VITAALLICHT
Requirements study

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1 Introduction

Several elements are vital for the existence of human life. One of those is light. Although we are not always aware of this, light regulates our biological rhythms (biological clocks) and has significant impact on the quality of our lives. In the evening we typically switch to more atmospheric lighting. We are aware that this influences our mood and emotions, since it makes us feel more comfortable. However there are also some other important effects of light that we are less aware of. For example, it influences our vitality, alertness and performance.

Our biological clock is important, because it regulates our 24-hourly sleep-wake rhythm, the circadian rhythm. It is located in the suprachiasmatic nucleus (SCN), on the hypothalamus, as shown in Figure 1. Light that passes through the eye reaches the retinohypothalamic tract (RHT), this nerve guides the signals of received light to the SCN. This is needed for the biological clock to keep the circadian rhythm synchronized with length of the days and nights (NSVV, 2006). Disruption of the biological clock, for example by exposure to light at night, can have harmful effects on the person, since it may lead to desynchronization of physiological and hormonal processes with a person’s activity patterns (Van Someren, Kessler, Mirmiran, & Swaab, 1997). But receiving bright light at the right time of the day can enhance the synchronization of the circadian rhythm with the corresponding daily activities and support health. Based on these insights a lot of research is done on light treatments of sleep- and mood disorders.

Some studies showed that daytime exposure to bright light could have a vitalizing effect on people suffering from dementia, and is able to slow down cognitive decline (Van Someren, Kessler, Mirmiran, & Swaab, 1997). As we all grow older there are certain factors that cause an increased chance on a weakened circadian rhythm, especially for elderly people. These factors may contribute to a decreased functioning of the biological clock. Such a factor is the decreased amount of light received through the eye. For instance due to the aging of the eye. Firstly, visual field area declines with age, so they start to see less (Sinoo, Van Hoof, & Kort, 2011). Also, the maximal pupil diameter decreases by circa 40%, as compared to adolescents, allowing less light to reach the retina. Also yellowing and turbidity of the vitreous humour causes less light to pass. An additional disadvantage of the yellowed eye is that it absorbs blue light (NSVV, 2006). Another factor is atrophy (shrivelling) of the cells of the SCN, this causes a direct decrease in the amount of light the biological clock receives. Because of these factors less light is received, which means more light is needed.
However, elderly don’t seem to receive this higher amount of light. Actually, there is reason to believe elderly receive even less light, this is because they go outside less (Shimada, et al., 2009). Reasons for elderly to go out less can be of physical nature (less energy, fear of falling) or psychological (fear for safety or getting lost). Considering the devitalizing effect of receiving insufficient light, mobility could be decreased even further. The decreased mobility will result in staying inside even more and receiving even less light. This in turn will reduce vitality, making the drive to go out even less, resulting in a vicious circle or a downwards spiral. With the continuous growth of the amount of elderly people in our society (CBS, 2012), it is of great importance they remain healthy and vital as long as possible and their quality of life remains high. In turn it will reduce the amount of people going to care homes, which is advantageous for these people, but also for the care costs.

A lot of research is being done on indoor lighting (Lek, et al., 2008; Sinoo, Van Hoof, & Kort, 2011; Beek, et al., 2006). Findings from studies on care homes suggest the lighting levels and colour temperatures are often too low\(^1\) for biological stimulation (Sinoo, Van Hoof, & Kort, 2011). Basically, the idea is to allow the elderly to receive the right amount of light inside their living room. Also, better lighting conditions showed to reduced derogation of Alzheimer’s disease patients (Van Someren, Kessler, Mirmiran, & Swaab, 1997), which is positive for their quality of life.

This project explores the requirements for an indoor lighting system. There are several different ways to implement this, with a variety of lighting levels and colour temperatures. However, there is no consensus about an optimal solution yet. One of such lighting systems is Vitaallicht. Vitaallicht is a standing floor lamp for home situations. The prototype of this system was made available to include in our experimental design. Vitaallicht differs from a regular lamp, because it is able to use a dynamic light pattern: it changes during the day in colour temperature and illuminance, simulating for instance a daylight cycle. In this basic pattern, the lamp is much brighter, and during noon much more blue, than regular lamps. It is specifically developed to stimulate the biological clock of humans, as does the daylight.

