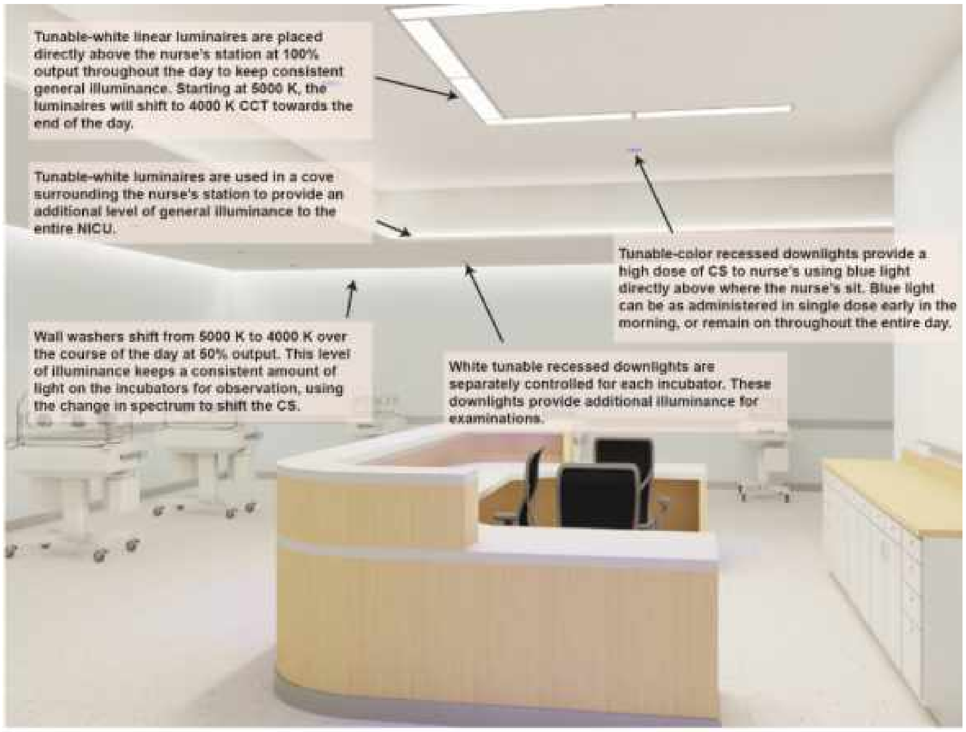
REDESIGN - Tunable CCT Lighting Plan



Infants

Cove

5000K — 4000K

Wall Washers

5000K — 4000K

Downlights

OFF

7:00 AM - 2:00 PM

CS: 0.3

> Cove lighting on at 100% output
  - 5000 K CCT

> Wall Washers on at 50% output
  - 5000 K CCT

> Downlights off
  - Remains off unless additional illuminance is needed for exams.

2:00 PM - 7:00 PM

CS: 0.3

> Cove lighting on at 100% output
  - 4000 K CCT

> Wall Washers on at 50% output
  - 5000 K CCT

> Downlights off
  - Remains off unless additional illuminance is needed for exams.

Nurse's Station

Recessed Linears

5000K — 4000K

Downlight - Option 1

OFF

Downlight - Option 2

OFF

7:00 AM - 2:00 PM

CS: 0.5

> Recessed linear luminaires on at 100% output
  - 5000 K CCT

> Downlights on at 100% output
  - Option 1 and 2: tuned to blue light for additional circadian stimulation in the morning.

2:00 PM - 7:00 PM

CS: 0.3

> Recessed linear luminaires on at 100% output
  - 4000 K CCT

> Downlights on or off
  - Option 1: off
  - Option 2: tuned to blue light for additional circadian stimulation during the day if preferred.

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Cove Lights with Color Tunable Linear LED

Cove lights are recessed or mounted horizontally on the wall and consist of a shield that hides linear fluorescent or LED light sources from view. Coves direct light upwards to the upper wall and ceiling to provide indirect, ambient light for a space.

Recessed Linear

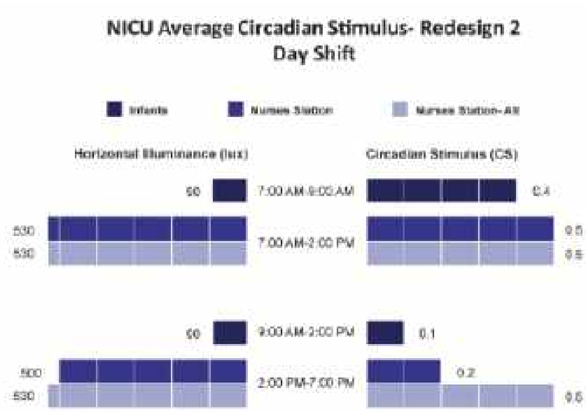
A recessed linear fixture houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid or another hard surface material. Designed to provide uniform illuminance levels throughout a room, they are often specified when a clean, continuous look is preferred. Recessed linear fixtures can house either linear fluorescent lamps or have a dedicated LED source.

Recessed Downlight with Color Tunable LED

Recessed downlights, sometimes called "cans," are mounted above the ceiling surface and provide task lighting for the area directly below or provide ambient illumination when installed at regular spacing. Downlights may have integrated LED sources or contain CFLs or LED replacement lamps.

Linear Wall Washer

Linear wall washers are mounted along the perimeter of the room. They provide ambient illumination. They may have integrated LED sources or contain linear fluorescents.



Infants

Cove

5000K — 4000K

Wallwashers

4000K

Downlights

OFF

7:00 AM - 9:00 AM	9:00 AM - 7:00 PM
CS: 0.4	CS: 0.1
E_H: 90 lux	E_H: 30 lux
E_V: 60 lux	E_V: 30 lux
LPD: 0.41 Watts/ ft^2	LPD: 0.24 Watts/ ft^2

Note: Nurses can cover incubator and CS would then be less than 0.1, but should allow for a CS level of 0.3 for 2 hours in the morning.

Nurse's Station

Recessed Linears

5000K — 4000K

Downlight - Option 1

OFF

Downlight - Option 2

OFF

7:00AM - 2:00PM	2:00PM - 7:00PM		
CS: 0.5	CS: 0.2		CS: 0.5
E_H: 530 lux	E_H: 500 lux	OR	E_H: 530 lux
E_V: 220 lux	E_V: 190 lux		E_V: 220 lux
LPD: 1.18 Watts/ ft^2	LPD: 0.82 Watts/ ft^2		LPD: 1.18 Watts/ ft^2

NURSE STATION - The nurse's station, 44'-6" x 26'-8'' , seats 11 nurses. It has a ceiling grid 9' above the floor. The nurse's station contains built in desks and office chairs.

BASE CASE - Lighting Plan

2x4 Troffers

3500 K

All Day

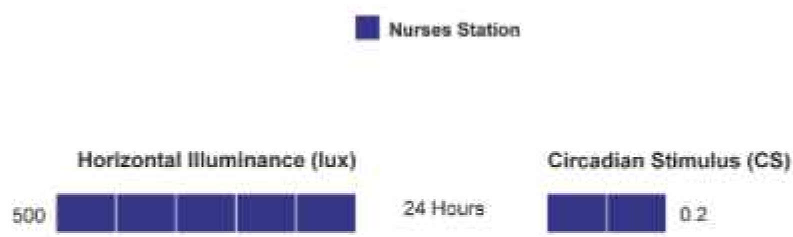
CS: 0.1

> Overhead 2x4 troffers on at 100% output
  - 3500 K CCT

Troffers

A recessed troffer houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid. Troffers are the most common source of illumination in commercial applications. They are relatively inexpensive and can provide high, uniform illuminance levels throughout a room. Troffers usually house linear fluorescent lamps, but more recently LED troffers are available for replacement of fluorescent troffers. Also, LED "tubes" are promoted as fluorescent lamp replacements.

