The effects of coloured light on atmosphere perception

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Preface
This Master thesis represents my graduation project at the Human Technology Interaction program of the Eindhoven University of Technology. In cooperation with the Visual Experiences department of Philips Research, I studied the effects of coloured light on atmosphere perception. During my study, I gained knowledge on conducting and reporting a scientific research and expanded this experience in the field of perception, lighting, colours, emotions and atmosphere.

I enjoyed my stay at Philips Research with the perception group and I would like to specially thank Ingrid Vogels for her guidance and contribution to my project. Also, I would like to thank my supervisors Wijnand IJsselsteijn and Yvonne de Kort of the Eindhoven University of Technology for giving me the opportunity to graduate in their field of expertise. Furthermore, I would like to thank Pieter Seuntiens and Stefan Swinkels for rebuilding the ceiling of the experimental room, Dragan Sekulovski for helping me with the measurements, Robert the Volder for his help in MatLab and the perception group for all the great coffee breaks. Last but not least, I want to thank my parents, family, friends and David Stibbe for their patience and unconditional support.

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Summary
Light is surrounding us everywhere and is needed to function in daily life. Light has an effect on visibility, health and well-being. It can even evoke emotional reactions and create certain atmospheres. Atmosphere can be described as the affective evaluation of an environment and is expected to be a more consisted variable than emotions or moods. Today’s technology makes it possible to create atmospheres not only by using general white light, but also decorative coloured light. However, the effects of coloured light on atmosphere have not yet been studied extensively, but are interesting for companies like Philips.

This study investigated how coloured light influences the perceived atmosphere in a space. Not only were the effects of coloured light on the perceived atmosphere studied, but also the effect on the perception, preference and suitability of the lighting. The characteristics of the lighting that varied were: the colour temperature of general white light and the lightness, saturation and hue of decorative coloured light.

A colour model was used to quantify the values of the independent factors, colour temperature, lightness and hue. To quantify the independent factor saturation, two pilot experiments were conducted to perceptually match the saturation level of all hues. The first pilot experiment perceptually equalized the saturation of one hue at different lightness levels. The second pilot experiment perceptually equalized the saturation level of all hues to the chosen saturation level of pilot 1.

The atmosphere was assessed by the atmosphere questionnaire developed by Vogels (2008). This questionnaire provided scores for four atmosphere dimensions: cosiness, liveliness, tenseness and detachment. Questions about characteristics, preference and suitability of the lighting were added to this questionnaire. In total nineteen light conditions were shown for participants to evaluate. For each of the four independent factors a Mixed Models Analysis of Variance was performed to analyse the results of nine dependent variables derived from the questionnaire.

The results indicated that coloured light does have a significant influence of atmosphere perception. The results showed for the general light that the light conditions presented in a cool white light setting were perceived as more bright, less cosy, less tense and less detached than light conditions presented in a warm white light setting. Furthermore, the warm white light setting was assessed to be more suitable for a living room and an office.

For the decorative light, the results showed effects of lightness, saturation and hue. High lightness was perceived as more bright, more lively and more preferred than low lightness. Maximum saturation found to be less cosy, more tense, less detached and less preferred. Also, maximum saturation was evaluated as less suitable for a living room and an office. The results for hue showed that red was perceived as less bright and cyan was perceived as more bright. Red, magenta and yellow were perceived as warm colours, blue and cyan as cool colours and green and white as neutral colours. Furthermore, red and yellow were perceived as most cosy, while magenta was perceived as least cosy compared to the other hues. For tenseness, red was perceived as most tense, whereas yellow was perceived as the least tense and. White was the least lively but most detached hue followed by cyan, while red was the least detached compared to the other hues. For preference, cyan and yellow were the most preferred. Red, yellow and white were assessed to be suitable for a living room, whereas cyan and white where suitable for an office.

This study gives a valuable start in the study of coloured lighting characteristics on the perceived atmosphere. However, future studies on spatial distribution, colour combinations, daylight and demographical features could improve the insight on the effects of coloured light on atmosphere perception.
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1 Introduction

Light is surrounding us everywhere, within enclosed spaces and outside in open spaces. Light is needed to function in daily life. It has an effect on visibility, health and well-being and it can influence one’s affective state. An affective state refers to the feelings, emotions and moods which one can experience (Izard, Kagan, & Zajonc, 1984), and it can be influenced by many environmental factors like sounds, smells or light. Colour can also have an influence on one’s affective state. Colours can be associated with emotions and events. For example, blue can remind people of ocean and relaxation and red can remind people of love and blood.

Although both light and colour can have an influence on a person’s emotions, the combination “coloured light” in relation to emotions has not been studied extensively. Contradictory results have been found on this topic, which can be explained by the fact that emotions are influenced by many environmental and non-environmental cues. Atmosphere perception is expected (Van Erp, 2008) to be a more stable and consistent to study compared to studying emotions in an environment. There has been some research done on the influence of light on the perceived atmosphere of an environment (Vogels, 2008). Atmosphere can be defined as the affective perception of an environment and as such it is not an affective state. However, it can evoke but it does not have to. For example, one can be sad but perceive the environment as lively or one can be happy but perceive the environment as stressed and because of the environment become less happy after some time.

