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

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Designing a modular, human-centric lighting system
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(main text only)

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Disclaimer:

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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 two main aims had been completed.

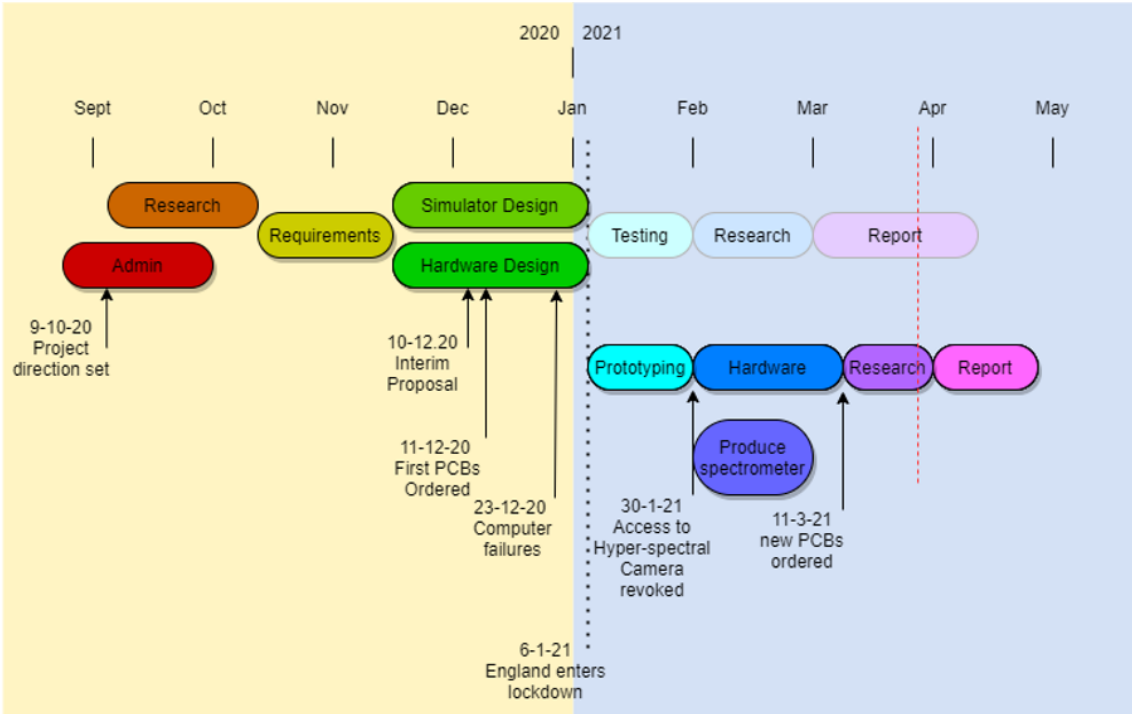


Figure 1.1: *How the lockdown in England affected the objectives of the project. Reasons for the changes are discussed later in the document.*

1.2.2. Objectives

The objectives used to achieve the aims have been 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 began 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 front-loading 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 arose.

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 large role in delivery of the project, and are discussed further in chapter 4.

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 4).

Chapter 2

Existing Work

2.1. Lighting

2.1.1. Introduction

Many people do not realise how much time they spend in unnatural 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 World's 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 lit after dark were used for cooking and as a social space (J. a. J. Gowlett, 2016).

This was until 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 Temperature (CCT) values could be achieved. A Compact Fluorescent Lamp (CFL) could directly replace an incandescent bulb using the same fitting.

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 is 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 are banned from being sold in the EU because they are so inefficient (EU, 2012). However, this does not mean they are all bad, they actually have many benefits: firstly, they produce light much more similar to firelight than modern lighting; they are also not hazardous, something 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 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 visible 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).

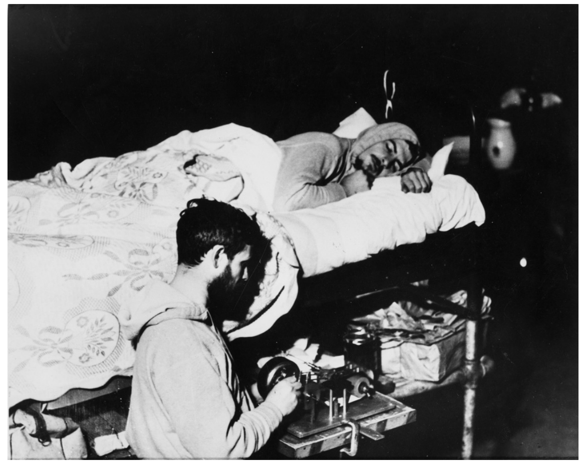


Figure 2.1: *Nathaniel Kleitman (foreground), donning an impressive beard, measures the sleep of Bruce Richardson (University of Chicago Photographic Archive, 2021).*

2.2. Circadian Rhythms

2.2.1. What is the Circadian Rhythm?

In 1729, the French scientist 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 (internal) 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 corrupt 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, ie. to keep them synchronised with the 24 hour day. 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 stimulus, or 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, concluding 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, X. 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).

[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).

An opsin is a light-sensitive protein that exists 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 Cells (ipRGC) (Berson, Dunn, and Takao, 2002), the signals from which are what keeps the SCN entrained, but to not contribute to conscious 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 ipRGC, blue light causes a 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), thereby dramatically affecting sleep.

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 has also been observed in many studies that flight attendants are 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 correlates to when it is taken, lead-

[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).

ing 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 winter 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 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). The meta-analysis also highlighted the importance of dawn simulation, which performed better than 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 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).

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 perceive 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

"Light affects our sleep more powerfully than any drug"

(Charles A. Czeisler, 2013)

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 them. 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. 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 an inconvenience to wear 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 going to sleep.

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 appropriate for home installation. Furthermore, as they are designed for business environments, many of these solutions do not account for later evening light 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 become 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.

Chapter 3

Methods

There were 4 major phases to the project: idea generation, project setup, development and research. Each of these phases was approached in a different way in acknowledgement of the differences of each.

3.1. Idea Generation

Phase I of the project was the time in which to identify a problem that could be addressed.

The initial idea was a running aid for use by natural movement specialists. Qualitative techniques were used to identify whether this would be an applicable solution to the lack of training aids for natural-running coaches. Interviews were conducted between February and September 2020 and many world renowned athletes and trainers were consulted. These interviews were semi-structured and took approximately 45 minutes to complete over video call, and were recorded for later processing, anonymisation and interpretation. Consent forms were signed by each participant confirming that they had read the information sheet provided and understood how to withdraw their data. Copies of these can be found in Appendix A.6.

The outcome of this process was that the industry being investigated was not in need of such a device to aid running coaching. The interviews did, however, highlight that almost all of the participants believed that some form of natural-lighting system would be beneficial for their clients and others.

Once the direction had been fixed towards the natural-lighting system, the analysis of the current state of the market was undertaken. The results of this informed what the aims and objectives of the project would be, and a summary of the findings can be found in chapter 2.7.

3.2. Project Setup

Once the direction of the project had been identified and confirmed as suitable, the groundwork began to create a solid foundation that the rest of the project could be built upon.

The risk assessment, security form, resources form and requirements document were all completed during this phase (See appendix A) to ensure that the project could be undertaken safely, securely, and with an effective and sustainable use of resources. The initial project plan was also compiled to give structure to the two semesters of work (Appendix A.2.1). This initial plan was drafted with the knowledge that it would change over the course of the project in the monthly reviews. Laying out an achievable but optimistic plan ensured that the project hit the ground running and began in the most effective way.

Before development began, the requirements documentation was drafted. This took place in a meeting between the two hardware developers and 45 functional and non-functional requirements were determined. This 3 page document was then adjusted to create a hierarchical structure to aid the ease of understanding and allowing sub-requirements to visually link to multiple parents. The final version of this document can be found in Appendix A.1. This allowed the requirements to be split into Key Features, High-Level Requirements, Functional Requirements and Implementation Options.

This phase was also used to identify the equipment that would be required to take measurements of the device, including gaining access to a hyper-spectral camera that could be used to record the output spectra. Meetings took place with Professor Darren Reynolds to arrange how access could be given. Meetings also took place to determine how the collaboration with V. Halenka would proceed; the physical design of the device would be split, but further usage and development of software was to be left to each researcher individually.

3.3. Development

This is the phase in which the device was actually produced. The tools required to capture the data that would be used to assess the results of the project were developed.

The approach employed during this phase was a results-driven, de-risk oriented approach to ensure that problems were handled quickly and effectively wherever they arose. This meant that from early in this phase, the ability to create data for the purposes of the study could occur, in one form or another.

Chapter 4 discusses in detail the process and outcomes of this section of the project, including technical content relating to the development of the device and test equipment.

3.4. Research

During the final phase of the project, the results were gathered using the methods discussed below. The simulator was calibrated using measurements from the spectrometer to ensure that the graphs that it output were close to the true spectral output of the device. This meant the spectra that would emulate the solar output could be created in software, saving the time that would need to be used to implement them on hardware and measure the outputs.

The spectral data needed to be extracted from the spectrometer images before it could be used. For this, the Tracker Physics software was used, in which a line profile could be drawn across the spectrum to determine the relative power of each point. However, the software required the calibration function to be manually loaded into each image to be extracted.

To streamline this process, another LabVIEW program was created, based on code generated from National Instrument's Vision Assistant. This allowed dozens of images to be converted in seconds once the calibration had been done in Tracker Physics. The code for this can be viewed in Appendix C.2. This code extracts the RGB channels from the image at a given height. The average value is then calculated for each pixel across the line and saved. An image of the resulting spectrum is also output.

3.4.1. Methodology

The research was undertaken with quantitative techniques ins such a way that numerate analysis could be done on the data. This allowed for concrete analysis of many of the aims and requirements, employing a logical approach to the assessment of the success of the project.

By collecting quantitative data, the device can easily be compared to other devices within the same field; this way, the results of this study can be immediately put into the context of the real world.

3.4.2. Data Collection

Four spectra were created and assessed: Daytime (DY), Sunset (ST), Twilight (TW), Night (NX). These spectra were created using the LabVIEW simulator to calculate the LED values required to produce them. They were then implemented on the device and measured again with the spectrometer to ensure accuracy.

The simulator was then used to create Spectral Power Density (SPD) graphs that were analogous to the physical outputs, and could be binned at any wavelength increment. Only the visual spectrum was considered, due to limitations in the measuring equipment.

A lux meter was then calibrated using a known source (a 230 lumen LED bulb) and used to calculate the luminous flux of the device which could then be expressed in $\mu W cm^{-2} nm^{-1}$, the standard units for luminous flux used when comparing lighting spectra.

Reference datasets were gathered from fluxometer.com (f.lux Software LLC, 2020) for the solar irradiance spectrum throughout the day, as well as a firelight spectrum for the night, and a sample of standard lights for comparison of results. f.luxometer was chosen as it carries a wide range of open-source spectra including many solar spectra. The curators of this data ensure that it is of high quality, and all their work is backed up by a large body of research (found at fluxometer.com).

3.4.3. Methods of Analysis

After the spectra had been normalised, they could then be compared using Matlab where the Spectral Angle Mapper (SAM) was used to determine the similarity of each spectrum to its respective reference spectrum suing a spectral angle error metric (Kruse et al., 1993). This was repeated for the other lights, so that comparisons could be drawn as to how effective the device is at mimicking the solar irradiance spectrum. The SAM is given by:

$$cos^{-1}\left(\frac{\sum_{i=1}^{nb} t_i r_i}{\left(\sum_{i=1}^{nb} t_i^2\right)^{1/2}\left(\sum_{i=1}^{nb} r_i^2\right)^{1/2}}\right) \tag{3.1}$$

where: t =test spectrum, r =reference spectrum, nb =number of bands

While this is used to compare the similarity between two given spectra, it was developed to identify component elements of materials using their hyper-spectral properties. This may mean that it is not well suited to smooth and broad spectra, such as the solar spectra being studied here. However, this is the most appropriate way to compare the morphologies of the results, though the numbers should be used only to supplement the other findings.

The Colour Rendering Index (CRI) was also tested using the standard techniques (C. Li et al., 2012). This is the ability for the light to correctly illuminate colours; a low CRI means that colours illuminated by this light would

Photoreceptor	Photopigment	Unit of Measure
Short-Wavelength (S) Cones	cyanolabe	Cyanopic lux
Medium-Wavelength (M) Cones	chlorolabe	Chloropic lux
Long-Wavelength (L) Cones	erythrolabe	Erythropic lux
intrinsically photosensitive Retinal Ganglion Cells (ipRGC)	melanopsin	Melanopic lux
Rods	Rod Opsin	Rhodopic lux

Table 3.1: *5 Photometric measures that effect cause circadian and neurophysiological responses in humans (Lucas et al., 2014)*

not look accurate to their true colour. This analysis was also conducted on the comparison illuminants.

Photometric measures that effect the circadian rhythm were also examined, with the effects of the light on each of the 5 photopigments (listed in Table 3.1) being quantified as per the techniques laid out by Lucas et al. (2014). These responses correspond to how the light will affect the circadian rhythm and other neurophysiological effects on the users. Comparisons of the effects of standard lights and the produced device are drawn to understand whether this is an improvement on existing solutions.

These techniques were selected as they would answer the questions as to the relevant performance of the device as stated in the requirements document (Appendix A.1). The quantification of these factors has been approached in the ways most relevant and have scientific backing in the fact that they are broadly used in the literature.

3.5. Wider Impact

No engineering can be undertaken without it having a wider impact on the world around us. This project is no exception, but every care has been taken to ensure the ethical, environmental, and financial sustainability of this project. The project itself has been undertaken with the UN sustainable development goals in mind all the time (UN, 15 spet 2015). Goals 3 and 11 - good health and well-being and sustainable cities and communities are the two most relevant to this project as it is trying to bring affordable, health-promoting lighting technology to the built environment.

However, the device still requires production, and while lead has been avoided and the device is fully RoHS compliant, due to the nature of electronics, it is hard to recycle. This is not abnormal for lighting, however, and the modular design was used to reduce waste; modules can be replaced or upgraded independently of each other. This device is also designed to be long-lasting - hence the use of LEDs. These considerations were implemented to minimise the negative long-term effect of the device.

Larger scale manufacturing has not been considered in this project, but would incur a much larger environmental impact. The cost of the project was a limiting factor, and for manufacture, JLCPCB would likely not be used for PCBs. The prototypes that were made were air-freighted to ensure the limited time of the project could be adhered to (especially with the pandemic situation). This has much higher environmental consequences than if the PCBs had been shipped, or produced locally.

Chapter 4

Results

4.1. Device

The main physical output of this project has of course been the device itself, which has already gone through a few iterations just in this short year.

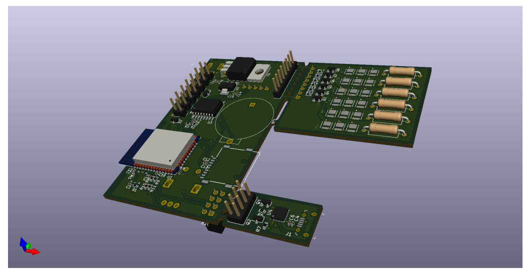


Figure 4.1: *3D render of the first set of PCBs created in KiCAD. Top right is the snappable LED module, the USB programmer is on the bottom right snappable daughter-board.*

4.1.1. Initial Designs

The schematic design for the device was done in KiCAD, an open-source electronics design software suite. This was chosen due to familiarity and the flexibility for adding components that are not built in. There are also extensive libraries, including a DigiKey library that adds many of the parts stocked by DigiKey for ease of design.