Nurse's Station Average Circadian Stimulus- Base Case



2x4 Troffers

3500 K

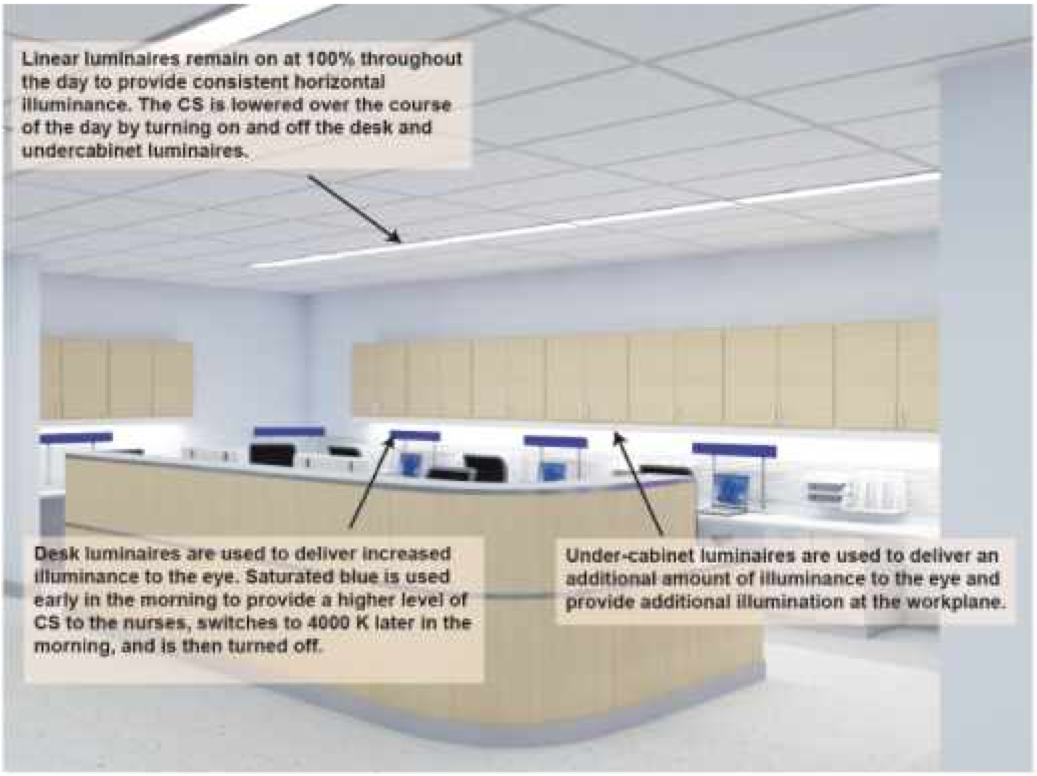
24 Hours

CS: 0.2

E_H: 500 lux

E_V: 130 lux

REDESIGN - Static CCT Lighting Plan



Linear Luminaires

4000 K

Undercabinet Luminaires

4000 K

Desk Luminaires - Option 1

OFF

Desk Luminaires - Option 2

OFF

7:00 AM - 1:00 PM

CS: 0.5

> Linear luminaires on at 100% output
  - 4000 K CCT

> Under-cabinet luminaires on at 100% output
  - 4000 K CCT

> Desk luminaires on at 100% output
  - Saturated blue, providing 50 lux to the overall vertical illuminance and giving a boost of high CS to the nurses.

1:00 PM - 4:00 PM

CS: 0.3

> Overhead luminaires on at 100% output
  - 4000 K CCT

> Under-cabinet luminaires on at 100% output
  - 4000 K CCT

> Desk luminaires on at 100% output
  - Option 1 shifts from blue to 4000 K CCT, which provides slightly lower CS and has less impact on the circadian system while providing more illuminance at the eye.
  - Option 2 remains at blue output until 4:00 PM, based on personal preference.

4:00 PM - 10:00 PM

CS: 0.2

> Overhead luminaires on at 100% output
  - 4000 K CCT

> Under-cabinet luminaires on at 100% output
  - 4000 K CCT

> Desk luminaires off

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REDESIGN - Static CCT Fixtures & Performance

Undercabinet Lights with Dedicated LED

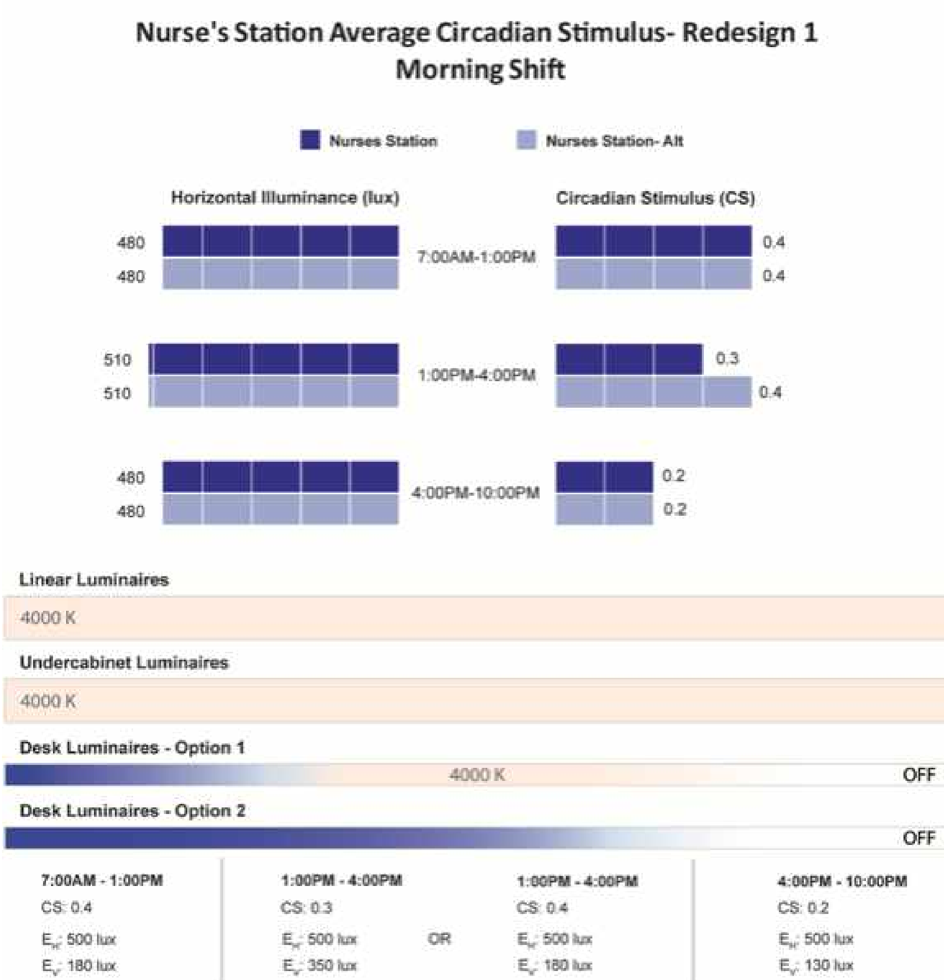
Undercabinet fixtures are mounted under wall cabinets and provide task lighting to the counters below. These fixtures should be installed close to the front of the cabinet and hidden from direct view by cabinetry moulding. Undercabinet fixtures use linear fluorescent (often T5) lamps, linear LED lamps, or have a dedicated LED source.

LED Desk Luminaire

Desk luminaires are placed at eye level where occupants will spend most of their day. They provide task illumination. They have integrated LED sources.

Recessed Linear

A recessed linear fixture houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid or another hard surface material. Designed to provide uniform illuminance levels throughout a room, they are often specified when a clean, continuous look is preferred. Recessed linear fixtures can house either linear fluorescent lamps or have a dedicated LED source.



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REDESIGN - Tunable CCT Lighting Plan

Overhead Luminaires

5000 K → 4000 K

Wall Washer Luminaires - Option 1

5000 K → 4000 K

Wall Washer Luminaires - Option 2

4000 K

7:00AM - 1:00PM

CS: 0.5

> Overhead luminaires on at 100% output
  - 5000 K CCT

> Wall washers on at 100% output
  - Saturated blue, providing 50 lux to the overall vertical illuminance and giving a boost of high CS to the nurses.

1:00PM - 4:00PM

CS: 0.3

> Overhead luminaires on at 100% output
  - 5000 K CCT

> Wall washers on at 100% output
  - Option 1 shifts from blue to 5000 K CCT. 5000 K has less of an impact on the circadian system, but provides more illuminance to the eye than blue, providing the nurses with a slightly lower CS.
  - Option 2 remains at saturated blue. Blue light can be used until 4:00PM if the user prefers this type of light.