When changing an atmosphere, for example by altering the colour of a room, it is much easier to vary the lights, especially since the introduction of LED lights, than changing the paint on the wall. Therefore, it would be quite interesting to know what the influence of coloured light is on the perceived atmosphere. Unfortunately, little knowledge is available about the effects of coloured light on atmosphere perception. One recent study (Moors, 2009) showed that coloured light has significant effects on the perceived atmosphere of a room. Moors used a combination of general white light and decorative colour light with two colours: red and blue. Unfortunately, those two colours were not quantified in terms of the colour attributes lightness and saturation. Therefore, it is not clear if the effect of blue versus red was due to a difference in lightness, saturation or hue.

A more controlled approach for studying the effects of coloured light on the perceived atmosphere was required. For this research not only the effects of light characteristics on the perceived atmosphere were studied, but also the effect on the perception, preference and suitability of the lighting. The light characteristics that varied were: the colour temperature, lightness, saturation and hue of coloured light. Consequently, the research question of this research is:

“What is the effect of coloured light on the perceived atmosphere of a room, the perception and preferences of the lighting and the suitability for different applications of a space?”

In this report the results are presented of the experiment that has been conducted to answer the research question by answering the following sub-questions.

- “What is the effect of colour temperature of white light?”
- “What is the effect of lightness?”
- “What is the effect of saturation?”
- “What is the effect of hue?”

The hypothesis of this research is that all these coloured light characteristics have an influence on the perceived atmosphere.

This report will first present a literature review of relevant studies. The next section will discuss the experimental design of this research followed by a section about the methods of the experiment. Then a section will elaborate on the results found in this investigation. Finally, a discussion of the results and recommendation for further research will be presented.
2 Literature
Currently, little knowledge is available in literature about the effects of lighting on perceived atmosphere. There have been investigations about the perception and preferences of light characteristics, emotions towards colour and atmosphere perception. In this section a literature review is presented to get background knowledge about these topics.

2.1 Perception of Light characteristics
The human eye is able to perceive light, which is an electromagnetic radiation of a wavelength between approximately 380 and 780nm (Boyce, 2003). Light entering the human eye is projected on the rod and cone cells of the retina (Kandel, Schwartz & Jessell, 2000). Rod cells support vision at low light levels while cone cells support colour vision and vision at normal light level. Three types of cone cells exist, which are sensitive for short, medium and long wavelengths. These cones support the vision of red, green and blue colours in the visible spectrum, which is called trichromatic colour vision (Wyszecki & Stiles, 2000). By combining the signals of the three cones, a variety of colours can be perceived by the human visual system.

Colour can be expressed in three visual characteristics: (1) brightness or lightness, (2) saturation and (3) hue (Munsell, 1946; Fairchild, 2005). Brightness can be defined as the perceived amount of light, making a distinction between bright and dim light. Saturation refers to the visual sensation according to which the perceived colour appears to be more or less chromatic. Hue, the last characteristic, distinguishes between colours by name, e.g. red, blue, green, yellow and so on, related to the dominant wavelength of the visible spectrum.

For a better understanding of the light characteristics used in this report the following concepts will be discussed in more detail: the brightness, the colour of white light (achromatic light) and coloured light (chromatic light).

2.1.1 Brightness of white light
As mentioned above, brightness indicates the perceived amount of light. The amount of light reflecting from a surface can be expressed in terms of luminance (cd/m²). Illuminance (lumen/m² or lx) is the amount of light that falls on a surface. Luminance and illuminance are related to the visual perception of brightness, but brightness and luminance or illuminance are not the same.

According to Weber’s law the just-noticeable difference (jnd) of brightness is \( \Delta I/I_0 = k \) (Wyszecki & Stiles, 2000), where \( I_0 \) is the reference intensity, \( \Delta I \) is the perceived difference (or jnd) and \( k \) is a constant. In a pilot study of Van Erp (2008) the jnd for brightness was studied in the same experimental room used for this study. He found \( \Delta I/I_0 = 0.12 \), which meant that a change of approximately 12% in brightness was required for participants to be able to see a difference in brightness.

Many studies have investigated the relation between the illuminance of a room and the perception of brightness. Research has found that a room with a higher illuminance is perceived as brighter compared to a room with lower illuminance (Davis & Gintherner, 1990). However, the perception of brightness is not solely dependent on illuminance but also on the spatial distributions of the light in the room. Loe, Mansfield & Rowlands (1994) reported that the average illuminance of a room within the 40 degrees horizontal viewing angle accounts best for the perception of brightness. The viewing angle is not the only dependent factor for the perception of room brightness. Iwai, Saito, Sumi & Sagakuti (2001) showed that the visual direction of the observer is also of importance for the perception of room brightness. Kato and Sekiguchi (2005) investigated the effect of visual direction on the impression of brightness. The results showed that illuminations in the horizontal direction were assessed as brighter than illuminations in the vertical direction.
2.1.2 Colour of White light

The colour of white light emitted by a light source can be characterized by its colour temperature (CT), measured in Kelvin (K) (Boyce, 2003). The colour temperature corresponds to the temperature of a black body radiator which has the same colour as the light source. As an example, a candle flame has a colour temperature of 2200K, 75Watt light bulb has a colour temperature of 2800K, halogen light has a colour temperature of approximately 3100K and daylight (clear sky) has a colour temperature of 6000-6500K varying over day (Hunt, 1991). Most often standard illuminants like D_s (noon daylight, 6500K), A (light bulb, 2800K) or E (equal amounts of energy at each wavelength, 5454K) are used when working with colour temperatures.