These designs were then laid out into prototype PCBs that were ordered through JLCPCB for economical production, including pick-and-place of the surface-mount components. These PCBs were designed with the USB and LED modules connected to the main board with mouse-bites, to allow for them to be snapped off after testing. This way the prototype board could be conveniently connected to all the required parts for testing, then could be snapped into its component parts for more accurate modelling of the final product. These snappable daughter boards could be reconnected to the main board via pin headers for each of the required connections, meaning they could be mounted directly back on to the main board, or connected via wires at a distance (in a more similar way to how the final product would function).

Unfortunately, due to England's national lockdown, this round of PCBs could not be retrieved and were returned to JLCPCB. This meant that alternative action had to be taken. Furthermore, due to the University's policy on soldering at home during the lockdown, they would not have been able to be completed either way.

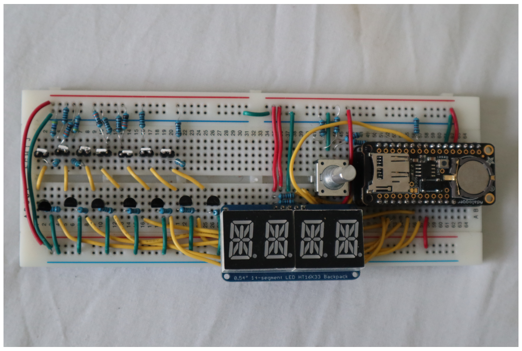


Figure 4.2: *The breadboard prototype used as a proxy for the real device.*

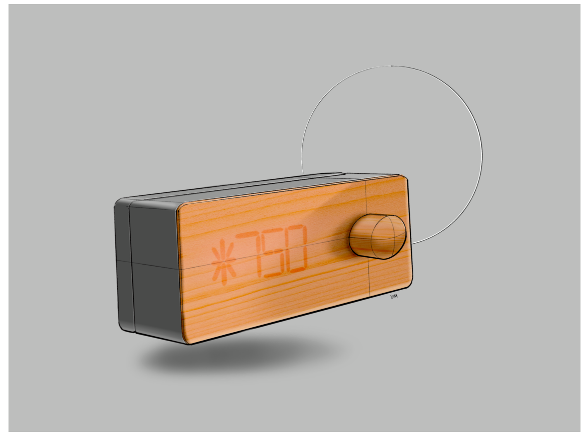


Figure 4.3: *The concept drawing of what the final controller module could look like, as imagined by a product designer.*

4.1.2. Breadboard

For this reason, an alternative approach was required. A solderless breadboard was acquired and breadboard-friendly components were ordered. A breadboard prototype was then produced from the original schematics, as shown in Figure 4.2.

An ESP32 board was required to ensure that the main function would be the same as the schematics. The Feather Huzzah32 from Adafruit was a board using the same programming chip (CP2104), as well as having the ESP32 and an optional "wing" that could add the PCF8523 Real Time Clock (RTC) and a micro-SD card slot, much the same as that on the schematic.

The same LEDs were used on the breadboard as were going to be used on the PCBs so that the outputs would be the same. The other components were kept as similar as possible, with all of the through-hole components remaining the same.

4.1.3. Firmware

The prototype was programmed in the Arduino language as many libraries were available that made reading the encoder, writing to the 14-segment display, and changing the brightness of the LEDs trivial.

4.1.4. Final Design

Once it had been confirmed that the breadboard prototype functioned fully and correctly, a new set of PCBs were ordered, this time with high confidence of them working.

The boards contained programming capabilities via a micro-usb, including auto-reset functionality for ease of programming. 2 levels of power regulation were included, the 12V that would be the main input and run the LEDs, as well as a 3.3V regulator to run all of the logic circuitry.

A physical reset button was added to ensure the device could be effectively tested and debugged easily. I2C was used to communicate with the RTC and the screen, and SPI was used to integrate the SD card.

All ICs were decoupled with a pair of capacitors, 1nF and 100nF to improve the transient response. All external ports were also protected by 15kV ESD diodes. Bulk capacitors were also used to ensure smooth power supply throughout the board, which itself had 4 layers: signal, ground, power, signal.

LEDs were controlled by low-side NPN transistors to decouple them from the logic circuitry. These were mounted on a separate 2-layer board with a large ground plane on both sides to aid thermal regulation.

Both the schematics and PCB layouts can be viewed in Appendix B.

A product designer was also employed to create a concept drawing for how the final controller device may look if it were developed into a real product. This is shown in Figure 4.3.

4.2. Simulator

Alongside the hardware development was the production of the simulator; created in LabVIEW, it was designed to approximate the spectral output of the device to be used to develop the spectra that would be implemented without having to have constant access to the measurement facilities. The LEDs' outputs were approximated using Gaussian and bell-shaped curves, generated in custom made sub-VIs. Sliders were used for simple LED adjustment and a button allows the user to save the current spectrum as a csv file for processing. The LabVIEW code for the simulator can be viewed in Appendix C.1.

The simulator was calibrated using actual measured spectral outputs from the device, with each LED output being individually tuned first, then all combinations of LEDs being assessed and validated to ensure the interactions between colours was correct. This ensured that the simulator functioned in the same way as the device in all possible scenarios.

4.3. Spectrometer

Measuring the actual device was also made significantly harder due to the lockdown. Access to the hyperspectral camera was revoked in line with the stay-at-home order. An alternative method for recording the spectra had to be found. Many potential solutions were discussed with machine vision specialists, but many of the proposed solutions were not-applicable as they could not capture the entire spectrum.

A spectrometer that could achieve full visible-spectrum range was produced which could be used to gather the spectral data from the device.

This spectrometer was based on a simple slit, that directed light towards a diffraction grating that split the light into its component colours which could be captured with a camera.

For the initial attempt, a box was used with a CD as a diffraction grating and mirror, reflecting the light towards the camera. However, the camera was mounted too far away and could not pick up good images of the spectrum.

The second attempt used a transmissive approach: the mirror-like layer of the CD was removed and the camera could be put directly against it. This time the box was too small, and

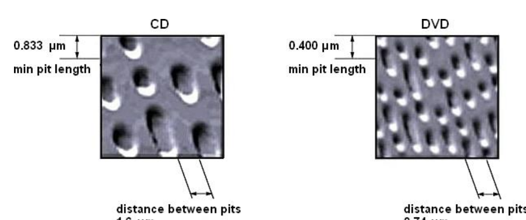
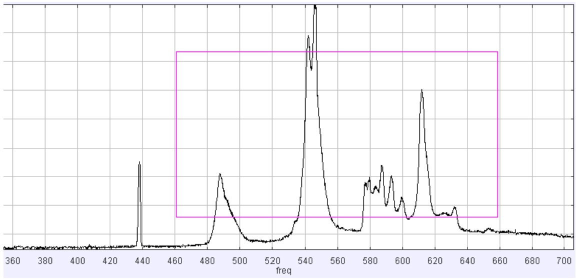
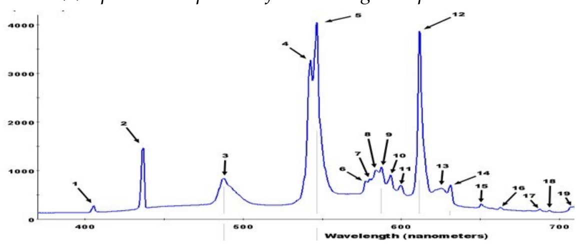


Figure 4.4: *Microscope images of a CD and DVD, the DVD has much smaller pits, equating it to a higher resolution diffraction grating (AVS-DiskCreator, 2019).*



(a) *Spectrum captured of CFL using the spectrometer*



(b) *Reference spectrum with labelled peaks (Padleckas, 2005)*

Figure 4.5: *Comparison of CFL spectra. The similarity, even down to the very small peaks (eg. peak 15) shows the impressive accuracy of the spectrometer.*

the slit could be seen in the frame of the image from the camera.

Finally for the third attempt - dubbed *Mk*.3 - a long tube was used as the body, so the camera could not see the slit. 2 Were produced: the reflective ($Mk.3_r$) and transmissive ($Mk.3_t$) models. The diffraction grating was replaced with a DVD to increase the number of lines per millimetre, increasing the detail in the resulting image (See Figure 4.4).

A Canon M50 DSLR camera with a 15-45mm lens was used to capture the images from the spectrometer.

4.4. Spectral Data

4.4.1. Spectrometer Validation

In order to calibrate the readings taken by the spectrometer, a known spectrum with multiple defined peaks must be captured. The peaks can then be labelled, and as the wavelength of each peak is known, a calibration curve can be defined. This equation is then used to scale the x-axis appropriately to show the corresponding wavelengths of all subsequent readings.

A Compact Fluorescent Lamp (CFL) was used for this process as the spectrum is clearly defined and contains many distinctive peaks. Figure 4.5 shows the comparison of the recorded CFL and a reference spectrum. This validates the accuracy of the spectrometer as these two spectra are remarkably similar. The process of extracting the spectrum from the image using the Tracker Physics software is shown in figure 4.6.

4.4.2. Comparing Spectra

After the spectrometer was validated, the real device data was collected as per the methods set out in chapter 3.

As shown in Table 4.1, the device consistently performs more closely to the given spectrum (with the exception of the NX condition due to the steepness of the curve of the device).

Figure D.1 (Appendix D.1), in which the spectra of the device, the reference spectrum,

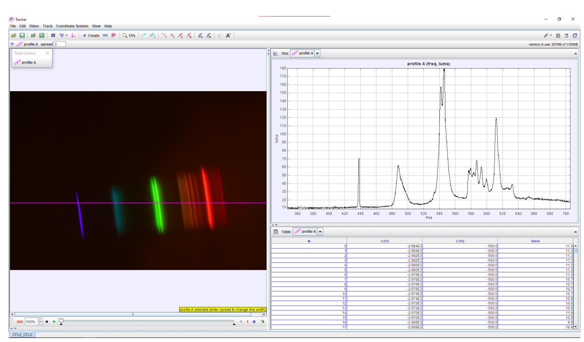


Figure 4.6: *The tracker Physics software being used to extract the spectrum (right) from the spectrometer image (left)*

	Device	HUE	CFL
Daytime (DY)	0.4954	0.6091	1.0192
Sunset (ST)	0.7967	1.0138	1.1108
Twilight (TW)	0.8226	0.9599	1.1108
Night (NX)	1.1688	1.0823	1.2047

Table 4.1: *The SAM values corresponding to the lights at different times of day*

and those of the Philips HUE and a regular LED are overlaid, backs up these findings. It can clearly be seen that the LED and Philips HUE contain many more frequencies not contained by the reference spectrum from the sun (or fire in the case of the NX condition). This is done in order to approximate the colour with the limited resources available, whereas the natural-lighting device approximates the colour through the approximation of the spectrum.

Figure 4.7 shows the 4 spectra on the same scale axes, with the y-scale reaching $5.93 \mu W cm^{-2} nm^{-1}$. The colour represents the Correlated Colour Temperature (CCT) which for the 4 conditions were 5197k, 2353k, 1107k and 606k respectively. The action spectrum of melatonin is also highlighted and the activation of melanopsin is overlaid on this.

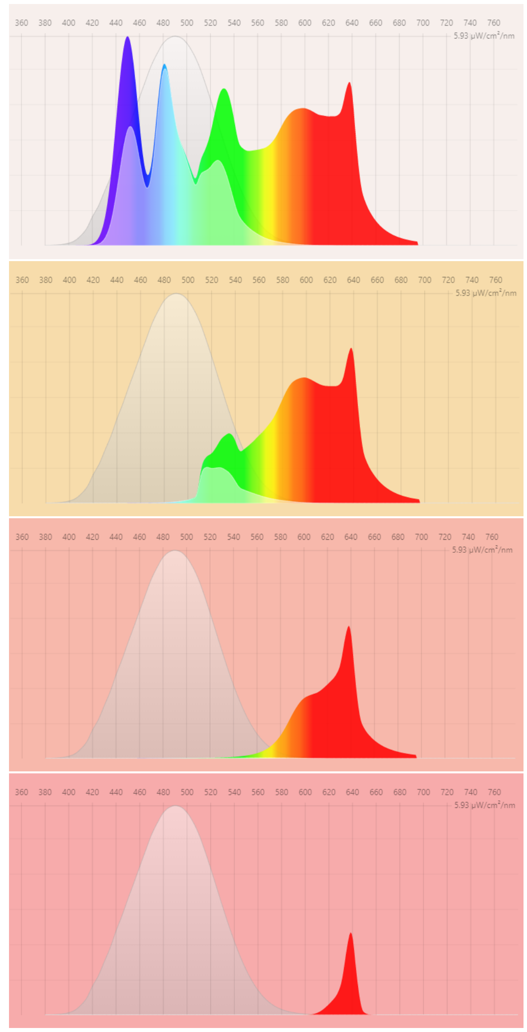


Figure 4.7: *The 4 spectra at real scale with the melanopsin action spectrum highlighted.*

4.4.3. Light Quality

In the DY condition, the CRI of the device was measured at 92.6 (out of 100) , which is considered artist quality, but obviously decreased through the other conditions: 66.8, 52.1 and 63.4 for ST, TW, NX respectively.

This high CRI shows the usefulness of this light for working during the day. Even artists and designers who need extremely accurate colour rendering would be able to use this light with faith that it is showing them the true colours.

The CFL and LED received scores of 83.9 and 63.9 respectively. This is because of the lack of certain wavelengths; when the light is reflected from a coloured surface, if that colour's wavelength is absent (eg. cyan in the LED), then the colour will look incorrect. The candle received a CRI of 94.3, despite containing very few short wavelengths. This is an interesting consideration for further study; how could this be achieved with an artificial light?

		Lux					
		Cyanopic	Chloropic	Erythropic	Melanopic	Rhodopic	Phase Shift
Device	DY	2060	2390	2390	2420	2390	2h38
	ST	7.83	1130	1510	347	612	2h23
	TW	1.58	228	494	14.8	45.8	14min
	NX	0	14.4	66.5	0.09	0.69	0min
Philips HUE	DY	1780	1710	1700	1460	1570	2h37
	ST	1390	1700	1790	1280	1460	2h36
	TW	1090	1350	1850	1120	1350	2h36
	NX	722	1500	1760	886	1130	2h35
Standard Bulbs	LED	78.1	94.9	97.3	81.0	87.3	1h25
	CFL	66.0	95.5	97.6	82.4	86.7	1h25
	Candle	0.98	2.95	4.15	1.57	1.93	0min

Table 4.2: *α-opic equivalent illuminance: how much each photo-pigment is activated by the light from the given sources.*

4.5. Circadian Effects

Table 4.2 shows how much each condition affects the circadian rhythm through the 5 photopigments in the eye. The melanopic lux is the most important factor of this calculation, followed by the cyanopic lux. The other photopigments have much smaller neurophysiological effects.

The last column of Table 4.2 shows the phase shift, which is how much one's circadian rhythm would shift when using this light, so a phase shift of 1h34 means, when using this light, your melatonin secretion is inhibited for 1h34 minutes after use.

From this table it can be seen that the device outperforms all of the other lamps that were tested. The produced device was brighter during the day than any of the other tested devices, but also had a smaller impact before sleep than anything but the candle (both had no effect), although the device, despite having no effect on sleep, was brighter than the candle in the chloropic and erythropic lux catagories, meaning it would be more effective at illuminating a space.

These results show that the device could be used in DY mode until no less than 2 hours and 40 minutes before sleep onset; ST mode can be used until 2 hours and 25 minutes before sleep. This shows that perhaps in order to prevent an excessively fast change in CCT, DY mode should transition to ST mode earlier, around 3 - 3.5 hours before sleep. 2.5 hours before sleep, TW mode should be initiated, which is appropriate up until the last 15 minutes before sleep onset, when NX mode can be employed. This will maximise the amount of the day spent in high CRI lighting, with a period for winding down (ST mode) before moving into the pre-sleep lighting, with TW mode. in this period, highly visual activities will become more difficult, but reading, puzzles, etc. will still be easily doable. Once NX mode is active, reading will still be possible, but many other activities will not, so this should be only used just before sleep (15 minutes).