In this study will include a literary review, an empirical study and measurement of the Vitaallicht prototype. The literary review investigates what the current guidelines for lighting levels and colour temperatures are. Furthermore it also investigates how the guidelines differ between subjects (elderly compared to (young) adults) and between environments (ergonomic compared to atmospheric). In the empirical study a diary study is performed. In this study, elderly participants kept a day to day diary. This was to try to gain insight in the daily routines, sleep-wake rhythms, their mood and their opinion about the lighting in their homes. In the second week of the diary study the Vitaallicht prototypes where put at the homes of the

\(^1\) Derived from the NSVV guideline (NSVV, 2006)
participants. During this second week participant could evaluate the prototype in the diary, giving us a better insight in the user preferences.
2 Literary Review
In this section the current guidelines for lighting levels will be investigated, mainly focused at older adults. In this review there is a distinction made between environmental lighting and lighting for visual tasks, like reading, which will be referred to as ergonomic lighting. Furthermore some extra literary research was done concerning the biological processes, to support the basis on which the guidelines will be based. The discussion will start off with these biological processes.

2.1 Light and biological stimulation
For human beings, the day-night cycle is of vital importance for their survival. Naturally, people use the day for activities, and use the night to recover, by sleeping. Our eyes need light to see and seeing allows us to interact with our environment. This can involve motoric tasks, but also cognitive like reading. Also, our skin is stimulated by the infrared light and ultraviolet light, and for example helps with the creation of vitamin D (NSVV, 2006). Light that passes through the eye is especially important for human performance. Non-visual effects are activated by the light, these are called the NIF (Non image forming)-effects (NSVV, 2006). These NIF-effects are less obvious, but not less important. NIF-effects influence our biological clock, so light helps the body to function in a way that is appropriate for the time of the day. The biological clock resides in the suprachiasmatic nucleus (SCN), near the hypothalamus (NSVV, 2006). Basically, it functions as a complicated oscillator, regulating day/night rhythms, week rhythms, month rhythms and seasonal rhythms. The biological clock regulates certain body processes and hormone levels, which makes humans with a well synchronized circadian rhythm able to perform best during the day, and sleep well during night. One of those cycles controls the production of the hormones melatonin and cortisol, which is very important for the sleep/wake rhythm. The pineal gland creates melatonin, the “sleep” hormone. With light stimulation, the SCN inhibits the secretion of melatonin, decreasing the sleepiness of the human. In the dark, melatonin creation will not be inhibited (NSVV, 2006). So regarding day and night cycles, if the melatonin level is low during the day and shows peaks during the night.

![Figure 2: Hormone levels during 2x24-hours cycle](image)

A second hormone of importance is cortisol. This is created in the adrenal cortex. This is often called the stress hormone, because stress increases its production. However, also light
stimulates the cortisol production. So the cortisol level also shows a correlation with the circadian rhythm, but inverted compared to the melatonin level (see Figure 2). Higher fluctuations in melatonin levels will occur when there is a strong circadian rhythm, and it helps elderly to be less sensitive to light at night. Melatonin is also an antioxidant and also raises the resistance of our immune system (Beek et al., 2006). Melatonin- and cortisol levels that follow the circadian rhythm, make us feel vital and alert during the day and help us sleep well at night and help us stay healthy. Synchronization of these cycles is guided by the sufficient light stimulation.

2.2 Illuminance en spectrum
The effectiveness of light on the biological clock is dependent of some specific properties of light. Namely intensity of certain wavelength within the spectrum, mainly the shorter wavelengths. The intensity level of illuminance is denoted by lux (lumen / m²). Although it will not always easily noticeable for the human eye, illuminance levels vary substantially during the day. Also the maximum level of illuminance of a day can differ allot from the next. As example, on a very dark day the light levels can be around 100 lux, while on a clear day the light levels will go over 10.000 lux (Schlyter, 2009). In direct sunlight they even go over 100.000 lux. Inside buildings it is often substantially less and regularly stay under a 1000 lux. An illuminance level below 1000 lux is not desirable, for enough biological stimulation at least 1000 lux is desired (Lek, et al., 2008). Light typically contains a mixture of different wavelengths creating a characteristic spectrum per light source. The human eye is able to see wavelengths between 390 to 700 nm (Starr, 2005). The NIF-effects are the strongest for light of the spectrum between 430 to 460 nm (blue light), as shown in Figure 3. In sum the NIF-effects are influenced by the intensity combined with duration, timing of the exposure, spectral composition and distribution of light on the retina (NSVV, 2006).