When the colour of the white light source deviates from the black body radiator, the colour of a white light source can be defined by the correlated colour temperature (CCT) which is most often used in practise. The CCT corresponds to the colour temperature for which the perceived colour is as similar as possible. The CCT can be evaluated on a bipolar scale from warm to cool (Boyce, 2003). David and Ginther (1990) showed that a low CCT of 2750K is perceived as “warm” whereas a high CCT of 5000K is perceived as “cool”.

The smallest difference in CT that people can discriminate depends on the CT. A good metric that describes the jnd in CT is the reciprocal mega klevin ($10^6$ K$^{-1}$). Judd (1932) found a threshold of 5.5(MK$^{-1}$) between 1800K and 11000K; i.e. a change of 5.5(MK$^{-1}$) in CT is required for humans to see a noticeable difference in CT.

2.1.3 Coloured light

When, in research, working with colour, it helps to have a colour classification system for creating order in the colour characteristics. For instance, Munsell’s (1946) colour system is one of the known and often used colour systems in colour research. By making a mathematical colour model of a colour system one can provide a colour space on which the colour model is mapped. The colour space aims to be perceptually uniform. Using a colour space makes the interpretation of colour better understandable for research means. There are numerous colour spaces known in research. In this report only the colour spaces used in this research are described in more detail.

XYZ & xyY Colour space

One of the first colour spaces was created in 1931 by the Commission Internationale de l’Éclairage (CIE) and was defined as CIE 1931 or CIEXYZ. This colour space is a mathematical model based on the experimental results of the trichromatic colour vision of humans. The values from this trichromatic colour vision were denoted as X, Y and Z, labelled the tristimulus values.

From this CIEXYZ colour space the CIE xyY colour space was derived. The two parameters x and y denote the chromaticity of a colour and the parameter Y denotes the luminance of a colour. A widely known figure is the chromaticity diagram (Figure 2.1) which shows a 2D graph of all chromaticity coordinates that exist in nature. In this figure the Planckian locus of the black body radiator is also shown which has been discussed in section 2.1.2.
Figure 2.1: The CIE xyY colour space chromaticity diagram. The outer curve show the wavelengths in nanometers and the black body curve represents the CT and CCT in Kelvin.

LAB Colour space

The CIEXYZ is useful to describe colour in physical terms but it cannot predict the perception of colour differences. CIEXYZ is an absolute colour space where equal differences between colours do not correspond to the perceived differences between the colours. For example, the same difference in XYZ coordinates can perceptually change red into orange while blue still remains blue. In order to create a colour space that is based on the quantification of the perception of colour differences, the CIE 1976 (L*a*b*) colour space, abbreviated CIELAB (Wyszecki & Stiles, 2000; Fairchild, 1998) has been derived from the CIEXYX colour space. The L* in the CIELAB colour space represents Lightness and ranges from 0 to 100, the a* refers to the redness-greenness and the b* refers to the yellowness-blueness (Figure 2.2).

Figure 2.2: The representation of the CIELAB colour space.

The CIELAB colour space uses Lightness to describe the perceived brightness of a colour relative to the brightness of a similarly illuminated white area. This similarly illuminated white area is called white point in CIELAB. For example, a white paper exposed outside in the sunlight has a different brightness that the same white paper exposed inside under a light bulb, but the lightness level of the
white paper outside is equal to the lightness level of the white paper inside. Therefore, the difference between CIEXYZ and CIELAB is that CIELAB is a colour space where the lightness is relative to a white point, while CIEXYZ is an absolute colour space.

The relative lightness used in CIELAB is based on the phenomenon “chromatic adaptation”. Human vision is sensitive to light and is always adapting to the light level in which one is present (Fairchild, 1998; Luo & Hunt, 1998; Wyszecki & Stiles, 2000). For example, walking out of a dark movie theatre into bright daylight the visual systems needs to adapt to the sudden bright light. In other words, one becomes more sensitive to bright light and less sensitive to dark light.

**LCH Colour space**

CIELAB provides a good computational model for predicting perceived colour differences. However, as discussed earlier, colours are expressed in brightness or lightness, saturation and hue, and not in terms of redness or blueness as in CIELAB. Saturation is an often used term that leads to confusion. Usually “colourfulness” is meant which is expressed in terms of saturation (s) or chroma (C), although these are not the same. Saturation is the colourfulness of an area compared to its brightness, whereas chroma is the colourfulness of an area compared to the brightness of a similarly illuminated area that appears white. However, saturation is more often used term and will therefore also be used in this report to describe colourfulness.

The CIE (L* C*h), in short CIELCH, is based on CIELAB (Figure 2.3) but expresses colours by Lightness (L*), Chroma (C*) and hue (h), which are closer to the three visual characteristics than the a* and b* of CIELAB.

