Parting the Clouds: Moving Towards an Affordable Natural-Lighting Solution

16019243

N. Appleton

Supervisor: Matthew Studley
BEng Robotics

Designing a modular, human-centric lighting system
12 pages; 2620 words

Faculty of Environment and Technology
UWE
UFMFX8-30-3
April 8, 2021

Disclaimer:

All of the work contained in this document is solely the work of N. Appleton.

Contents

Chapter 1

Introduction

1.0. Let there be Light

"*God said, 'Let there be light,' and there was light. God saw that the light was good, and he separated the light from the darkness. God called the light 'day,' and the darkness he called 'night'. And there was evening, and there was morning — the first day.*" ~Genesis 1:3-5.

Since the dawn of life itself, we have been exposed to the natural light of the sun, and the distinct separation of day and night. However, our modern, fast-paced lifestyle no longer allows for such long periods of time being wasted and unproductive in darkness.

As the literature reveals more and more ways in which this divergence harms our well-being, it seems that a serious re-think of our environments - and how we light them - is required.

1.1. Gap in the Market

Light has been shown to have serious ramifications on many facets of life: excess blue light in the evenings causing sleep deficiency; lighting affecting lifestyle-related diseases; insufficient blue-light exposure being a risk factor for depression and other mood disorders; and plenty more that are discussed in chapter 2.

Chapter 2.7 outlines why the existing products attempting to solve this problem are not appropriate, and thus why a new solution must be developed.

1.2. Aims and Objectives

This project set out to try to develop an affordable, modular, broad-application natural lighting solution.

1.2.1. Aims

There were 2 main aims that the device set out to achieve: 'To produce an affordable device that replicates the visual solar spectrum as closely as is feasible' and 'to validate the device by measuring the output spectra across the day'.

Initially, further aims included developing the device as a product by improving user experience through user interface, web apps, and other expanded functionality. This would have been researched using qualitative methods such as opinion surveys to assess the interest in the device in the consumer market. These aims were set out as stretch goals that could be undertaken when the 2 main aims had been completed.

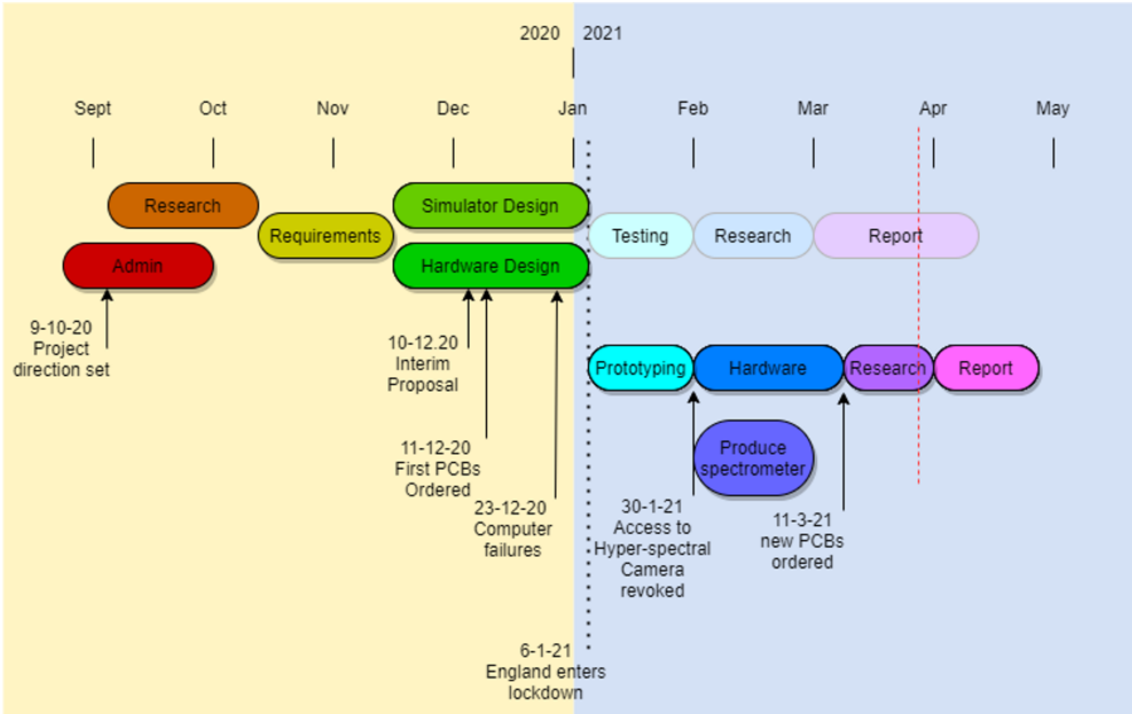


Figure 1.1: *How the lockdown in England affected the objectives of the project. Reasons for the changes are discussed later in the document.*

1.2.2. Objectives

The objectives used to achieve the aims have been a lot more dynamic throughout the project. The initial plan of producing and testing 2 rounds of printed circuit boards (PCBs) before using these to validate the spectral outputs was heavily influenced by the pandemic. See Fig 1.1.

Both N. Appleton and V. Halenka were involved in the design of the hardware, as it was a useful device for both areas of research. The success of these devices was assessed against the requirements specification (Appendix A.1 and is discussed in chapter (REF).

One of the most important aims of the project from the beginning was the development of the simulator. This allowed for a contingency for that spectral measurements to be obtained even in the absence of physical hardware. The simulator was also used to explore the desired outputs of the device and how they could be achieved.

1.2.3. Scope

Keeping the scope of the project relatively flexible was an important factor due to the pandemic. Designing the hardware, which was scheduled to be done by February, was severely impacted by the lockdown that begun on the 1st of January 2021.

Due to the "modular" construction of the aims, the qualitative, product-based research and much of the usability development had to be left for future research and development. In removing these aims from the project, it allowed the primary objective to be successfully achieved.

Had the pandemic not had such a profound effect, the main aims would have likely been completed earlier, allowing for progression to the secondary research goals. However, going into the project, there was no way to know how the year would pan out. Using this dynamic scope worked very well and allowed the successful completion of the primary area of research.

1.3. Project Management

AGILE Kanban The project was approached using a Kanban-style AGILE workflow, using the $ClickUp^{TM}$ project management software to organise tasks, subtasks, Gantt charts, meeting minutes, relevant literature and more. Using just one piece of software to organise all of this reduced the friction and chance of errors. For example, when updating Gantt charts, the Kanban boards and tasks are automatically updated to reflect these changes and vice versa.

Weekly meetings Both weekly supervisor meetings, and weekly meetings between the hardware developers took place to ensure that all areas of the project were progressing as planned. Alterations to the scheduled work could be discussed and approved at these meetings, further reducing the friction when needing feedback. Minutes of these meetings were made on the $ClickUp^{TM}$ software and copies were printed and pasted into the project logbook.

Logbook The logbook has been used as a hard-copy of all the digital documents that were produced throughout the project including interviews, requirements documentation, meeting minutes, invoices, design documentation and Gantt charts. All work has been logged to ensure data is not lost and the project could continue even in the event of the researcher being replaced.

Gantt Charts The project plan Gantt charts were updated on a monthly basis to ensure their relevance and to take into account the most up-to-date information. These updates happened in meetings between the development team to allow timescales to be discussed before implementation. All Gantt charts are displayed in appendix A.2.

Time Constraints As with any project, there have been some strictly imposed time constraints throughout the year. Weekly supervisor meetings meant that there was always a two-way stream of information so as to put less importance on each meeting.

It was important that the experimentation could be completed by the end date of the project, and that at least initial results could be gathered before the progress review that took place at the end of March.

Contingencies From the beginning of the project, a focus has been placed on creating effective contingencies to ensure that the main experimentations would give results. This has been especially true within a hardware-based project during the pandemic. The flexible aims have been discussed earlier, but many other contingencies were put in place. Building a simulator was a big priority to ensure that results could be gathered in the event of failure to obtain hardware.

Risks and Mitigation The project has been focused on de-risking throughout by frontloading the highest-risk tasks to ensure that, in the case of failure, objectives can still be met. For example, hardware development happened early on in the project to allow time to overcome any of the issues that came up.

This method of risk identification and mitigation proved extremely effective during the pandemic, when many of the unwanted outcomes came to pass.

The risk-assessment and resources forms have been kept up-to-date throughout the project to ensure that a safe working environment can be guaranteed. Few changes were made to these documents as the initial copies were good reflections of the risks and resources required.

Reflection The successful completion of all the main outcomes of the project is a testament to the good planning that has been observed from the beginning.

The continued planning and de-risking, alongside the effective use of supervision, have ensured that all the primary aims were achieved within the timeframe. This, in turn, allowed the adherence to milestones and deadlines, including the progress review. Contingencies played a big role in delivery of the project, and are discussed further in chapter **??**.

Mitigating any potential risks through the use of the risk-assessment (Appendix A.3 early in the project allowed for progress to be made safely and appropriately.

The Engineering Council's UK-SPEC has been consulted throughout the project and a spreadsheet has been kept up to date containing relevant evidence of each competency. This has helped to keep the project relevant to engineering professionalism and personal development. The logbook has been used as the main repository for all of the relevant documentation, minutes, notes and technical details. Using this, alongside $ClickUp^{TM}$ for planning tasks and time management, has streamlined the workflow, allowing for much more efficient use of time.

Overall, the management of this project has been executed excellently and, despite the pandemic, all changes to circumstance have been overcome (more in chapter **??**).

Chapter 2

Existing Work

2.1. Lighting

2.1.1. Introduction

Many people do not realise how much time they spend in un-natural lighting conditions. In 2001, a study published in *Nature* magazine found that the average American spends more than three quarters of their time inside (Klepeis et al., 2001). More recent studies have put this number as high as 90% (Opinium, 2018), and when most buildings do not get adequate sunlight in the day, the time spent under man-made light sources can be significant. Furthermore, after dark, almost all buildings are lit artificially, very few people around the world do not spend their nights in lit environments.

Falchi et al. (2016) found that 86% of the worlds population, and 99% of the US and European population live under "light polluted" skies. The world uses so much light, that one third of humanity, 60% of Europeans, and 80% of North Americans cannot see the Milky Way.

2.1.2. History

It wasn't always this way. For only the most recent 1.5 million years - a blink of the evolutionary eye - have humans been able to harness the power of fire to extend the usable time of day (J. A. J. Gowlett and Wrangham, 2013). It is important to note, however, that fire does not try to emulate daylight; fires used after dark were used for cooking and as a social space (J. a. J. Gowlett, 2016).

It was not until Humphrey Davy and Michael Faraday's contributions to science allowed Davy to produce the first functional electric light: the arc lamp (Knight, 1998). Since that fateful day, humans' relationship with night has grown increasingly distant. In 1878, Swan presented the first incandescent lamp, patented by Edison in 1880 (though it is believed that others were developing this technology concurrently) . These bulbs are very inefficient; the peak wavelength is determined by the temperature of the gas in the bulb. In order for visible emission to occur, very high temperatures must be achieved - and still the majority of the light will be infra-red (IR) and not visible to the human eye (Montoya et al., 2017).

The next widely adopted innovation was discharge lamps such as sodium lamps and fluorescent tubes, as many Correlated Colour Temperatures (CCTs) could be achieved. Compact Fluorescent Tubes (CFTs) could directly replace Incandescent bulbs using the same fittings.

While LEDs gained widespread popularity

in the early 21st century (Matsumoto and Onuma, 2020), the first visible light LED was produced back in 1962 by Nick Holonyak (Holonyak and Bevacqua, 1962), based on the even earlier LEDs of Oleg Losev from 1927 (Zheludev, 2007). It wasn't until 1995 that a non-red LED was produced, solving the issue of monochromasity of LED technology (it was blue) (S. Nakamura, 1995).

Once white LEDs could be produced, it led to the "Third Revolution" of indoor lighting (Montoya et al., 2017), and now LEDs are ubiquitous in modern life. New LED technology continues to be developed, such as the Organic LED (OLED), which are cheaper and offer better colour rendition. OLED technology has only recently been applied to indoor lighting (Phelan, 2018), although there are some promising developments in the field (Bender, Marchesan, and Alonso, 2015). However there is still some way to go before OLEDs replace LEDs in artificial lighting technology.

2.1.3. Energy Consumption and Environmental Considerations

Incandescent bulbs are not efficient. in fact, they're banned from being sold in the EU because they're so inefficient (EU, 2012). However, this doesn't mean they're all bad, they actually have many benefits; firstly, they produce light much more similar to firelight than modern lighting/ they are also not hazardous, somethin g which cannot be said for fluorescents and LEDs, which also require higher resource depletion to create (Lim et al., 2013). But LEDs use 85% less energy and last 50 times longer than incandescents (Mottier, 2010). This is significant when considering that 20-40% of most buildings power consumption is from lighting alone (Pérez-Lombard, Ortiz, and

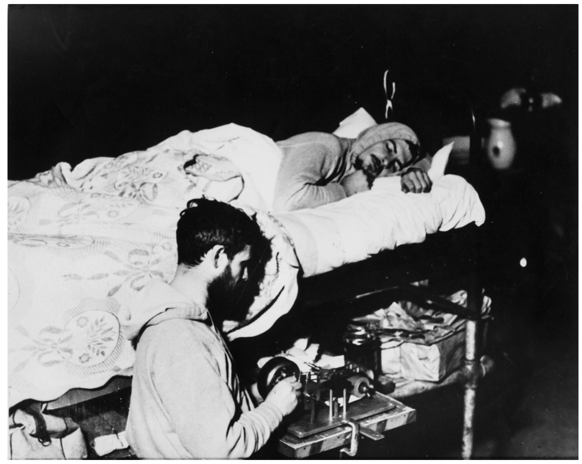


Figure 2.1: *Nathaniel Kleitman (foreground), donning an impressive beard, measures the sleep of Bruce Richardson (University of Chicago Photographic Archive, 2021).*

Pout, 2008), accounting for as much as 10% of all power consumed in Europe (Bertoldi, Hirl, and Labanca, 2012). Considering this, and that LEDs can theoretically convert 100% of electrical energy to visable light (thermal regulation is key) (Jordan, Hutter, and Oppermann, 2012), it is clear why the wide scale adoption of LED technology has been so rapid (Matsumoto and Onuma, 2020).

2.2. Circadian Rhythms

2.2.1. What is the Circadian Rhythm?

In 1729, the French scientissst Jean-Jacques d'Ortous de Mairan used plants kept completely in the dark to determine that their diurnal cycles were not caused by external light stimulus, but rather were regulated by some endogenous clock (De Mairan, 1729).