The colour temperature is determined by the combination of different wavelengths in the light, as a sum of the spectrum. As seen in Figure 4 the low colour temperatures are more warm and red, while the high values are more blue and cold. In our culture, the bright cold light is associated with activity, while the warm light is associated with cosiness and relaxation (NSVV, 2006).

![Figure 3: Relative spectral sensitivity of eyesight (V(λ)), and for NIF-effects (B(λ)) (Van Bommel, 2010)](image-url)
Noon is a very important moment of the day for biological stimulation, as the light levels are at maximum radiance and the colour blue is least filtered by the atmosphere, leading to a higher colour temperature. These colour temperatures lie around 6000K as is shown in Figure 4. None the less such high colour temperatures as experienced outside are not comfortable for indoor lighting, especially living situations. At noon a lower colour temperature between 4000K and 5000K is more appropriate for an indoor lighting system.

2.3 Optimal Lighting Levels
The ideal lighting level is dependent of the situation as well as a single person’s visual characteristics, so there is not one specific lighting level that is optimal for everyone.

When a visual task is performed (like reading), it typically requires more light compared to relaxed situations (conversing, listening to music). It also differs from person to person, this is a matter of preference, but it is also dependent on the quality of the eyes, since it affects the subjective lighting experience.

2.3.1 The aging eye
As people age, the quality of their sight decreases. This is caused by several changes that occur, such as (Aries, Van der Vries, & Westerlaken, 2010):
- The pupil dilates less, allowing less light to enter
- Yellowing, dimness, thickening and inflexibility of the lens
- Turbidity of the vitreous humour
- Decreased density of photoreceptors
- Decreased eye fluid regulation

These factors cause less light to be transmitted through the eye onto the receptors. Light entering the eye gets scattered more strongly and the yellowing of the eye absorbs the blue component of the light. This also causes a bigger sensitivity for blinding of light (Aries, Van der Vries, & Westerlaken, 2010)

These aging effects combined, allows elderly (65+) to receive only 30% of the light compared to the amount they received as an adult (25+). However, this is wavelength dependent: Figure 5 (Van Bommel, 2010) shows the light transmittance of a 65 year olds relative to a 25 year olds. Interesting to see is that the short wavelengths are filtered the more than longer wavelengths.
Possible cause for this stronger filtering of the short wavelengths is that light is more deflected by the eye lens and more absorbed by the yellowing of the lens which causes less of it to reach the retina (NSVV, 2006).

This decrease in light transmittance of the eye is often connected to atrophy (shrinkage) of the SCN. This has led to the hypothesis that elderly people need more light, especially of the shorter wavelengths, to correct as much as possible for the amount of light they receive less. This should lead to less shrinkage of the SCN, maintaining the functionality of the biological clock of elderly people (NSVV, 2006).

2.4 Light levels for the aging eye

Lighting is of functional value but should be comfortable as well, this complicates the determination of an optimal lighting level. Functional lighting is aimed at creating a lighting condition for optimal visual performance. Visual performance is needed for household tasks like cleaning as well as leisure tasks like puzzling and reading. This is important for older adults, because insufficient functional lighting increases the risk of bumping against- or tripping over objects, intake of wrong medicines, headaches and irritated eyes (Aries, Van der Vries, & Westerlaken, 2010).

2.4.1 Light for visual tasks

Current research that is being done is about how lighting levels can help elderly as good as possible. The international norm, which is based on the regular (not aged) eye, is 500 lux for visual tasks like reading and 750 lux for refined visual tasks like handiwork (NEN-EN 12464, 2003). This is not enough for the aged eye, so higher lighting levels should be used. However, caution is advised when using very bright levels for elderly, since they get blinded more easily and can have a lot of other visual problems. It is of great importance that they are experienced as pleasant to them. A study by Evans (2010) showed that elderly with low to very low vision
were best able to read at a high intensity light of 3500 lux, however, the individual preferences differed a lot. So personal factors prove to play a big role as well, this is why it might be best to individually assess the preference and performance with different lighting levels when providing an optimal lighting for older people (Evans, 2010). Davis and Garza (2002) concluded that a lighting level above 1000 lux had the best visual performance for visual tasks and were best appreciated by the participants, aged between 62 and 76 years. Spectral composition did not seem of great influence on visual performances (Aries, Van der Vries, & Westerlaken, 2010).