![Figure 2.3: The CIELAB and CIELCH colour spaces.](image)

Although in theory it seems rather easy to define colour in terms of hue, saturation and lightness, in practice this turns out to be more difficult, because the perception of these colour characteristics are not dependent at his moment. There is no universally accepted model for colour science as today’s models all have their flaws. Stalmeier and de Weert (1994) noted, for example, that when the saturation of an object increases the perceived brightness also increases, which is known as the Helmhholz-Kohlrausch effect. Closely related to the Helmhholz-Kohlrausch effect is the Hunt effect (Fairchild, 1998), which states that the saturation increases with its luminance level. Also, Stalmeier and de Weert found in their research that at the same luminance an achromatic stimulus (black, grey
and white) appears to be less bright than a chromatic (coloured) stimulus. These effects show that in practice working with colour is challenging and these effects need to be taken into consideration for this research.

2.2 Preferences, Emotions and Associations

In the previous sections, a general introduction on light characteristics has been provided. However, knowledge on the perception of light characteristics such as brightness, colour temperature and colour is not sufficient for understanding how people respond to these stimuli. In this section, first the concepts affective state, preference and associations will be described and next, the impact of white light and colours on these aspects is discussed.

An affective state corresponds to an emotion, mood or a subjective feeling (Blechman, 1990). Mood is less intense, less specific and long lasting compared to emotions. An emotion is a biological response to current environmental stimuli whereas a mood is a mental response to emotions and is effecting the expectations about the future (Batson, Shaw & Oleson, 1992). Emotions can be experienced in different intensities depending on the importance of the circumstances (Lazarus, 1982). Several models exist for describing and measuring emotions based on behavioural or cognitive response of a person. Ekman (1992) classified emotions based on facial expressions and introduced a basic universal list of emotions like anger, fear, happiness, disgust, sadness and surprise. Other methods use a dimensional approach, like the Positive Affect Negative Affect Scale (PANAS) model (Watson, Clark & Tellegen, 1988). In the PANAS model the positive scale corresponds to emotions like: excited, inspired, proud and determined whereas emotions like: hostile, scared, guilty and nervous belong to the negative dimension. The model of Mehrabian and Russell (1974) used a slightly different model for emotion dimensional approach called the Pleasure-Arousal-Dominance (PAD) emotion model. The Pleasure dimension describes the valence of an emotion, i.e. positive or negative. The Arousal dimension expresses the activity level of one’s mental and physical state. The last dimension, Dominance, refers to the amount of control over the circumstances.

A preference for an object or event refers to the choice or motivation of an individual between alternatives based on one’s emotion experiences. For example, one can have a preference for the summer because one usually feels happy during summer. This does not mean that one cannot be happy if it is winter. The same holds for an association, which is a memorized experience related to an object or person. For instance, summer reminds people of happiness and when seeing a summer holiday picture the picture is associated with happiness.

2.2.1 White light

As mentioned before, white light can differ in illuminance level and colour temperature. It is important to know if there is a relationship between these factors and the affective state of humans, in order to know if the experimental design of this research should take into account make illuminance level and colour temperature. First the preference of people for of white light will be discussed in this subsection, followed by the emotional responses evoked by white light and ending with peoples’ association regarding white light.

Preferences

Numerous studies have been done on the preferred illuminance level and colour temperature of white light. While people can perceive light as bright or dim, warm or cool, red or blue and soft or colourful, not all light conditions are equally preferred. The Kruithof-curve (Figure 2.4) was introduced by the research of Kruithof (1941) and is one of the most traditional models used to show which combination of illuminance and CCT levels are perceived as a pleasant light condition.
Figure 2.4: The Kruithof-curve where the coloured middle area shows the preferred combination of CCT and illuminance level for pleasantness.

However, Boyce and Cuttle (1990) claim in their research that the boundaries of the Kruithof-curve are not entirely correct. Boyce and Cuttle found that the CCT (2700K or 6500K) had little effect on the participants’ preference of lighting in a space. On the other hand, the preference was influenced by the illuminance level (30 to 600lx): “high illuminance levels are said to be more pleasant, comfortable, clearer, stimulating, brighter, colourful, natural, friendly, warm, uniform and less hazy, oppressive, dim and hostile” (Boyce & Cuttle, 1990). Van Erp (2008) also found that people prefer high intensities (330lx) over low intensities (30lx). In addition, he found that people prefer lighting with a low CCT (2800K) over lighting with a high CCT (6000K). Research of Nakamura and Karasawa (1999) and Manav (2005) support the results that low CCT values are more preferred than high CCT values. However, preference depends on the applications or task at hand.

In general, white light is preferred above coloured light as the general illumination of a space. Specially when reading, writing or chatting neutral lighting is preferred. The main reason in that the human skin looks unnatural in coloured light. White light creates a neutral and realistic view in an environment (confidential report by Philips Research).

**Emotions**

Not only the effects of white light on preference have been studied, but also the effects of white light on peoples emotions. High CCT (5600K) was found to be physiological more arousing and stressful compared to a low CCT (2700K) (McColl & Veitch, 2001). McCloughan, Aspinall & Webb (1999) found that warm white light under low illuminance levels (150lx) feels more calm and more awake compared to high illuminance levels (1500lx). They also found a relationship between colour temperature on anxiety and hostility. Anxiety and hostility becomes larger for high CCT (4000K) at high illuminance compared to low CCT (3000K) at high illuminance. For illuminance, a relation between assessed illuminance and mood was found (Küller, Ballal & Laike, 2006), where the mood appeared to be negative when lighting was experienced as too bright or too dark.