Chapter 5

Discussion & Conclusions

Chapter 2.7 discussed different solutions that exist to the posed problem of human-centric lighting. How the results discussed in chapter 4 fit into this landscape is discussed below.

5.1. A Holistic Solution

One of the main drawbacks discussed in chapter 2.7 was the lack of broad-application lights that respect the human both visually and non-visually. Products such as the wake up lamps and Philips HUE exist and can are appropriate for certain times of day, but as shown in chapter 4, even when using Philips HUE bulbs with specialist software to create a night-friendly light, it causes a 2 and a half hour phase shift of the circadian rhythm.

This device was produced for around £30, plus a further £20 for the display. Considering the economies of scale, this could be significantly reduced. The review of existing solutions highlighted that one of the problems with the current market is the affordability - or lack thereof - of some of the more well developed products. The findings of this project show that a device that is capable of outperforming the high-end Philips HUE smart bulbs can be produced very cheaply. This contradicts the findings of the review, with its conspicuous lack of affordable devices. The exception to this is some of the wake up lights, but their lack of features and specificity of appropriate usage times undermine their effectiveness as a holistic solution.

A normal power cable connected to a 12V transformer (widely available) can be used to power this device, or any other 12V supply - providing the current doesn't exceed the rating of the source (the current drawn by the device depends on how many LEDs are being used). The use of LEDs has significantly reduced the power drawn by the device over traditional lighting methods, and the lifespan will be significantly increased. The modularity of the device further increases the lifespan and accessibility. As mentioned in chapter 2.1.3, LEDs can be 100% efficient if thermal regulation is adequate; the use of large ground planes on the device ensures the best thermal shedding possible which in turn will lead to reduced power consumption for the users. However, the efficiency of the LEDs was not directly tested.

5.2. Requirements Analysis

Of the nine functional requirements laid out in the requirements documentation, five have been successfully achieved, and the other four are still achievable if development of the device were to continue.

The Key Features are much harder to quantitatively assess, which is why they were broken down into the sub-requirement. As each of the high-level requirements can be considered met, it follows that so too can the Key Features.

Many of the implementation options were integrated into the design and even if they are not used, this allows for "future proofing" of any modifications and expansions that can be made in the future.

5.3. Effect of the Device

The effects of the device on sleep are briefly discussed in chapter 4.5. As mentioned there, the device is appropriate for daytime use until a few hours before bed, when an artificial sunset would occur, after which the device can be used up until sleep onset.

But there are more benefits of this than just sleep. The lowering of the CCT will aid evening relaxation of the users, as will the gentle red colour. This goes for the daytime too, when bright, daylight-style LEDs are preferred to induce a comfortable environment.

Alongside the night-time effects, how the device affects mornings should also be considered. The high brightness, especially seen in the Cyanopic and Melanopic ranges, indicate that the device would aid with generating a strong Cortisol Awakening Response (CAR).

This in turn would theoretically correlate to better performance throughout the day, as well as increasing well-being and mood. With this light following from a simulated dawn, the device could certainly help bipolar disorder, SAD and potentially type II diabetes.

Another interesting observation is the similarity of the response of the photoreceptors. The measured Chloropic, Erythropic and Rhodopic lux were all 2390, with the melanopic lux being a close 2420. This means that the experience of the light produced by the device will be very balanced. The Cyanopic lux was the only outlier, but as this photopigment can be more easily damaged by harmful blue light, this may be a benefit. Further study would need to take place on these effects.

5.4. Limitations of Results

While good insight has been given into the usefulness of the device for sleep and daytime use, the limitations of the methods used must also be considered.

For example, the use of the SAM for this application may not be fully appropriate. This technique is usually used for constituent element identification. However, there is no standard for comparing lighting spectra, hence why this technique was used.

Another limitation was that sleep was not directly measured, but due to the scope of this project, that would not have been feasible. The field of sleep research is vast, and the literature culminates at to the techniques used here to identify the activation of the 5 photopigments and calculating the neurophisiological effects they cause. Similarly, no study on the further consequences of using the light has been conducted, and the effects on mood and disease, although also backed by a lot of research, are speculative.

5.5. Other Expected Results

The further aims of the project, to develop the device as a product and gauge interest, would have been researched using qualitative and quantitative methods. These data would have been used to validate the existing research on mood and lighting, as well as lighting's effects on peoples' impressions of a space.

Unfortunately, this data was not able to be collected due to the pandemic situation. The hypothesis of this area was that the light would give a room a brighter, airy feel when in DY mode, but calming and relaxing in ST mode. This would have corroborated the findings of the papers outlined in chapter 2.5.

5.6. Evaluation

5.6.1. Project and Process

Over the course of the project, many difficulties have been faced, with the pandemic causing drastic changes to plans and schedules. From the outset, contingencies and buffers were leveraged to ensure that the main aims could be fulfilled despite unforeseen circumstances.

Due to the careful planning and execution of the project, with a strong focus on derisking, front-loading work and contingencies, the main aims of the project have been achieved.

From the beginning of the project, there has been a clear flow put in place to ensure that the required tasks get done. By effectively utilising project management techniques and software, the project has remained on course, despite the best efforts of the pandemic to derail it. Solutions to all the major problems that this year has posed were worked through and effective solutions were found. This was possible through communication with specialists, the weekly meetings that have been taking place and through thorough research of the problem and existing or alternative solutions.

Throughout the project, the ability to proactively seek solutions to problems that have arisen has improved. Now, at the end of the project, any problems that occur are confidently and swiftly dealt with.

The interaction with the logbook has also increased. Though at the beginning the logbook was being effectively used, towards the end the updating process of the logbook became a lot more habitual and more effective notes were taken on processes undertaken.

5.6.2. UK-SPEC

The Engineering Council's UK-SPEC is extremely important when considering one's professionalism as an engineer. This project has been designed from the start to reflect as many of the competencies of the UK-SPEC as possible.

A large portion of the project has been spent designing hardware, through the application of industry-learned knowledge into practical an physical outcomes. This covers competencies **A** and **B**.

The project has been independently run and, while collaboration has occurred on the design of the device, the project itself was self-led (competency **C**). Through meetings and other external communication, the project has been able to reach otherwise inaccessible equipment and knowledge, showing competence in section **D** of the UK-SPEC.

And finally, a personal commitment has been made to professionalism as an engineer, and the external consequences of undertaking this project. The scrutiny undertaken at the beginning of the project to ensure safe and secure working practices reflects this final competency.

For a full skills-matrix of how each competency has been achieved, see Appendix **??**.

The wider social impact of this project has been discussed, but it should be reiterated that this device is fundamentally designed to bring well-being to the built environment, while avoiding the existing problems of distributive justice that currently exist.

5.7. Further Research

Obviously while this project achieved what it set out to do, produce a low cost device that is appropriate for use at any time of day, there is much more that could be done to further this work. Development of the device into a more market-ready product as well as conducting research on the product-market fit and how consumers respond to the product. While this has begun, with product designers being consulted and concept are being produced, there is a lot more that could be done in this area.

Another area of further study could be furthering the technology itself. The current device, while small, portable, easy to use and low power, will not in itself cause a systemic change to how we approach lighting. If the device could be condensed into a much smaller package, a single IC for example, then designers and developers could use it to create many more solutions that are applicable to an even broader range of problems.

5.8. Conclusion

Through the course and completion of this project, not only has it been shown that a device that a device which is designed around the human responses to light can be produced cheaply, but much personal and professional development has occurred.

The project has leveraged many facets of professionalism and provided an opportunity to demonstrate effective working practices used to see through the successful completion of all the main aims.

Albeit a shame that the secondary aims could not be undertaken, the pandemic situation has meant that many problems have caused a multitude of changes to the plans of how the project would progress. Despite all of these difficulties, results were still gathered successfully and all the facets of the device that were planned to be quantified successfully were.

The tools used for the management of this project, from the Kanban-style AGILE approach to the use of the logbook have all provided their own benefits and learning points that can be taken into the future as a demonstration of good engineering practice. This is also true of the focus on the UK-SPEC and a lot of evidence has been gathered for the competencies therein.

On top of all of this, the project has been thoroughly enjoyable throughout, if stressful at times. All of the challenges presented, the work undertaken and research done have all been an opportunity for problem solving, learning, and growth.

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].

AVSDiskCreator (2019). *AVS4YOU >> AVS Disc Creator >> Introduction into Disc Types >> Optical Disc Structure*. Available from: https://onlinehelp.avs4you.com/AVS-Disc-Creator/Introduction/DiscStructure.aspx [Accessed Apr. 22, 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 Bio-*

logical 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].

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

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

Kruse, F. A., A. B. Lefkoff, J. W. Boardman, K. B. Heidebrecht, A. T. Shapiro, P. J. Barloon, and A. F. H. Goetz (May 1993). The Spectral Image Processing System (SIPS)—Interactive Visualization and Analysis of Imaging Spectrometer Data. en. *Remote Sensing of Environment* [online]. Airbone Imaging Spectrometry. 44 (2), pp. 145–163. ISSN: 0034-4257. DOI: 10.1016/0034-4257(93)90013-N. Available from: https://www.sciencedirect.com/science/article/pii/003442579390013N [Accessed Apr. 21, 2021].

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].

Li, Cheng, M. Ronnier Luo, Changjun Li, and Guihua Cui (2012). The CRI-CAM02UCS Colour Rendering Index. en. *Color Research & Application* [online]. 37 (3), pp. 160–167. ISSN: 1520-6378. DOI: 10.1002/col.20682. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/col.20682 [Accessed Apr. 21, 2021].

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].

Lucas, Robert J., Stuart N. Peirson, David M. Berson, Timothy M. Brown, Howard M. Cooper, Charles A. Czeisler, Mariana G. Figueiro, Paul D. Gamlin, Steven W. Lockley, John B. O'Hagan, Luke L. A. Price, Ignacio Provencio, Debra J. Skene, and George C. Brainard (Jan. 2014). Measuring and Using Light in the Melanopsin Age. en. *Trends in Neurosciences* [online]. 37 (1), pp. 1–9. ISSN: 0166-2236. DOI: 10.1016/j.tins.2013.10.004. Available from: https://www.sciencedirect.com/science/article/pii/S0166223613001975 [Accessed Apr. 21, 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. *En-*

ergy 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].

Padleckas, H (2005). File:Fluorescent Lighting Spectrum Peaks Labelled.Svg. en. *Wikipedia* [online]. Available from: https://en.wikipedia.org/wiki/File:Fluorescent_lighting_spectrum_peaks_labelled.svg [Accessed Apr. 22, 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].

UN (15 spet 2015). "Resolution Adopted by the General Assembly on 1 September 2015". In: *Transforming Our World: The 2030 Agenda for Sustainable Development*. Vol. 70. 1.

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.

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].

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].

Glossary

blue light Short wavelength, high-energy - usually below 550nm. 1, 8, 9, 10, 11, 12, 25

CAR Cortisol Awakening Response. 9, 25

CCT Correlated Colour Temperature. 5, 22, 23, 25

CFL Compact Fluorescent Lamp. 5, 21, 22

CRI Colour Rendering Index. 15, 22, 23

DY Daytime. 15, 22, 23, 26

ESD Electro-static Discharge. 19

IC Integrated Circuit. 19, 27

ipRGC intrinsically photosensitive Retinal Ganglion Cells. 8, 16

L Long-Wavelength. 16

luminous flux the perceived power of a light source, measured in lumen. 15, 45

lux the SI unit of illuminance, measured by luminous flux per unit area. Equivalent to $lumens/m^2$. 15

M Medium-Wavelength. 16

NX Night. 15, 21, 22, 23

PCBs Printed Circuit Boards. iii, 2, 16, 18, 19, 58

RTC Real Time Clock. 19

S Short-Wavelength. 16

SAD Seasonal Affective Disorder. 9, 10, 11, 25

SAM Spectral Angle Mapper. 15, 22, 25

solar irradiance spectrum the spectrum output by the sun as measured from the surface of the earth. 15, 68