4:00PM - 10:00PM

CS: 0.2

> Overhead luminaires on at 100% output
  -4000 K CCT

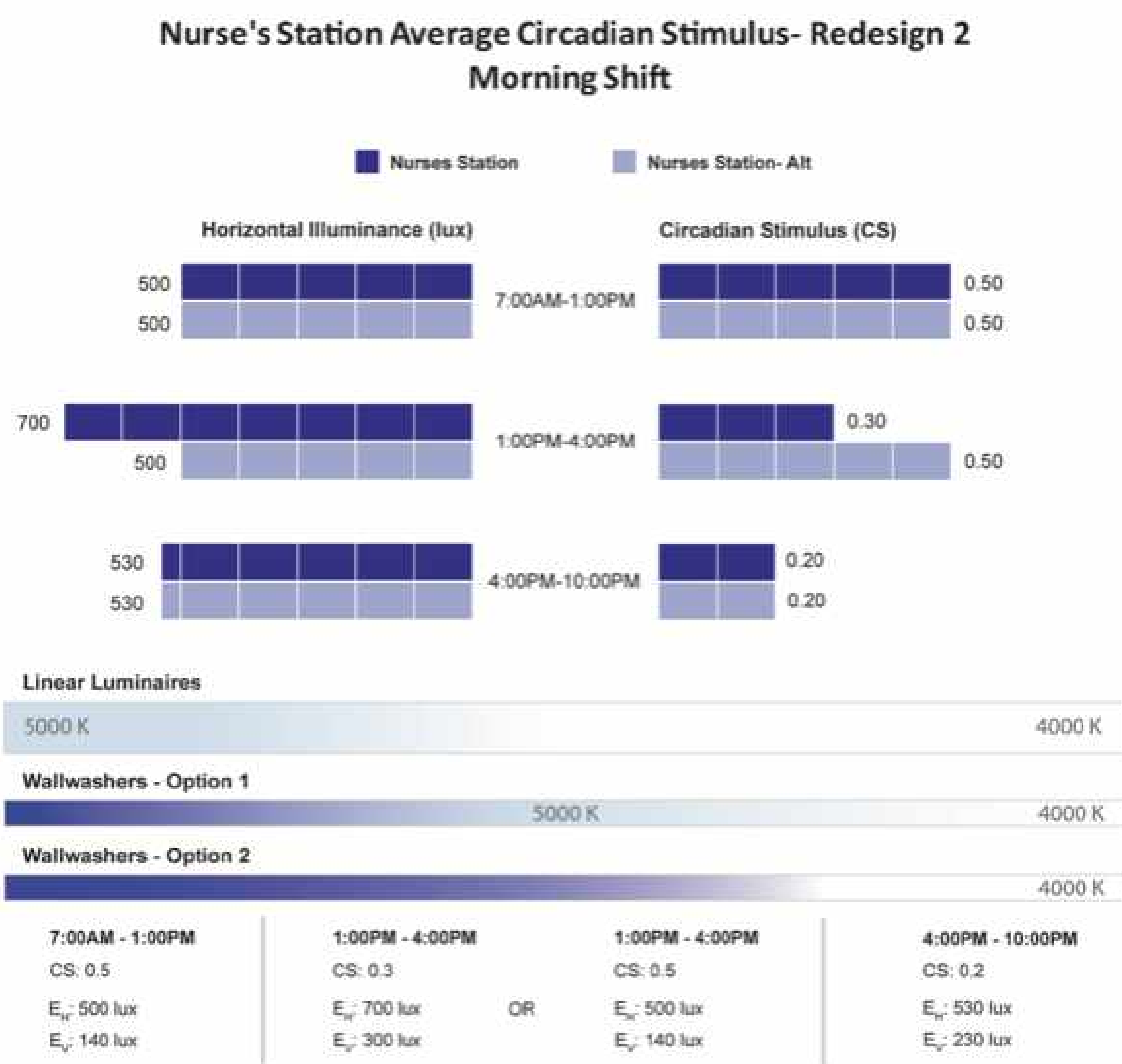
> Wall washers on at 75% output
  - Option 1 shifts from 5000 K to 4000 K CCT. 4000 K has a minimal impact on the CS, but still provides a small amount of illuminance to the work plane, aiding in visual stimulation for the nurses.
  - Option 2 shifts from blue to 4000K CCT.

Recessed Linear

A recessed linear fixture houses light sources above the ceiling line, typically fitting into a modular dropped ceiling grid or another hard surface material. Designed to provide uniform illuminance levels throughout a room, they are often specified when a clean, continuous look is preferred. Recessed linear fixtures can house either linear fluorescent lamps or have a dedicated LED source.

Linear Wall Washer

Linear wall washers are mounted along the perimeter of the room. They provide ambient illumination. They may have integrated LED sources or contain linear fluorescents.



brightgreen.

9. Light Spectrum and its effects on consumer behavior - driving sales in Retail

a. Dynamic Lighting through Human Centric Lighting

i. Human Centric Lighting: Going beyond Energy Efficiency

A.T Kearney (2013) a consulting firm that conducted a joint market study with Lighting Europe and The German Electrical Electronic Manufacturers' Association (ZVEI) on Human Centric Lighting shows that this concept can become a multibillion-euro business covering around 7% of the general lighting market in Europe.

Human-centric lighting is intended to promote a person's wellbeing, mood, and health. An outstanding growth trajectory is expected for this market, which has not been the focus of customers, industry, and policymakers so far. This growth is fueled by the technology transition from conventional light sources to LED modules. While the energy efficiency and durability of LED modules are widely known in the market, little attention has been paid to their advanced controllability and related applications.

Lighting is not neutral in terms of human health, and adverse effects, such as disturbance of sleep/wake cycles, mood disorders and possibly even cancer pathologies may be the consequences of ignoring new findings on non-visual effects of light. For this purpose, a diversity of light sources with different biological effectiveness, bigger surfaces that reflect or emit light and light management systems that control the proper timing of lighting are needed. Improving lighting quality has a known impact on vision and health. Therefore, there are possibilities for application in nearly all situations of our daily lives.

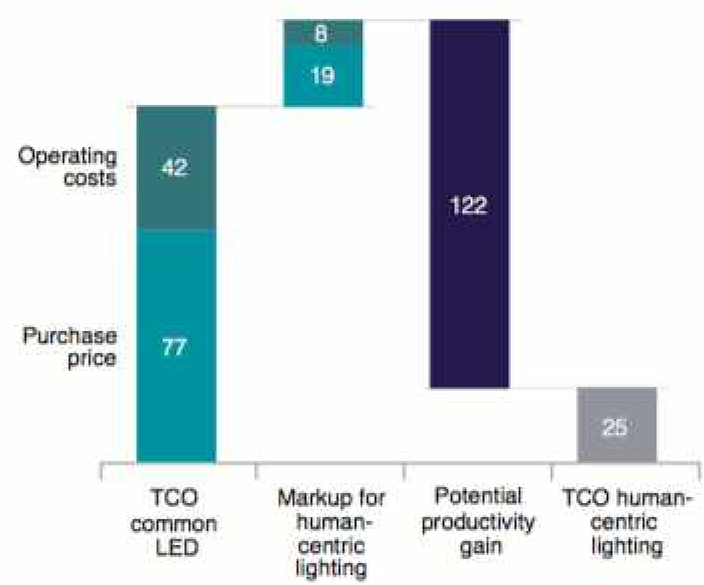
Nevertheless, little is known in public and politics about human-centric lighting. A consensus in society that good lighting is essential for a person's wellbeing has prevailed for a long time. However, discussions have been superficial and are often not driven by facts. This (sic) is the result of the challenges of separating causes and effects, which often seem vague and depend on the individual appraisal of surrounding conditions. After the 2001 discovery of a third photoreceptor in the human eye, in addition to rods and cones, effects on circadian rhythms could be related to specific light conditions. This discovery scientifically manifested the general public consensus. It represented a major leap forward, facilitating further research and development activities by both academia and industry. Today, specific lighting solutions can be produced and installed in ways that specifically support the human circadian rhythm, enhance concentration, prevent sleeping disorders and improve overall well being.

Within the range of human-centric lighting systems, two major distinctions can be made: On one-hand, biologically effective lighting represents lighting systems that are appropriate to stimulate the biological organism, thus improving cognitive performance. On the other hand, emotionally effective lighting systems are designed to create emotionally stimulating environments and an appealing atmosphere. Thus, human-centric lighting simultaneously takes into account our requirements for good vision as well as our emotional and biological needs.

The diverse positive effects of human-centric lighting allow its usage along various dimensions of our everyday life. It can be used in offices and our homes, in schools and retirement homes, for industrial and even recreational purposes. Wholesale, retail and hospitality can benefit from new lighting solutions, and products can be presented in new ways. For example, fashion products can be presented under true daylight conditions, even deeply in-house, far away from any window. It can also promote extended daytime in shopping malls.

Despite all qualitative effects on human wellbeing and mood, there is evidence that the utilization of human-centric lighting solutions has a clear financial benefit as well, as outlined in a case study for a factory workshop in Figure 3.

Figure 3: Total cost of ownership (TCO) of human centric vs. common LED lighting (in € k)



Source: LightingEurope JWG "Light and Health", A.T. Kearney

Case study of a factory workshop:
Compared to common LED systems, we assume a 25% markup on purchase prices and 20% markup on power consumption for the human-centric lighting system.

For a workshop with an area of 1,500 square meters, a 1.7% productivity gain is needed to offset this additional cost of ownership, calculated over a period of 10 years.

However, studies indicate that productivity gains of up to 7.7% are possible in blue-collar environments, e.g., due to higher concentration (less failures) or improved motivation (more Output). Assuming that ten employees each completed six tasks per day with a contribution margin of €12/task under common lighting conditions, human-centric lighting could facilitate an absolute productivity gain of up to €12.2k per year. Thus, human-centric lighting would allow a win-win situation, not only influencing the workers' mood positively but also leading to improved productivity, offsetting the initial investments quickly.

ii. The Circadian Advantage, using HCL to boost Wellness and Sales

Rattner (2017) indicates that Central to any discussion of light is the circadian rhythm. A mashup of the Latin words for "approximately" (circa) and "day" (Diem), the term refers to the roughly 24-hour period it takes the earth to revolve once around its axis. Many aspects of human physiology are biologically pegged to this period, most noticeably the internal clock that controls our sleep-wake cycle. For example, the release of the hormone melatonin, which prepares us for sleep, is triggered by the onset of darkness, whereas the cool light of morning suppresses its production, enabling us to fully awaken and become energized before the cycle repeats itself again (sic). Other hormones ebb and flow to regulate bodily functions throughout the cycle as well. Regardless of the myth of the depressed, debauched, and destitute artist, the truth is that being at your best creatively means being at your best physiologically and psychologically. Attuning your sleep-wake cycle to the circadian rhythm is an important step in that quest.