Fleischer, Krueger & Schierz (2001) studied the effect of white light on the PAD dimensions. They found that low illuminance levels were evaluated low on the Pleasure and Dominance component and high CCT values were evaluated high on the Arousal component. However, the study of Fleischer et al. was performed in an office with differed direct and indirect lighting. Therefore, these finding are prone to differences in contextual setting of the room and the spatial distribution of light. Furthermore, there is evidence that the emotional response to light depends on many factors such as
type of environment, the task, gender and culture of the user (Oi & Takahashi, 2007; Knez & Kers, 2000)). However, these variables are not taken into account for this research.

**Associations**

People can have certain associations with white light. Van Erp (2008) found in his research that associations of white light depend on illuminance and colour temperature. Cool white light at low illuminance was associated with boring and hospitals. Cool white light at high illuminance reminded people of hospitals, laboratories, offices and a dentist. Warm white light at low illuminance was associated with an evening, living room, twilight and bed room, whereas warm white light at high illuminance was associated with sun, beach, afternoon and living room.

2.2.2 Colour

After discussing the effects of white light the next step is to focus on colour. Colour can also have an influence on emotions, physical reactions or association and most often symbolizes a feeling (Ståhl, Sundström, & Höök, 2005). Minor attention has been given in literature on how coloured light influences the perception and emotion of people. However, many researchers have investigated the human preferences of colour, their emotions toward colour and associations with colours by using coloured patches instead of coloured light. Therefore, most studies reported below used colour patched, unless stated differently.

**Preferences**

The preference of colour has been studied worldwide by many researchers. The preferences discussed below are based on studies done in western cultures, because of cross-cultural differences.

Blue is most likely to be one’s favourite colour and is found to be the most preferred hue (Gamgöz, Yener & Güvenç, 2001; Valdez & Mehrabian, 1994). The least preferred hue is yellow (Granger, 1955; Eysenck, 1941). Guilford (1934) suggested that preference is not only hue depend but also the brightness and saturation of a colour is important. Further research found that medium saturation is more preferred than low saturation (Hogg, 1969). However, the preference of hue is also highly depended on personal experiences (Ou, Luo, Woodcock & Wright, 2003), e.g. one could have a positive feeling from the past to the colour purple or a negative feeling to the colour blue.

**Emotions**

As mentioned before, preference is depending on personal experiences. This is also the case for colour-associated emotions which rely on one’s past experience and preferences (Manav, 2005; Camgöz et al., 2001; Kaya & Epps, 2004). In spite of this, several researchers have studied if characteristics of colour can be matched to emotions.

A recent study of Goa and Xin (2006) divided the emotional response to colour into three indexes for describing colour emotions: the activity index, the potency index and the definition index. The indexes contain descriptive scales like, “warm-cool”, “light-dark” and “soft-hard”. The results showed that the emotional indexes were mainly dependent on the colour characteristics brightness and saturation but, little or none on hue. However, this research was conducted among people with an Asian cultural background and therefore these results could be sensitive for cultural differences. Nonetheless, these results agreed with those of Gamgöz et al. (2001) who found that luminance has the strongest influence on colour emotions followed by saturation. The similarity between these studies suggested that colour emotions are independent of culture, except for the scales “tense-relaxed” and “like-dislike” (Ou, et al., 2003).

In an earlier study, Valdez and Mehrabian (1994) used their PAD emotion model on colours for creating a colour emotion model. Interestingly, the results showed, similar to the previous studies, a relationship of brightness and saturation on emotional responses, and a weak relationship of hue. Brighter colours appeared to be more pleasant, less arousing and less dominant than darker colours. Saturated colours appear to be more arousing and more dominant than less saturated colours. Although hue appeared weak on emotions, a consistent support for a relationship for hue on pleasure was found. The most pleasant colours were blue, blue-green, green, purple-blue, red-purple and purple whereas red-yellow, green-yellow and yellow are the least pleasant.
Associations

Besides colour preferences and emotion towards colour which so far have been discussed, people often have association with colour. Many studies have investigated how and which emotions could be related to colours. Ryberg (1991, as cited in Ståhl, et al., 2005) categorized affective beliefs related to colours and found that blue stands for intuition, idealism, serenity and concentration, green is associated with dream, hope and sensitivity, yellow with intellect, logic, communication and curiosity, purple with ecstasy, power and artistry and red with instincts, impulsive, strength and courage.

In addition, Kaya and Epps (2004) studied the associations of colour based on past experiences. This research matched the colours to a situational context; i.e. participants were asked what the colour reminded them of. The results showed that blue reminds people of terms like cool, calm, ocean, water, and relaxing, green is associated with relaxation, calmness, comfort, peace, nature, spring, grass and health, yellow stands for happiness, excitement, sun flowers, summer and energetic, purple is associated with sadness, children, power, boredom and spirituality and red reminds people of passion, love, blood, evil and danger.