SPD Spectral Power Density. 15

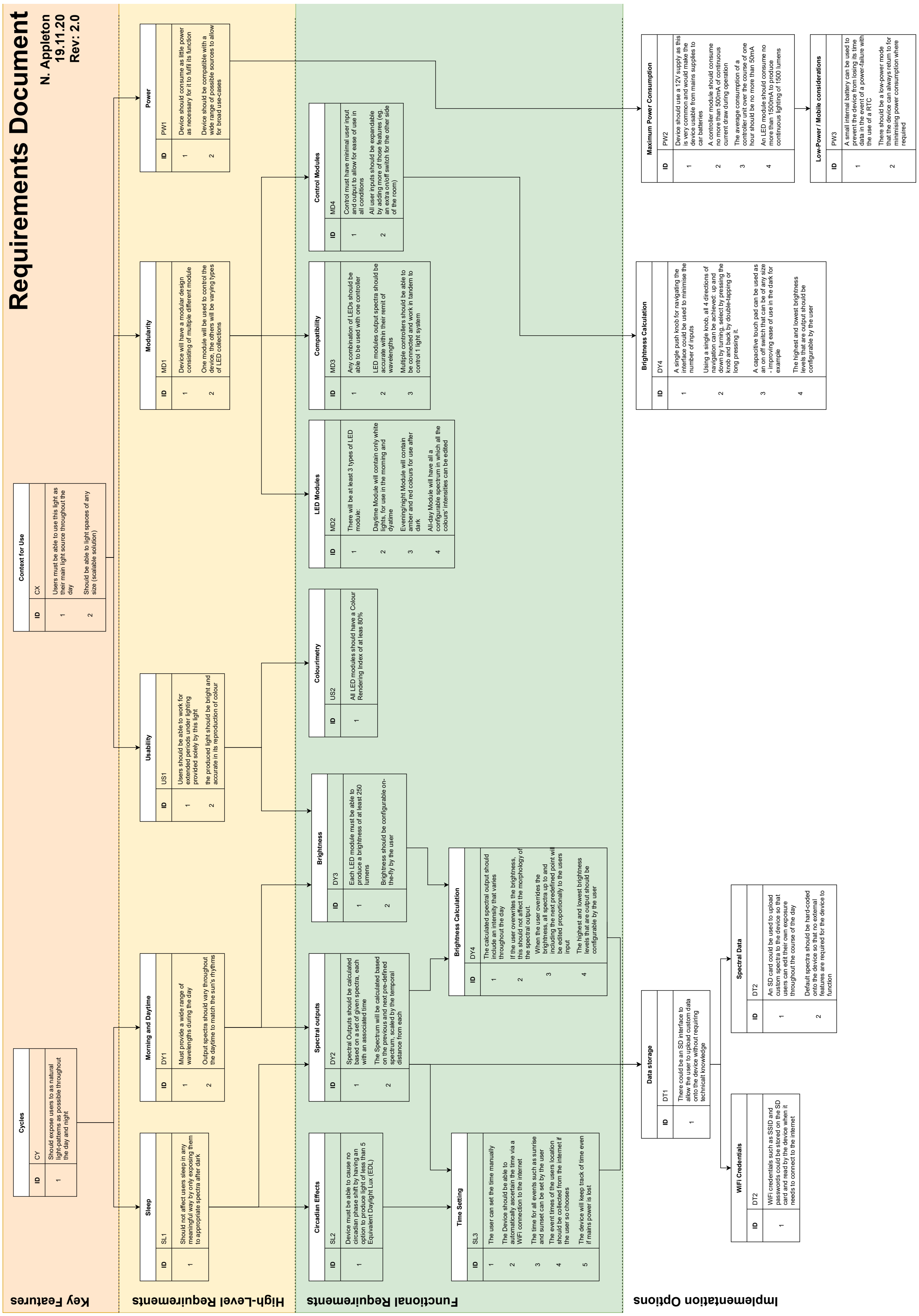
ST Sunset. 15, 22, 23, 26

TW Twilight. 15, 22, 23

Appendix A

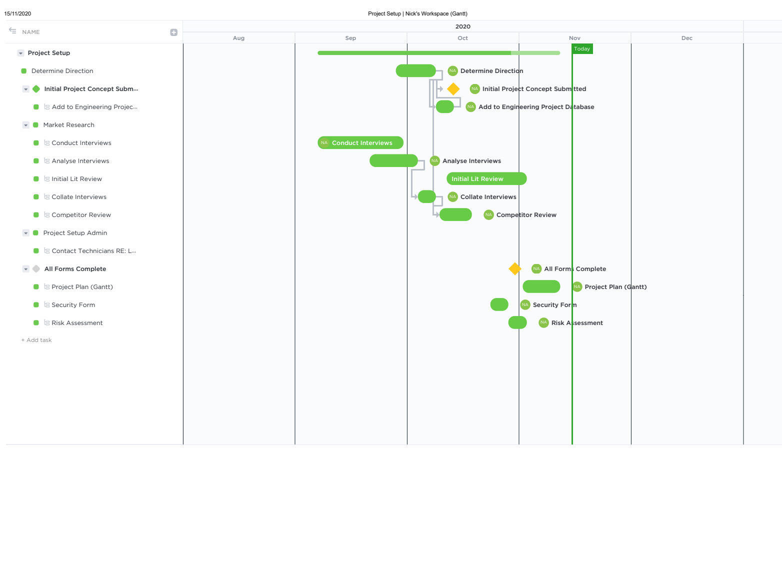
Project Documents

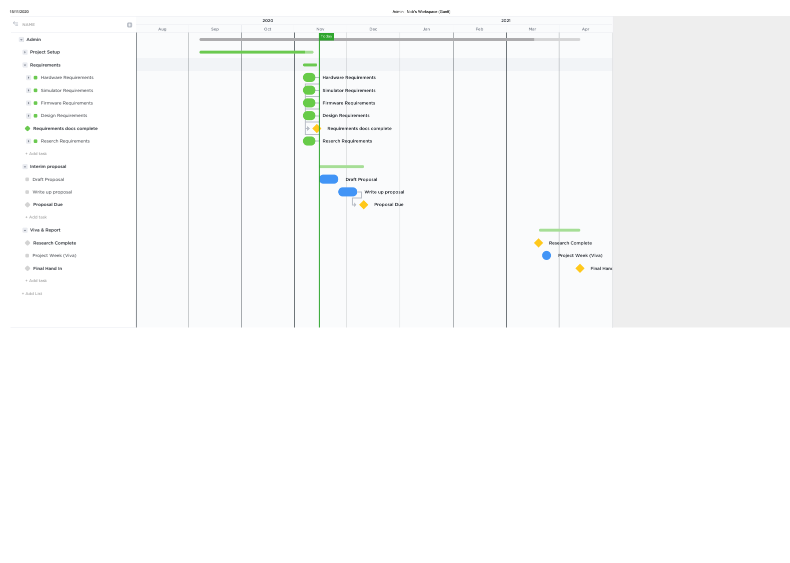
A.1. Device Requirements

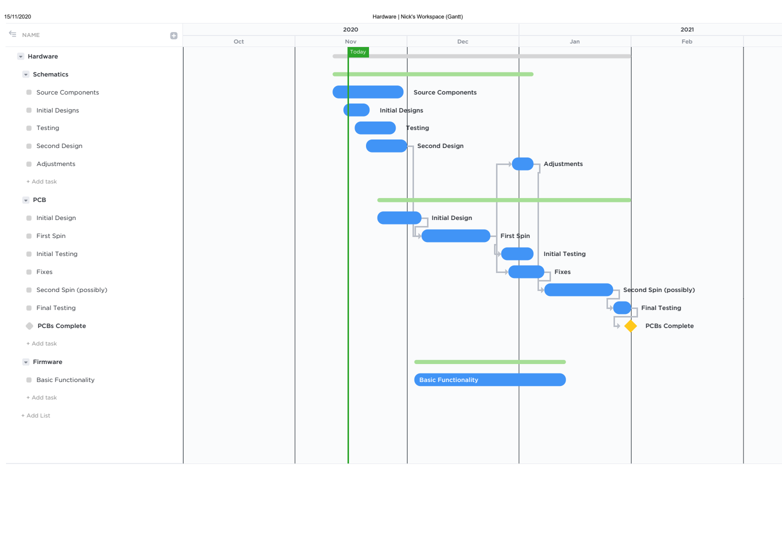


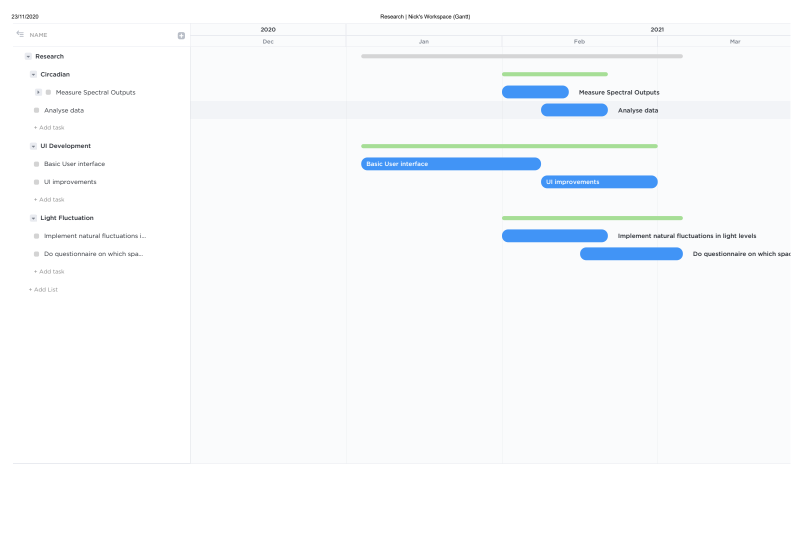
A.2. Gantt Charts

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









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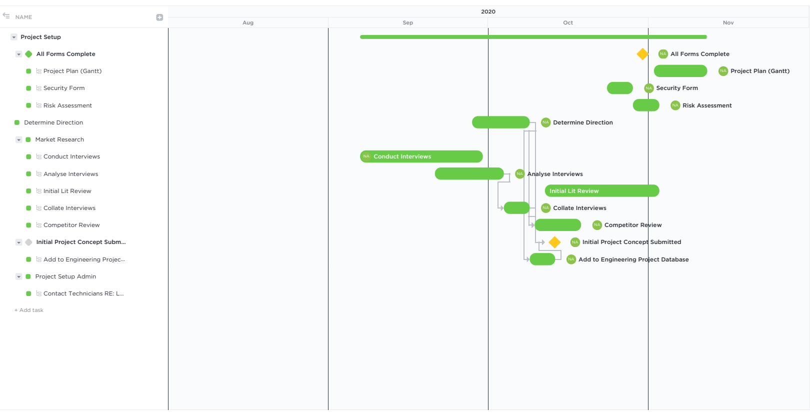

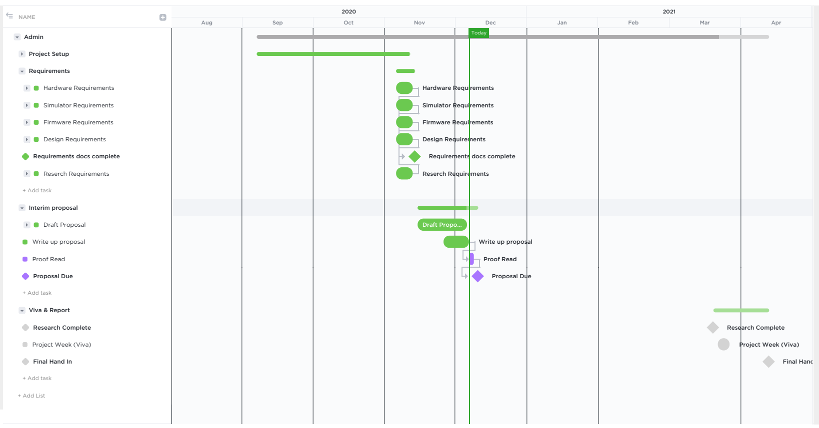

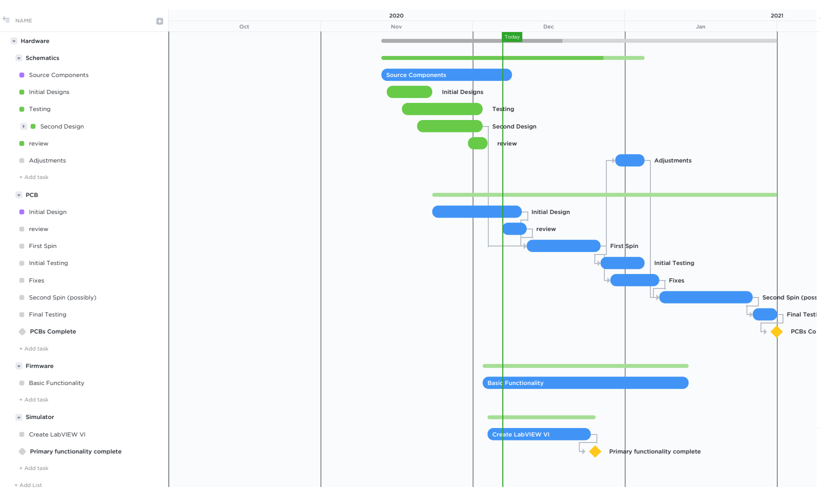

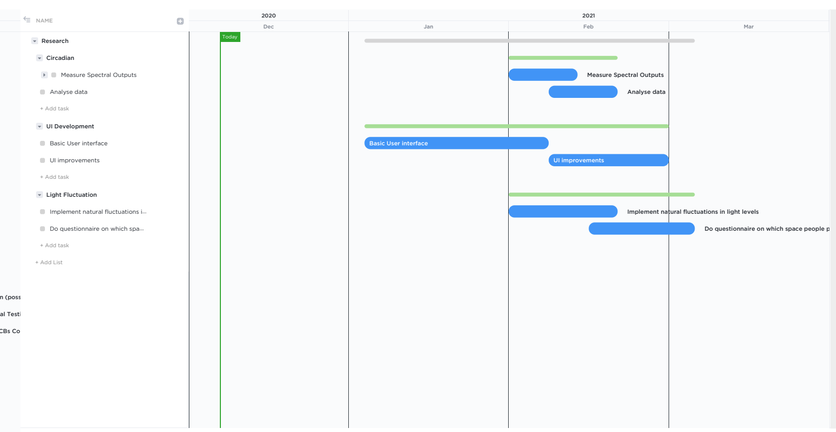

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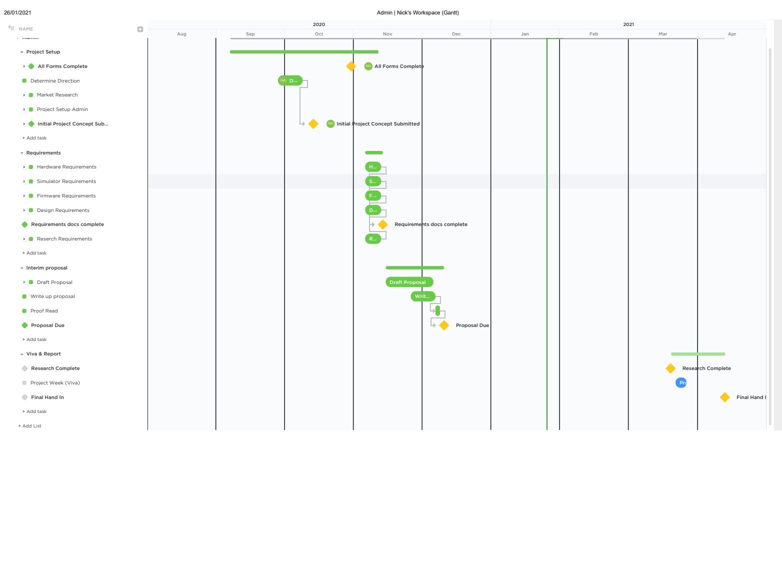