2.4.2 Light for NIF-effects
With elderly people, especially demented elderly, circadian rhythms tend to become unstable and decrease in amplitude. Studies have shown that stimulating the NIF-effect, by offering extra light, decreases the negative consequences of a badly functioning circadian rhythm (Van Someren, Riemersma, & Swaab, 2005).

For non-visual effects of light (NIF effects) there is a different spectral sensitivity, as we have seen in figure 3. A different sensitivity in terms of lighting levels may exist as well. Lek et al. (2008) found at least 1000 lux is desirable. But for elderly, the decrease in light transmittance of the eye and possibly weakened circadian rhythms should be taken into account, which makes it likely the needed light level should be higher. Compared to a 20 years old, a 60 years old needs 3 times as much light (NSVV, 2006).

Blue light is most effective for stimulating NIF-effects, especially with wavelengths of 430 to 460 nm, resulting in higher colour temperatures. However this is experienced as cold, bright and uncosy. More preferred are lower, warmer colour temperatures. For example, Kolanowski (1990) found elderly preferred a warm-white colour of 2700K, with a full spectrum.

2.5 The optimal light condition
In conclusion, some important technical factors for a lighting system are found: - It should be able to offer high capacity: For functional lighting the literature suggest very high lighting levels (up to 4000 lux) minimally 1000 lux. However the optimal level differs per situation and per person, which forms the next factor: - It should be adaptable. Fine-tuning to an optimum is lacking in the literature. There is no general optimal lighting level, because it is dependent of personal preference and eye condition (Evans, 2010). Therefore it is best if the lighting level is adjustable by the person itself. It is also possible to determine an optimum by measuring visual performance individually, but this is a much more labour intensive method.
- A strong spectral component of blue (430 to 460 nm). An important factor for stimulating NIF-effects, is the spectrum. The blue part stimulates NIF-effects the most. Also, additional blue light compensates for the yellowed eye lens (Aries, Vlies & Westerlaken, 2010).

- The spectrum should be full and ‘warm’. Although blue light is beneficial, it is often experiences as cold, bright and uncosy. The colour temperature should be warm, which makes the amount of blue light dependent on the amount of longer wavelengths already in the spectrum. Thus how much of the blue spectrum can be added such that the colour temperature is still pleasant. Basically, this means a full spectrum is required.
3 Vitaallicht Prototype

During this study there was a prototype of an indoor lighting system made available, this prototype is called Vitaallicht, designed and developed by Maarten Voorhuis. The Vitaallicht Lamp is a standing floor lamp with a specialized configuration of LED’s. For controlling purpose the LED are split into two arrays, such that an intensity difference within its own spectrum can be created. The first part is the blue “cold” part of spectrum, the second part is the yellow-red “warm” part (see Figure 6). The prototype is fitted with a microprocessor to regulate the LED-array’s. With the help of an internal clock and a small piece of code the lamp is able to follow a dynamic day pattern. This pattern is two dimensional. First dimension is intensity of the light, the second is the colour temperature. The microprocessor controls the colour temperature and total light intensity slowly over time via intensity of the two arrays. For example; making the lamp follow a dynamic day like pattern, soft warm-white (part 1 at 40%, part 2 at 40%) in the morning, to intense cold white (part 1 at 100%, part 2 at 80%) in the midday to warm-white (part 1 at 50%, part 2 at 60%) in the evening.

Figure 6: Spectrum of vitaallicht prototype, 1 = cold spectrum , 2 = warm spectrum. (All LED’s at full power)

* note that two parts are only indicative and do not represent the true spectrum.
To measure the abilities of this lamp it is only measured at full power, meaning both LED-array’s at maximum capacity. The pattern selected was a non-dynamic constant maximum output. This is necessary to see if the vitaallicht prototype meets the minimal technical requirements, as found in the literature.