Amazingly, it wasn't until 1938 that someone repeated this experiment on humans. Dr. Nathaniel Kleitman was a professor of of Physiology at University of Chicago who was later

Table 2.1: *The 5 potential factors for circadian entrainment (Charles A. Czeisler et al., 1981)*

	Factor
I.	Knowledge of time of day
II.	Light Dark cycle
III.	Social Contacts
IV.	Timing of food availability
V.	Scheduling of bed rest and activity

to discover Rapid-Eye Movement (REM) sleep; he is known as the father of sleep research. Together with his PhD student, Bruce Richardson, and a pair of metal beds, they descended into Mammoth Cave in Kentucky for 32 days without any natural lighting stimuli. They found that their sleep-wake cycle did not descend into sporadic bouts of sleep, but rather stayed at a periodic length of around 26 hours, undeniably longer than the 24 hour day. This showed that humans have an internal time-keeping system that lasts about (*circa*) one day (*dian*); they named it the circadian rhythm (Kleitman, 1987).

Siffre (1964) repeated this experiment, delving, himself, into a cavern for 2 months, and discovered much the same results. Meanwhile, Von Aschoff and Wever (1962) kept participants in a sealed cellar for 8-19 days, also discovering a circadian rhythm of over 25 hours.

As circadian rhythms are not 24 hours long, they need to be synchronised daily, and thus must rely on a periodic stimulus to entrain them. There were 5 factors that were thought could contribute to this entrainment of the circadian rhythm, as shown in Table 2.1.

Factor **I** (knowledge of time) was shown to be insignificant (J. N. Mills, 1964). Factor **II** (light-dark cycles) is the most powerful in many animals and plants, but Aschoff et al. (1971) concluded that this effect was too weak in humans, and that factor **III** (social cues) must be our central zeitgerber.

However, when inspecting the facilities used for these experiments, Charles A. Czeisler et al. (1981) realised that the researchers "*permitted the subjects to use kitchen, bathroom, bedside and desk lamps as sources of self-selected light during the 'dark' phase of each cycle*", prompting a reassessment of the role of light in the entrainment of human circadian rhythms in which he found that light-dark cycles have a "*direct synchronising effect*" on human circadian rhythms. They then went on to publish the landmark study titled *Bright light resets the human circadian pacemaker independent of the timing of the sleep-wake cycle* (C. A. Czeisler et al., 1986).

2.2.2. Melatonin and Melanopsin

The circadian rhythm is controlled by a part of the brain called the Hyperthalimus (Stephan and Zucker, 1972). Specifically, in the Suprachiasmatic Nucleus (SCN), located above the optic nerve (Welsh et al., 1995). The SCN sends signals to the pineal gland (Cassone, 1998; Borjigin, Li, and Snyder, 1999) which is responsible for the production and regulation of melatonin.[1]

Melatonin is known as the sleep hormone, or to some: the "chemical expression of darkness" (Reiter, 1991), and builds up throughout the evening and is essential for sleep onset (J. Arendt, 2003).

In 2000, a novel Opsin was found in the human eye (Provencio, Rodriguez, et al., 2000). An opsin is a light-sensitive protein that ex-

[1]There is much intrigue and mystery around the pineal gland, with many believing that it is where conciousness is generated in the brain (Bob and Fedor-Freybergh, 2008). René Descartes referred to the pineal gland as the "seat of the soul" (Lokhorst, 2020).

ists in the visual cells in the eye and is what converts the energy from photons of light into electrical signals that are sent to the brain (Terakita, 2005). It was soon discovered that the action spectrum of this new opsin, malanopsin, did not match any of the action spectra of the known visual cells (rods and cones), implying there was a new cell that we were not yet aware of (Thapan, Josephine Arendt, and Skene, 2001).[2] This cell was found to be the intrinsically photosensitive Retinal Ganglion Cell (ipRGC) (Berson, Dunn, and Takao, 2002), the signals from which are what keeps the SCN entrained, but to not contribute to concious vision (Berson, 2007). This explains why some blind people have circadian rhythms that can be entrained with light, as discussed in the review by Allen (2019).

2.2.3. Blue Light

It has been established that light is of great significance in circadian regulation, and that "moderate illumination" of around 500 lux (Laakso et al., 1993), or even "room light" of less than 200 lux (Gooley et al., 2011) can cause a phase shift in the circadian rhythm. Furthermore, due to the action spectrum of the ipRGCs, blue light causes as much larger effect than longer-wavelength light (Lockley, Brainard, and Charles A. Czeisler, 2003).

The effect of blue light is so potent, that even one second pulses of blue light through closed eyelids are enough to suppress melatonin production (Mariana G Figueiro, Bierman, and Mark S Rea, 2013).

[2]Interestingly, melanopsiin has been found to be much more similar to invertebrate opsins than they are to visual mammalian opsins (Provencio, Jiang, et al., 1998). This, as well as the fact almost all animals produce melatonin, shows it is a truly ancient part of our biology (Davies, Foster, and Hankins, 2014).

There are a few existing solutions attempting to tackle this problem. For example, the use of amber glasses can filter out blue wavelengths before they reach the retina, and have been shown to improve sleep when worn in the evenings (Kimberly and Phelps, 2009).

2.3. Health Implications

In a meta analysis, Sanchez-Barcelo et al. (2010) discuss the potential effects of melatonin in a host of situations, including *"ocular diseases, blood diseases, gastrointestinal tract diseases, cardiovascular diseases, diabetes, rheumatoid arthritis, fibromyalgia, chronic fatigue syndrome, infectious diseases, neurological diseases, sleep disturbances, aging and depression [as well as being] used as a complementary treatment in anaesthesia, hemodialysis, in vitro fertilization and neonatal care"*.

2.3.1. Cancer

We've known for a long time that total visual blindness is protective against many types of cancer (Hahn, 1991; Feychting, Österlund, and Ahlbom, 1998; Flynn-Evans et al., 2009). It was also observed in many studies that flight attendants were more likely to develop breast cancer, as summed up in the meta analysis by Tokumaru et al. (2006). This effect was also observed in night-shift workers, shown in two large reviews of the existing evidence (Kolstad, 2008; Stevens, 2009). It is also known that the circadian rhythm has a cancer-suppressing effect (Fu and Lee, 2003) and that circadian disruption is a promoting factor for lung cancer (Papagiannakopoulos et al., 2016). An extensive meta analysis even found that chemotherapy toxicity is correlated to when it is taken, leading to the entire field of chronotherapy (Focan, 1995; Dallmann, Brown, and Gachon, 2014).

The correlation of circadian regulation and cancer is so well recognised, that even the WHO classes night-shift work as a class 2A carcinogen (WHO, 2013). However, even those not engaging in abnormal working hours may have an increased risk; Stevens et al. (2014) blames electric lighting directly as the cause of breast cancer being the leading cause of cancer death among women worldwide.

2.3.2. Diabetes

Although 415 million people worldwide live with Type II Diabetes, it is a preventable and reversible disease (Fung, 2018). Type II diabetes is a lifestyle disease, mostly caused by diet, whereby insulin resistance is built up such that blood sugar can no longer be absorbed by cells. A contributing factor to this is melatonin, which has been shown to aid blood glucose homoeostasis (Bouatia-Naji et al., 2009). Melatonin receptors influence fasting glucose levels (Prokopenko et al., 2009) and when completely removed, can even induce insulin resistance (Contreras-Alcantara, Baba, and Tosini, 2010).

Another study found that social jetlag - the jetlag-like effect of inconsistent waking times, ie. waking up later at the weekend - is a risk factor for obesity, itself the largest risk factor for Type II Diabetes and a host of other health issues (Roenneberg et al., 2012)

2.3.3. Seasonal Affective Disorder

Seasonal Affective Disorder (SAD) is caused by a lack of light in the wither months when the sun is lower and takes a shorter path across the sky (Charmane I. Eastman, 1990). It has been long considered a fact that bright light helps alleviate the symptoms of SAD (Magnusson and Kritbjarnarson, 1991; lee et al., 1997; Charmane I. Eastman et al., 1998), but this has actually been quite a controversial topic, with others claiming that the placebos in these studies were not adequate, and such that the antidepressant effect can be attributed to placebo effect (C. I. Eastman, M. A. Young, and Fogg, 1993). A comprehensive meta-analysis found that only 13% of studies published between 1975 and 2003 were adequate in their methods (Golden et al., 2005). It also highlihgted the importance of dawn simulation, which beats out both bright-light and placebo effects significantly Avery et al. (2001).

2.4. Cortisol and Attentiveness

Melatonin is essential for sleep, building throughout the evening and peaking in the middle of the night. Similarly, Cortisol - produced in the adrenal gland - helps us wake up, and peaks around mid-morning. This is known as the Cortisol Awakening Response (CAR) and is, of course, also regulated by the circadian rhythm (Fries, Dettenborn, and Kirschbaum, 2009).

Cortisol is the hormone of wakefulness and alertness and such it has been shown that a higher spike in morning cortisol is correlated with better cognitive performance (P. D. Evans et al., 2011), and general daytime cortisol improves alertness (Chapotot et al., 1998). It is clear, then, that we want to maximise the CAR, which can be done through exposure to short-wavelength (blue) light after awakening (Mariana G. Figueiro and Mark S. Rea, 2012). Dawn-simulation has also been shown to improve the CAR - more so than just blue light - as well as improving melatonin regulation, increasing well-being, mood and cognitive performance (Gabel et al., 2013).

"Light affects our sleep more powerfully than any drug"

(Charles A. Czeisler, 2013)

It is also well documented that cortisol is a large contributing factor to mood disorders, especially bipolar disorder (A. H. Young, 2004). A study by D. Sit et al. (2007) found that *"Women with bipolar illness are highly sensitive to morning bright light treatment"*, following this up a decade later with a double-blind placebo controlled trial that found that 68.2% of the bright light participants had their bipolar disorder go into remission, compared with only 22.2% in the placebo group (D. K. Sit et al., 2017).

2.5. Mood and Lighting

Lighting arrangements affect how we percieve spaces (Durak et al., 2007), with the general finding being that daylight-style LEDs are the most comfortable during daytime hours (Cajochen et al., 2019). It is also known that red ambient lighting is more relaxing than blue (Laufer et al., 2009), and that blue causes more stimulation that red (S. Schweitzer et al., 2016). Pulsating orange light has also been shown to be even more relaxing (Wan et al., 2012), it seems as though this could have a link to the fact it is a closer approximation to firelight.

Full-spectrum lighting has been thought to improve cognitive performance and mood states (Berry, 1984), however this is somewhat controversial and likely to be a placebo effect (Veitch, Gifford, and Hine, 1991).

2.6. Summary of Literature

Over the past 150 years, electric lighting has gone from a pipe-dream to an everyday necessity, increasing the length of the productive day.

Alongside these developments, circadian science has been driving forward, from observations of the nature of free-running circadian rhythms to the discovery that light has profound affects upon it. Blue light's effect is especially powerful and is becoming more and more ubiquitous as our technology advances. As Charles A. Czeisler (2013) says in his landmark perspective piece entitled *Casting the Light on Sleep Deficiency: "Technology has effectively decoupled us from the natural 24-hour day to which our bodies evolved"*.

This decoupling is dangerous for many aspects of our health. Not only is sleep important for all aspects of health and well-being, melatonin itself has a promising effect on many diseases including type II diabetes, SAD, cancer, and many others. Cortisol, melatonin's sister hormone, is also essential for a healthy life and promotes attentiveness, alertness and cognitive function.

Looking to the past for answers, we see that the output spectra of more outdated technologies such as incandescent bulbs are far more appropriate for evening use than the more modern fluorescent tubes and LEDs. But these older technologies are far less energy efficient, to the point that their sale is banned in the EU. On the other hand, the adoption of more energy efficient technologies should not come at the expense of human health (Boyce, 2010) due to excessive blue light exposure - which has also been shown time and again to damage our eyes in excessive quantities (Ueda et al., 2009; Kuse et al., 2014; Niwano et al., 2014; Marek et al., 2018; M. Nakamura et al., 2018).

Blue light is not all bad, though. Its effects on SAD, bipolar disorder, and cognitive ability show that it is all about giving our body the right light at the right time of day. Some people already strive for this by using blue-light blocking glasses or RGB LED bulbs that can be set to change colour. These technologies are flawed, though: glasses are a hassle to wear and carry around and RGB LEDs only approximate perceived colours by combining red, green and blue, thereby ensuring there is more short-wavelength light that is desirable (Gilewski, 2018).

This has led many to believe that an overhaul in the lighting used in the built environment is of paramount importance, with many papers calling for immediate action (A. R. Webb, 2006; Boyce, 2010; Grose, 2014).

2.7. Existing Solutions

An analysis of existing solutions was undertaken early in the project to understand what already exists in this field. The products could be generalised into 4 categories:

2.7.1. Wake-Up Lights

Ranging from £20 to £200, these products usually come in the form of an alarm clock with a built in light to wake up the user with a simulated dawn. With many varying features across the models, most contain an FM radio.

These lamps are used as a bedside light and are not appropriate for lighting a whole space. As they are focused on morning light, many use inappropriate spectra to be used before bed.

While these devices utilise an artificial dawn - shown to have many beneficial effects - there are few studies on these devices themselves.

2.7.2. Bulb Replacements

Various forms of smart-light exist on the market currently, most notably the Philips Hue. this can be set to fade to warmer light in the evenings and brighter light during the day to encourage winding-down and focus respectively.

However the basis of these are very much visual entertainment, not circadian entrainment. Using RGB LEDs, they are less than ideal for use before bed and need serious modifications to automatically change temperature.

These bulbs are expensive, too. For a starter kit including the base unit and just 4 bulbs, Philips charge almost £200.

Circadian bulbs also exist. These are fitted to dimmer circuits and change temperature instead of dimming. BIOS lighting have a natural-spectrum bulb that can be used both in day and night. However, these require manual adjustment throughout the day and require dimmer circuits to be installed.

2.7.3. Industrial Circadian Lighting

There are many companies offering bespoke services to fit circadian lighting systems into office spaces and warehouses. However these are very expensive and not applicable for home installation. Furthermore, as they are designed for business environments, many of these solutions do not account for later evening that can aid with sleep onset.

2.7.4. Software Based

Windows, OSX, iOS and Android all now have built in blue light filters that can be turned on to limit the amount of blue light that the screen emits. The intensity and time that it comes on can usually be adjusted by the user. Specialist software such as f.lux can also be used for this purpose but with greater flexibility.

2.7.5. Discussion

All of the devices discussed here have one other feature in common: as they are all LED devices based on providing a visual cue and are not designed based on the evidence in the literature at the forefront (perhaps with industrial solutions as the exception), the spectra of these devices can be questionable.

Also, none of these products are designed to get dim enough to be used late at night. They are all for use leading into the evening, but once the user is in bed, these become insufficient solutions.

2.8. Implementation

The ideas discussed in this chapter were used to inform the requirements specification (Appendix A.1). The output spectra of the lamp will have to be respectful of biological considerations: no light produced within the melanopsin action spectrum during the evening, but high blue light in the morning. Dawn simulation must be achievable on the device to gain many of the benefits.