The challenge is that we are far removed from the purely natural environments of our caveman ancestors, for whom the sun was the sole source of light and who did not spend around 90% of their waking hours indoors, as we do. The absence of daylight can wreak on mind and body; the researchers found that people who work in windowless environments on average get 46 minutes less sleep on work nights, experience lower-quality rest, and are less physically active during the workday than colleagues who are afforded adequate exposure. Artificial illumination can thoroughly disrupt our circadian rhythms by exposing us to blue light at all hours of the day and not just from light bulbs. Our computer screens, mobile devices, televisions, and assorted electronic doodads (sic) all emit light in the blue spectrum.

(Abdullah et al., 2016) The effect of light on us is diverse and complex. In particular, when it comes to our circadian systems, light is often the most important environmental factor. Light modulates our neural and physiological processes depending on the wavelength, time, duration and intensity of exposure. These non-visual effects of light include improving mood and long-term memory.

It should be noted that these biological processes (e.g., mood and attention) reflect circadian rhythms. In general, a variable and adaptable lighting system could help ensure circadian stability. For example, it has been shown that circadian instability in shift-workers can be minimized by the appropriate use of light. Jet lag, another form of circadian disruption, could also potentially be reduced by light exposure.

We believe there is a potential opportunity for developing circadian aware technology — systems that play to our biological strengths (and weaknesses). Moreover, a system that focuses on stimulating our creative ability by providing appropriate support, depending on the task, along with taking individualized circadian rhythms into consideration (sic).

Andre Wiggerich (2017) mentions that a high-quality lighting system can thus not only enhance the optimal presentation of products and the design of the ambience but beyond that very decisively contribute to the service quality of the employees. HCL supports in a targeted and long-term manner the health, wellbeing, and performance of people by way of holistic planning and implementation of the visual, emotional and, in particular, the biological effects of light.

(Ixtenso.com, 2017) Over the past ten years, energy efficiency thanks to LED technology, has shaped both the lighting market and the retail sector. Lighting became more efficient, smarter and comparable in price with today's halogen and similar lighting options. Now, the effect of light on the wellbeing of people takes centre stage. Human-centric Lighting (HCL) refers to biologically effective lighting that can affect human health in a non-visual, subconscious manner. It sounds complicated but is essentially just a question of adjusting the colour temperature to the natural pattern of light during the day and night.

In a position paper on the use of HCL, the Lighting Association of ZVEI German Electrical and Electronic Manufacturers Association (Zentralverband Elektrotechnik- und Elektronikindustrie e.V.) thus recommends using the new findings on the effects of light on humans sensibly and implementing lighting systems that cater to the biological needs of users.

> This lighting concept is aimed at always providing users with the type of lighting that matches the respective living and working conditions. That means 'cooler' white light during the day and less and 'warmer' light at night. The Association recaps: This type of biologically effective lighting supports people during periods of activity and periods of rest, regulates the long-term sleep-wake cycle, promotes better sleep and more energy during the day, directly activates and increases motivation and productivity (Ixtenso.com, 2017)

Retail can take advantage of this new knowledge in several areas. Undoubtedly the greatest benefits can be achieved in shift and warehouse work because working hours at any time of the day are an increasingly important issue, especially in e-commerce logistics. Customers like to order products around the clock and prefer to have them delivered as quickly as possible. In this case, it's obvious to create pleasant lighting conditions for warehouse employees, which helps to support their work without disrupting their internal clock. The HCL practical application at Edeka Store in Germany has proven that it can boost sales and improve the well being of both the Customer and Staff, leading to a more enjoyable shopping experience and excellent customer service.

Does lighting boost retail sales? (Faithfull, 2015) Munish Datta, head of the facilities management at M&S, which recently embarked on a big LED rollout at hundreds of its food stores, said that the benefits of increased sales could ultimately outweigh the savings from energy efficiency. Anyone who can prove that a new lighting scheme will save money from the bottom line and increase sales on the top line has a powerfully persuasive argument - among these was a 21-week field research project by Dutch Cooperative supermarket group Plus and Philips Lighting back in 2010 which yielded results of increased basket sales by 1.93 %. A further laboratory study conducted by Zumtobel and Gruppe Nymphenburg measured responses to various lighting scenarios in shops on an empirical basis.

> Again and again, we find that the importance of lighting at the point of sale is dramatically underestimated. Instead, the focus is on fancy packaging and shop design, says Dr Hans-Georg Häusel of Gruppe Nymphenburg,but actually, the goods on display will only touch people's emotions if they are presented in the right light. (Faithfull, 2015)

iii. Case Studies

(Molony, 2018) Human-centric lighting boosts supermarket sales by 28%

The trial of the technology at an Edeka Store in Lower Saxony (Lighting and Control System was supplied by Cologne-based retail lighting specialist Oktolite) saw total sales increase by 12% compared to a nearby reference store, with confectionary sales rising by 28%, fruit, and vegetables by 26%, wines, and spirits by 23% and pre-packaged meat by 23%. The scientific study, conducted over 10 months, also saw customer dwell times boosted by 21 % and employee absence tumble by 35%. The sensational results will provide tangible evidence to proponents of human-centric lighting. It can give clients a significant return on investment.

Circadian Lighting - The colour temperature and illuminance simulate the natural course of sunlight

In the morning the lighting is a neutral-white colour temperature of 4000K with a horizontal illuminance of 700 lux. At midday and in the afternoon the colour temperature rises to a cool white 5000K and the illuminance to 1,000 lux horizontally. Towards evening the horizontal illuminance drops to 600 lux, and the colour temperature falls to a warm 3000K. The phase shifts take place over a long period of time (sic)and are not directly perceptible for customers and employees. The program of changes is adapted to the seasonal course of the sun.

The settings were designed to have a positive effect on staff and customers by 'activating' them during the day and reducing daytime sleepiness, and 'deactivating' them in the evening, all using the lighting's colour temperature and intensity. In three waves, both employees and customers were surveyed in the two stores with regards to wellbeing, satisfaction, and perceptions of the environment in the course of the day. As well as the sales increase, the HCL had other positive effects, including a 25% better sleep quality in the transition months of March and October. The number of sickness-related days of absence was reduced by more than 35% given constant exposure to circadian lighting.

Customers assessed the lighting to be 33% more natural and appreciated the natural atmosphere of the lighting that simulates the natural course of the sun. To evaluate the shopping experience (sic), customers were additionally asked the reason why they decided to shop at the respective supermarket. The study found that 35% of the customers decided in favour of shopping at the Human-centric lit store because of the 'special atmosphere' and 23% because of the 'good service'.

Increase in sales per section

(Lighting.philips.com, 2014) Retail Scene Magazine

Research on the impact of daylight is continuously evolving. Here are some highlights of relevant studies.

Sheffield, a British city some 250 km north of London, is the setting for an innovative new approach to lighting by retailer Marks & Spencer. The familiar high-street brand has fitted out its Ecclesall Road Simply Food store with 100% LED technology. At the same time, M&S took the decision to make use of 'daylight harvesting' – incorporating 'sun pipes' and taking advantage of the free natural daylight which pours in through the windows.

Luminaires automatically dim in response to the external brightness, so the store maintains a constant level of light. And the fittings can even be programmed to turn themselves off completely when the level of daylight reaches a certain level. It all plays a part in delivering the most environmentally -friendly shop in the Marks & Spencer retail estate. The local store manager, Allison Burnley, is delighted with the results. "We've created a fresh, modern shopping environment for our customers," she says.

Feeling better

Daylight improves health and wellbeing. It increases mood and morale while lowering fatigue and reducing eye strain, according to authors Edwards & Torcellini (2002).

An uplift in sales

A study in California (Heschong, 2003) measured sales over 34 months in 73 different stores. One-third of the shops had diffuse skylights fitted which let in natural daylight; the other two-thirds did not. After controlling for a number of different factors including population, floor space and parking, the researchers concluded that the daylight uplifted sales by between 1% and 6%. Critically, the additional sales represented a much larger financial benefit to retailers than the energy savings from using natural light. The increased profits were, in fact, between 19 and 100 times greater than the reduced energy bills.

Although the reasons for the result are still debated, it might be that products have higher visibility in daylight and look more attractive through better colour rendering. The variability in natural light might also help to keep customers and staff more alert.

b. Best Practices for Retail Lighting Design

i. Lighting Design methods for Supermarkets

Good lighting is a fundamental part of creating the right atmosphere for any space. It is essential in Retail space as it can affect your customer's shopping behaviour.