3.1 Measurement setup
Measurements were done using a spectroradiometer (model: Jeti Specbos 1201). In Figure 7, a schematic overview is shown of the setup and the different measurement points. Figure 8 and Figure 9 are photos of the measurement conditions and setup.

Figure 7: Schematic overview with different points of measurement

Figure 8: vertical measurement with points at 1-, 2- & 3m

Figure 9: horizontal measurement with laser target
Two series of measurements were performed on the lamp. The first is called the start-up condition, the second the final. The reference measurement was made directly after the lamp was turned on. The first set of measurements were taken 20 minutes after switching on the lamp, the lamp was still cold. The second set of measurements were taken after the lamp was 3 hours continuously in operation, the LED’s and the heat sink were warmed up.

The measurement took place in a dark room, hence the light measured is only light from the lamp. The measurement device was never aimed directly at the source and the laser target in the device to aim at the same position on a white surface for each measurement. A white surface was used to assure the reflection of the light has the same spectrum as the light form the source. Measurements were taken at 1-, 2- and 3 meter from the white surface on the wall, all on a height of 1,30 meter, which is approximately eye-height in a sitting position. The measurements are taken at the front of the spectroradiometer, the device can function as a good representation the amount of light reaching the a human eye. this has to do with the way the device measures. On front of the spectroradiometer there is a difusorcap thus the device only measures the light passing through this cap. This also makes it possible to measure in a horizontal or vertical plane, specific viewing directions and at different distances from a source. The measured light in the vertical measurements consists of the light from the reflection of the surface it was aimed at combined with the light coming directly from the source. In the horizontal measurement it was only the reflection from the white surface.

### 3.2 Results

The vitaallicht prototype shows a very specific characteristic spectrum, Figure 6

There is a specific characteristic visible. The lamp has an extra strong peak, when the lamp heats up this peak ranges from 445 nm (in start-up condition) to 447 nm (in final condition).

In Table 1 the results of the vertical measurements are shown (setup shown in Figure 8). It includes the light levels in lux, as well as the colour temperature in Kelvin, for distances of one, two and three meters.

Table 2 shows the results of the horizontal measurements, at a height of 1,15 meter (setup shown in Figure 9).
### Table 1: Measurements on the vertical axis

<table>
<thead>
<tr>
<th>Distance m</th>
<th>lux (start-up)</th>
<th>K (start-up)</th>
<th>lux (final)</th>
<th>K (final)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1382,00</td>
<td>4393</td>
<td>1268,00</td>
<td>4455</td>
</tr>
<tr>
<td></td>
<td>1369,00</td>
<td>4403</td>
<td>1268,00</td>
<td>4451</td>
</tr>
<tr>
<td></td>
<td>1366,00</td>
<td>4404</td>
<td>1268,00</td>
<td>4450</td>
</tr>
<tr>
<td><strong>avg.</strong></td>
<td><strong>1372,33</strong></td>
<td><strong>4400,00</strong></td>
<td><strong>1268,00</strong></td>
<td><strong>4452,00</strong></td>
</tr>
<tr>
<td>2</td>
<td>343,00</td>
<td>4265</td>
<td>328,30</td>
<td>4265</td>
</tr>
<tr>
<td></td>
<td>343,20</td>
<td>4268</td>
<td>327,20</td>
<td>4269</td>
</tr>
<tr>
<td></td>
<td>342,50</td>
<td>4269</td>
<td>327,80</td>
<td>4298</td>
</tr>
<tr>
<td><strong>avg.</strong></td>
<td><strong>342,90</strong></td>
<td><strong>4267,33</strong></td>
<td><strong>327,77</strong></td>
<td><strong>4300,00</strong></td>
</tr>
<tr>
<td>3</td>
<td>169,40</td>
<td>4201</td>
<td>168,30</td>
<td>4232</td>
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<tr>
<td></td>
<td>168,80</td>
<td>4203</td>
<td>168,60</td>
<td>4231</td>
</tr>
<tr>
<td></td>
<td>168,90</td>
<td>4205</td>
<td>168,30</td>
<td>4229</td>
</tr>
<tr>
<td><strong>avg.</strong></td>
<td><strong>169,03</strong></td>
<td><strong>4203,00</strong></td>
<td><strong>168,40</strong></td>
<td><strong>4230,67</strong></td>
</tr>
</tbody>
</table>

### Table 2: Measurements on the horizontal axis

All measurement results are shown in one graph, Figure 10. The results of the vertical measurements are shown by the green, red, and orange coloured lines, on the distances of respectively 1-, 2-, and 3 meter. The horizontal measurement is represented by the blue coloured line.