Research showed also a difference between positive-negative and warm-cool associated colours (Kaya, 2004; Manav, 2006). Green is the colour with the most positive associations following by yellow. Red and purple are the colours most associated with negative feelings together with black. Blue can be both negative as well as positive, but blue-green is most definitely positive. Overall warm colours are associated with daylight, sun and light, while cool colours are associated with gray, overcast and cold.

2.3 Atmosphere

Atmosphere differs from emotions in a way that it is not an affective state, but an affective evaluation of an environment (Vogels, 2008). The difference between emotion and atmosphere can be described with the following example: “If I am thinking of all the work I have to do I would still feel pretty stressed in a relaxed environment. However, in a stressful environment I will never feel relaxed”. Hence, atmosphere can have an influence on one’s affective state but it is not a necessary result. On the other hand, the perceived atmosphere with its environmental variables is expected to be independent of people’s emotions. Although people can have different opinions about the perceived atmosphere, Vogels (2008) assumes atmosphere to be more stable than measuring emotions.

One of the first researchers studying the evaluation of an environment was Flynn, Hendrick, Spencer and Martyniuk (1979). By using semantic differential rating scales Flynn et al. measured subjective responses towards an environment. After a factor analysis of the rating scales data, Flynn et al. indicated that there are three major factors of impressions of an environment: (1) visual clarity, (2) spaciousness and (3) evaluative. Flynn et al. applied their factors on light and investigated the effect of light on the impression of an environment. He found that people judged the illuminated environment on three light characteristics: (1) uniform-non uniform, (2) bright-dim, (3) overhead/peripheral. They also studied the relation between these relative light dimensions and the impression dimension.

Another way for evaluating an environment is the PAD-model (Mehrabian & Russell, 1974), as discussed previously. Russell and Pratt (1980) demonstrated that an environment could be described by the dimensions Pleasure and Arousal. The dimensions Dominance was not applicable for evaluating an environment because one cannot control an affective response to an environment.

A different way of evaluating the environment is by means of perceived atmosphere. A measurement tool was introduced by Vogels (2007) for quantifying perceived atmosphere; the atmosphere questionnaire consisted of 38 atmosphere terms. De Vries and Vogels (2007) showed that light has an effect on the perceived atmosphere, which shows that the questionnaire can discriminate different extreme light conditions. Additionally, Van Erp (2008) showed that atmosphere can be described with four factors that can be interpreted as: cosiness, liveliness, tenseness and detachment. Terms like safe, cosy, intimate and pleasant are used to describe cosiness and terms like lively, inspiring and stimulating are used for liveliness. Tenseness is related to terms like terrifying, threatening, tense and oppressive and detachment is related to terms like business-like, formal and chilly.
So far, few researchers have studied the effects of light and colour on atmosphere. The next subsections presents an overview of the literature on light and colours in relation to atmosphere, distinguishing between white light and colour.

### 2.3.1 White light

In the research of Flynn et al. (1979) the evaluation of an environment was measured for several lighting conditions. Flynn et al. found that illuminated environments which are perceived as bright are more preferred than environments which are perceived as dim. Furthermore, non-uniform illuminated environments are perceived as interesting and relaxed, whereas uniform illuminated environments are perceived as spacious. Additionally, Flynn (1977) concluded that the lighting impression is independent of the way objects are arranged in a room.

Van Erp (2008) studied the effects of the intensity, colour temperature and spatial distribution of white general light on perceived atmosphere described by the four atmosphere factors of the model of Vogels (2008). Van Erp found that non-uniform light was perceived as more *cosy*, more *lively*, less *tense* and equally *detached* compared to uniform distributed light with the same perceived room brightness and colour temperature. In addition, uniform distributed light at low CCT was perceived as more *cosy*, less *lively*, less *tense* and less *detached*. Furthermore, high intensity resulted in a more *lively*, less *tense*, less *cosy* (for low CCT) and more *detached* (for high CCT) atmosphere.

In addition, Custers (2008) found in his research that brighter light was perceived as more *tense* and less *cosy* and when the perceived glare and sparkle of the lighting increased, the atmosphere was perceived as more *lively* and less *detached*. The difference in tenseness among these studies could be due to contextual factors; Custers investigated his research in a retail environment, while Van Erp (2008) preformed a controlled experiment in an empty room.

### 2.3.2 Colour

Because this research aims at investigating the effect of coloured light on atmosphere, it is interesting to see what is known so far on colour and atmosphere. One of the few studies on colour in relation to atmosphere is done by Dijkstra, Pieterse and Pruyn (2008). Their research focussed on quicker and better recovery of patients in a hospital room by influencing the atmosphere. They concluded that wall colour can alter the atmosphere of a space. They found that the colour green created a more relaxing atmosphere while an orange room made the atmosphere more arousing.

In an earlier study, Kwallek, Soon and Lewis (2007) used different coloured offices. Kwallek et al. found that warm colour, like red, made the environment more arousing compared to cool colours. With cool colours on the other hand, like green and blue, the environment was perceived as relaxed. Note that, both research of Dijkstra et al. and Kwallek et al. used painted walls to change atmosphere.