(Cooper, 2017) According to Retailite senior lighting design specialist Patty Tartaglia, some retailers have reported a 10 per cent increase in sales following a lighting redesign, which makes sense given around 80 per cent of the sensory information the brain receives comes from the eyes. "Great lighting is not just about how the customer sees a retail display or the retail space, but how it makes them feel—with the effects being on a subconscious level," she said.

This (sics) means retailers need to consciously consider the use of light in-store, and at each stage of a customer's journey. For example, there will be great differences in the mood/reaction you want to create (and therefore the lighting you would use) in different areas of your store, from the storefront to store displays and the payment area. "From brand perceptions to consumer engagement, lighting creates an emotional connection between your consumer and your business," said Tartaglia. "Once it is clear lighting isn't simply about illumination, a consumer's in-store experience and engagement will thrive."

(Con-techlighting.com, 2018) There are a number of (sic) factors to consider when lighting a retail space; the size and shape of the space, the intended audience, and the intended message the brand conveys. Many elements come into play, such as colour, reflection, contrast, and energy efficiency, that make a retail lighting design successful. Supermarket lighting must have great colour; choosing a light with the right colour temperature and CRI is crucial. All light sources are not equal.

Two white light sources may look the same, but can render colours differently or provide a different feel to space. By using lamps of the same Correlated Color Temperature and with the same, or very similar, Color Rendering Indices, space will have even, consistent illumination throughout. Supermarket environments need to make the patrons feel comfortable while highlighting important merchandise and store areas. Simply increasing brightness is not only a waste of electricity but is also not effective. Bright stores with lots of glare make customers uncomfortable and less likely to return. The key is layering light and using contrast throughout the space. There are four basic layers of retail Lighting: General Lighting, also called ambient, accent lighting, task lighting, and decorative lighting. Measured in footcandles, the IESNA has illuminance level recommendations based on the type of lighting, the type of space, the type of customer, and how the lighting will be used (see figure below). By layering these light types, depth and dimension are added to the space.

Areas/Tasks	Description	Type of Activity Area*	Illuminance (FC)[2]
Circulation	Area not used for display or appraisal of merchandise or for sales transactions	High Activity	30
		Medium Activity	20
		Low Activity	10
Merchandise (Including Showcases and Wall Displays)	That plane area, horizontal to vertical, where merchandise is displayed and readily accessible for customer examination	High Activity	100
		Medium Activity	75
		Low Activity	30
Feature Displays[3]	Single item or items requiring special highlighting to visually attract and set apart from the surround	High Activity	500
		Medium Activity	300
		Low Activity	150
Show Windows			
Daytime Lighting			
General			200
Feature			1000
Nighttime Lighting			
General			100-200
Feature			500-1000

*One store may encompass all three types within the buildings.

High Activity: Merchandise is usually displayed in bulk and is readily recognizable as to its use. Evaluation and viewing time is short. Minimal sales assistance and few customer amenities are available. Included in this category are mass merchandisers, warehouse sales, grocery and discount stores, auto parts departments, and hardware departments.

Medium Activity: Merchandise is familiar, but the customer may require time or help in evaluation of quality or usage or in the decision to buy. Some sales assistance and customer amenities are available. Included in this category are department and specialty stores.

Low Activity: Merchandise is generally exclusive, of the finest quality and highest price. Personal services and premium customer amenities are expected. Shopping is generally unhurried. Included in this category are fashion boutiques, designer signature shops, jewelry stores, fur salons, and fine art galleries.

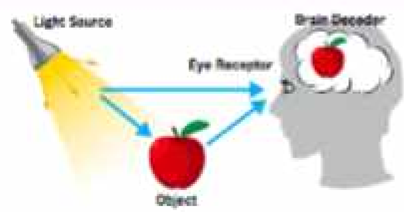
1. IESNA Lighting Handbook, 8th Edition
2. Maintained on the task or in the area at any time.
3. Lighting levels to be measured in the plane of the merchandise.

Contrast is achieved by using an increased illumination within the different types of light, commonly task and accent, to emphasize featured merchandise against the general light levels. Contrast can be used to create visual hierarchies within the retail environment, enabling attention to be drawn to and focused on certain merchandise based on the contrast ratio. For example, a 2:1 contrast ratio, with the accent lighting being two times brighter than the general lighting level, creates a barely recognizable contrast. Whereas a 30:1 contrast ratio will create a strong focal effect on the focal items.

2:1 Ratio

30:1 Ratio

OPTICAL PERFORMANCE



Performance requirements for lamps and integrated luminaires:
1. Visual appearance of light on a surface
2. Numerical performance, light level, and efficiency
3. Visual appearance and glare control of the luminaire itself

GENERAL LIGHTING - Recommended light levels for general lighting is 30 - 50 footcandles. With minimal illumination of the merchandise, general lighting allows the staff to perform daily tasks such as cleaning and re-stocking, as well as customer circulation throughout the space. Diffused general light ensures a sense of well-being, which makes customers feel comfortable and more likely to stay longer in the store. A simple way to achieve this is by arranging recessed fixtures using reflectors, baffles, and lensed trims in overlapping positions. Perimeter lighting, or wall washing, helps define merchandising spaces, provides vertical lighting and makes the retail space feel larger (sic). Done with sconces or wall washers (sic), vertical lighting creates a pleasant, welcoming environment and adds to the visibility and visual impact of the displays on the walls. It is important that vertical surfaces are (sic) lit for visual comfort, spaciousness, and visual and directional cues. Vertical brightness influences the customers' impression of the store by making orientation easier, helping to define merchandising spaces, and aiding in making the space's appearance to be larger, open and more welcoming for the consumer.

TASK LIGHTING - Completing the sale is the most important retail task; it is the final interaction between the customer and staff. Pendant luminaires at the point of sale are a great way to provide task lighting. Perimeter lighting, or wall washing, helps define merchandising spaces, provides vertical lighting and makes the retail space feel larger. Done with sconces or wall washers, vertical lighting creates a pleasant, welcoming environment and adds to the visibility and visual impact of the displays on the walls. It is important that vertical surfaces are lit (sic) for visual comfort, spaciousness, and visual and directional cues. Vertical brightness influences the customers' impression of the store by making orientation easier, helping to define merchandising spaces, and aiding in making the space's appearance to be larger, open and more welcoming for the consumer. Light for sales work; enabling staff to quickly and accurately wrap packages, run register sales and credit card transactions, minimizing mistakes and returns. Recommended light levels for task areas are 538 – 2153 Lux. When lighting a task area, take into account the difference in brightness, or contrast, between the task area and the surrounding space. A 3:1 ratio of task lighting to general illumination provides a nice contrast for evaluating merchandise, reading tags, labels, or packaging and reading signs that identify store departments. The amount of light needed on the task, or luminance, is usually the most flexible variable of task lighting and can be increased to compensate for low contrast levels.

ACCENT LIGHTING - The key is to make this illumination more precise and of higher intensity than the surrounding ambient light. Track fixtures, recessed housings with adjustable trims and concealed adjustable illumination with point source lamps provide directional control and are especially effective for accent lighting. They are easy to aim precisely to highlight the products' best attributes and influence the customers' impression. Accenting everything and emphasizing nothing is a common mistake with accent lighting; always keep in mind that there such a thing as providing too much light. The IESNA recommends a 5:1 ratio of accent lighting to ambient light to make merchandise stand out and create a significant visual effect; dark merchandise may require a higher ratio to bring out detail. Recommended light levels for accent lighting are between 150 – 500 footcandles. For feature displays, higher ratios of 15:1 or 30:1 are used, especially to create a sparkle in jewellery or crystal.

DECORATIVE LIGHTING - Decorative lighting includes pendants, sconces, chandeliers, table and or lamps, and cylinders. Decorative lighting should complement and add visual interest to the interior, as well as provide or contribute to the overall lighting plan. Pendants should be mounted 8 - 12 feet above the finished floor (a.f.f.), so they are still within view, but not too low as to deter the shopping experience. Pendants displayed over counters should be hung 36 - 48 inches above the horizontal plane so customers can peer into the glass without being hindered by the luminaire. Wall sconces and wall-mounted cylinders should be mounted approximately 5-1/2 feet a.f.f.; this helps to create a sense of human scale, especially in a large space. Adding décor, beauty and style using decorative lighting is also an important reflection of a store's brand image and reinforces the theme and style of the space. Decorative lighting can also contribute a feeling of hospitality and comfort to the retail experience, putting shoppers at ease and encouraging a longer visit, which can potentially lead to more sales.