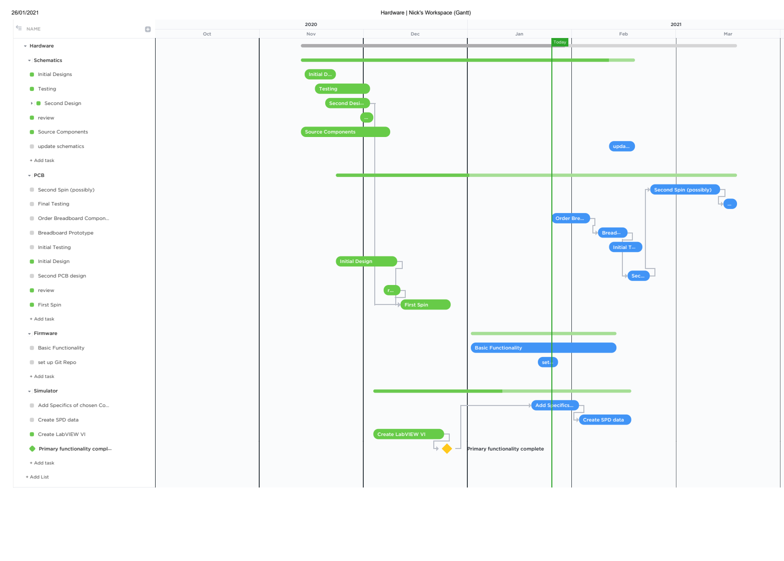

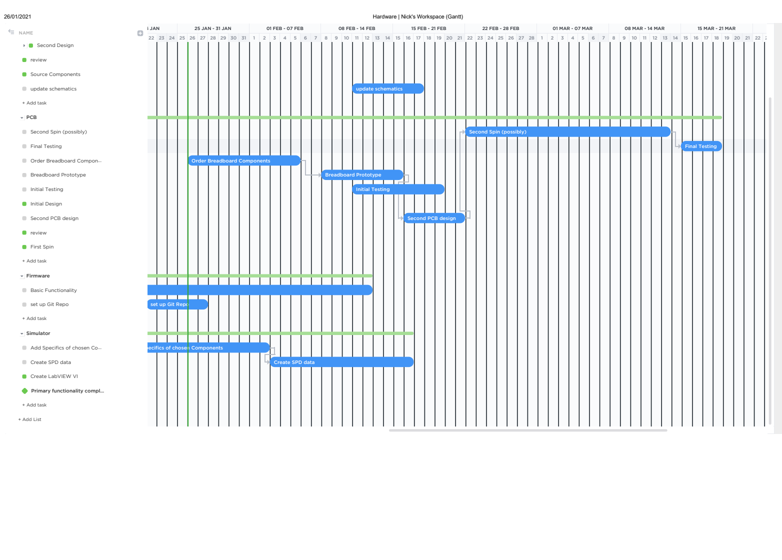

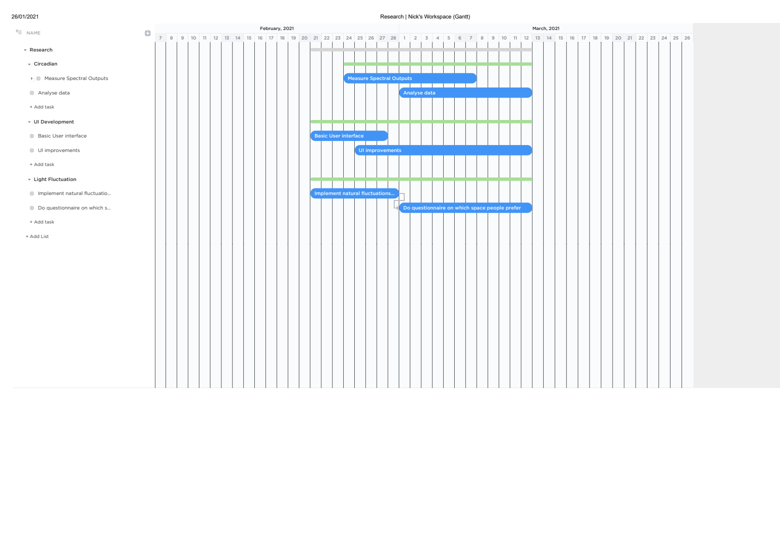

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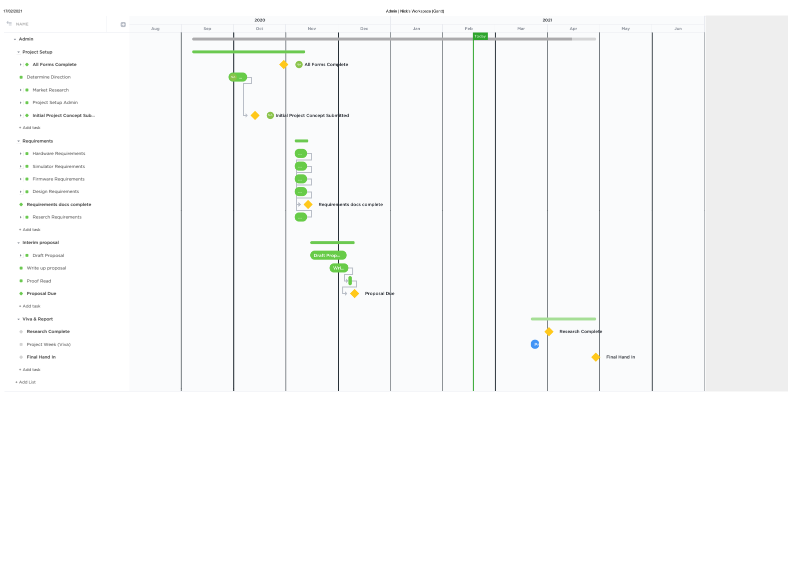
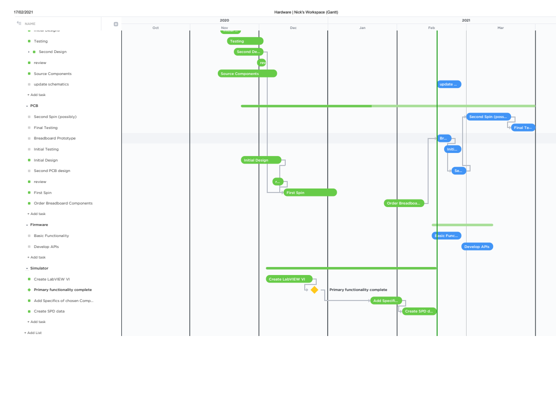
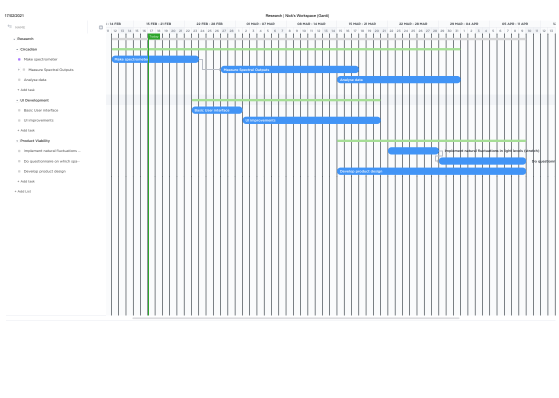


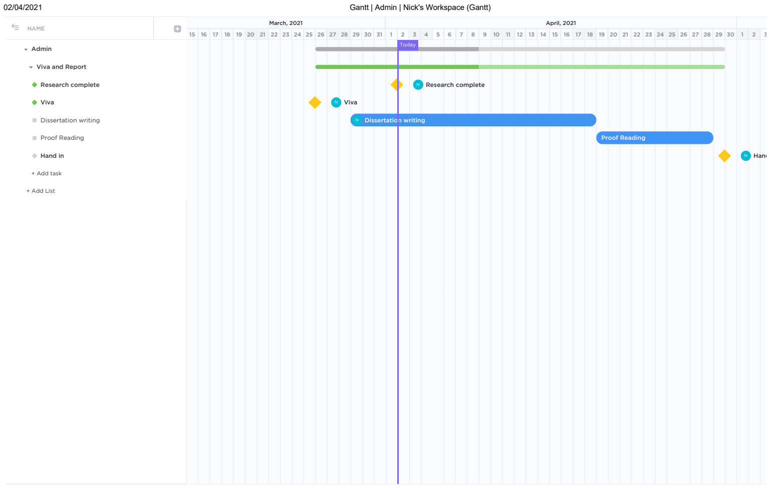




A.2.5. Apr 2^{nd} 2021

02/04/2021

Gantt | Admin | Nick's Workspace (Gantt)



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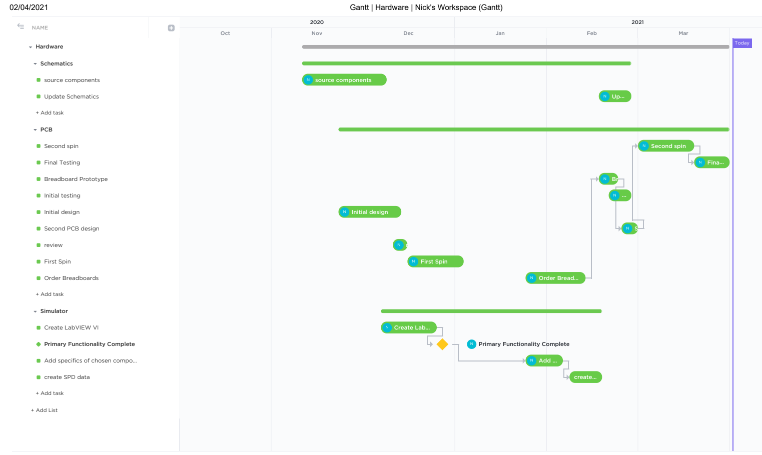
02/04/2021

Gantt | Hardware | Nick's Workspace (Gantt)



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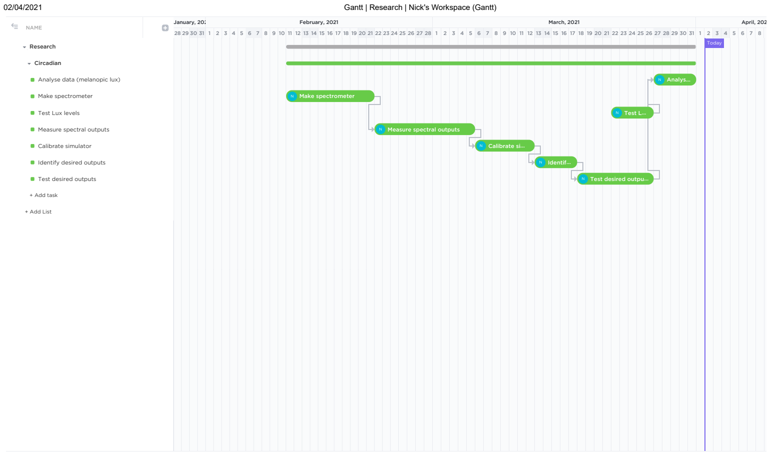
02/04/2021

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:	**Assessed by:**	**Endorsed by:**
Producing a natural-cycle based lighting system	Matthew Studley	
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

A.4. Resources

Dissertation Project Resources Form

Name: Nicholas Appleton Student ID: 16019243

Supervisor: Matthew Studley

[If you are carrying out a desk-based study and/or are only using the library or ITS facilities available at UWE, the faculty's risk assessment procedures will sufficiently cover your activities. In these circumstances, you should identify this on your risk assessment form, which you should attach - along with this form - to your Interim Research Proposal.]

Please sign below to confirm your request for resources.

Student: ……………………………………………………………………… 02/04/21

Supervisor: ………………………………………………………………………….

Further Resources – *what else will you need?*

R-Block workshop	☐	Laser cutting	☐
N-Block workshop	☒	Large format printing	☐
3D printing	☐	Miscellaneous	☐
Labs:			
Structures	☐	Car/flight simulator	☐
Materials	☐	Engine test bays	☐
Composites	☐	Robotics	☐
Hydraulics	☐	Dynamics	☐
Wind tunnel/aero	☐		

If you have ticked any of the above, please fill out a risk assessment of your activities.

Have you spoken to a technician? Yes x Not yet ☐

Materials - *outline the materials required for your project:*

Electronic components

- *LEDs*
- *SD card*
- *Alphanumeric Display*
- *Input and Output ports*
- *PCBs (printed and placed – including components)*
- *Optical Encoder*
- *RTC module*
- *Spectrometer equipment*

A.5. Security

- **UK Engineering Council Guidance on Security**

Security is an important consideration for any project and in any workplace. UK SPEC provides guidance on security and outlines how it expects professional engineers to conduct themselves with respect to security. This guidance is split into six key principles. Your task is to visit the UK SPEC security page and read through the tips provided for each principle.

Using the tips on the webpage provide at least one example for each of the six principles that you can directly link to your project or that should be considered in the role of Professional Engineer. Then summarise your findings in the comments box below.

The link is https://www.engc.org.uk/security

- How would you adopt a security-minded approach to your project?

- be responsive to changes in the operating environment, including the impact of changes in use of the asset or system, its wider connectivity and emerging threats and vulnerabilities. With the current situation with working from home and potential changes to the working environment, this will be relevant to how I consider security.
- remember that security risk assessment is an aid to professional judgement, not a substitute for it. I will continue to assess any and all security risks throughout the project to ensure that any risks are neutralised as quickly as possible.

- What should you consider in order to apply responsible judgement and take a leadership role?

- working with other professionals to ensure informed, proportionate, holistic judgements. When I am working with other professionals – eg. When using equipment like a hyper-spectral camera – I will strive to ensure that we both are remining security minded throughout the work
- being prepared to challenge assumptions and proposals. If when working with one of these professionals, they do something that could potentially cause a security risk, I will certainly be prepared to challenge them and stop them from presenting those risks.

- How will you ensure that your project complies with legislation and codes, while understanding intent and prepared to seek further improvements?

- be aware of, and comply with, the security-related laws in countries where they operate or where their products or services will be used. As I will be developing a prototype product, I will ensure that I am aware of the relevant laws and will comply with them entirely when developing my product.
- be open-minded and avoid using regulations to facilitate complacency. By constantly evaluating the security risks, I will ensure that I am constantly staying on the ball, and not becoming complacent.

- How do you ensure good security-minded communications?

- adopt appropriate measures to protect sensitive information when it is communicated, used and stored, both within and beyond their organisation. Whenever sharing information, I will ensure that it is done in a secure way, and I will communicate when it needs to remain secure.
- recognise the persistent nature and accessibility of information published on the internet or otherwise made publicly available. Before making any information publicly available on the internet, I will ensure to conduct a thorough review of the content and redact or not publish any sensitive information.

A.6. Interview Documents

Consent Form

Walking Back to Nature: Developing an Unobtrusive Device to Measure Kinetics and Kinematics of Gait

This consent form will have been given to you with the Participant Information Sheet. Please ensure that you have read and understood the information contained in the Participant Information Sheet and asked any questions before you sign this form. If you have any questions please contact a member of the research team, whose details are set out on the Participant Information Sheet

If you are happy to take part in an interview, please sign and date the form. You will be given a copy to keep for your records.

- I have read and understood the information in the Participant Information Sheet which I have been given to read before asked to sign this form;
- I have been given the opportunity to ask questions about the study;
- I have had my questions answered satisfactorily by the research team;
- I agree that anonymised quotes may be used in the final Report of this study;
- I understand that my participation is voluntary and that I am free to withdraw at any time until the data has been anonymised, without giving a reason;
- I agree to take part in the research

Name (Printed)…………………………………………………………………………

Signature…………………………………………………… Date……………………

Information Sheet For Interviewees

Project Title: Walking Back to Nature: Developing an Unobtrusive Device to Measure Kinetics and Kinematics of Gait

You are being invited to take part in this research project. Before you decide to do so, it is important you understand why the research is being done and what it will involve.

Please take time to read the following information carefully and discuss it with others if you wish. Ask the research student if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

The researcher (Nicholas Appleton) can be contacted at nicholas2.appleton@live.uwe.ac.uk

The project supervisor (Matthew Studley) can be contacted at Matthew2.Studley@uwe.ac.uk

Thank you for your time.

What is the purpose of the project?

This project aims to develop a small, unobtrusive device that can be used by natural movement specialists (Physiotherapists, Personal Trainers, Rewilding Coaches, etc.) to measure the motion and forces involved in a person's gait. By using minimal hardware and flexible materials, the device can be used to measure the true function of the foot - unlike devices on the market currently which require restrictive shoes to function. The purpose of this interview is to capture requirements sought by professionals in the movement industry.

Why have I been invited to take part?

As a professional in the movement industry, we are interested in gaining your views and opinions on what is important in a device as described above. You may also be asked about your experiences as a movement specialist where these are relevant to the research. The purpose of these questions is to gain an understanding of what requirements are necessary to the potential users of the device.

Do I have to take part?

You do not have to take part in this research. It is up to you to decide whether or not you want to be involved. If you do decide to take part, you will be given a copy of this information sheet to keep and will be asked to sign a consent form. If you do decide to take part, you are able to withdraw from the research without giving a reason until the point at which your data is anonymised and can therefore no longer be traced back to you. This point will take place 4 weeks from the date you signed your consent form. If you want to withdraw from the study within this period, please write to N. Appleton (nicholas2.appleton@live.uwe.ac.uk). Deciding not to take part or to withdrawal from the study does not have any penalty.

What will happen to me if I take part and what will I have to do?

If you agree to take part you will be asked to take part in a video interview that will last between 20 minutes and an hour. The interview will be recorded and saved using a unique identifier that will be used to re-identify you if you choose to withdraw from the study within the period. Once the requirements capture has taken place, the video recording will be deleted.

What are the benefits of taking part?

By taking part in this interview, you are helping to develop a tool that could be used to help people regain their natural movement and improve their health. The device will be created around specifications built from the information you provide in this interview.

What are the possible risks of taking part?

We do not foresee or anticipate any significant risk to you in taking part in this study. If, however, you feel uncomfortable at any time you can ask for the interview to stop.

What will happen to your information?

All the information we receive from you will be treated in the strictest confidence. All the information that you give will be kept confidential and anonymised. Voice recordings will be destroyed securely immediately after anonymised value extraction. Your anonymised data will be analysed together with other interview and file data, and we will ensure that there is no possibility of identification or re-identification from this point.

Where will the results of the study be published?

Results of the research will be part of the student's undergraduate dissertation. You will not be identified in this piece of work. If you wish to be given a copy of the resulting dissertation, please indicate so on the consent form.

Who has ethically reviewed this project?

This research has been ethically approved by Matthew Studley of the Department of Engineering, Design and Mathematics.