The most recent study (Moors, 2009) done on atmosphere included coloured lights instead of painted walls. Like Kwallek et al. (1996) Moors used the colours red and blue at two saturation levels to create different atmospheres. The colours were used for decorative lighting. This was always combined with general white lighting for which the CCT, intensity, and spatial distribution were varied. A significant effect of hue was found on *cosiness*; red was perceived as more *cosy* than blue and blue even gets less *cosy* when combined with cool white light. Saturation, on the other hand, had no significant effect on cosiness. However, a small effect of saturation on *liveliness* was found, which shows that high saturation was perceived as more *lively* than lower saturated conditions. Also, red was perceived to be more *lively* than blue. High saturation was perceived as more *tense* than lower saturation, but no effect of hue on *tenseness* was found. The last atmosphere dimension *detachment* showed a main effect of saturation; high saturation was perceived as less *detached* than low saturation. Furthermore, the results revealed an effect of hue; blue was perceived as more *detached* than red. This effect was amplified by the colour temperature of the white light; blue became more *detached* at cool white light than at warm white light.

Although Moors (2008) found significant results on colour and atmosphere, the colours were not accurately quantified in terms of the colour attributes lightness and saturation. For LED lighting systems, as used by Moors, red has usually a higher luminance than blue, and blue has a higher saturation than red. So, comparing red to blue would be difficult because not only the hue is different
but also the brightness and saturation. In this research a similar study has been performed where the colour attributes are controlled, so the effect of on atmosphere is measured in a more controlled method.

To sum up the main effects described in the literature, an overview is presented in Table 2.1.

*Table 2.1: Overview of literature on preferences, emotions, associations and atmosphere.*

<table>
<thead>
<tr>
<th></th>
<th>Preferences</th>
<th>Emotions</th>
<th>Associations</th>
<th>Atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White light</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low illuminance</td>
<td>less preferred</td>
<td>more calm, more awake, low on pleasure, low on dominance</td>
<td>evening, boring</td>
<td>less detached, more tense</td>
</tr>
<tr>
<td>High illuminance</td>
<td>more preferred</td>
<td></td>
<td>office, afternoon</td>
<td>more lively</td>
</tr>
<tr>
<td>Low CT</td>
<td>more preferred</td>
<td></td>
<td>sun</td>
<td>more cozy, less tense</td>
</tr>
<tr>
<td>High CT</td>
<td>less preferred</td>
<td>more arousing, more stressful, high on arousal</td>
<td>hospital</td>
<td>more detached, less lively</td>
</tr>
<tr>
<td><strong>Colour</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bright colours</td>
<td></td>
<td>more pleasant, less arousing, less dominant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturated colours</td>
<td></td>
<td>more pleasant, more aroused, less dominant</td>
<td></td>
<td>more tense, less detached, more lively</td>
</tr>
<tr>
<td>Red</td>
<td>most preferred</td>
<td></td>
<td>love, blood, sadness, boredom, water, see nature, peace</td>
<td>less lively, more cosy</td>
</tr>
<tr>
<td>Purple</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td>least preferred</td>
<td></td>
<td></td>
<td>more relaxed, more relaxing</td>
</tr>
<tr>
<td>Warm colours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cool colours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 Experimental Design

The purpose of this research was to study if coloured lighting has an influence on the perceived atmosphere and what is the effect of the colour attributes lightness, saturation and hue.

In this research, general white light was combined with coloured decorative lighting. White general lighting can vary in brightness, colour temperature and spatial distribution. However, brightness and spatial distribution were not varied in this research because the number of conditions would be too large. In a previous research the effect of colour temperature was largest (Moors, 2009) and therefore only the colour temperature was chosen to be an independent factor for white light. In case of the coloured decorative lighting, lightness, saturation and hue were varied. Like the general white light, the spatial distribution of the decorative lighting has not been taken into consideration.

Ideally, the design for this research would be to present several light conditions that differ in colour temperature of white light (warm vs. cool), lightness (high vs. low), saturation (low vs. high) and hue (red vs. magenta vs. blue vs. cyan vs. green vs. yellow vs. white) of the decorative lighting. Unfortunately, it was not possible with the LED lighting system used, based on the output of the LED lighting system. The LED lighting system had a Red, Green and Blue LED of which Blue had a lower lightness and higher chroma compared to Red and Green. When the lightness of Red and Green was decreased, the chroma radically decreased as well. Therefore, not all hues could reach the same high (or low) lightness at the same high (or low) chroma. Even more, when matching the chroma of the different hues, the visual output was not perceived as having the same saturation and when changing lightness or chroma, the perceived hue of some colours started to diverge. In order to solve these problems, two pilot experiments were carried out to visually equalize the saturation of different hues at different lightness levels. In this section the realisation of the experimental design will be discussed in more detail.