HOW TO ILLUMINATE FOOD APPLICATIONS - (Fagerhult.com, 2019) The groceries in a food store should feel appealing, tasteful and fresh. Shopping for groceries is all about engaging senses. For the Deli area - this should have a fresh look. Here it is beneficial to work with focused light and contrasts. Lower the general light and add specially developed luminaires for these products. The look of meat, fish, cheese, and deli is affected by the quality of light. Accent Lighting is beneficial in the Fruit, Vegetables and Flowers section. Lower the general lighting and add spotlights or recessed spotlights in the ceiling. This (sic) is an area where the ceiling height can be lowered which enables you to work more with the atmosphere. If it has high ceilings, choose a spotlight with good light output. Another option is to use a spotlight with a warmer light temperature of 2700 K. Or use a tuneable version in which you can change the colour temperature after the colour of the displayed items.

Achieving the right CCT for the Fresh Produce and Food product display is essential in stimulating purchase impulse from Customers. (Ixtenso.com, 2019) Franz Heckmanns states that the lighting of the different product categories in the supermarket should reflect the interpretation of customers on what makes merchandise particularly attractive in their eyes. Like in the produce section, for example.

> In our experience, fruits and vegetables are best featured in brighter, warm light like sunshine in October; bakeries and cheese departments use light that’s more in the yellow range in contrast to the frozen food section for example. Opinions differ when it comes to meat counters: while the Central European customer prefers to see meat in red tones, other countries disagree. The challenge here is to showcase the merchandise in the most positive light but not to misrepresent it. (Ixtenso.com, 2019)

(Lighting.philips.com, 2014) SHELF SERVICE - Tips for Keeping Food Fresh

Shelf service

our tips for keeping food fresh

Of course, there are a whole range of factors that have an impact on the freshness of food. Temperature, humidity and packaging are all vitally important. Not to mention the initial product quality. All the same, it's important not to underestimate the role of light. Here are some tips and advice on how it affects different types of food.

Lettuce and leafy vegetables

High light levels on pre-packaged leafy vegetables will significantly decrease their shelf life, but will improve the shelf life of fresh crop products and stimulate the growth of potted herbs. So if you're looking for firmness and greenness in your fresh crops, it's important to keep light levels up.

Infrared is the other part of the equation. With traditional light sources, radiation increases the temperature on the surface of salad leaves. That means you'll see faster dehydration and deterioration in appearance. It's a problem easily avoided with LED technology, which has no infrared light.

Light sensitive products

Any products that grow beneath the ground – tubers (such as potatoes), onions, garlic and root vegetables – need to be stored in dark conditions. If you want to maximise shelf life and avoid the risk of deterioration, it's important to keep light levels down.

White asparagus, white mushrooms and chicory are other products that benefit from being stored in the dark to prevent discoloration.

Reddening of products

It's generally recommended to lower the light level if you're worried about your products reddening too much. Take a green pepper, for instance. If you're selling it in a 'traffic light' pack, you don't want it to ripen too fast under the light and become orange or red. In a highly lit environment that's a real possibility.

Ultraviolet light is an issue too, as it can lead to an undesirable darkening of your red products. And high doses may also damage the surface texture. A safe choice is to avoid UV, which is possible with using LED.

Green vegetables

Although most vegetables won't suffer from medium-level lighting, a high light level can often lead to faster discoloration of specific greens such as cucumbers and broccoli (which you may be surprised to know is technically a flower). Every product on the supermarket shelf is different though. Because an iceberg lettuce has such a high level of water content, it's usually not affected by light in the same way as other varieties of the popular salad staple. And recent research suggests that Brussels Sprouts may even benefit from the extra light, staying fresher longer.

Meat

Although discoloration of meat doesn't necessarily mean that the product has deteriorated, customers may choose not to buy for cosmetic reasons, which can lead to wastage. Lowering light levels will generally lead to a longer shelf life.

Infrared will increase the surface temperature of the meat, which is a more serious issue, as it speeds up the process of decay. It's therefore recommended that meat should be kept out of infrared light.

With sliced meat, the emphasis should be on optimizing the spectrum. Research shows that this can lead to an increased shelf life. See page 56.

And remember... light isn't the only factor in discoloration

If you see foods such as broccoli turning yellow, light may not be the only issue. Ethylene is commonly used as a ripening agent or 'plant hormone' – particularly on bananas and avocados. If other sensitive fruit and vegetables are placed too closely alongside the ethylene-treated products, it can start to ripen prematurely too.

1. Spotlight on the Health, Beauty and Wellness Section

A market study by A.T Kearney emphasizes the (Wing et al., 2018) growing consumer demand for more personalized solutions on Health, Beauty and Wellness categories. Retailers have to show-and-tell shoppers they recognize them as individuals, as the “self-care” movement gains traction in culture and in (sic) the mind of the shopper; through new marketing programs and viewing the consumer as a patient, innovative merchandising strategies are born. Educational signage that makes consumer-based solutions easier to find, creative aisle and end-cap layouts, category curation, a creative approach to selecting and featuring new products, and instituting a new system of associate training and rewards encourage a different and more relevant interaction with customers during their in-store wellness journey.

Successful Health, Beauty and Wellness retailers are on Trend, Create narratives, Educate Consumers, Provide services and are available Online. Product offerings need to extend beyond the four walls of the store. Successful retailers grow sales by integrating and participating in every stage of a consumer’s health, beauty, and wellness journey by connecting through apps, educational websites, and wellness events.

(Rayner, 2002) Mark Dickens, a partner at Design and Planning strategist - Astound points out “It’s easy and convenient for customers doing a weekly supermarket shop to pick up health and beauty goods at the same time.”

> Slowly but surely, supermarkets are trying to create a browsable environment. If customers can be persuaded to stay longer in a category, it stands to reason (sic) they will spend more.So how, precisely, is this done? Nigel Stern continues: We make the health and beauty section look and feel different from the rest of the store. We might use a softer finish – plastic shelving instead of steel, for instance. At Asda, we put in curved fixtures to give a more ‘feminine’ feel. Then we might lower the ceilings to create intimacy, while simultaneously giving brighter illumination – this mirrors the department store experience – so customers can see colours more accurately. It all adds to a feeling of pampering. (Rayner, 2002)

Bright lighting is most especially important to impart a sense of Cleanliness, add Glamour and Luxury to your display, and this also allows customers to read labels. Getting the lighting right is an essential factor to consider in designing your Health, Beauty and Wellness section.

2. Coloured Lighting, the key to retail success

Are pastel-coloured uplights the key to retail success? (Leeming, 2017) The use of pastel-coloured uplights in retail displays has been found to increase sales in a new study. The installation of the lights in a particular area of a store in Germany was found to increase basket values by 6 %. The same combination of lights also increased customer visits to the revamped section of the store by 15 % when compared to an area lit with standard store lighting.

Philips Lighting produced the study in conjunction with major German grocer Globus with the expressed aim of finding lighting that increased sales. 'As a retailer to stay ahead of the competition, you have to create a multi-sensory environment and a 'wow-factor' in your stores,' commented Norbert Scheller, store manager at the Globus Supermarket in Saarbrucken where the experiment took place.

The researchers spent two months testing different lighting conditions in the supermarket. Three settings were tested, including the store's uniform overhead lighting, regular spotlights and a combination of spotlights with pastel-coloured uplights. Retailers have traditionally lit stores using uniform white overhead lighting. The research showed that the 59 spotlights used in the experiment strengthened the appearance of products by increasing contrast. Adding coloured uplighting, aimed at the ceiling also helped to differentiate the promotional zone making it more visible.

Neuromarketing research on Food Retailing in the case of various parameters of store illumination and consumer response emphasizes the importance of product merchandising through lighting (Berčík, et al., 2015) One of the methods to increase the culture of the sales environment and the attractiveness of displayed products are smart solutions within store lighting. It is the only tool that can be precisely controlled and measured by several parameters such as colour temperature, light intensity, illumination angle, and colour rendering index. Customer behaviour in sales areas is strongly influenced by the perception of surroundings and feelings of well-being. Light is an important marketing tool due to the fact that it has an impact on consumer emotions and retail atmosphere; it increases retail space and enables easier orientation for customers. It is the only tool that can be precisely controlled and measured by several parameters such as colour temperature, light intensity, illumination angle, and colour rendering index. The research is focused on accent lighting in the segment of fresh, unpackaged food. Using a mobile 16-channel electroencephalography (EEG equipment) from EPOC and a mini camera we observed response time and the emotional status (sic) (valence), in order to reveal true consumer preferences in different lighting conditions (colour temperature and colour rendering index) and non-traditional colors (yellow, purple, red, blue, and green) for the selected food type.

Due to that is the first impression of the customer important when entering the store and which is influenced to a significant level by the lighting used in the store (Ebster & Garaus, 2011). Basic and accent lighting affects(sic) as well as how are the goods and used colours displayed in the store (colour rendering index). Various types of light sources can cause the same object to appear in a different colour. That reflects the fact that light sources have a different spectral structure, even though they can have the same chromaticity temperature (He, 2010).

The fact is that the right display (colour rendering index) can influence customers´emotions more directly (Bitner, 1992). Proofs indicate that some colours (mainly red) create a feeling of excitement and encouragement to eat and others (for example, blue) make a relaxed environment (Lowrey, 2012). The lighting of the store can be the most effective factor to increase general feelings of satisfaction because it supports comfort, convenience and favourable emotional reactions (Summers & Hebert, 2001).