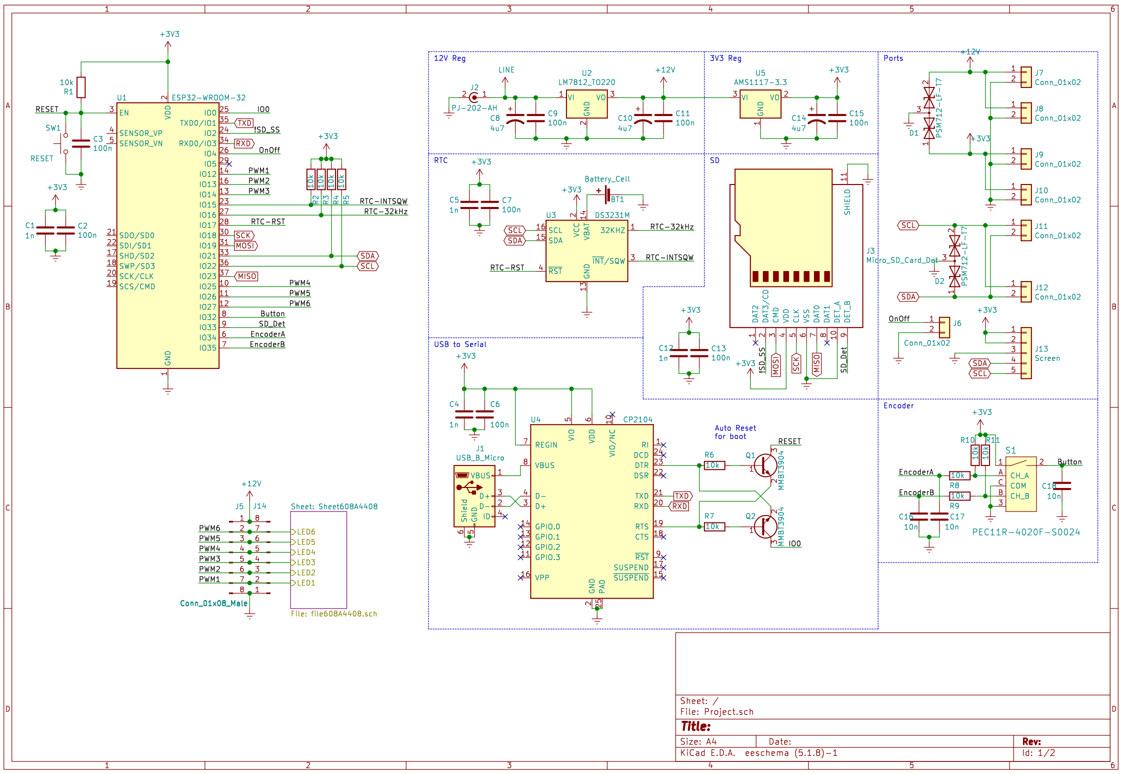
What if I have more questions or do not understand something?

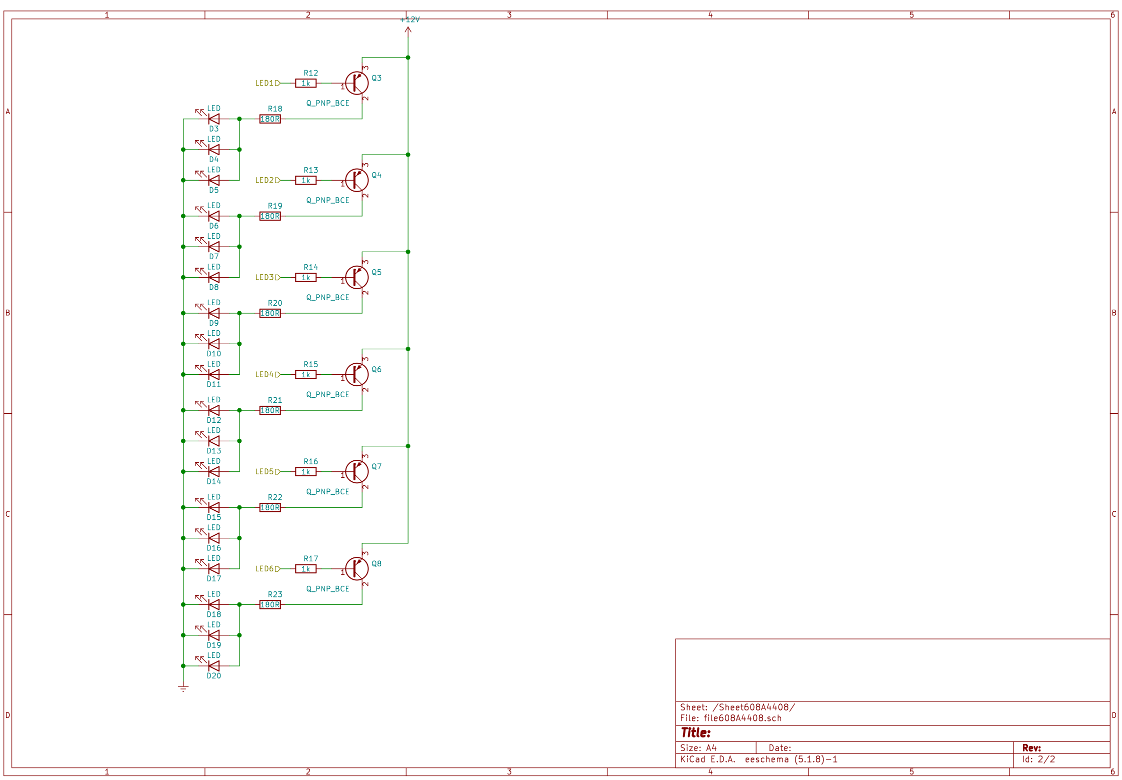
If you would like any further information about the research, please contact in the first instance:
N. Appleton nicholas2.appleton@live.uwe.ac.uk

Thank you for agreeing to take part in this study.

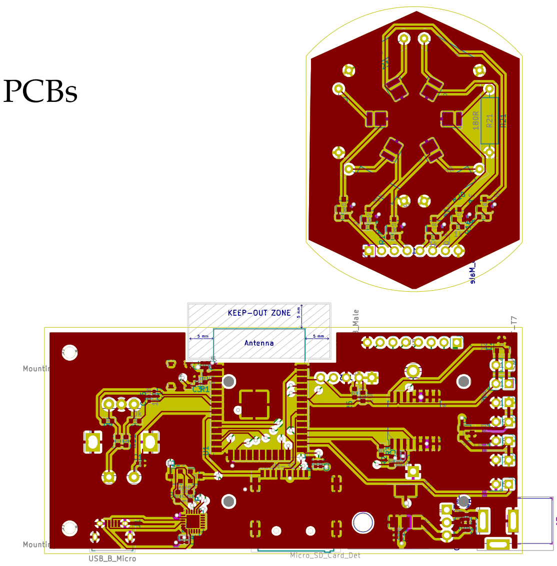
You will be given a copy of this Participant Information Sheet and your signed consent form to keep

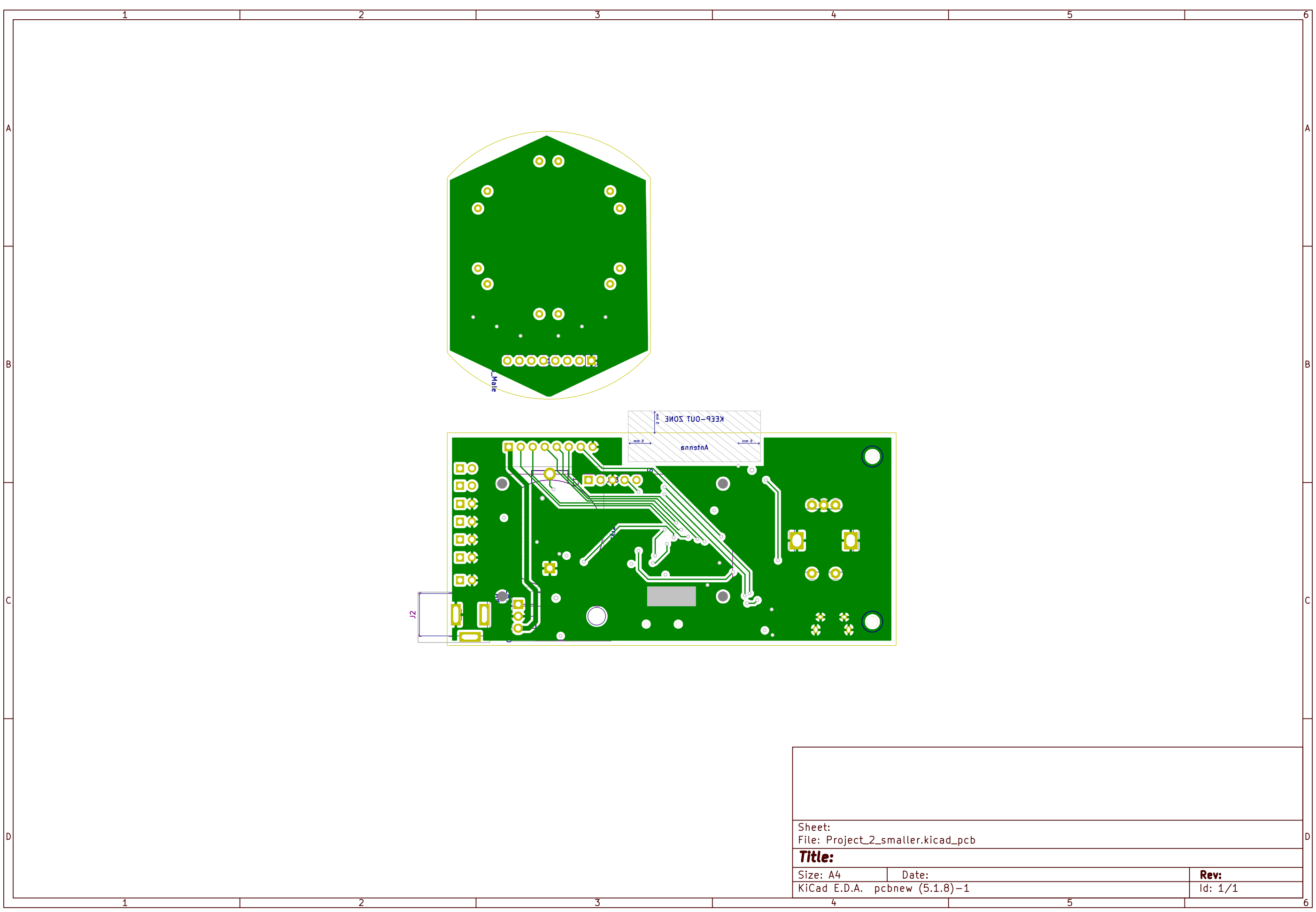
B.1. SCHEMATICS





B.2. PCBs


KEEP-OUT ZONE
Antenna
USB_B_Micro
Micro_SD_Card_Det
Sheet:
File: Project_2_smaller.kicad_pcb
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. pcbnew (5.1.8)-1
Id: 1/1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File: Project_2_smaller.kicad_pcb
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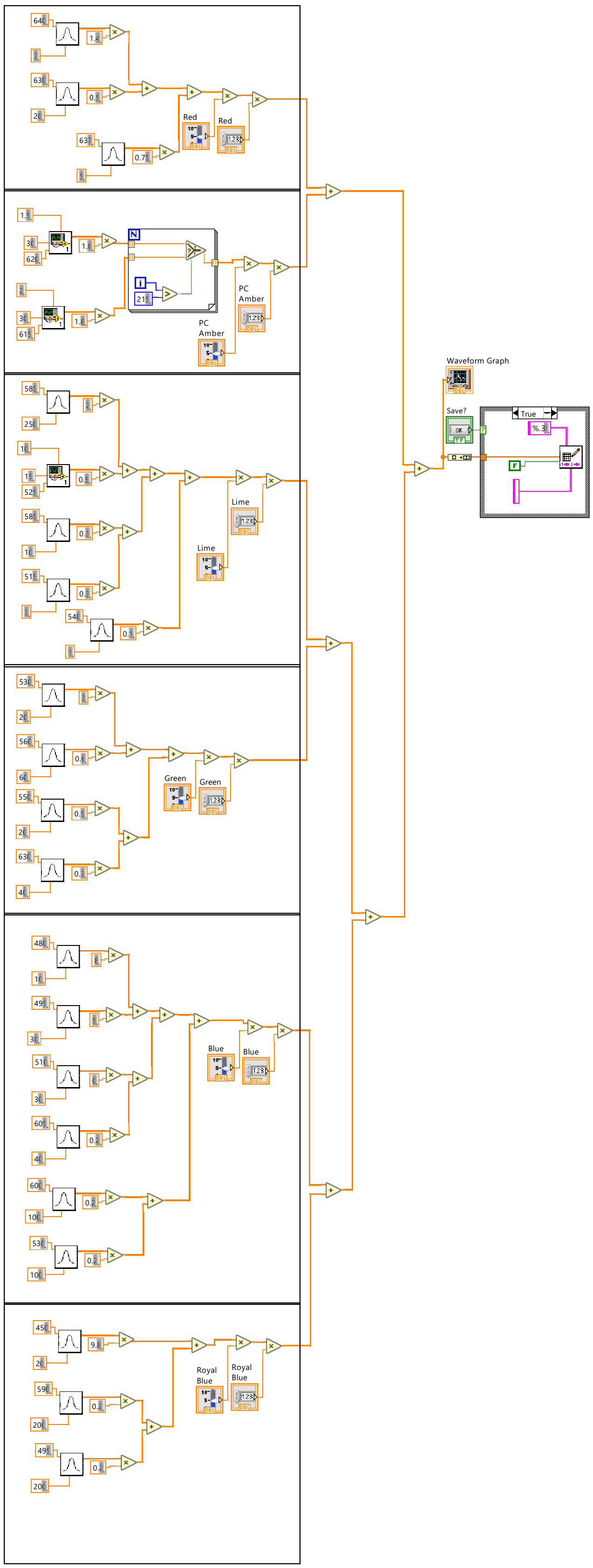
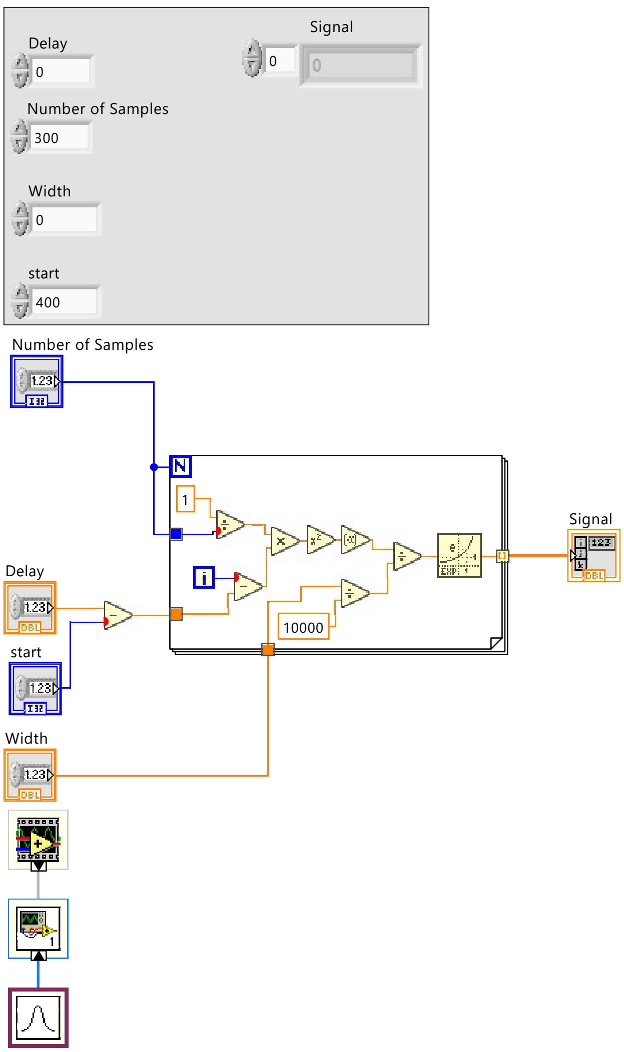
Appendix C