<table>
<thead>
<tr>
<th>Distance m</th>
<th>lux (start-up)</th>
<th>K (start-up)</th>
<th>lux (final)</th>
<th>K (final)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,15</td>
<td>215,40</td>
<td>4369</td>
<td>206,10</td>
<td>4412</td>
</tr>
<tr>
<td></td>
<td>216,50</td>
<td>4369</td>
<td>204,30</td>
<td>4410</td>
</tr>
<tr>
<td></td>
<td>215,30</td>
<td>4370</td>
<td>205,70</td>
<td>4409</td>
</tr>
<tr>
<td><strong>Gem.</strong></td>
<td><strong>215,73</strong></td>
<td><strong>4369,33</strong></td>
<td><strong>205,37</strong></td>
<td><strong>4410,33</strong></td>
</tr>
</tbody>
</table>
When taking a closer look into the data we notice the following things when the lamp heats up. Over time, the overall amount of light decreases slightly and the overall colour temperature rises slightly. The slight decrease in light is visualized by the thickness of the lines in Figure 10. In this graph the upper line is the reference line, this is the initial measurement taken from 1 meter directly after switching on the lamp. Figure 10 and Table 1 and 2 now clearly show the decrease in luminance. Both tables also show the slight increase in colour temperature, this means that when looking in the graph the lower colour temperature (the red / orange / yellow / green part of the spectrum) drops with a bigger amount of radiation then the higher colour temperature (the blue part of the spectrum) thus increasing the average colour temperature. Thus the surface of the decrease in Figure 10 is larger in the lower colour temperatures.
3.3 Technical Discussion

The Vitaallicht prototype produces, within the range of 1 meter at full power, over the minimal requirements of 1000 lux found in the literature. Even though the intensity slightly decreases, due to warming up while in use, by approximately a 100 lux (in 3 hours) at the 1 meter distance it is still above 1200 lux, which is enough for the NIF effects to occur.

The colour temperature at 1 meter is approximately 4400K, depending on the time the lamp has been in operation. This can be seen as a good replication of a noon daylight situation. With the capacity of the lamp to reach a noon daylight representation and a dynamic pattern it is indeed very likely that the lamp is capable of simulating a day cycle, although the lower light settings and capabilities of the Vitaallicht prototype are not tested. As a side note: the colour temperature slightly rises with 30K to 40K, but this is not a significant change.

Taking a closer look at the spectrum of the Vitaallicht prototype. It shows a very high peak in the blue part of the spectrum, 1,6 times the yellow/red spectrum, see Figure 11.

Comparing the spectrums of different types of lighting, we see some salient differences. The natural daylight contains a lot of blue light (Figure 12). We can see that in the light sources that are developed for therapy (Figure 13) the spectral composition contains a lot of blue light in the spectrum as well. The sun has a so called full spectrum. It is a full spectrum when the light source emits light over the full range of the spectrum, without interruptions or extreme spikes. Where the daylight therapy light has a closer representation of the light from the sun its peak of blue light lies around 480 nm being just outside the best range for the NIF effect (430 nm – 460 nm). Vitaallicht has the blue light peak at bit lower around 445 nm so at the top sensitivity for the NIF effect. Both the therapy and the vitaallicht lamp get close to the full spectrum of the sun, where vitaallicht has a bigger gap the therapy lamp has some extreme spikes. When looking from a biological view the vitaallicht has a better positioned blue peak.

To give a short overview of what regular lighting systems reach with regard to spectrum, in Figure 14 and Figure 15 are shown the spectrum characteristics of respectively regular TL-Lighting and for a regular incandescence light bulb. The TL-light shows a few small peaks of which a few of them are in the blue spectrum, however the peaks are so small that the biological effect will barely occur, the spectrum is also very scattered with lots of spikes and
thus far from the full spectrum of the sun. The regular incandescence light bulb has again a skewed full spectrum and is very minimal in the amount of blue light emitted.
4 References