Lighting in stores does not influence consumers on the place of sales, but it is a stimulus at specific products (meat, bakery products, fruit, and vegetables). While discount stores are more brightly lit aimed to make the shopping more effective, on the other hand, store departments with lower levels of lighting try to strike feelings of relaxation.

A higher intensity of basic lighting, but which does not blind the customers is common for larger shop formats and ranges from 600 to 800 lux (Bean, 2014). In most cases are brightly (sic) lit stores more successful than the dark ones, because the lighting rings (sic) drama to the store and can represent a real communication tool (Floor, 2006). The study (Areni & Kim, 1994) found out that brighter indoor lighting of the store makes a more positive impression on consumer perception reflected in the time spent looking at the goods.

We conducted a test of the accent lighting, given the fact that the store lighting represents a significant part of the shopping environment and with some types of fresh non-packed goods is the only and crucial marketing tool. To demonstrate the influence of lighting on consumer's emotions, we simulated the environment of the fresh food department (fruit and vegetables).

We found out by testing the non-standard forms of the accent lighting (colours) on the basis of their mutual comparison via a non-parametric test that the significant differences in the emotions of tested participants exist between yellow and purple, and purple and green colour. On the contrary, minimal variations in emotions were measured between green and red, as well as green and yellow.

	Green	Purple	Yellow	Red
Red	H0	H1 (even at 0.05)	H1	X
Yellow	H0	H1 (also at 0.05)	X	
Purple	H1	X		
Green	X			

H0 – same = no difference
H1 – different = difference
Test at α=0,1

Table 7. Wilcoxon signed rank test – comparison of individual colours

	Yellow	Red	Purple	Green
-1	39	39	31	34
0	9	8	5	9
1	19	20	31	24
	67	67	67	67

Table 8. Comparison of primary emotions with individual colours

This crucial finding is related to the fact that in the case of purple colour used to illuminate the fruit were detected the most positive emotions, see Fig. 6. Relatively more positive emotions appeared in the case of green colour, where there is roughly the same amount of negative emotions than with purple colour. More significant changes of valence with purple colour compared to other ones can be caused by the fact that it is the least natural colour for the lighting in this case of apples and oranges; therefore it aroused a certain level of attention in the respondents. Almost identical valence with yellow and red colour was most probably caused by the technology of colour mixing in the used RGB spotlights.

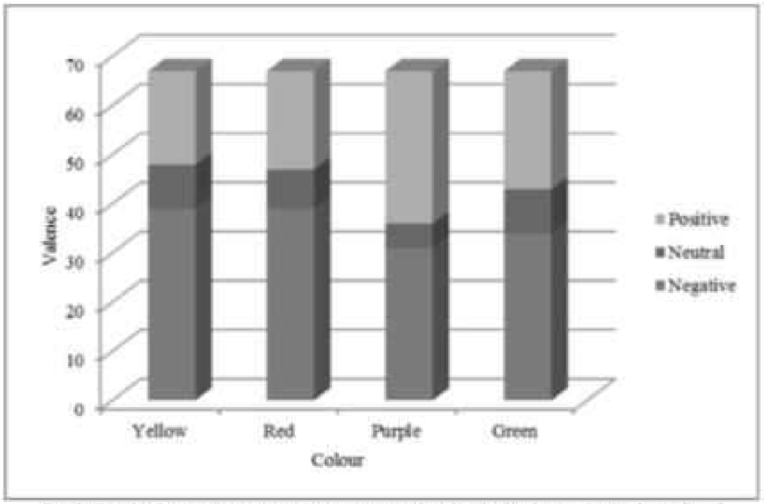


Fig.6. Graph of primary emotions comparison with individual colours - range from -1 to 1

Fig. 7 was created for better illustration of a comparison of two chosen respondents (man and woman) with non-standard purple lighting regarding that the most positive emotions were detected with this type of lighting. The x-axis in the graph represents the time sequence, and when we interpret it, we focus on the last interval (25 - 30) only, whereas the chosen respondents were looking at the purple colour in this stage and so we observe the relevant emotions detected with the colour. On the y-axis, we watch the emotional state of the researched subject (excitement, engagement, meditation, frustration).

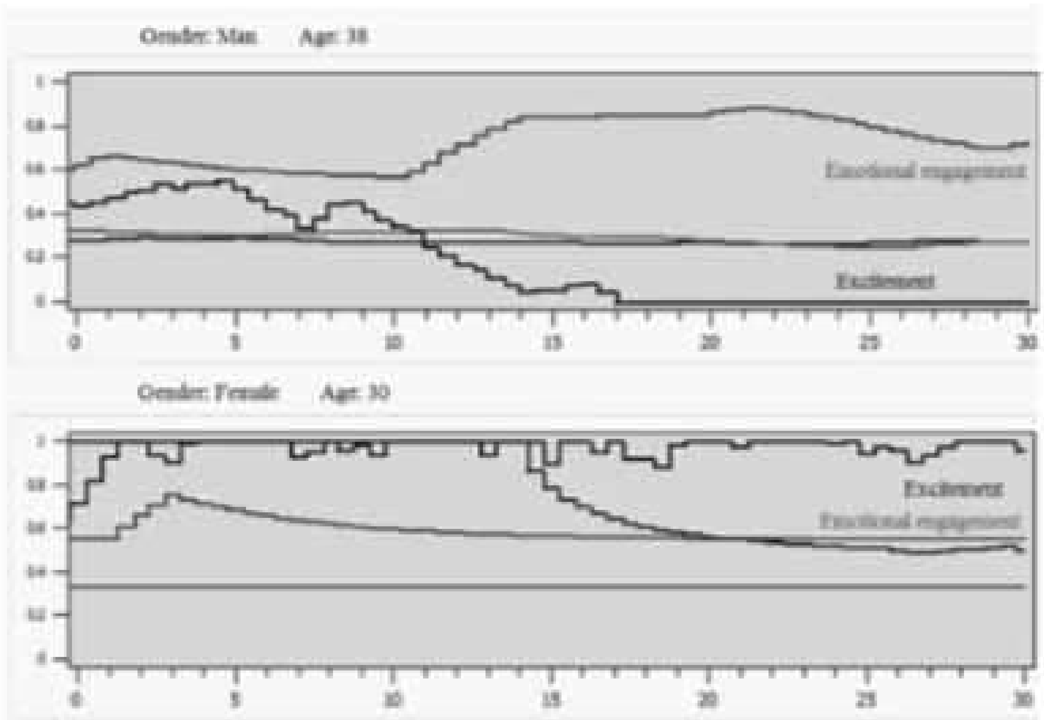


Fig 7. Comparison of emotions of two respondents with non-standard purple lighting

From the picture is (sic) obvious that the lighting did not cause a change of state of mind indicator, like the excitement because the level of the red line is close to zero value. In addition, the value of emotional engagement was decreasing at that time. Similarly, this type of lighting did not cause any crucial changes in woman perception. Levels of all emotions, including the state of mind indicator, stayed the same. With respect to higher levels of excitement, in this case, is (sic) possible to presume higher sensitivity of sensory organs to the shown stimuli.

All spontaneous decisions run in our subconscious, the first impression being the decisive element. The human brain tries to classify into categories(sic) of positive, negative, friend, enemy, it is attractive yes or no, although all this happens so fast. It means that a man perceives certain stimuli and that their classification is in the background of a certain motivation. Attractively lit fruit, which creates the impression of fresh, juicy products, immediately causes irritation in the brain by creating various illusions. The customer can theoretically implement rational thinking, but every appeal has an emotional ground which is later rationally reasoned. It means that if the customer´s mind has once decided that the product is good, it simply excludes and ignores everything rational that contradicts. The brain is just set like that some things are appropriately adjusted and the customers have only a small chance to resist it.

ii. Impact of Lighting as a Visual Merchandising Tool

(Saeed, 2015) An appealing merchandising display can trigger a shopper's buying intent and eagerness. There are so many other factors responsible for the sales of merchandise, but the display is one of the leading tools for retailers to trigger the shoppers "appetite" for shopping. Eighty percent of the impressions are shaped by sight that's why it is very important for retailers to plan visual merchandising carefully and understand its impact on the sales and image of the product and store (Agnihotri, 2009).

According to LaGiusa and Perney (1974), illuminating the store environment can draw the attention of the consumers, affect consumers' perception of the store and patronage intention. Hu and Jasper (2006) assert that illumination improves the aesthetics of the store and may result in a competitive advantage. The study further concluded that proper illumination can be a source of keeping customers in store for a longer period of time because of its pleasing effect, which in turn could further increase the chances of impulse purchasing. Summers and Hebert (2001) also support that lighting and better illumination influences the consumer's attention. Gobe, (1990), Rea (1993), Lopez (1995), concluded that shoppers "touch" and" pick up" the products that are properly illuminated and have a positive effect on consumer purchase intention.