LabVIEW Code

C.1. Simulator

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Signal
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Number of Samples
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Signal
Delay
start
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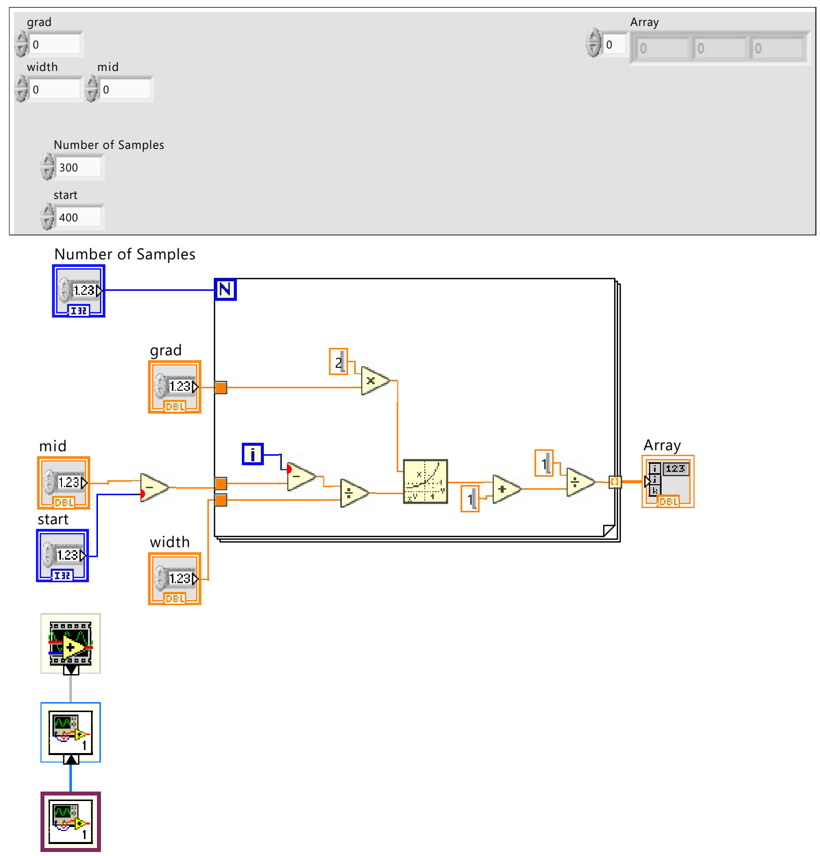
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width
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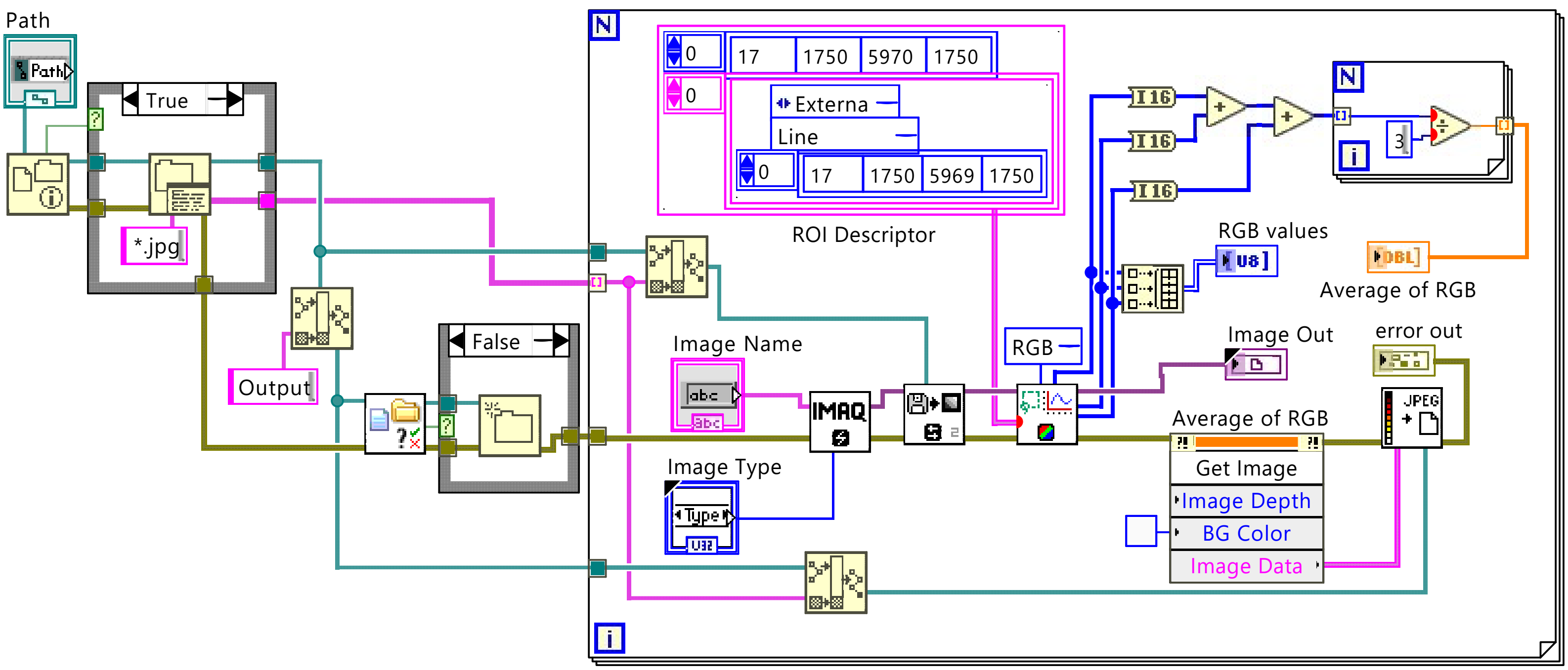
grad
2
mid
i
start
1
width
Array

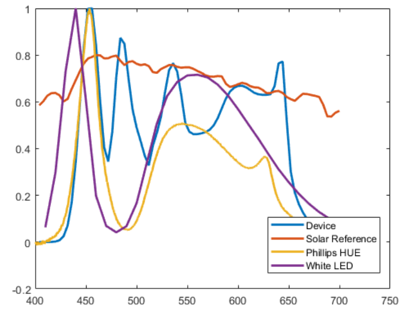
C.2. Spectrum Extractor



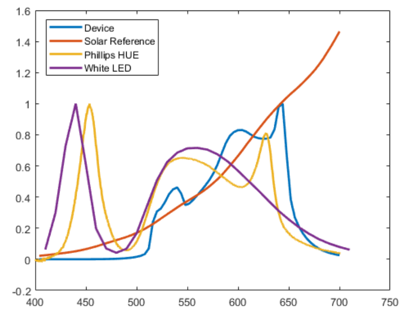
Appendix D

Results

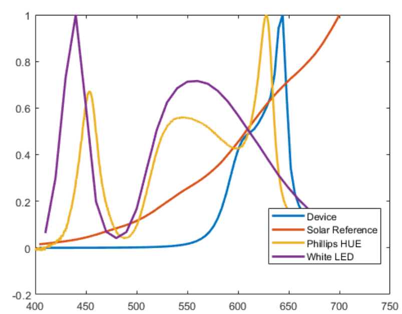
D.1. Spectral Comparisons



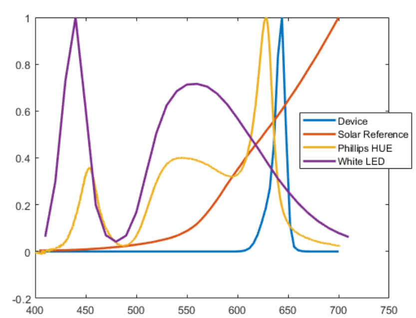
(a) *Morning Spectrum*



(b) *Afternoon Spectrum*



(c) *Evening Spectrum*



(d) *Night Spectrum*

Figure D.1: *The 4 collections of spectra: one for each time of day.*

D.2. Data Used

Wavelength	Device				Philips HUE				Other	
	morning	afternoon	evening	night	morning	afternoon	evening	night	CFL	LED
400	1.50E-03	7.00E-04	7.00E-04	0.00E+00	-6.14E-04	-3.86E-04	-8.47E-04	-9.18E-04	2.20E-03	4.47E-04
404	2.00E-03	7.00E-04	7.00E-04	0.00E+00	1.39E-03	1.07E-03	6.96E-04	5.66E-04	1.29E-03	5.78E-04
408	2.90E-03	8.00E-04	8.00E-04	0.00E+00	3.03E-03	2.13E-03	1.83E-03	1.28E-03	2.89E-04	8.69E-04
412	5.40E-03	9.00E-04	9.00E-04	0.00E+00	6.48E-03	5.49E-03	4.97E-03	3.39E-03	1.89E-04	1.35E-03
416	1.43E-02	9.00E-04	9.00E-04	0.00E+00	1.05E-02	8.51E-03	7.30E-03	5.02E-03	1.68E-04	2.21E-03
420	4.60E-02	1.00E-03	1.00E-03	0.00E+00	1.77E-02	1.39E-02	1.10E-02	7.22E-03	1.50E-04	3.61E-03
424	1.46E-01	1.10E-03	1.10E-03	0.00E+00	3.10E-02	2.43E-02	1.93E-02	1.26E-02	3.12E-04	5.93E-03
428	4.12E-01	1.20E-03	1.20E-03	0.00E+00	5.18E-02	4.04E-02	3.13E-02	2.14E-02	3.29E-03	9.78E-03
432	9.89E-01	1.40E-03	1.30E-03	0.00E+00	7.78E-02	6.07E-02	4.72E-02	3.14E-02	6.16E-03	1.56E-02
436	2.00E+00	1.50E-03	1.40E-03	0.00E+00	1.10E-01	8.51E-02	6.57E-02	4.36E-02	2.32E-03	2.50E-02
440	3.41E+00	1.70E-03	1.60E-03	0.00E+00	1.39E-01	1.10E-01	8.51E-02	5.64E-02	3.70E-04	3.88E-02
444	4.86E+00	2.00E-03	1.70E-03	0.00E+00	1.50E-01	1.18E-01	9.21E-02	6.09E-02	1.98E-04	5.61E-02
448	5.80E+00	2.30E-03	1.90E-03	0.00E+00	1.30E-01	1.01E-01	7.82E-02	5.17E-02	1.96E-04	7.29E-02
452	5.81E+00	2.80E-03	2.10E-03	0.00E+00	8.94E-02	7.03E-02	5.39E-02	3.55E-02	1.93E-04	8.26E-02
456	4.90E+00	3.50E-03	2.30E-03	0.00E+00	6.01E-02	4.64E-02	3.61E-02	2.37E-02	1.87E-04	8.03E-02
460	3.52E+00	4.50E-03	2.50E-03	0.00E+00	4.16E-02	3.25E-02	2.50E-02	1.66E-02	1.95E-04	6.95E-02
464	2.35E+00	5.80E-03	2.80E-03	0.00E+00	2.80E-02	2.18E-02	1.70E-02	1.14E-02	2.02E-04	5.74E-02
468	2.01E+00	7.70E-03	3.10E-03	0.00E+00	1.85E-02	1.46E-02	1.13E-02	7.51E-03	2.00E-04	4.86E-02
472	2.74E+00	1.03E-02	3.50E-03	0.00E+00	1.29E-02	1.02E-02	8.02E-03	5.40E-03	2.75E-04	4.17E-02
476	4.12E+00	1.41E-02	3.90E-03	0.00E+00	9.01E-03	7.18E-03	5.87E-03	4.09E-03	8.39E-04	3.64E-02
480	5.08E+00	1.93E-02	4.40E-03	0.00E+00	8.15E-03	6.99E-03	6.05E-03	4.64E-03	2.38E-03	3.35E-02
484	4.93E+00	2.64E-02	4.90E-03	0.00E+00	8.86E-03	8.19E-03	7.58E-03	6.12E-03	3.41E-03	3.27E-02
488	4.08E+00	3.62E-02	5.60E-03	0.00E+00	1.20E-02	1.15E-02	1.09E-02	9.61E-03	2.79E-03	3.36E-02
492	3.30E+00	4.94E-02	6.30E-03	0.00E+00	1.75E-02	1.73E-02	1.69E-02	1.50E-02	1.67E-03	3.52E-02
496	2.85E+00	6.78E-02	7.20E-03	0.00E+00	2.55E-02	2.55E-02	2.50E-02	2.22E-02	9.29E-04	3.76E-02

500	2.51E+00	9.44E-02	8.30E-03	0.00E+00	3.47E-02	3.51E-02	3.44E-02	3.07E-02	4.59E-04	4.01E-02
504	2.15E+00	1.41E-01	9.60E-03	0.00E+00	4.47E-02	4.50E-02	4.43E-02	3.96E-02	2.67E-04	4.26E-02
508	1.91E+00	2.95E-01	1.11E-02	0.00E+00	5.40E-02	5.47E-02	5.36E-02	4.78E-02	2.04E-04	4.48E-02
512	2.39E+00	1.02E+00	1.29E-02	0.00E+00	6.15E-02	6.22E-02	6.15E-02	5.48E-02	1.69E-04	4.67E-02
516	2.72E+00	1.31E+00	1.51E-02	0.00E+00	6.81E-02	6.88E-02	6.77E-02	6.05E-02	1.49E-04	4.82E-02
520	3.12E+00	1.40E+00	1.77E-02	0.00E+00	7.24E-02	7.30E-02	7.19E-02	6.43E-02	1.44E-04	4.96E-02
524	3.73E+00	1.57E+00	2.10E-02	0.00E+00	7.51E-02	7.59E-02	7.50E-02	6.66E-02	2.34E-04	5.07E-02
528	4.27E+00	1.79E+00	2.51E-02	0.00E+00	7.61E-02	7.72E-02	7.59E-02	6.81E-02	6.76E-04	5.18E-02
532	4.45E+00	1.92E+00	3.02E-02	0.00E+00	7.76E-02	7.82E-02	7.66E-02	6.90E-02	3.16E-03	5.28E-02
536	4.24E+00	1.97E+00	3.67E-02	0.00E+00	7.72E-02	7.80E-02	7.70E-02	6.88E-02	1.07E-02	5.40E-02
540	3.66E+00	1.80E+00	4.49E-02	0.00E+00	7.68E-02	7.73E-02	7.65E-02	6.82E-02	1.75E-02	5.53E-02
544	2.97E+00	1.49E+00	5.56E-02	0.00E+00	7.64E-02	7.72E-02	7.61E-02	6.81E-02	1.40E-02	5.65E-02
548	2.75E+00	1.53E+00	6.96E-02	0.00E+00	7.54E-02	7.65E-02	7.50E-02	6.75E-02	6.20E-03	5.77E-02
552	2.68E+00	1.64E+00	8.80E-02	0.00E+00	7.49E-02	7.55E-02	7.45E-02	6.65E-02	1.99E-03	5.90E-02
556	2.69E+00	1.76E+00	1.13E-01	0.00E+00	7.32E-02	7.38E-02	7.30E-02	6.51E-02	7.27E-04	6.04E-02
560	2.71E+00	1.90E+00	1.46E-01	0.00E+00	7.19E-02	7.26E-02	7.15E-02	6.41E-02	4.15E-04	6.18E-02
564	2.74E+00	2.03E+00	1.93E-01	0.00E+00	6.97E-02	7.04E-02	6.99E-02	6.27E-02	3.17E-04	6.32E-02
568	2.79E+00	2.19E+00	2.56E-01	0.00E+00	6.70E-02	6.83E-02	6.71E-02	6.02E-02	6.25E-04	6.46E-02
572	2.90E+00	2.37E+00	3.45E-01	0.00E+00	6.47E-02	6.59E-02	6.52E-02	5.82E-02	1.95E-03	6.58E-02
576	3.08E+00	2.62E+00	4.67E-01	0.00E+00	6.21E-02	6.34E-02	6.31E-02	5.72E-02	3.45E-03	6.66E-02
580	3.33E+00	2.91E+00	6.31E-01	0.00E+00	5.90E-02	6.08E-02	6.12E-02	5.57E-02	4.47E-03	6.71E-02
584	3.57E+00	3.19E+00	8.41E-01	0.00E+00	5.64E-02	5.91E-02	5.94E-02	5.51E-02	4.62E-03	6.70E-02
588	3.74E+00	3.39E+00	1.09E+00	0.00E+00	5.43E-02	5.71E-02	5.89E-02	5.55E-02	4.20E-03	6.67E-02
592	3.84E+00	3.49E+00	1.34E+00	2.00E-04	5.18E-02	5.57E-02	5.90E-02	5.67E-02	3.56E-03	6.59E-02
596	3.88E+00	3.54E+00	1.55E+00	8.00E-04	5.00E-02	5.56E-02	6.06E-02	6.03E-02	2.88E-03	6.46E-02
600	3.89E+00	3.55E+00	1.70E+00	3.40E-03	4.91E-02	5.76E-02	6.48E-02	6.80E-02	3.29E-03	6.30E-02
604	3.85E+00	3.50E+00	1.78E+00	1.17E-02	4.86E-02	6.10E-02	7.27E-02	7.98E-02	1.58E-02	6.05E-02
608	3.78E+00	3.43E+00	1.83E+00	3.40E-02	4.95E-02	6.76E-02	8.45E-02	9.77E-02	2.48E-02	5.80E-02
612	3.71E+00	3.36E+00	1.88E+00	8.27E-02	5.12E-02	7.73E-02	1.01E-01	1.23E-01	1.58E-02	5.52E-02