The existing solutions have shown that the device must be low cost, and fully automated to bridge all of the shortcomings of the current devices. The device should also be simple to install and not require additional technology such as a smartphone.

References

Allen, Annette E (Dec. 2019). Circadian Rhythms in the Blind. en. *Current Opinion in Behavioral Sciences* [online]. Visual Perception. 30, pp. 73–79. ISSN: 2352-1546. DOI: 10.1016/j.cobeha.2019.06.003. Available from: https://www.sciencedirect.com/science/article/pii/S2352154619300439 [Accessed Mar. 7, 2021].

Arendt, J. (Mar. 2003). Importance and Relevance of Melatonin to Human Biological Rhythms: Melatonin and Human Rhythms. en. *Journal of Neuroendocrinology* [online]. 15 (4), pp. 427–431. ISSN: 09538194, 13652826. DOI: 10.1046/j.1365-2826.2003.00987.x. Available from: http://doi.wiley.com/10.1046/j.1365-2826.2003.00987.x [Accessed Nov. 30, 2020].

Aschoff, J., M. Fatranska, H. Giedke, P. Doerr, D. Stamm, and H. Wisser (Jan. 1971). Human Circadian Rhythms in Continuous Darkness: Entrainment by Social Cues. en. *Science* [online]. 171 (3967), pp. 213–215. ISSN: 0036-8075, 1095-9203. DOI: 10.1126/science.171.3967.213. Available from: https://science.sciencemag.org/content/171/3967/213 [Accessed Mar. 7, 2021].

Avery, David H, Derek N Eder, Mary Ann Bolte, Carla J Hellekson, David L Dunner, Michael V Vitiello, and Pat N Prinz (Aug. 2001). Dawn Simulation and Bright Light in the Treatment of SAD: A Controlled Study. en. *Biological Psychiatry* [online]. 50 (3), pp. 205–216. ISSN: 0006-3223. DOI: 10.1016/S0006-3223(01)01200-8. Available from: https://www.sciencedirect.com/science/article/pii/S0006322301012008 [Accessed Mar. 15, 2021].

Bender, V. C., T. B. Marchesan, and J. M. Alonso (June 2015). Solid-State Lighting: A Concise Review of the State of the Art on LED and OLED Modeling. *IEEE Industrial Electronics Magazine* [online]. 9 (2), pp. 6–16. ISSN: 1941-0115. DOI: 10.1109/MIE.2014.2360324.

Berry, J. L. (1984). Work Efficiency and Mood States of Electronic Assembly Workers Exposed to Full-Spectrum and Conventional Fluorescent Illumination. en, p. 1. Available from: https://www.elibrary.ru/item.asp?id=7387470 [Accessed Mar. 18, 2021].

Berson, David M. (Aug. 2007). Phototransduction in Ganglion-Cell Photoreceptors. en. *Pflügers Archiv - European Journal of Physiology* [online]. 454 (5), pp. 849–855. ISSN: 1432-2013. DOI: 10.1007/s00424-007-0242-2. Available from: https://doi.org/10.1007/s00424-007-0242-2 [Accessed Mar. 6, 2021].

Berson, David M., Felice A. Dunn, and Motoharu Takao (Feb. 2002). Phototransduction by Retinal Ganglion Cells That Set the Circadian Clock. eng. *Science (New York, N.Y.)* [online]. 295 (5557), pp. 1070–1073. ISSN: 1095-9203. DOI: 10.1126/science.1067262.

Bertoldi, Paolo, Bettina Hirl, and Nicola Labanca (2012). Energy Efficiency Status Report 2012–Electricity Consumption and Efficiency

Trends in the EU-27. *European Commission Joint Research Centre Institute for Energy and Transport, Ispra, Italy*.

Bob, Petr and Peter Fedor-Freybergh (2008). Melatonin, Consciousness, and Traumatic Stress. en. *Journal of Pineal Research* [online]. 44 (4), pp. 341–347. ISSN: 1600-079X. DOI: 10.1111/j.1600-079X.2007.00540.x. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-079X.2007.00540.x [Accessed Mar. 7, 2021].

Borjigin, Jimo, Xiaodong Li, and Solomon H. Snyder (1999). THE PINEAL GLAND AND MELATONIN: Molecular and Pharmacologic Regulation. *Annual Review of Pharmacology and Toxicology* [online]. 39 (1), pp. 53–65. DOI: 10.1146/annurev.pharmtox.39.1.53. Available from: https://doi.org/10.1146/annurev.pharmtox.39.1.53 [Accessed Mar. 7, 2021].

Bouatia-Naji, Nabila, Amélie Bonnefond, Christine Cavalcanti-Proença, Thomas Sparsø, Johan Holmkvist, Marion Marchand, Jérôme Delplanque, Stéphane Lobbens, Ghislain Rocheleau, Emmanuelle Durand, Franck De Graeve, Jean-Claude Chèvre, Knut Borch-Johnsen, Anna-Liisa Hartikainen, Aimo Ruokonen, Jean Tichet, Michel Marre, Jacques Weill, Barbara Heude, Maithé Tauber, Katleen Lemaire, Frans Schuit, Paul Elliott, Torben Jørgensen, Guillaume Charpentier, Samy Hadjadj, Stéphane Cauchi, Martine Vaxillaire, Robert Sladek, Sophie Visvikis-Siest, Beverley Balkau, Claire Lévy-Marchal, François Pattou, David Meyre, Alexandra I. F. Blakemore, Marjo-Riita Jarvelin, Andrew J. Walley, Torben Hansen, Christian Dina, Oluf Pedersen, and Philippe Froguel (Jan. 2009). A Variant near MTNR1B Is Associated with Increased Fasting Plasma Glucose Levels and Type 2 Diabetes Risk. en. *Nature Genetics* [online]. 41 (1), pp. 89–94. ISSN: 1546-1718. DOI: 10.1038/ng.277. Available from: https://www.nature.com/articles/ng.277 [Accessed Mar. 15, 2021].

Boyce, Peter R. (Feb. 2010). Review: The Impact of Light in Buildings on Human Health. en. *Indoor and Built Environment* [online]. 19 (1), pp. 8–20. ISSN: 1420-326X. DOI: 10.1177/1420326X09358028. Available from: https://doi.org/10.1177/1420326X09358028 [Accessed Nov. 25, 2020].

Cajochen, C, M Freyburger, T Basishvili, C Garbazza, F Rudzik, C Renz, K Kobayashi, Y Shirakawa, O Stefani, and J Weibel (Nov. 2019). Effect of Daylight LED on Visual Comfort, Melatonin, Mood, Waking Performance and Sleep. en. *Lighting Research & Technology* [online]. 51 (7), pp. 1044–1062. ISSN: 1477-1535. DOI: 10.1177/1477153519828419. Available from: https://doi.org/10.1177/1477153519828419 [Accessed Mar. 18, 2021].

Cassone, Vincent M. (Jan. 1998). Melatonin's Role in Vertebrate Orcadian Rhythms. *Chronobiology International* [online]. 15 (5), pp. 457–473. ISSN: 0742-0528. DOI: 10.3109/07420529808998702. Available from: https://doi.org/10.3109/07420529808998702 [Accessed Mar. 7, 2021].

Chapotot, Florian, Claude Gronfier, Christophe Jouny, Alain Muzet, and Gabrielle Brandenberger (Dec. 1998). Cortisol Secretion Is Related to Electroencephalographic Alertness in Human Subjects during Daytime Wakefulness1. *The Journal of Clinical Endocrinology & Metabolism* [online]. 83 (12), pp. 4263–4268. ISSN: 0021-972X. DOI: 10.1210/jcem.83.12.5326. Available from: https://doi.org/10.1210/jcem.83.12.5326 [Accessed Mar. 18, 2021].

Contreras-Alcantara, S, K Baba, and G Tosini (2010). Removal of Melatonin Receptor Type 1 Induces Insulin Resistance in the Mouse. *Obesity*. 18 (9), pp. 1861–1863.

Czeisler, C. A., J. S. Allan, S. H. Strogatz, J. M. Ronda, R. Sanchez, C. D. Rios, W. O. Freitag, G. S. Richardson, and R. E. Kronauer (Aug. 1986). Bright Light Resets the Human Circadian Pacemaker Independent of the Timing of the Sleep-Wake Cycle. en. *Science* [online]. 233 (4764), pp. 667–671. ISSN: 0036-8075, 1095-9203. DOI: 10.1126/science.3726555. Available from: https://science.sciencemag.org/content/233/4764/667 [Accessed Nov. 30, 2020].

Czeisler, Charles A. (May 2013). Perspective: Casting Light on Sleep Deficiency. en. *Nature* [online]. 497 (7450), S13–S13. ISSN: 1476-4687. DOI: 10.1038/497S13a. Available from: https://www.nature.com/articles/497S13a [Accessed Nov. 30, 2020].

Czeisler, Charles A., Gary S. Richardson, Janet C. Zimmerman, Martin C. Moore-Ede, and Elliot D. Weitzman (1981). Entrainment of Human Orcadian Rhythms by Light-Dark Cycles: A Reassessment. en. *Photochemistry and Photobiology* [online]. 34 (2), pp. 239–247. ISSN: 1751-1097. DOI: 10.1111/j.1751-1097.1981.tb08993.x. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1751-1097.1981.tb08993.x [Accessed Feb. 27, 2021].

Dallmann, Robert, Steven A. Brown, and Frederic Gachon (Jan. 2014). Chronopharmacology: New Insights and Therapeutic Implications. *Annual review of pharmacology and toxicology* [online]. 54. ISSN: 0362-1642. DOI: 10.1146/annurev-pharmtox-011613-135923. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3885389/ [Accessed Mar. 15, 2021].

Davies, Wayne I. L., Russell G. Foster, and Mark W. Hankins (2014). The Evolution and Function of Melanopsin in Craniates. en. In: *Evolution of Visual and Non-Visual Pigments*. Ed. by David M. Hunt, Mark W. Hankins, Shaun P Collin, and N. Justin Marshall. Springer Series in Vision Research. Boston, MA: Springer US, pp. 23–63. ISBN: 978-1-4614-4355-1. DOI: 10.1007/978-1-4614-4355-1_2. Available from: https://doi.org/10.1007/978-1-4614-4355-1_2 [Accessed Mar. 6, 2021].

De Mairan, JJ (1729). Observation Botanique. *Histoire de l'Academie Royale des Sciences Paris* [online]. Available from: https://ci.nii.ac.jp/naid/10021910265/ [Accessed Feb. 11, 2021].

Durak, Ayşe, Nilgün Camgöz Olguntürk, Cengiz Yener, Dilek Güvenç, and Yusuf Gürçınar (Oct. 2007). Impact of Lighting Arrangements and Illuminances on Different Impressions of a Room. en. *Building and Environment* [online]. 42 (10), pp. 3476–3482. ISSN: 0360-1323. DOI: 10.1016/j.buildenv.2006.10.048. Available from: https://www.sciencedirect.com/science/article/pii/S0360132306003830 [Accessed Mar. 18, 2021].

Eastman, C. I., M. A. Young, and L. F. Fogg (Jan. 1993). 26 - A Comparison of Two Different Placebo-Controlled SAD Light Treatment Studies. en. In: *Light and Biological Rhythms in Man*. Ed. by L. Wetterberg. Wenner–Gren Center International Symposium Series. Amsterdam: Pergamon, pp. 371–383. DOI: 10.1016/B978-0-08-042279-4.50030-3. Available from: https://www.sciencedirect.com/science/

article/pii/B9780080422794500303 [Accessed Mar. 15, 2021].

Eastman, Charmane I. (Nov. 1990). Natural Summer and Winter Sunlight Exposure Patterns in Seasonal Affective Disorder. en. *Physiology & Behavior* [online]. 48 (5), pp. 611–616. ISSN: 0031-9384. DOI: 10.1016/0031-9384(90)90199-E. Available from: https://www.sciencedirect.com/science/article/pii/003193849090199E [Accessed Mar. 15, 2021].

Eastman, Charmane I., Michael A. Young, Louis F. Fogg, Liwen Liu, and Patricia M. Meaden (Oct. 1998). Bright Light Treatment of Winter Depression: A Placebo-Controlled Trial. en. *Archives of General Psychiatry* [online]. 55 (10), p. 883. ISSN: 0003-990X. DOI: 10.1001/archpsyc.55.10.883. Available from: http://archpsyc.jamanetwork.com/article.aspx?doi=10.1001/archpsyc.55.10.883 [Accessed Dec. 2, 2020].

EU (2012). *Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC (Text with EEA Relevance)*. eng. Text. Available from: https://www.legislation.gov.uk/eudr/2012/27/2020-01-01 [Accessed Nov. 30, 2020].

Evans, P. D., C. Fredhoi, C. Loveday, F. Hucklebridge, E. Aitchison, D. Forte, and A. Clow (Mar. 2011). The Diurnal Cortisol Cycle and Cognitive Performance in the Healthy Old. en. *International Journal of Psychophysiology* [online]. 79 (3), pp. 371–377. ISSN: 0167-8760. DOI: 10.1016/j.ijpsycho.2010.12.006. Available from: https://www.sciencedirect.com/science/article/pii/S0167876010007737 [Accessed Mar. 18, 2021].

Falchi, Fabio, Pierantonio Cinzano, Dan Duriscoe, Christopher C. M. Kyba, Christopher D. Elvidge, Kimberly Baugh, Boris A. Portnov, Nataliya A. Rybnikova, and Riccardo Furgoni (June 2016). The New World Atlas of Artificial Night Sky Brightness. en. *Science Advances* [online]. 2 (6), e1600377. ISSN: 2375-2548. DOI: 10.1126/sciadv.1600377. Available from: https://advances.sciencemag.org/content/2/6/e1600377 [Accessed Feb. 10, 2021].

Feychting, Maria, Bill Österlund, and Anders Ahlbom (1998). Reduced Cancer Incidence among the Blind. *Epidemiology* [online]. 9 (5), pp. 490–494. ISSN: 1044-3983. Available from: https://www.jstor.org/stable/3702524 [Accessed Mar. 15, 2021].

Figueiro, Mariana G, Andrew Bierman, and Mark S Rea (Oct. 2013). A Train of Blue Light Pulses Delivered through Closed Eyelids Suppresses Melatonin and Phase Shifts the Human Circadian System. *Nature and Science of Sleep* [online]. 5, pp. 133–141. ISSN: 1179-1608. DOI: 10.2147/NSS.S52203. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3795006/ [Accessed Nov. 30, 2020].

Figueiro, Mariana G. and Mark S. Rea (July 2012). Short-Wavelength Light Enhances Cortisol Awakening Response in Sleep-Restricted Adolescents. en. *International Journal of Endocrinology* [online]. 2012, e301935. ISSN: 1687-8337. DOI: 10.1155/2012/301935. Available from: https://www.hindawi.com/journals/ije/2012/301935/ [Accessed Mar. 18, 2021].