Indeed, Dynamic Lighting should be part of your Visual Merchandising. (Downey, 2018) Dynamic lighting involves the colour of the light, the intensity, direction, and even movement that turns shoppers into customers. To feature a product, place a brighter light on it. Using an incandescent lamp - which is sharper and brighter - can highlight its details and importance. Keep surrounding areas dim to focus attention. Bright lights, in general, tend to exude a positive vibe that can increase purchases. When using coloured lights, match the colours of your packaging or product to a light in the same colour family such as a hunter green package with a light green light or a deep red with a pink light. This will avoid unpleasant colour clashing. Colour also influences our mood. Remember that colours in the blue family will have more of a calming effect where reds tend to excite and stimulate.

iii. Techniques for Cosmetic Store Lighting

(Miller, 2019) The retail beauty industry faces unique challenges that go well beyond an attractive or trendy lighting design. Store lighting must not only have emotional appeal but also offer enough light to show cosmetic colours and undertones accurately. It's a symbiotic balancing act where practicality and aesthetics link intrinsically to buyer comfort and confidence. Beauty and cosmetics are intimately connected to self-image and esteem. There is perhaps no other shopping experience where the customer is under as much scrutiny as when shopping for makeup or skincare. A clothing boutique or department store has dressing rooms, but beauty retail (sic) customers must use magnifying mirrors in full view of onlookers and store staff. There is no door to close for privacy while making those oftentimes(sic) funny makeup faces in the mirror. KEEP IT GLOWING - Crafting this delicate balance is a special skill that some lighting designers have perfected. When given the task of designing lighting for a cosmetics retailer, these experts know what they want, what they don't want, and where some retailers are falling short. For example, Diego Burdi, the design director at the Toronto-based Burdifilek, made some substantial changes when his firm redesigned the lighting for Murale beauty boutiques in Canada.

> With 75 percent of lighting as fluorescents, the spaces were too task-oriented and lacked the proper lighting and colour rendition for an end-user to really (sic) see themselves accurately, he says. We knew we needed to create a space with a greater ratio of indirect lighting in order to create a brighter ambience to fill the space with a glow. (Miller, 2019)

Jules Gim, associate vice president at Callison RTKL in Baltimore, agrees that the beauty consumer herself must be at the center of lighting design.

> With beauty stores, we choose to focus on how the customer looks, she says. It's one of the differences compared to a lot of stores where it's focused on the merchandise–whereas, with beauty stores, you want to make sure that the lighting is very flattering on people's faces and that the colour rendition is correct. (Miller, 2019)

Callison RTKL is responsible for the lighting design of many luxury beauty retailers, so Gim knows how important it is that customers feel positive about themselves and the products they sample and purchase. When she enters a beauty store, she goes straight for the mirrors. "I always look at myself to see if they got the lighting right."

Shelly, of Regency Lighting Studio, goes a step further and stresses that lighting not only can delight the senses but also "can become a noticeable distraction and detriment to the function and beauty of a space" when done wrong. He stresses that when lighting sources are too cool in temperature (blue tones as opposed to warmer tones), customers look dull and lackluster. So how do you achieve balance? Gim believes soft ambient lighting is the key. While directed light is good for highlighting merchandise, it should be balanced by indirect lighting close to mirrors to flatter all skin tones. She compares the technique to old-fashioned theatrical dressing rooms. She says: "Like Las Vegas dressing rooms, where they have the marquee lighting that's literally(sic) the frame around the mirrors that performers use while applying makeup. All that soft light is on your face—and not behind you."

Burdi points out that products are often improperly lit, making items difficult to choose from or hard to find–an issue he had to address in the Murale redesign.

> We used halogens to create focusable light in every area with the right colour temperature. The end(sic) result successfully achieved a space that did not rely on task lighting, so end users could migrate everywhere around the store while shopping for products and still see themselves in their best light (Miller, 2019).

These types of choices can influence your bottom line. Spacesmith's Miller asserts that poor product sales can be directly attributed to inadequate lighting. "How merchandise is featured drastically affects the choices of consumers when shopping. The way in which a product is displayed and called to attention can influence a consumer in their purchasing choices," he says.

He and others have identified a universal solution: more-flexible lighting options with fixtures that can be angled. Direct lighting is affordable to install and can pay off in increased sales as strategically placed, and lighted products gain more(sic) attention. Spacing products far apart, such as in display cases, also helps. This makes the items appear special or one-of-a-kind. This technique can be especially effective when paired with products that have a unique or metallic finish or sparkly packaging. Miller suggests illuminating items from behind to achieve an eye-catching glow. Be careful to avoid harsh shadows, though. They're unflattering and make it difficult to discern colour properly. Both Gim and Shelly advise using high colour rendering light sources within the neutral temperature range of 3,000K to 3,500K.

Gim also recommends installing makeup mirrors with adjustable lighting – a day to evening, sunlight or candlelight. This customizable approach allows customers to envision how makeup will look for a wedding, a night out or a day at the office. An example of this is HiMirror Plus - a Smart - Ambient Makeup Light that comes with innovative LED lights to simulate five different lighting scenarios: sunset view, outside on a sunny day, brightly lit office, shopping mall or supermarket and restaurant or party venue. These settings will help you apply your makeup appropriately for the occasion and location.

Getting the perfect foundation or makeup to match your skin tone is a challenging task because store lighting is not always ideal for colour matching products to skin tones. What is the Best Lighting for Makeup Application? (Gluskin, 2019) Fluorescents can make us put too much makeup on, and pink-tinted lights can make us miss spots. Step away from fluorescent lights, for obvious reasons. It's not just you; no one, and we mean no one, looks good in it. Cool, fluorescent white light is unforgiving and overly bright. This unflattering lighting can cause you to overdo it with the foundation, bronzer, or blush in order to compensate for the lack of colour on your face. Yellow light can make you look tired and sick, which may cause you to go overboard on the powder and concealer in an effort to(sic) neutralize your face and hide dark spots. Rosy light can make complexions appear healthy and vibrant, which sounds great, but it's all a lie. Due to our radiant appearance in this lighting, we tend to slack on the concealer, only to later realize that we missed a blaring blemish or dark spot. Downlighting shines down on wrinkles and pigmentation and casts shadows under the eyes, making you look instantly older.

The best condition for applying makeup is a warm or natural light source. Natural sunlight provides the most accurate reflection of your face, but for those cloudy days when fresh rays aren't an option, warm white light, like LED, is the next best thing. It closely resembles the colour spectrum of natural light while evenly distributing light across the entire face. Create cross illumination or side lighting to ensure that the light evenly diffuses across your whole face. Be aware of setting up lights solely above the mirror. They'll illuminate the forehead, forcing you to tilt your head too far up and making it difficult to apply makeup with precision.

iv. Smart and Connected Lighting

Promote a unique shopping experience with a Smart and Connected Lighting. Successful implementations of Connected Lighting have led to increased sales and boost customer satisfaction. (Halper, 2018) A trial of connected lighting at a French hypermarket has led to a dramatic increase in sales from customers who used the app. The giant E.Leclerc retail store in Langon in southwestern France has reported that revenue rose between 34 percent and 42 percent from certain customers who over the last few months wirelessly connected their smartphones to Bluetooth-equipped ceiling lights delivering discounts and information.

A total of 771 people used the E.Leclerc app that gave them access to the Internet of Things (IoT) lighting system at the 75,000-ft2 outlet. The 800 LED luminaires are equipped with Bluetooth beacons for indoor positioning to transmit information such as product offers and location to customers' phones.

One group of customers that E.Leclerc had already categorized as high turnover spent 34 percent more than in the previous year. Another group, of typically less-frequent buyers, spent 42 percent more. E. Leclerc says it's pleased with the results, not just for the revenue boost but also for the overall improvement in customer engagement, including the indoor positioning system's ability to gather insights on individual customer behaviour.

> This is a place where our customers can experience a completely new way of shopping, reported store CEO Alain Lafforgue. Thanks to virtual customer interaction, we're getting to know our customers and learning more about their individual(sic) wishes. With this knowledge, we will be able to increase satisfaction levels and thereby generate greater customer loyalty. (Halper, 2018)

E. Leclerc chose Bluetooth technology, which uses the radio spectrum, over another technology called visible light communication, which sends data to phones via LED light waves. While VLC is more accurate than Bluetooth in navigating customers to a particular product, E.Leclerc considered Bluetooth to be accurate enough, especially since navigation was less important in the E.Leclerc project in which many customers generally know the store's layout. One advantage that Bluetooth has over VLC is that users can keep their phones in their pocket, whereas VLC requires the user to keep the phone pointed at ceiling lights.

Proponents of lighting-based Bluetooth note that the lighting infrastructure is pervasive and thus provides a ready-made and unobtrusive place to put beacons. On top of that, the beacons can draw from the same power supply that delivers electricity to luminaires, thus avoiding the need to use beacons powered by batteries, which can be problematic. The supplier of the connected lighting system to the Langon store is Zumtobel.

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