616	3.68E+00	3.32E+00	1.97E+00	1.68E-01	5.47E-02	8.97E-02	1.24E-01	1.53E-01	6.46E-03	5.23E-02
620	3.66E+00	3.31E+00	2.09E+00	2.88E-01	5.57E-02	9.75E-02	1.38E-01	1.71E-01	4.75E-03	4.91E-02
624	3.66E+00	3.31E+00	2.22E+00	4.27E-01	4.88E-02	8.48E-02	1.20E-01	1.52E-01	5.24E-03	4.53E-02
628	3.68E+00	3.34E+00	2.39E+00	6.20E-01	3.71E-02	5.80E-02	7.95E-02	9.83E-02	4.02E-03	4.20E-02
632	3.88E+00	3.57E+00	2.74E+00	1.05E+00	2.86E-02	3.87E-02	4.94E-02	5.71E-02	1.74E-03	3.88E-02
636	4.45E+00	4.18E+00	3.48E+00	1.92E+00	2.31E-02	2.84E-02	3.33E-02	3.65E-02	8.42E-04	3.57E-02
640	4.49E+00	4.27E+00	3.69E+00	2.30E+00	2.07E-02	2.34E-02	2.54E-02	2.62E-02	7.67E-04	3.28E-02
644	3.02E+00	2.86E+00	2.39E+00	1.19E+00	1.82E-02	1.98E-02	2.06E-02	2.03E-02	1.23E-03	2.96E-02
648	1.75E+00	1.63E+00	1.26E+00	2.64E-01	1.62E-02	1.70E-02	1.78E-02	1.66E-02	1.40E-03	2.70E-02
652	1.23E+00	1.15E+00	8.59E-01	4.58E-02	1.44E-02	1.51E-02	1.51E-02	1.39E-02	1.04E-03	2.45E-02
656	9.44E-01	8.97E-01	6.72E-01	1.20E-02	1.29E-02	1.35E-02	1.35E-02	1.23E-02	9.49E-04	2.23E-02
660	7.36E-01	7.08E-01	5.37E-01	3.40E-03	1.17E-02	1.20E-02	1.19E-02	1.07E-02	9.04E-04	2.01E-02
664	5.78E-01	5.62E-01	4.34E-01	8.00E-04	1.09E-02	1.09E-02	1.10E-02	9.93E-03	6.20E-04	1.78E-02
668	4.57E-01	4.48E-01	3.53E-01	2.00E-04	9.68E-03	9.51E-03	9.61E-03	8.60E-03	5.08E-04	1.60E-02
672	3.65E-01	3.60E-01	2.90E-01	0.00E+00	8.66E-03	8.56E-03	8.60E-03	7.79E-03	4.68E-04	1.44E-02
676	2.93E-01	2.91E-01	2.40E-01	0.00E+00	8.22E-03	8.26E-03	8.41E-03	7.51E-03	4.96E-04	1.29E-02
680	2.38E-01	2.36E-01	2.00E-01	0.00E+00	6.53E-03	6.69E-03	6.84E-03	5.97E-03	7.07E-04	1.14E-02
684	1.95E-01	1.94E-01	1.68E-01	0.00E+00	6.36E-03	6.50E-03	6.50E-03	5.54E-03	9.26E-04	1.01E-02
688	1.61E-01	1.60E-01	1.42E-01	0.00E+00	5.83E-03	5.85E-03	5.86E-03	5.29E-03	9.52E-04	8.97E-03
692	1.34E-01	1.34E-01	1.21E-01	0.00E+00	5.41E-03	5.49E-03	5.33E-03	4.90E-03	1.04E-03	8.01E-03
696	1.13E-01	1.13E-01	1.04E-01	0.00E+00	4.90E-03	4.92E-03	4.84E-03	4.45E-03	7.75E-04	7.12E-03

Wavelength	solar irradiance spectrum			
	morning	afternoon	evening	night
404	5.85E-01	2.25E-02	1.54E-02	4.22E-03
408	6.02E-01	2.49E-02	1.70E-02	4.53E-03
412	6.26E-01	2.79E-02	1.90E-02	4.38E-03
416	6.37E-01	3.06E-02	2.09E-02	5.28E-03
420	6.38E-01	3.35E-02	2.29E-02	4.83E-03
424	6.28E-01	3.69E-02	2.52E-02	5.28E-03
428	6.02E-01	4.02E-02	2.75E-02	5.58E-03
432	6.13E-01	4.38E-02	2.99E-02	6.04E-03
436	6.56E-01	4.74E-02	3.24E-02	6.79E-03
440	6.93E-01	5.19E-02	3.55E-02	7.24E-03
444	7.30E-01	5.69E-02	3.89E-02	8.15E-03
448	7.65E-01	6.24E-02	4.26E-02	8.90E-03
452	7.85E-01	6.87E-02	4.69E-02	9.81E-03
456	7.92E-01	7.56E-02	5.16E-02	1.12E-02
460	8.00E-01	8.28E-02	5.65E-02	1.22E-02
464	7.99E-01	9.07E-02	6.20E-02	1.33E-02
468	7.86E-01	9.92E-02	6.78E-02	1.43E-02
472	7.87E-01	1.07E-01	7.33E-02	1.60E-02
476	7.94E-01	1.15E-01	7.86E-02	1.75E-02
480	7.98E-01	1.23E-01	8.41E-02	1.89E-02
484	7.76E-01	1.31E-01	8.96E-02	2.08E-02
488	7.57E-01	1.39E-01	9.50E-02	2.26E-02
492	7.71E-01	1.48E-01	1.01E-01	2.46E-02
496	7.74E-01	1.58E-01	1.08E-01	2.69E-02
500	7.63E-01	1.70E-01	1.16E-01	2.94E-02
504	7.57E-01	1.82E-01	1.24E-01	3.18E-02
508	7.61E-01	1.96E-01	1.34E-01	3.44E-02
512	7.53E-01	2.11E-01	1.44E-01	3.73E-02
516	7.27E-01	2.26E-01	1.55E-01	4.03E-02
520	7.24E-01	2.44E-01	1.67E-01	4.39E-02
524	7.41E-01	2.62E-01	1.79E-01	4.77E-02
528	7.49E-01	2.80E-01	1.91E-01	5.19E-02
532	7.58E-01	2.98E-01	2.03E-01	5.61E-02
536	7.57E-01	3.15E-01	2.15E-01	6.13E-02
540	7.50E-01	3.33E-01	2.27E-01	6.73E-02
544	7.46E-01	3.50E-01	2.39E-01	7.47E-02
548	7.48E-01	3.66E-01	2.50E-01	8.31E-02

552	7.48E-01	3.82E-01	2.61E-01	9.29E-02
556	7.41E-01	3.98E-01	2.72E-01	1.05E-01
560	7.32E-01	4.14E-01	2.82E-01	1.18E-01
564	7.24E-01	4.31E-01	2.94E-01	1.35E-01
568	7.13E-01	4.50E-01	3.07E-01	1.55E-01
572	7.08E-01	4.70E-01	3.21E-01	1.76E-01
576	7.08E-01	4.92E-01	3.36E-01	1.99E-01
580	7.10E-01	5.16E-01	3.52E-01	2.23E-01
584	7.09E-01	5.42E-01	3.70E-01	2.48E-01
588	6.78E-01	5.71E-01	3.90E-01	2.75E-01
592	6.64E-01	6.01E-01	4.11E-01	3.01E-01
596	6.69E-01	6.33E-01	4.32E-01	3.26E-01
600	6.75E-01	6.65E-01	4.54E-01	3.50E-01
604	6.81E-01	6.98E-01	4.77E-01	3.74E-01
608	6.77E-01	7.34E-01	5.01E-01	3.99E-01
612	6.67E-01	7.68E-01	5.24E-01	4.23E-01
616	6.62E-01	8.01E-01	5.47E-01	4.45E-01
620	6.61E-01	8.35E-01	5.70E-01	4.67E-01
624	6.52E-01	8.67E-01	5.92E-01	4.89E-01
628	6.38E-01	9.00E-01	6.15E-01	5.13E-01
632	6.38E-01	9.30E-01	6.35E-01	5.35E-01
636	6.45E-01	9.59E-01	6.55E-01	5.58E-01
640	6.47E-01	9.87E-01	6.74E-01	5.81E-01
644	6.38E-01	1.01E+00	6.92E-01	6.05E-01
648	6.21E-01	1.04E+00	7.10E-01	6.32E-01
652	6.12E-01	1.06E+00	7.27E-01	6.58E-01
656	6.04E-01	1.09E+00	7.42E-01	6.83E-01
660	6.20E-01	1.11E+00	7.58E-01	7.09E-01
664	6.35E-01	1.13E+00	7.75E-01	7.36E-01
668	6.33E-01	1.16E+00	7.93E-01	7.64E-01
672	6.29E-01	1.19E+00	8.12E-01	7.92E-01
676	6.26E-01	1.22E+00	8.32E-01	8.20E-01
680	6.21E-01	1.25E+00	8.56E-01	8.48E-01
684	5.88E-01	1.29E+00	8.81E-01	8.78E-01
688	5.38E-01	1.33E+00	9.09E-01	9.08E-01
692	5.37E-01	1.37E+00	9.37E-01	9.38E-01
696	5.54E-01	1.42E+00	9.68E-01	9.69E-01
700	5.61E-01	1.46E+00	1.00E+00	1.00E+00

Appendix E

UK-SPEC

ID	Details	Context	Evidence	Notes
A	**Use engineering knowledge and understanding to apply technical and practical skills.**			
A1	Review and select appropriate techniques, procedures and methods to undertake tasks	Looking at techniques for measuring light and circadian effects	Logbook - learning about spectroscopy, lux, lumens, illuminangce, irradiance, etc.	Due to the pandemic, there have been many changes of direction which have each required a clear and correct selection of procedures and techniques to get the task done
A2	Use appropriate scientific, technical or engineering principles.	Developing circuit designs and Printed Circuit Boards (PCBs) in KiCAD, employing techniquesa learnt in industry to ensure robust design	Gerber Files as well as all .KiCad_PCB and .sch files, Physical PCBs	Using KiCAD software to develop a schematic and produce a PCB design.
B	**Contribute to the design, development, manufacture, construction, commissioning, operation or maintenance of products, equipment, processes, systems or services.**			
B1	Identify problems and apply appropriate methods to identify causes and achieve satisfactory solutions.	The hyperspectral camera was no longer usable, the reason for this needed to be identifieed and an alternative stratergy implemented	Emails to Darren Reynolds	Completing this project in a pandemic year has meant that many problems have arisen, and in many times, it is hard to identify the causes without access to professional equipment.
B2	Identify, organise and use resources effectively to complete tasks, with consideration for cost, quality, safety, security and environmental impact.	When making decisions about what components to use, we first identify the minimum requirements of the component. This could include tolerances and electrical characteristics and package size. We then find a selection of matching components and select the cheapest that fits all the requirements. We also ensure to track all costs and invoices that are incurred as this is an R&D project, it is important to keep a record.	Invoices in logbook	In the hardware design, we have been careful to choose only RoHS complient components. As the budget has been extremely limited, and the product is designed to be affordable, the cost of components has been carefully watched.
C	**Accept and exercise personal responsibility.**			
C1	Work reliably and effectively without close supervision, to the appropriate codes of practice.	This project has been an individual one, and while I have been working with Vojtech fo much of the project, we have both taken seperate roles and self-led our practices	Meeting minutes and logbook entries	
C2	Accept responsibility for work of self or others.	The work done by both Vojtech and me reflects our mutual responsibility in the project	Meeting minutes	See supervisor and Vojtech meeting minutes
C3	Accept, allocate and supervise technical and other tasks.	Many times in meetings, I have delagated work to Vojtech to ensure that we complete all the required tasks	Meeting minutes	See supervisor and Vojtech meeting minutes
D	**Use effective communication and interpersonal skills.**			
D1	Use oral, written and electronic methods for the communication in English1 of technical and other information.	Reflected in the interim proposal and progress report in which a written document and oral presentation were completed respectively. The technical aspects of the report needed to be communicated fully and effectively	Interim Proposal and Oral Presentation	Meeting minutes, emails (eg. sourcing the hyperspectral camera) Writen reoprts such as teh interim proposal
D2	Work effectively with colleagues, clients, suppliers or the public, and be aware of the needs and concerns of others, especially where related to diversity and equality	Many points have occured in the project in which I have had to contact professionals in the field to give feedback or suggestions on directions. Interviews were conducted at the beginning of the project to assess the usefulness of the initial project idea. Frequent supervisor meetings as well as meetings with vojetech have occured throughout the project	See Emails throghout the project. Minutes and interview notes in logbook	Working with Vojtech, considering needs of working from home and helping him with the language in the reports etc as English isn't his first language
E	**Make a personal commitment to an appropriate code of professional conduct, recognising obligations to society, the profession and the environment.**			
E1	Comply with the Code of Conduct of your institution.	IET "Members shall actively promote public awareness and understanding of the impact and benefits of engineering and technology achievements". Much of the project is bringning awareness to the issue of light at night.	See literature review	Complying with ethics of UWE and its policies (eg. soldering) as well as providing a risk assessment for work completed
E2	Manage and apply safe systems of work	Despite it making the project more difficult, I have ensured that safe working practices have been included, such as not soldering at home and avoiding social isolation in the pandemic	logbook notes	Risk assessment completed for the project
E3	Undertake engineering work in a way that contributes to sustainable development. This could include an ability to: • Operate and act responsibly, taking account of the need to progress environmental, social and economic outcomes simultaneously.	Sustainability of the device has been a focus point, making sure only RoHS complient components are used, not over or underordering components. The project itself is also trying to fix a problem with social sustainability such as health and wellbeing	logbook, component orders, literature review	The project is angled from a health perspective, so all of the work has been focussed on social and ecenomic outcomes. Of course the environment is also being considered and that has been reflected in the requirements document.
E4	Carry out and record CPD necessary to maintain and enhance competence in own area of practice including: • Undertake reviews of own development needs • Plan how to meet personal and organisational objectives • Carry out planned (and unplanned) CPD activities • Maintain evidence of competence development • Evaluate CPD outcomes against any plans made • Assist others with their own CPD			
E5	Exercise responsibilities in an ethical manner	Communications with interviewees	Consent forms, anonymisation process, etc.	Every stage of the project has required there to be ethical considerations on how to proceed,, from choosing components to interpreting the results.