Flynn-Evans, Erin E., Richard G. Stevens, Homayoun Tabandeh, Eva S. Schernhammer, and Steven W. Lockley (Nov. 2009). Total Visual Blindness Is Protective against Breast Cancer. en. *Cancer Causes & Control* [online]. 20 (9), pp. 1753–1756. ISSN: 1573-7225. DOI: 10.1007/s10552-009-9405-0. Available from: https://doi.org/10.1007/s10552-009-9405-0 [Accessed Mar. 15, 2021].

Focan, C. (Jan. 1995). Circadian Rhythms and Cancer Chemotherapy. en. *Pharmacology & Therapeutics* [online]. 67 (1), pp. 1–52. ISSN: 0163-7258. DOI: 10.1016/0163-7258(95)00009-6. Available from: https://www.sciencedirect.com/science/article/pii/0163725895000096 [Accessed Mar. 15, 2021].

Fries, Eva, Lucia Dettenborn, and Clemens Kirschbaum (Apr. 2009). The Cortisol Awakening Response (CAR): Facts and Future Directions. en. *International Journal of Psychophysiology* [online]. Central and Peripheral Nervous System Interactions: From Mind to Brain to Body. 72 (1), pp. 67–73. ISSN: 0167-8760. DOI: 10.1016/j.ijpsycho.2008.03.014. Available from: https://www.sciencedirect.com/science/article/pii/S0167876008007940 [Accessed Mar. 6, 2021].

Fu, Loning and Cheng Chi Lee (May 2003). The Circadian Clock: Pacemaker and Tumour Suppressor. en. *Nature Reviews Cancer* [online]. 3 (5), pp. 350–361. ISSN: 1474-1768. DOI: 10.1038/nrc1072. Available from: https://www.nature.com/articles/nrc1072 [Accessed Mar. 15, 2021].

Fung, Dr Jason (Apr. 2018). *The Diabetes Code: Prevent and Reverse Type 2 Diabetes Naturally*. en. Greystone Books Ltd. ISBN: 978-1-77164-266-8.

Gabel, Virginie, Micheline Maire, Carolin F. Reichert, Sarah L. Chellappa, Christina Schmidt, Vanja Hommes, Antoine U. Viola, and Christian Cajochen (Oct. 2013). Effects of Artificial Dawn and Morning Blue Light on Daytime Cognitive Performance, Well-Being, Cortisol and Melatonin Levels. *Chronobiology International* [online]. 30 (8), pp. 988–997. ISSN: 0742-0528. DOI: 10.3109/07420528.2013.793196. Available from: https://doi.org/10.3109/07420528.2013.793196 [Accessed Mar. 18, 2021].

Gilewski, Marian (Nov. 2018). The Ecological Harmfulness of RGB LED Light. en. *DEStech Transactions on Environment, Energy and Earth Sciences* [online]. 1 (epeee), pp. 89–93. ISSN: 2475-8833. DOI: 10.12783/dteees/epeee2018/26471. Available from: http://dpi-proceedings.com/index.php/dteees/article/view/26471 [Accessed Nov. 28, 2020].

Golden, Robert N., Bradley N. Gaynes, R. David Ekstrom, Robert M. Hamer, Frederick M. Jacobsen, Trisha Suppes, Katherine L. Wisner, and Charles B. Nemeroff (Apr. 2005). The Efficacy of Light Therapy in the Treatment of Mood Disorders: A Review and Meta-Analysis of the Evidence. *American Journal of Psychiatry* [online]. 162 (4), pp. 656–662. ISSN: 0002-953X. DOI: 10.1176/appi.ajp.162.4.656. Available from: https://ajp.psychiatryonline.org/doi/full/10.1176/appi.ajp.162.4.656 [Accessed Mar. 15, 2021].

Gooley, Joshua J., Kyle Chamberlain, Kurt A. Smith, Sat Bir S. Khalsa, Shantha M. W. Rajaratnam, Eliza Van Reen, Jamie M. Zeitzer, Charles A. Czeisler, and Steven W. Lockley (Mar. 2011). Exposure to Room Light before Bedtime Suppresses Melatonin Onset and Shortens Melatonin Duration in Humans. en. *The Journal of Clinical Endocrinology &*

Metabolism [online]. 96 (3), E463–E472. ISSN: 0021-972X. DOI: 10.1210/jc.2010-2098. Available from: https://academic.oup.com/jcem/article/96/3/E463/2597236 [Accessed Nov. 26, 2020].

Gowlett, J. a. J. (June 2016). The Discovery of Fire by Humans: A Long and Convoluted Process. *Philosophical Transactions of the Royal Society B: Biological Sciences* [online]. 371 (1696), p. 20150164. DOI: 10.1098/rstb.2015.0164. Available from: https://royalsocietypublishing.org/doi/full/10.1098/rstb.2015.0164 [Accessed Feb. 10, 2021].

Gowlett, John A. J. and Richard W. Wrangham (Mar. 2013). Earliest Fire in Africa: Towards the Convergence of Archaeological Evidence and the Cooking Hypothesis. *Azania: Archaeological Research in Africa* [online]. 48 (1), pp. 5–30. ISSN: 0067-270X. DOI: 10.1080/0067270X.2012.756754. Available from: https://doi.org/10.1080/0067270X.2012.756754 [Accessed Feb. 10, 2021].

Grose, Margaret (Dec. 2014). Artificial Light at Night: A Neglected Population Health Concern of the Built Environment. EN. *Health Promotion Journal of Australia: Official Journal of Australian Association of Health Promotion Professionals* [online]. 25 (3), p. 193. Available from: https://search.informit.org/documentSummary;dn=885318179531061;res=IELAPA [Accessed Nov. 30, 2020].

Hahn, Robert A. (1991). Profound Bilateral Blindness and the Incidence of Breast Cancer. *Epidemiology* [online]. 2 (3), pp. 208–210. ISSN: 1044-3983. Available from: https://www.jstor.org/stable/25759883 [Accessed Mar. 15, 2021].

Holonyak, Nick and S. F. Bevacqua (Dec. 1962). COHERENT (VISIBLE) LIGHT EMISSION FROM Ga(As1-xPx) JUNCTIONS. *Applied Physics Letters* [online]. 1 (4), pp. 82–83. ISSN: 0003-6951. DOI: 10.1063/1.1753706. Available from: https://aip.scitation.org/doi/abs/10.1063/1.1753706 [Accessed Feb. 10, 2021].

Jordan, R., M. Hutter, and H. Oppermann (Sept. 2012). "Challenges in LED Packaging and Green Lighting". In: *2012 Electronics Goes Green 2012+*, pp. 1–8.

Kimberly, Burkhart and James R Phelps (Dec. 2009). Amber Lenses to Block Blue Light and Improve Sleep: A Randomized Trial. *Chronobiology International* [online]. 26 (8), pp. 1602–1612. ISSN: 0742-0528. DOI: 10.3109/07420520903523719. Available from: https://doi.org/10.3109/07420520903523719 [Accessed Nov. 30, 2020].

Kleitman, Nathaniel (Sept. 1987). *Sleep and Wakefulness*. en. University of Chicago Press. ISBN: 978-0-226-44073-6.

Klepeis, Neil E., William C. Nelson, Wayne R. Ott, John P. Robinson, Andy M. Tsang, Paul Switzer, Joseph V. Behar, Stephen C. Hern, and William H. Engelmann (July 2001). The National Human Activity Pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Pollutants. en. *Journal of Exposure Science & Environmental Epidemiology* [online]. 11 (3), pp. 231–252. ISSN: 1559-064X. DOI: 10.1038/sj.jea.7500165. Available from: https://www.nature.com/articles/7500165 [Accessed Feb. 10, 2021].

Knight, David (Feb. 1998). *Humphry Davy: Science and Power*. en. Cambridge University Press. ISBN: 978-0-521-56539-4.

Kolstad, Henrik A (2008). Nightshift Work and Risk of Breast Cancer and Other Cancers—a Critical Review of the Epidemiologic Evidence. *Scandinavian Journal of Work, En-*

vironment & Health [online]. 34 (1), pp. 5–22. ISSN: 0355-3140. Available from: https://www.jstor.org/stable/40967685 [Accessed Dec. 2, 2020].

Kuse, Yoshiki, Kenjiro Ogawa, Kazuhiro Tsuruma, Masamitsu Shimazawa, and Hideaki Hara (June 2014). Damage of Photoreceptor-Derived Cells in Culture Induced by Light Emitting Diode-Derived Blue Light. en. *Scientific Reports* [online]. 4 (1), p. 5223. ISSN: 2045-2322. DOI: 10.1038/srep05223. Available from: https://www.nature.com/articles/srep05223/ [Accessed Dec. 2, 2020].

Laakso, Maija-Liisa, Taina Hätönen, Dag Stenberg, Aino Alila, and Sabrina Smith (1993). One-Hour Exposure to Moderate Illuminance (500 Lux) Shifts the Human Melatonin Rhythm. en. *Journal of Pineal Research* [online]. 15 (1), pp. 21–26. ISSN: 1600-079X. DOI: 10.1111/j.1600-079X.1993.tb00505.x. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-079X.1993.tb00505.x [Accessed Nov. 30, 2020].

Laufer, L., E. Láng, L. Izsó, and E. Németh (Dec. 2009). Psychophysiological Effects of Coloured Lighting on Older Adults. en. *Lighting Research & Technology* [online]. 41 (4), pp. 371–378. ISSN: 1477-1535. DOI: 10.1177/1477153509336803. Available from: https://doi.org/10.1177/1477153509336803 [Accessed Mar. 18, 2021].

lee, T. M. C., C. C. H. Chan, J. G. Paterson, H. L. Janzen, and C. A. Blashko (Aug. 1997). Spectral Properties of Phototherapy for Seasonal Affective Disorder: A Meta-Analvsis. en. *Acta Psychiatrica Scandinavica* [online]. 96 (2), pp. 117–121. ISSN: 0001-690X, 1600-0447. DOI: 10.1111/j.1600-0447.1997.tb09915.x. Available from: http://doi.wiley.com/10.1111/j.1600-0447.1997.tb09915.x [Accessed Dec. 2, 2020].

Lim, Seong-Rin, Daniel Kang, Oladele A. Ogunseitan, and Julie M. Schoenung (Jan. 2013). Potential Environmental Impacts from the Metals in Incandescent, Compact Fluorescent Lamp (CFL), and Light-Emitting Diode (LED) Bulbs. *Environmental Science & Technology* [online]. 47 (2), pp. 1040–1047. ISSN: 0013-936X. DOI: 10.1021/es302886m. Available from: https://doi.org/10.1021/es302886m [Accessed Nov. 30, 2020].

Lockley, Steven W., George C. Brainard, and Charles A. Czeisler (Sept. 2003). High Sensitivity of the Human Circadian Melatonin Rhythm to Resetting by Short Wavelength Light. *The Journal of Clinical Endocrinology & Metabolism* [online]. 88 (9), pp. 4502–4505. ISSN: 0021-972X. DOI: 10.1210/jc.2003-030570. Available from: https://doi.org/10.1210/jc.2003-030570 [Accessed Mar. 18, 2021].

Lokhorst, Gert-Jan (2020). Descartes and the Pineal Gland. In: *The Stanford Encyclopedia of Philosophy*. Ed. by Edward N. Zalta. Fall 2020. Metaphysics Research Lab, Stanford University. Available from: https://plato.stanford.edu/archives/fall2020/entries/pineal-gland/ [Accessed Mar. 7, 2021].

Magnusson, Andres and Helgi Kritbjarnarson (Feb. 1991). Treatment of Seasonal Affective Disorder with High-Intensity Light: A Phototherapy Study with an Icelandic Group of Patients. en. *Journal of Affective Disorders* [online]. 21 (2), pp. 141–147. ISSN: 0165-0327. DOI: 10.1016/0165-0327(91)90061-V. Available from: http://www.sciencedirect.com/science/article/pii/016503279190061V [Accessed Dec. 2, 2020].

Marek, Veronika, Stéphane Mélik-Parsadaniantz, Thierry Villette, Fanny Montoya, Christophe Baudouin, Françoise Brignole-Baudouin, and Alexandre Denoyer (Oct. 2018). Blue Light Phototoxicity toward Human Corneal and Conjunctival Epithelial Cells in Basal and Hyperosmolar Conditions. en. *Free Radical Biology and Medicine* [online]. 126, pp. 27–40. ISSN: 0891-5849. DOI: 10.1016/j.freeradbiomed.2018.07.012. Available from: http://www.sciencedirect.com/science/article/pii/S0891584918312541 [Accessed Dec. 2, 2020].

Matsumoto, Shigeru and Hiroki Onuma (Dec. 2020). Measuring Household Ability to Adopt New Technology: The Case of Light-Emitting Diodes (LEDs). en. *Journal of Cleaner Production* [online]. 277, p. 123323. ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2020.123323. Available from: https://www.sciencedirect.com/science/article/pii/S0959652620333680 [Accessed Feb. 10, 2021].

Mills, J. N. (Nov. 1964). Circadian Rhythms during and after Three Months in Solitude Underground. *The Journal of Physiology* [online]. 174 (2), pp. 217–231. ISSN: 0022-3751. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1368949/ [Accessed Mar. 7, 2021].

Montoya, Francisco G., Antonio Peña-García, Adel Juaidi, and Francisco Manzano-Agugliaro (Apr. 2017). Indoor Lighting Techniques: An Overview of Evolution and New Trends for Energy Saving. en. *Energy and Buildings* [online]. 140, pp. 50–60. ISSN: 03787788. DOI: 10.1016/j.enbuild.2017.01.028. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0378778816314967 [Accessed Nov. 30, 2020].

Mottier, Patrick (Jan. 2010). *LED for Lighting Applications*. en. John Wiley & Sons. ISBN: 978-0-470-61029-9.

Nakamura, Maho, Tomohiro Yako, Yoshiki Kuse, Yuki Inoue, Anri Nishinaka, Shinsuke Nakamura, Masamitsu Shimazawa, and Hideaki Hara (Dec. 2018). Exposure to Excessive Blue LED Light Damages Retinal Pigment Epithelium and Photoreceptors of Pigmented Mice. en. *Experimental Eye Research* [online]. 177, pp. 1–11. ISSN: 0014-4835. DOI: 10.1016/j.exer.2018.07.022. Available from: http://www.sciencedirect.com/science/article/pii/S0014483518304342 [Accessed Dec. 2, 2020].

Nakamura, Shuji (May 1995). InGaN/AlGaN Blue-light-emitting Diodes. *Journal of Vacuum Science & Technology A* [online]. 13 (3), pp. 705–710. ISSN: 0734-2101. DOI: 10.1116/1.579811. Available from: https://avs.scitation.org/doi/abs/10.1116/1.579811 [Accessed Feb. 10, 2021].

Niwano, Yoshimi, Taro Kanno, Atsuo Iwasawa, Masahiko Ayaki, and Kazuo Tsubota (July 2014). Blue Light Injures Corneal Epithelial Cells in the Mitotic Phase in Vitro. en. *British Journal of Ophthalmology* [online]. 98 (7), pp. 990–992. ISSN: 0007-1161, 1468-2079. DOI: 10.1136/bjophthalmol-2014-305205. Available from: https://bjo.bmj.com/content/98/7/990.2 [Accessed Dec. 2, 2020].

Opinium (Oct. 2018). *Brits Spend 90% of Their Time Indoors*. en-GB. Available from: https://www.opinium.com/brits-spend-90-of-their-time-indoors/ [Accessed Feb. 10, 2021].

Papagiannakopoulos, Thales, Matthew R. Bauer, Shawn M. Davidson, Megan Heimann, Lakshmipriya Subbaraj, Arjun Bhutkar, Jordan Bartlebaugh, Matthew G. Vander Heiden, and Tyler Jacks (Aug. 2016). Circadian Rhythm Disruption Promotes Lung Tumorigenesis. en. *Cell Metabolism* [online]. 24 (2), pp. 324–331. ISSN: 1550-4131. DOI: 10.1016/j.cmet.2016.07.001. Available from: https://www.sciencedirect.com/science/article/pii/S1550413116303126 [Accessed Mar. 15, 2021].

Pérez-Lombard, Luis, José Ortiz, and Christine Pout (Jan. 2008). A Review on Buildings Energy Consumption Information. en. *Energy and Buildings* [online]. 40 (3), pp. 394–398. ISSN: 0378-7788. DOI: 10.1016/j.enbuild.2007.03.007. Available from: https://www.sciencedirect.com/science/article/pii/S0378778807001016 [Accessed Feb. 11, 2021].

Phelan, Giana M. (2018). OLED Lighting Hits the Market. en. *Information Display* [online]. 34 (1), pp. 10–15. ISSN: 2637-496X. DOI: 10.1002/j.2637-496X.2018.tb01054.x. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/j.2637-496X.2018.tb01054.x [Accessed Feb. 10, 2021].

Prokopenko, Inga, Claudia Langenberg, Jose C. Florez, Richa Saxena, Nicole Soranzo, Gudmar Thorleifsson, Ruth J. F. Loos, Alisa K. Manning, Anne U. Jackson, Yurii Aulchenko, Simon C. Potter, Michael R. Erdos, Serena Sanna, Jouke-Jan Hottenga, Eleanor Wheeler, Marika Kaakinen, Valeriya Lyssenko, Wei-Min Chen, Kourosh Ahmadi, Jacques S. Beckmann, Richard N. Bergman, Murielle Bochud, Lori L. Bonnycastle, Thomas A. Buchanan, Antonio Cao, Alessandra Cervino, Lachlan Coin, Francis S. Collins, Laura Crisponi, Eco J. C. de Geus, Abbas Dehghan, Panos Deloukas, Alex S. F. Doney, Paul Elliott, Nelson Freimer, Vesela Gateva, Christian Herder, Albert Hofman, Thomas E. Hughes, Sarah Hunt, Thomas Illig, Michael Inouye, Bo Isomaa, Toby Johnson, Augustine Kong, Maria Krestyaninova, Johanna Kuusisto, Markku Laakso, Noha Lim, Ulf Lindblad, Cecilia M. Lindgren, Owen T. McCann, Karen L. Mohlke, Andrew D. Morris, Silvia Naitza, Marco Orrù, Colin N. A. Palmer, Anneli Pouta, Joshua Randall, Wolfgang Rathmann, Jouko Saramies, Paul Scheet, Laura J. Scott, Angelo Scuteri, Stephen Sharp, Eric Sijbrands, Jan H. Smit, Kijoung Song, Valgerdur Steinthorsdottir, Heather M. Stringham, Tiinamaija Tuomi, Jaakko Tuomilehto, André G. Uitterlinden, Benjamin F. Voight, Dawn Waterworth, H.-Erich Wichmann, Gonneke Willemsen, Jacqueline C. M. Witteman, Xin Yuan, Jing Hua Zhao, Eleftheria Zeggini, David Schlessinger, Manjinder Sandhu, Dorret I. Boomsma, Manuela Uda, Tim D. Spector, Brenda WJH Penninx, David Altshuler, Peter Vollenweider, Marjo Riitta Jarvelin, Edward Lakatta, Gerard Waeber, Caroline S. Fox, Leena Peltonen, Leif C. Groop, Vincent Mooser, L. Adrienne Cupples, Unnur Thorsteinsdottir, Michael Boehnke, Inês Barroso, Cornelia Van Duijn, Josée Dupuis, Richard M. Watanabe, Kari Stefansson, Mark I. McCarthy, Nicholas J. Wareham, James B. Meigs, and Gonçalo R. Abecasis (Jan. 2009). Variants in MTNR1B Influence Fasting Glucose Levels. en. *Nature Genetics* [online]. 41 (1), pp. 77–81. ISSN: 1546-1718. DOI: 10.1038/ng.290. Available from: https://www.nature.com/articles/ng.290 [Accessed Mar. 15, 2021].

Provencio, Ignacio, Guisen Jiang, Willem J. De Grip, William Pär Hayes, and Mark D. Rollag (Jan. 1998). Melanopsin: An Opsin in Melanophores, Brain, and Eye. en. *Proceedings of the National Academy of Sciences* [online]. 95 (1), pp. 340–345. ISSN: 0027-8424, 1091-6490. DOI: 10.1073/pnas.95.1.340. Available from: https://www.pnas.org/content/95/1/340 [Accessed Mar. 6, 2021].

Provencio, Ignacio, Ignacio R. Rodriguez, Guisen Jiang, William Pär Hayes, Ernesto F. Moreira, and Mark D. Rollag (Jan. 2000). A Novel Human Opsin in the Inner Retina. en. *The Journal of Neuroscience* [online]. 20 (2), pp. 600–605. ISSN: 0270-6474, 1529-2401. DOI: 10.1523/JNEUROSCI.20-02-00600.2000. Available from: http://www.jneurosci.org/lookup/doi/10.1523/JNEUROSCI.20-02-00600.2000 [Accessed Nov. 26, 2020].

Reiter, Russel J. (Aug. 1991). Melatonin: The Chemical Expression of Darkness. en. *Molecular and Cellular Endocrinology* [online]. 79 (1), pp. C153–C158. ISSN: 0303-7207. DOI: 10.1016/0303-7207(91)90087-9. Available from: https://www.sciencedirect.com/science/article/pii/0303720791900879 [Accessed Mar. 6, 2021].

Roenneberg, Till, Karla V. Allebrandt, Martha Merrow, and Céline Vetter (May 2012). Social Jetlag and Obesity. English. *Current Biology* [online]. 22 (10), pp. 939–943. ISSN: 0960-9822. DOI: 10.1016/j.cub.2012.03.038. Available from: https://www.cell.com/current-biology/abstract/S0960-9822(12)00325-9 [Accessed Mar. 15, 2021].

Sanchez-Barcelo, E.J., M.D. Mediavilla, D.X. Tan, and R.J. Reiter (July 2010). Clinical Uses of Melatonin: Evaluation of Human Trials. *Current Medicinal Chemistry* [online]. 17 (19), pp. 2070–2095. DOI: 10.2174/092986710791233689.

Schweitzer, S., C. Schinagl, G. Djuras, M. Frühwirth, H. Hoschopf, F. Wagner, B. Schulz, W. Nemitz, V. Grote, S. Reidl, P. Pritz, M. Moser, and F. P. Wenzl (Sept. 2016). "Investigation of Gender- and Age-Related Preferences of Men and Women Regarding Lighting Conditions for Activation and Relaxation". In: *Fifteenth International Conference on Solid State Lighting and LED-Based Illumination Systems*. Vol. 9954. International Society for Optics and Photonics, p. 99540L. DOI: 10.1117/12.2237897. Available from: https://www.spiedigitallibrary.org/conference-proceedings-of-spie/9954/99540L/Investigation-of-gender--and-age-related-preferences-of-men/10.1117/12.2237897.short [Accessed Mar. 18, 2021].

Siffre, Michel (1964). *Beyond Time*. London: Chatto and Windus.

Sit, Dorothy, Katherine L. Wisner, Barbara H. Hanusa, Stacy Stull, and Michael Terman (2007). Light Therapy for Bipolar Disorder: A Case Series in Women. en. *Bipolar Disorders* [online]. 9 (8), pp. 918–927. ISSN: 1399-5618. DOI: 10.1111/j.1399-5618.2007.00451.x. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1399-5618.2007.00451.x [Accessed Mar. 18, 2021].

Sit, Dorothy K., James McGowan, Christopher Wiltrout, Rasim Somer Diler, John (Jesse) Dills, James Luther, Amy Yang, Jody D. Ciolino, Howard Seltman, Stephen R. Wisniewski, Michael Terman, and Katherine L. Wisner (Oct. 2017). Adjunctive Bright Light Therapy for Bipolar Depression: A Randomized Double-Blind Placebo-Controlled Trial.

American Journal of Psychiatry [online]. 175 (2), pp. 131–139. ISSN: 0002-953X. DOI: 10.1176/appi.ajp.2017.16101200. Available from: https://ajp.psychiatryonline.org/doi/full/10.1176/appi.ajp.2017.16101200 [Accessed Mar. 18, 2021].

Stephan, Friedrich K. and Irving Zucker (June 1972). Circadian Rhythms in Drinking Behavior and Locomotor Activity of Rats Are Eliminated by Hypothalamic Lesions. en. *Proceedings of the National Academy of Sciences* [online]. 69 (6), pp. 1583–1586. ISSN: 0027-8424, 1091-6490. DOI: 10.1073/pnas.69.6.1583. Available from: https://www.pnas.org/content/69/6/1583 [Accessed Feb. 27, 2021].

Stevens, Richard G. (Aug. 2009). Light-at-Night, Circadian Disruption and Breast Cancer: Assessment of Existing Evidence. en. *International Journal of Epidemiology* [online]. 38 (4), pp. 963–970. ISSN: 0300-5771. DOI: 10.1093/ije/dyp178. Available from: https://academic.oup.com/ije/article/38/4/963/851153 [Accessed Dec. 2, 2020].

Stevens, Richard G., George C. Brainard, David E. Blask, Steven W. Lockley, and Mario E. Motta (2014). Breast Cancer and Circadian Disruption from Electric Lighting in the Modern World. en. *CA: A Cancer Journal for Clinicians* [online]. 64 (3), pp. 207–218. ISSN: 1542-4863. DOI: 10.3322/caac.21218. Available from: https://acsjournals.onlinelibrary.wiley.com/doi/abs/10.3322/caac.21218 [Accessed Dec. 2, 2020].

Terakita, Akihisa (Mar. 2005). The Opsins. en. *Genome Biology* [online]. 6 (3), p. 213. ISSN: 1474-760X. DOI: 10.1186/gb-2005-6-3-213. Available from: https://doi.org/10.1186/gb-2005-6-3-213 [Accessed Mar. 6, 2021].

Thapan, Kavita, Josephine Arendt, and Debra J. Skene (2001). An Action Spectrum for Melatonin Suppression: Evidence for a Novel Non-Rod, Non-Cone Photoreceptor System in Humans. en. *The Journal of Physiology* [online]. 535 (1), pp. 261–267. ISSN: 1469-7793. DOI: 10.1111/j.1469-7793.2001.t01-1-00261.x. Available from: https://physoc.onlinelibrary.wiley.com/doi/abs/10.1111/j.1469-7793.2001.t01-1-00261.x [Accessed Nov. 30, 2020].

Tokumaru, Osamu, Kosuke Haruki, Kira Bacal, Tomomi Katagiri, Taisuke Yamamoto, and Yutaka Sakurai (May 2006). Incidence of Cancer Among Female Flight Attendants: A Meta-Analysis. en. *Journal of Travel Medicine* [online]. 13 (3), pp. 127–132. ISSN: 1195-1982. DOI: 10.1111/j.1708-8305.2006.00029.x. Available from: https://academic.oup.com/jtm/article/13/3/127/1816549 [Accessed Dec. 2, 2020].

Ueda, Toshihiko, Takako Nakanishi-Ueda, Hajime Yasuhara, Ryohei Koide, and William W. Dawson (Dec. 2009). Eye Damage Control by Reduced Blue Illumination. en. *Experimental Eye Research* [online]. 89 (6), pp. 863–868. ISSN: 0014-4835. DOI: 10.1016/j.exer.2009.07.018. Available from: http://www.sciencedirect.com/science/article/pii/S0014483509002206 [Accessed Dec. 2, 2020].

University of Chicago Photographic Archive (2021). *Kleitman, Nathaniel : Photographic Archive : The University of Chicago*. Available from: http://photoarchive.lib.uchicago.edu/db.xqy?one=apf1-03489.xml [Accessed Feb. 27, 2021].

Veitch, Jennifer A., Robert Gifford, and Donald W. Hine (Mar. 1991). Demand Characteristics and Full Spectrum Lighting Effects on Performance and Mood. en. *Journal of Environmental Psychology* [online]. 11 (1), pp. 87–95. ISSN: 0272-4944. DOI: 10.1016/S0272-4944(05)80007-6. Available from: https://www.sciencedirect.com/science/article/pii/S0272494405800076 [Accessed Mar. 18, 2021].

Von Aschoff, Jürgen and Rütger Wever (Aug. 1962). Spontanperiodik des Menschen bei Ausschluß aller Zeitgeber. de. *Naturwissenschaften* [online]. 49 (15), pp. 337–342. ISSN: 1432-1904. DOI: 10.1007/BF01185109. Available from: https://doi.org/10.1007/BF01185109 [Accessed Mar. 7, 2021].

Wan, S H, J Ham, D Lakens, J Weda, and R Cuppen (2012). The Influence of Lighting Color and Dynamics on Atmosphere Perception and Relaxation. en, p. 4.

Webb, Ann R. (July 2006). Considerations for Lighting in the Built Environment: Non-Visual Effects of Light. en. *Energy and Buildings* [online]. Special Issue on Daylighting Buildings. 38 (7), pp. 721–727. ISSN: 0378-7788. DOI: 10.1016/j.enbuild.2006.03.004. Available from: http://www.sciencedirect.com/science/article/pii/S0378778806000648 [Accessed Nov. 26, 2020].

Welsh, David K, Diomedes E Logothetis, Markus Meister, and Steven M Reppert (Apr. 1995). Individual Neurons Dissociated from Rat Suprachiasmatic Nucleus Express Independently Phased Circadian Firing Rhythms. en. *Neuron* [online]. 14 (4), pp. 697–706. ISSN: 0896-6273. DOI: 10.1016/0896-6273(95)90214-7. Available from: https://www.sciencedirect.com/science/article/pii/0896627395902147 [Accessed Feb. 27, 2021].

WHO (Sept. 2013). The Breast Cancer Conundrum. en. *Bulletin of the World Health Organization* [online]. 91 (9), pp. 626–627. ISSN: 0042-9686. DOI: 10.2471/BLT.13.020913. Available from: http://www.who.int/entity/bulletin/volumes/91/9/13-020913.pdf [Accessed Mar. 15, 2021].

Young, Allan H. (Dec. 2004). Cortisol in Mood Disorders. *Stress* [online]. 7 (4), pp. 205–208. ISSN: 1025-3890. DOI: 10.1080/10253890500069189. Available from: https://doi.org/10.1080/10253890500069189 [Accessed Mar. 18, 2021].

Zheludev, Nikolay (Apr. 2007). The Life and Times of the LED — a 100-Year History. en. *Nature Photonics* [online]. 1 (4), pp. 189–192. ISSN: 1749-4893. DOI: 10.1038/nphoton.2007.34. Available from: https://www.nature.com/articles/nphoton.2007.34 [Accessed Feb. 10, 2021].

Bibliography

Broadbent, Arthur D. (Jan. 2017). Colorimetry, Methods. en. In: *Encyclopedia of Spectroscopy and Spectrometry (Third Edition)*. Ed. by John C. Lindon, George E. Tranter, and David W. Koppenaal. Oxford: Academic Press, pp. 321–327. ISBN: 978-0-12-803224-4. DOI: 10.1016/B978-0-12-803224-4.00014-5. Available from: http://www.sciencedirect.com/science/article/pii/B9780128032244000145 [Accessed Nov. 9, 2020].

Cuttle, C (Feb. 2013). A New Direction for General Lighting Practice. en. *Lighting Research & Technology* [online]. 45 (1), pp. 22–39. ISSN: 1477-1535. DOI: 10.1177/1477153512469201. Available from: https://doi.org/10.1177/1477153512469201 [Accessed Nov. 30, 2020].

Davis, Scott, Dana K. Mirick, and Richard G. Stevens (Oct. 2001). Night Shift Work, Light at Night, and Risk of Breast Cancer. en. *JNCI: Journal of the National Cancer Institute* [online]. 93 (20), pp. 1557–1562. ISSN: 0027-8874. DOI: 10.1093/jnci/93.20.1557. Available from: https://academic.oup.com/jnci/article/93/20/1557/2519561 [Accessed Dec. 2, 2020].

UN-DESA (2016). The Sustainable Development Goals Report 2016. *UN* [online]. Available from: https://www.un-ilibrary.org/economic-and-social-development/the-sustainable-development-goals-report-2016_3405d09f-en.

f.lux Software LLC (2020). *F.Luxometer*. en. Available from: https://fluxometer.com/rainbow/ [Accessed Dec. 2, 2020].

Hansen, Johnni (Jan. 2001). Increased Breast Cancer Risk among Women Who Work Predominantly at Night. en-US. *Epidemiology* [online]. 12 (1), pp. 74–77. ISSN: 1044-3983. Available from: https://journals.lww.com/epidem/fulltext/2001/01000/increased_breast_cancer_risk_among_women_who_work.13.aspx [Accessed Dec. 2, 2020].

Hastings, Michael and Elizabeth S. Maywood (2000). Circadian Clocks in the Mammalian Brain. en. *BioEssays* [online]. 22 (1), pp. 23–31. ISSN: 1521-1878. DOI: 10.1002/(SICI)1521-1878(200001)22:1<23::AID-BIES6>3.0.CO;2-Z. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/%28SICI%291521-1878%28200001%2922%3A1%3C23%3A%3AAID-BIES6%3E3.0.CO%3B2-Z [Accessed Feb. 27, 2021].

Hawes, Breanne K., Tad T. Brunyé, Caroline R. Mahoney, John M. Sullivan, and Christian D. Aall (Jan. 2012). Effects of Four Workplace Lighting Technologies on Perception, Cognition and Affective State. en. *International Journal of Industrial Ergonomics* [online]. 42 (1), pp. 122–128. ISSN: 0169-8141. DOI: 10.1016/j.ergon.2011.09.004. Available from: http://www.sciencedirect.com/science/article/pii/S0169814111001193 [Accessed Dec. 2, 2020].

Husse, Jana, Gregor Eichele, and Henrik Oster (2015). Synchronization of the Mammalian Circadian Timing System: Light Can Control Peripheral Clocks Independently of the SCN Clock. en. *BioEssays* [online]. 37 (10), pp. 1119–1128. ISSN: 1521-1878. DOI: 10.1002/bies.201500026. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/bies.201500026 [Accessed Feb. 27, 2021].

Lehrl, S., K. Gerstmeyer, J. H. Jacob, H. Frieling, A. W. Henkel, R. Meyrer, J. Wiltfang, J. Kornhuber, and S. Bleich (Apr. 2007). Blue Light Improves Cognitive Performance. en. *Journal of Neural Transmission* [online]. 114 (4), pp. 457–460. ISSN: 1435-1463. DOI: 10.1007/s00702-006-0621-4. Available from: https://link.springer.com/article/10.1007/s00702-006-0621-4 [Accessed Dec. 2, 2020].

Lewy, A. J., T. A. Wehr, F. K. Goodwin, D. A. Newsome, and S. P. Markey (Dec. 1980). Light Suppresses Melatonin Secretion in Humans. en. *Science* [online]. 210 (4475), pp. 1267–1269. ISSN: 0036-8075, 1095-9203. DOI: 10.1126/science.7434030. Available from: https://science.sciencemag.org/content/210/4475/1267 [Accessed Nov. 9, 2020].

Lie, Jenny-Anne S., Jolanta Roessink, and Kristina Kjærheim (Feb. 2006). Breast Cancer and Night Work among Norwegian Nurses. en. *Cancer Causes & Control* [online]. 17 (1), pp. 39–44. ISSN: 1573-7225. DOI: 10.1007/s10552-005-3639-2. Available from: https://doi.org/10.1007/s10552-005-3639-2 [Accessed Dec. 2, 2020].

Lockley, Steven W., Erin E. Evans, Frank A.J.L. Scheer, George C. Brainard, Charles A. Czeisler, and Daniel Aeschbach (Feb. 2006). Short-Wavelength Sensitivity for the Direct Effects of Light on Alertness, Vigilance, and the Waking Electroencephalogram in Humans. *Sleep* [online]. 29 (2), pp. 161–168. ISSN: 0161-8105. DOI: 10.1093/sleep/29.2.161. Available from: https://doi.org/10.1093/sleep/29.2.161 [Accessed Mar. 7, 2021].

Martin, Jeanne Sophie, Marc Hébert, Élise Ledoux, Michaël Gaudreault, and Luc Laberge (Apr. 2012). Relationship of Chronotype to Sleep, Light Exposure, and Work-Related Fatigue in Student Workers. *Chronobiology International* [online]. 29 (3), pp. 295–304. ISSN: 0742-0528. DOI: 10.3109/07420528.2011.653656. Available from: https://doi.org/10.3109/07420528.2011.653656 [Accessed Nov. 23, 2020].

McCloughan, C L B, P.A. Aspinall, and R.S. Webb (Jan. 1999). The Impact of Lighting on Mood. en. *Lighting Research and Technology* [online]. 31 (3), pp. 81–88. ISSN: 1477-1535. DOI: 10.1177/096032719903100302. Available from: http://lrt.sagepub.com/cgi/doi/10.1177/096032719903100302 [Accessed Dec. 2, 2020].

Mhatre, M. C., P. N. Shah, and H. S. Juneja (June 1984). Effect of Varying Photoperiods on Mammary Morphology, DNA Synthesis, and Hormone Profile in Female Rats. eng. *Journal of the National Cancer Institute*. 72 (6), pp. 1411–1416. ISSN: 0027-8874.

Mills, Peter R., Susannah C. Tomkins, and Luc JM Schlangen (Jan. 2007). The Effect of High Correlated Colour Temperature Office Lighting on Employee Wellbeing and Work Performance. en. *Journal of Circadian Rhythms* [online]. 5 (1), p. 2. ISSN: 1740-3391. DOI: 10.1186/1740-3391-5-2. Available from: https://doi.org/10.1186/1740-3391-5-2 [Accessed Dec. 2, 2020].

Mohawk, Jennifer A., Carla B. Green, and Joseph S. Takahashi (2012). Central and Peripheral Circadian Clocks in Mammals. *Annual Review of Neuroscience* [online]. 35 (1), pp. 445–462. DOI: 10.1146/annurev-neuro-060909-153128. Available from: https://doi.org/10.1146/annurev-neuro-060909-153128 [Accessed Nov. 30, 2020].

O'Leary, Erin S., Elinor R. Schoenfeld, Richard G. Stevens, Geoffrey C. Kabat, Kevin Henderson, Roger Grimson, Marilie D. Gammon, and M. Cristina Leske (Aug. 2006). Shift Work, Light at Night, and Breast Cancer on Long Island, New York. en. *American Journal of Epidemiology* [online]. 164 (4), pp. 358–366. ISSN: 1476-6256, 0002-9262. DOI: 10.1093/aje/kwj211. Available from: http://academic.oup.com/aje/article/164/4/358/84124/Shift-Work-Light-at-Night-and-Breast-Cancer-on [Accessed Dec. 2, 2020].

Otálora, B. B., J. A. Madrid, N. Alvarez, V. Vicente, and M. A. Rol (2008). Effects of Exogenous Melatonin and Circadian Synchronization on Tumor Progression in Melanoma-Bearing C57BL6 Mice. en. *Journal of Pineal Research* [online]. 44 (3), pp. 307–315. ISSN: 1600-079X. DOI: 10.1111/j.1600-079X.2007.00531.x. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1600-079X.2007.00531.x [Accessed Dec. 2, 2020].

Owen, J. and Josephine Arendt (Mar. 1992). Melatonin Suppression in Human Subjects by Bright and Dim Light in Antarctica: Time and Season-Dependent Effects. en. *Neuroscience Letters* [online]. 137 (2), pp. 181–184. ISSN: 0304-3940. DOI: 10.1016/0304-3940(92)90399-R. Available from: https://www.sciencedirect.com/science/article/pii/030439409290399R [Accessed Mar. 7, 2021].

Parma, Mikulas, Petr Baxant, and Jan Skoda (2015). "Comparison of Spectral Power Distribution of Various Light Sources in Correlation to Human Circadian System". en. In: *Proceedings of the 21st International Conference LIGHT SVĚTLO 2015*. Brno, Czech republic: Fakulta elektrotechniky a komunikacnich technologii VUT v Brne, pp. 25–28. ISBN: 978-80-214-5244-2. DOI: 10.13164/conf.light.2015.25. Available from: http://hdl.handle.net/11012/51628 [Accessed Dec. 2, 2020].

Richards, Jacob and Michelle L. Gumz (2012). Advances in Understanding the Peripheral Circadian Clocks. en. *The FASEB Journal* [online]. 26 (9), pp. 3602–3613. ISSN: 1530-6860. DOI: 10.1096/fj.12-203554. Available from: https://faseb.onlinelibrary.wiley.com/doi/abs/10.1096/fj.12-203554 [Accessed Nov. 30, 2020].

Schernhammer, Eva S., Candyce H. Kroenke, Francine Laden, and Susan E. Hankinson (Jan. 2006). Night Work and Risk of Breast Cancer. en-US. *Epidemiology* [online]. 17 (1), pp. 108–111. ISSN: 1044-3983. DOI: 10.1097/01.ede.0000190539.03500.c1. Available from: https://journals.lww.com/epidem/FullText/2006/01000/Night_Work_and_Risk_of_Breast_Cancer.19.aspx [Accessed Dec. 2, 2020].

Schernhammer, Eva S., Francine Laden, Frank E. Speizer, Walter C. Willett, David J. Hunter, Ichiro Kawachi, and Graham A. Colditz (Oct. 2001). Rotating Night Shifts and Risk of Breast Cancer in Women Participating in the Nurses' Health Study. en. *JNCI: Journal of the National Cancer Institute* [online]. 93 (20), pp. 1563–1568. ISSN: 0027-8874. DOI:

10.1093/jnci/93.20.1563. Available from: https://academic.oup.com/jnci/article/93/20/1563/2519563 [Accessed Dec. 2, 2020].

Schweitzer, Marc, Laura Gilpin, and Susan Frampton (2004). Healing Spaces: Elements of Environmental Design That Make an Impact on Health. eng. *Journal of Alternative and Complementary Medicine (New York, N.Y.)* [online]. 10 Suppl 1, S71–83. ISSN: 1075-5535. DOI: 10.1089/1075553042245953.

Senthilnathan, Samithamby and Kanthasamy Sathiyasegar (Aug. 2019). *Circadian Rhythm and Its Importance in Human Life*. en. SSRN Scholarly Paper ID 3441495. Rochester, NY: Social Science Research Network. DOI: 10.2139/ssrn.3441495. Available from: https://papers.ssrn.com/abstract=3441495 [Accessed Dec. 3, 2020].

Sun-Young, Lee (2005). An Experiment on Lighting Environment for some Behavior in Housing. kor. *Journal of the Korean housing association* [online]. 16 (4), pp. 65–71. ISSN: 2234-3571. Available from: https://www.koreascience.or.kr/article/JAKO200504840631548.page [Accessed Dec. 2, 2020].

The Sustainable Development Goals Report 2016.Pdf (2020). Available from: https://unstats.un.org/sdgs/report/2016/The%20Sustainable%20Development%20Goals%20Report%202016.pdf [Accessed Dec. 3, 2020].

van den Heiligenberg, Simone, Petra Deprés-Brummer, Hervé Barbason, Bruno Claustrat, Michel Reynes, and Francis Lévi (May 1999). The Tumor Promoting Effect of Constant Light Exposure on Diethylnitrosamine-Induced Hepatocarcinogenesis in Rats. en. *Life Sciences* [online]. 64 (26), pp. 2523–2534. ISSN: 00243205. DOI: 10.1016/S0024-3205(99)00210-6. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0024320599002106 [Accessed Dec. 2, 2020].

Vandewalle, Gilles, Simon N. Archer, Catherine Wuillaume, Evelyne Balteau, Christian Degueldre, André Luxen, Derk-Jan Dijk, and Pierre Maquet (June 2011). Effects of Light on Cognitive Brain Responses Depend on Circadian Phase and Sleep Homeostasis. en. *Journal of Biological Rhythms* [online]. 26 (3), pp. 249–259. ISSN: 0748-7304. DOI: 10.1177/0748730411401736. Available from: https://doi.org/10.1177/0748730411401736 [Accessed Dec. 2, 2020].

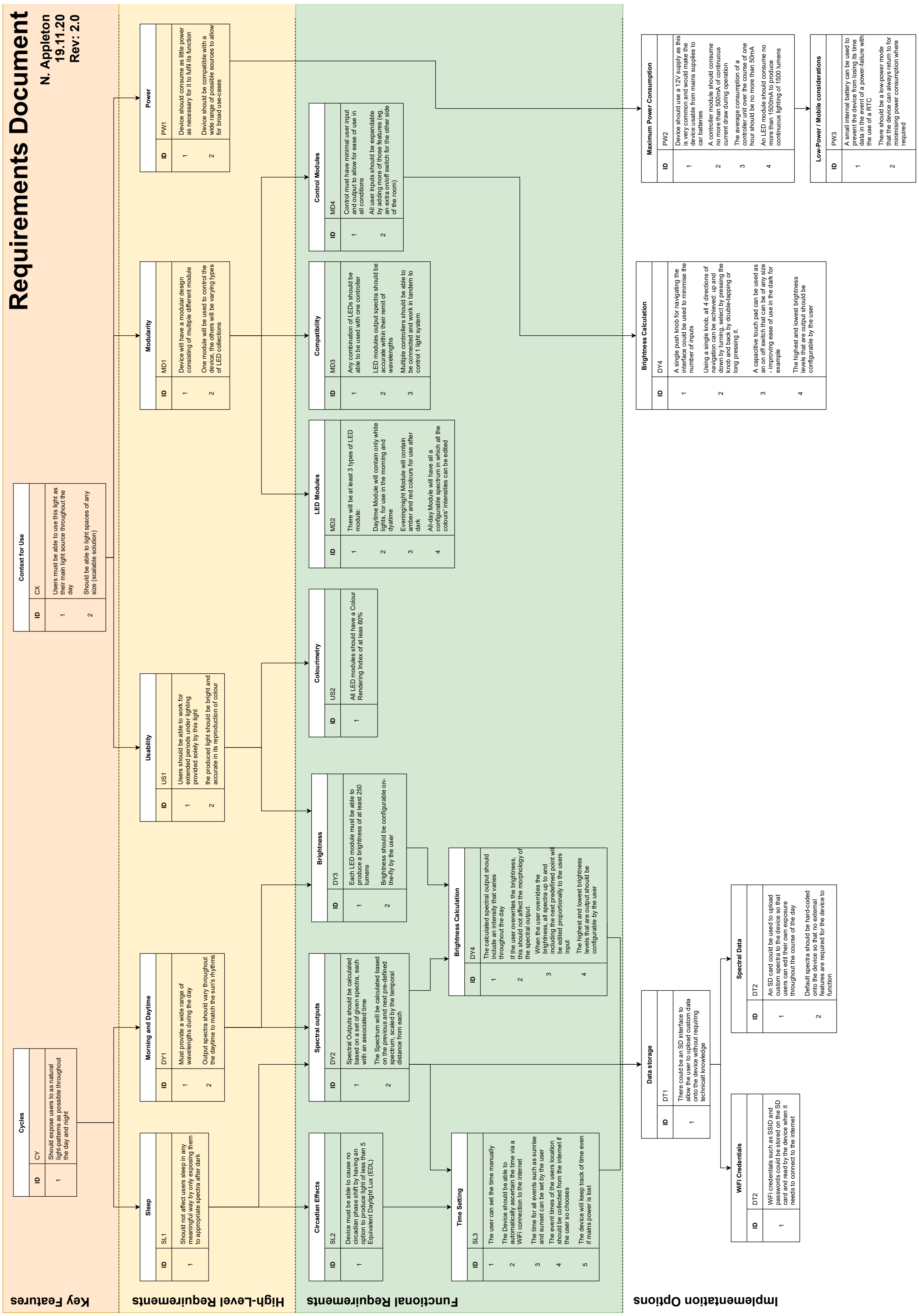
Wager-Smith, Karen and Steve A. Kay (Sept. 2000). Circadian Rhythm Genetics: From Flies to Mice to Humans. en. *Nature Genetics* [online]. 26 (1), pp. 23–27. ISSN: 1546-1718. DOI: 10.1038/79134. Available from: https://www.nature.com/articles/ng0900_23 [Accessed Feb. 27, 2021].

Zeitzer, Jamie M., Derk-Jan Dijk, Richard E. Kronauer, Emery N. Brown, and Charles A. Czeisler (2000). Sensitivity of the Human Circadian Pacemaker to Nocturnal Light: Melatonin Phase Resetting and Suppression. en. *The Journal of Physiology* [online]. 526 (3), pp. 695–702. ISSN: 1469-7793. DOI: 10.1111/j.1469-7793.2000.00695.x. Available from: https://physoc.onlinelibrary.wiley.com/doi/abs/10.1111/j.1469-7793.2000.00695.x [Accessed Mar. 7, 2021].

Appendix A

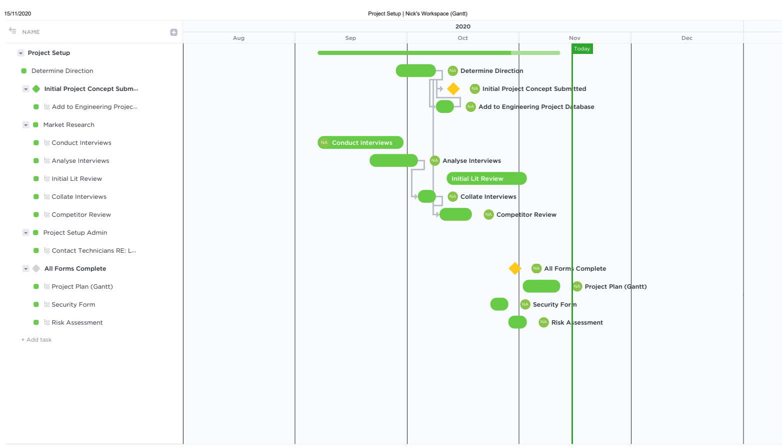
Documents

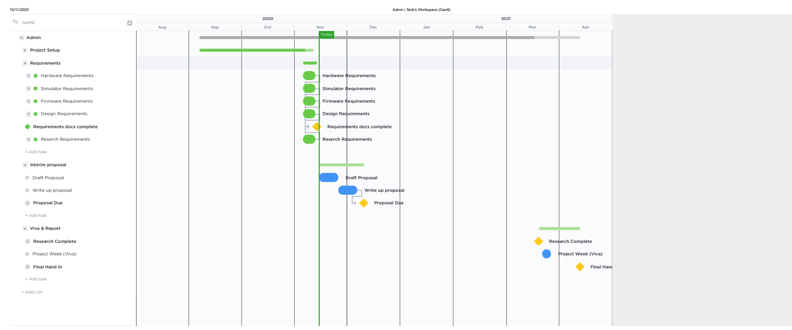
A.1. Device Requirements

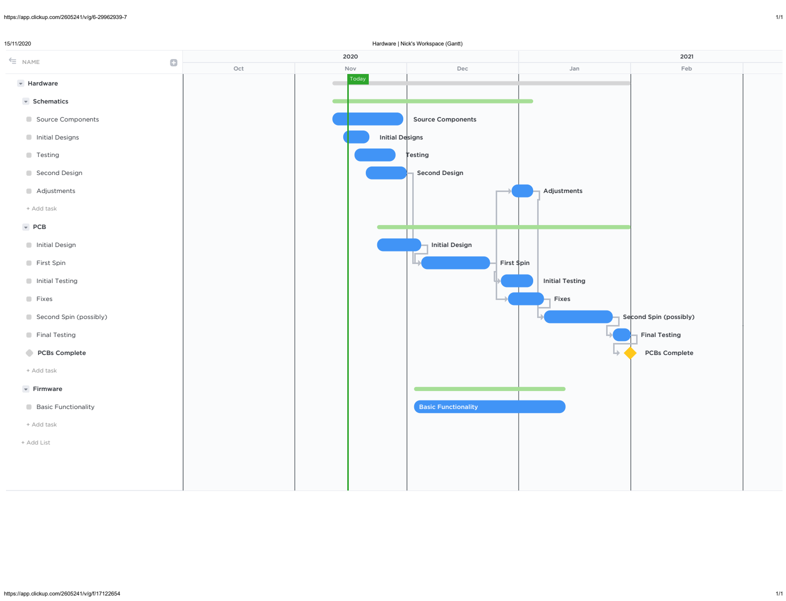


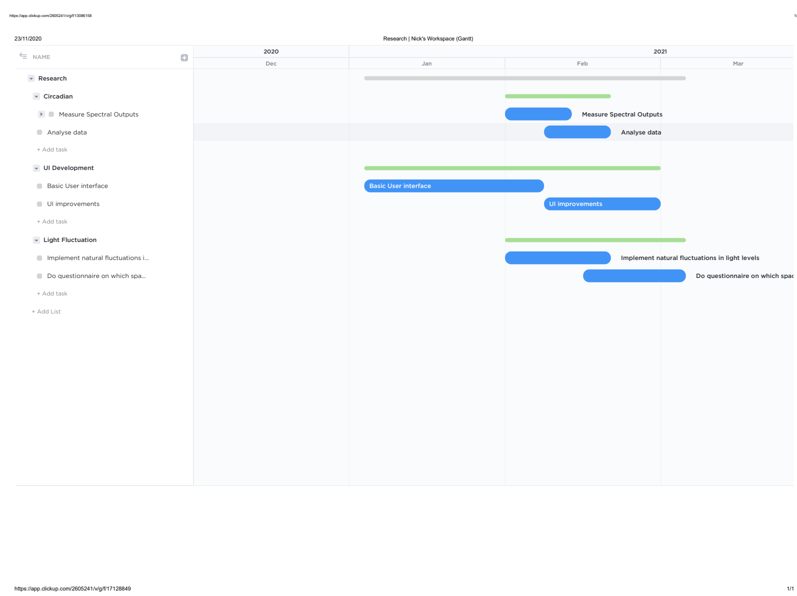
A.2. Gantt Charts

A.2.1. Nov 15^{th} 2020 (initial)

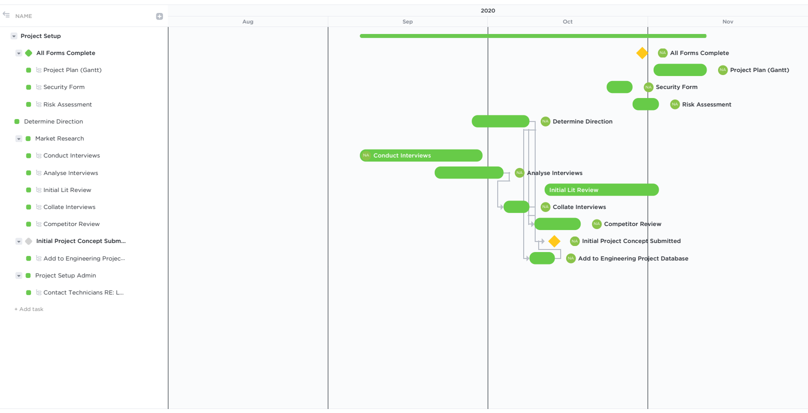


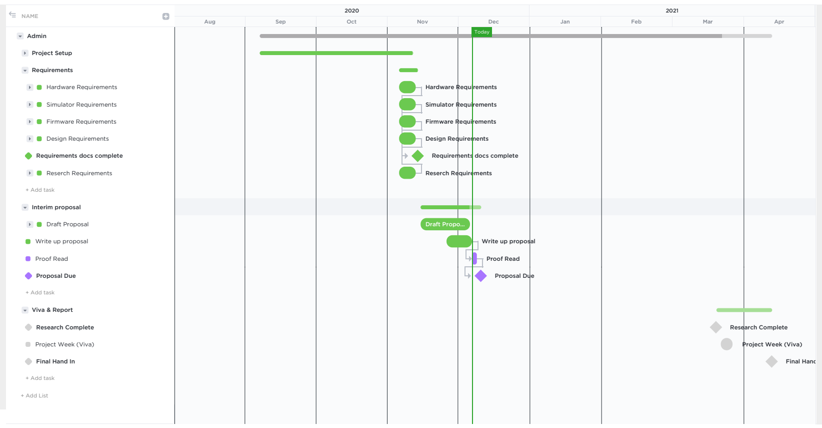


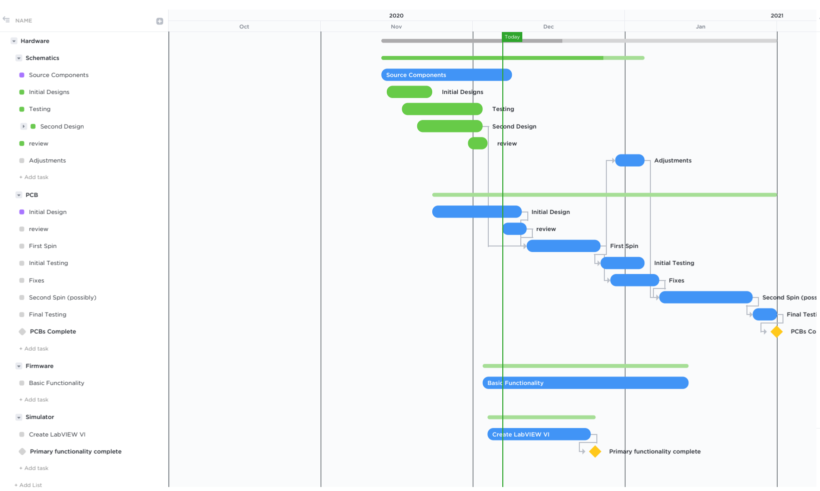


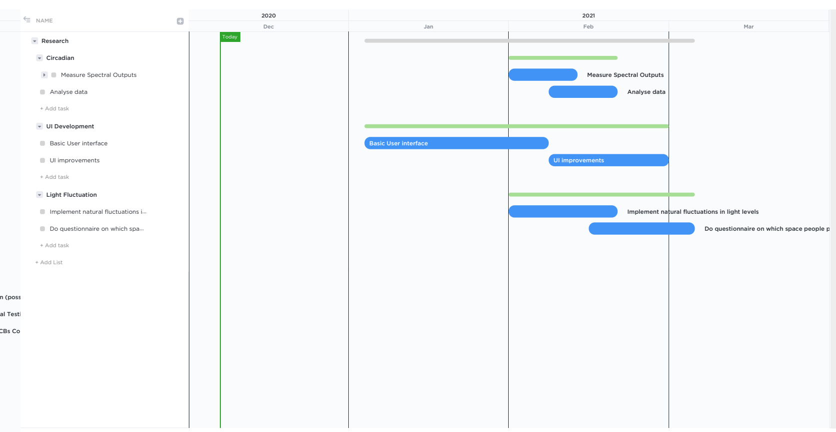


A.2.2. Dec 12th 2020

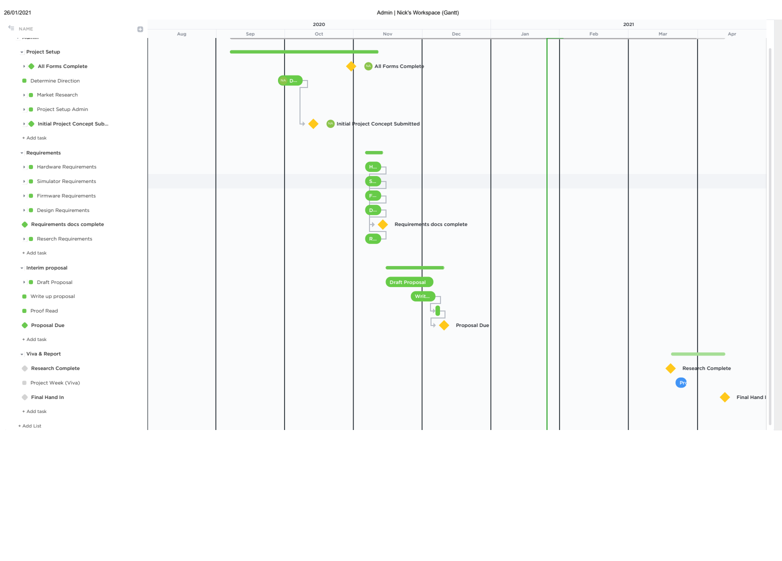


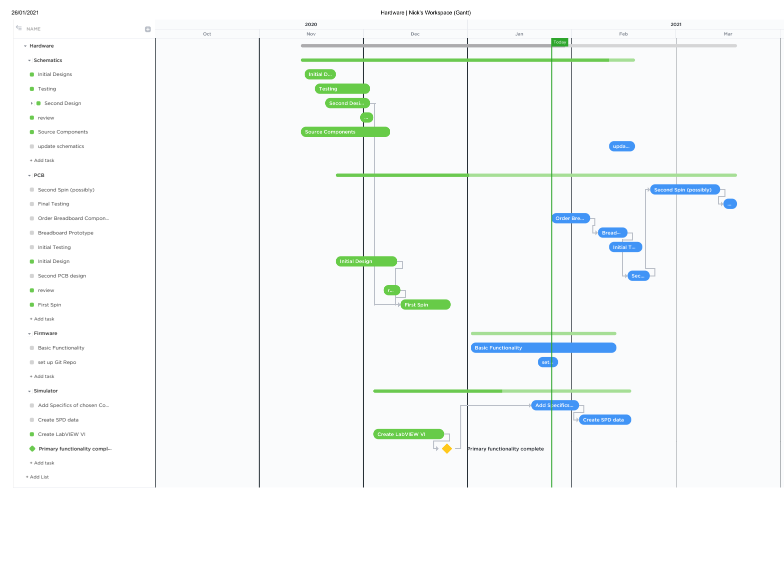


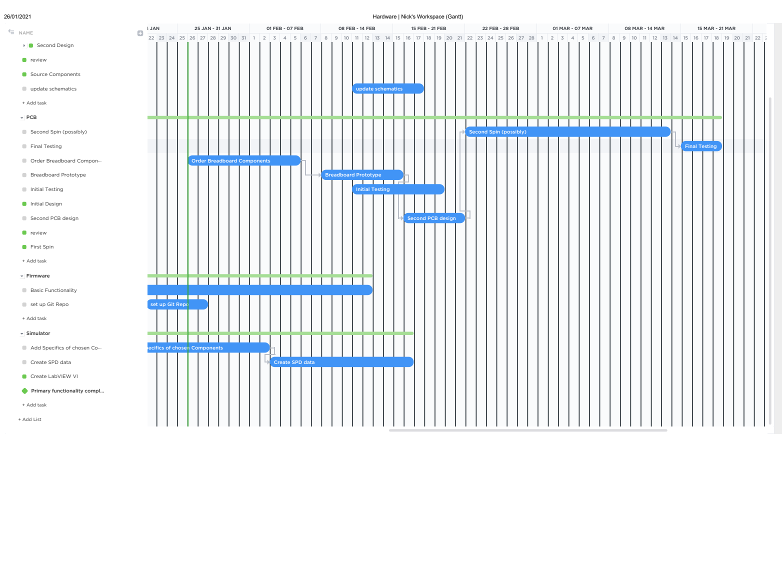


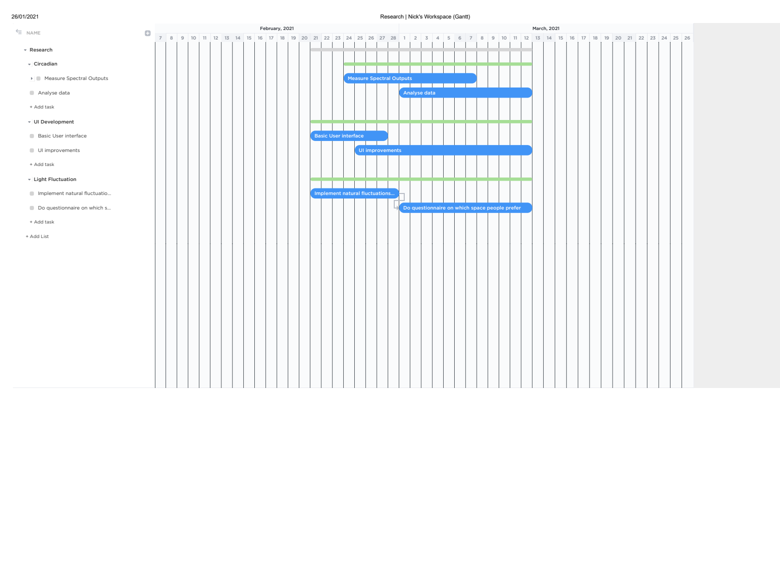


A.2.3. Jan 26^{th} 2021

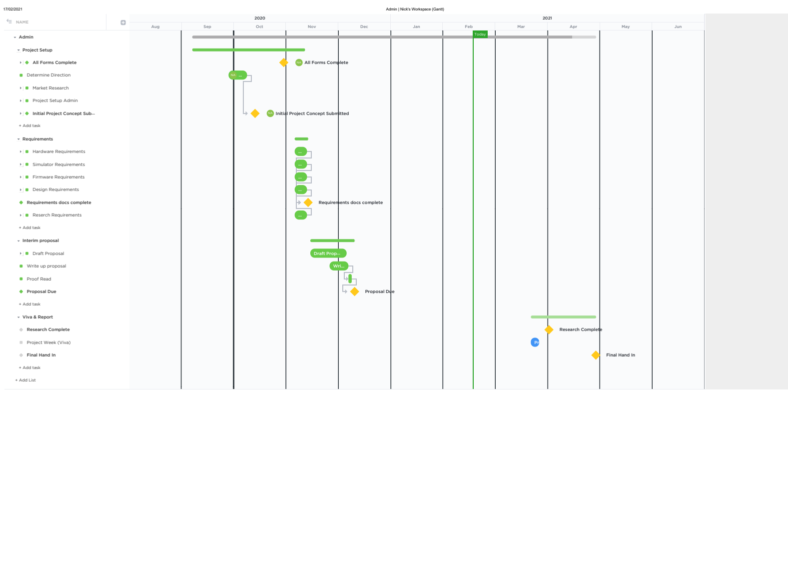


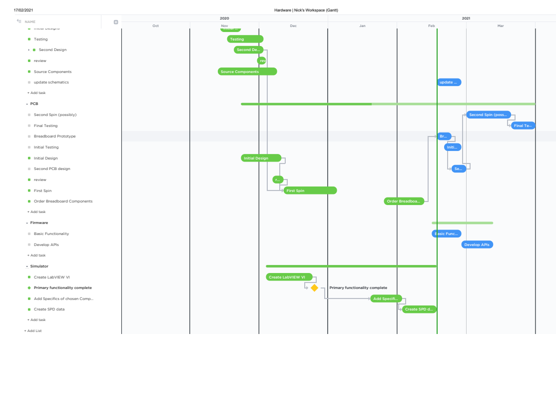


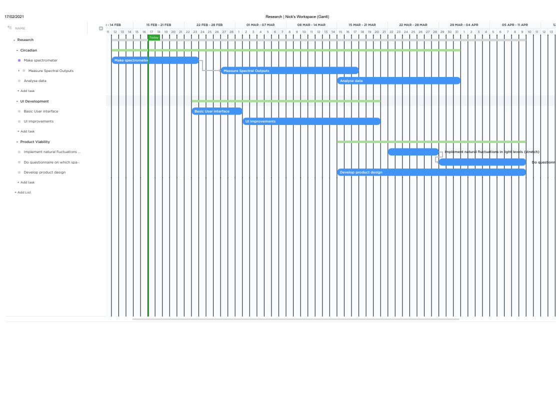




A.2.4. Feb 17^{th} 2021

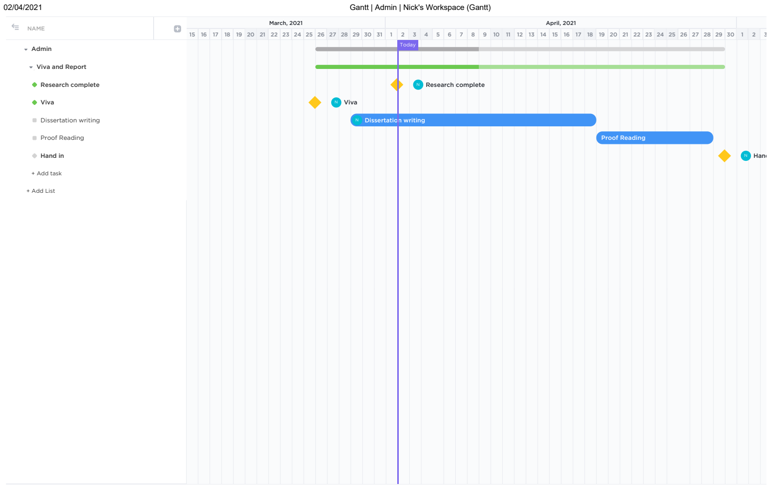






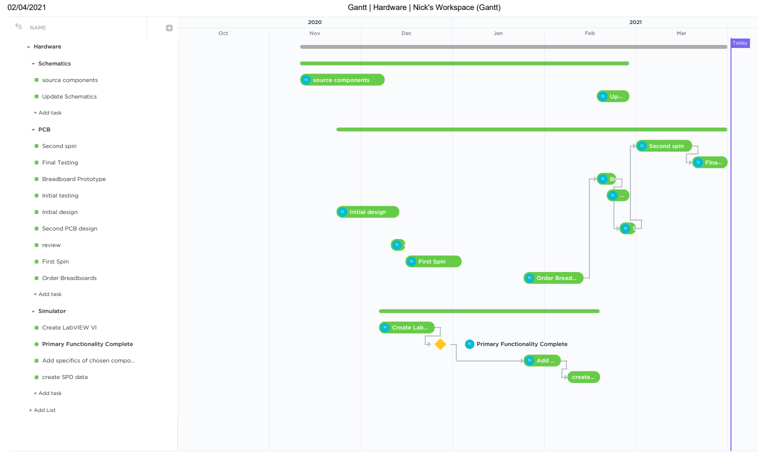
A.2.5. Apr 2^{nd} 2021

02/04/2021 Gantt | Admin | Nick's Workspace (Gantt)



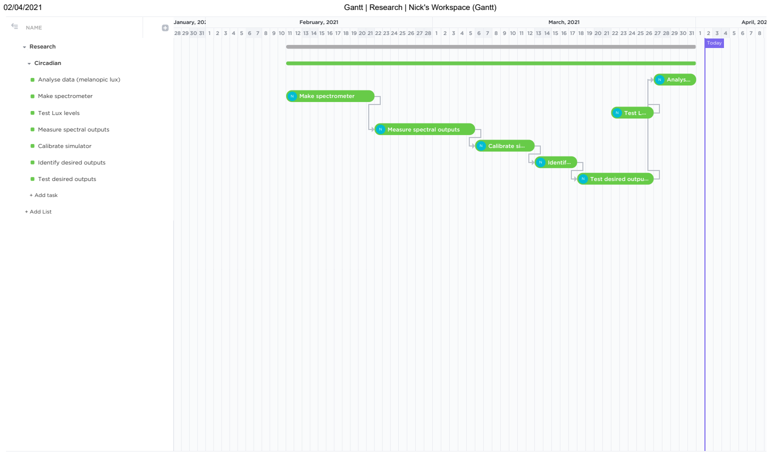
https://app.clickup.com/4713725/v/g/4fv7x-15?pr=8846896 1/1

02/04/2021 Gantt | Hardware | Nick's Workspace (Gantt)



https://app.clickup.com/4713725/v/g/4fv7x-22 1/1

02/04/2021 Gantt | Research | Nick's Workspace (Gantt)



https://app.clickup.com/4713725/v/g/4fv7x-29 1/1

A.3. Risk Assessment

University of the West of England BRISTOL

GENERAL RISK ASSESSMENT FORM

Without exception

Describe the activity being assessed: Producing a natural-cycle based lighting system	**Assessed by:** Matthew Studley	**Endorsed by:**
Who might be harmed: Nick Appleton (NA) **How many exposed to risk:** 1	**Date of Assessment:** **02/04/21**	**Review date(s):**

Hazards Identified ***(state the potential harm)***	**Existing Control Measures**	**S**	**L**	**Risk Level**	**Additional Control Measures**	**S**	**L**	**Risk Level**	**By whom and by when**	**Date completed**
Potential use of Lab equipment	Existing risk assessment including mitigations	3	2	6	Keeping a clean workspace and ensuring that equipment is used properly and switched off when not in use	3	1	3	NA - consistently	Ongoing
Covid-19 Risk from face-to-face meetings	Government and University rules and guidance	3	3	9	Conducting all meetings online without exception	3	1	3	NA – Every meeting	Ongoing
Soldering: very high temperature, hand-held iron		2	3	6	Make sure to store the iron in the holder when it is not being used. Minimise the number of sessions spent soldering, while not allowing any rushing to occur.	2	2	4	NA – all soldering	Ongoing
High-power electronics pose an electrocution risk		4	2	8	Whenever handling electronics, wearing a grounding bracelet connected to an anti-static mat and earthing point to discharge any potentially harmful electrical surges. Testing the device with lower power inputs.	2	1	2	NA – whenever handling electronics	Ongoing
Isolation from working from home and related stress		3	3	6	Implement stress-relief measures and ensure that overworking doesn't occur by time-boxing various tasks and implementing effective project-management strategies. Seeing peers (when the covid restrictions allow).	2	1	2	NA – Always under evaluation	Ongoing