3.1 Experimental Room

The pilots and main experiment were all performed in a Light Lab, a room of 6.1m x 3.7m x 3.0m (LxWxH) with white walls, a window with a closed white shutter and a grey carpet. The Light Lab contained several luminaires, but not all were used for the experiments (Figure 3.1). The squared fluorescent luminaire (7), positioned in the centre of the Light Lab, was used for creating warm and cool general white light. The fluorescent luminaire consisted of a (Philips TBS770 6x14W/827/865 HFD AC-MLO CVC) fitting containing four luminaires with high CCT (Philips Master TL5 HE 14W/865 SLV) and two luminaires with a low CCT (Philips Master TL5 HE 14W/827 SLV), these luminaires generated diffuse light. For creating coloured light, six RGB LED-spots (number 1-6, Figure 3.1) were used, three spots projected light towards one wall and three spots projected light toward the opposite wall. These LED-spots consisted of (Philips Fiorenza Rainbow) high-power RGB Luxeon LEDs which can mix colours for dynamic or static lighting. The luminaires were controlled by a laptop using the software system “Flexible Multisystem V1.6” (CIT Engineering N.V.).

![Figure 3.1: An overview of the luminaires at the ceiling of the Light Lab. Luminares 1-6 are LED-spots, 7 is a fluorescent luminaire.](image-url)
White light luminaire

The luminaire that was used for creating general white light was located in the centre of the ceiling (number 7, Figure 3.1). The warm white light had a low CCT of 2800K and the cool light a high CCT of 6000K. The illuminance of the white light was, at table height, 185lx in the middle of the room and 22lx in the corners of the experimental room.

The warm white light and cool white light were defined as the white-point for the experimental conditions. The white-point is necessary for describing colours of the decorative lighting in the CIELCH space later on. The white point was calculated by measuring the luminance and chromaticity of the white light, measured on the wall below the middle LED-spot (number 4, Figure 3.1) at 2.5m from the ground. A spectrophotometer (PR-655, Photo Research) was used with a 2° standard observers angle (Speranskaya, 1959). The spectrophotometer measured the luminance and chromaticity in CIE XYZ. For this research the XYZ values were converted to L* C* h values. The white-point for the warm white light condition was L*=36, C*=0 and h=0 (X=8,6; Y=7,9; Z=1,7). For the cool white light condition this was L*=35, C*=0 and h=0 (X=6,6; Y=7,3; Z=5,7). Note, L*=100 was measured at maximum R, G and B for all six LED spots and the white light luminaire. Therefore, the white point (only white light luminaire and no LED spots) was L*=35-36.

Coloured light luminaire

Six luminaires (number 1-6, Figure 3.1) that created the coloured decorative lighting were directed towards the wall. These LED-spots could create a large variety of colours by changing the RGB input. Each LED-spot was characterized by measuring CIE XYZ for each R, G and B value, ranging from R=0, B=0, G=0 till R=255, B=255, G=255. This measurement was necessary to know which L* C* h values could be made with these LED-spots by converting the XYZ values into L* C* h values using the white point as described above.

The luminance and chromaticity measurement was taken at the centre of the LED-spot on the wall, 2.5m from the ground at a 2° observer's angle. One luminaire (number 4, Figure 3.1) was responsible to define the coloured conditions that were chosen for the experiment. The other luminaires (number 1-3, 5 and 6, Figure 3.1) were adjusted to match the colour of luminaire number 4 (Figure 3.1). Therefore, the coloured lighting in the experimental room would be perceived as equally coloured.

3.2 Difficulties experimental design

As said before, creating a complete design based on the output of the LED lighting system was not possible. Looking at the measured data it became obvious that blue was the most problematic colour in the design. Blue had a low lightness and a high chroma (Figure 3.2a). The low lightness of blue (L*= 47) would be the reference for low lightness. For the high lightness the reference point selected was red (L*= 76), since this was the maximum lightness that could be made for all colours except for blue.

Preferably, the hue for each colour should be fixed when changing lightness or chroma. Yet, when changing from high lightness to low lightness at the same hue value the perceived hue started to diverge, especially for red which at high lightness was more orange than red. In addition, when the chroma was varied, blue was problematic and changed into violet or white. These are short comings of the CIELCH model and not due to the LED system. The same problems still occurred, but less outraged, when using saturation in stead of chroma (Figure 3.2b). Due to these difficulties in saturation, the high saturation level became the maximum saturation level which one hue could provide. The low saturation levels were perceptually matched to the weakest saturated hue, which have been defined by two pilot experiments.
3.3 Pilot experiment

3.3.1 Participants Pilots
In both pilot experiments, the same ten people participated, of which two persons were female. Their age ranged between 27 to 37 years with an average of 32 years. All participants were Philips Research employees and working in a colour research area. These colour experts were used because they can distinguish between saturation and lightness, which non-experts will more likely confuse. According to the Ishihara (1999) test, all participants were tested negative for colour deficiency.

3.3.2 Pilot 1: Equal saturation for Lightness
To perceptually equalize the saturation of one hue to that of other hues at different lightness levels, first the saturation of one hue for the two lightness levels was matched. The hue that had the lowest saturation would be the point of reference for all the other colours. Visually the colour “cyan” appeared to be the weakest in saturation (Figure 3.2b). Furthermore, cyan at low lightness appeared to be less saturated than at high lightness and therefore, cyan at low lightness became the reference point.

The colour cyan at low lightness was presented on one spot of one wall and the colour cyan at high lightness was presented on opposite sides of the wall. Both colours cyan were presented by the LED spots number 3 and 4 (Figure 3.1) and changed sides after tuning so both conditions where presented by both spots. The white light (cool or warm) in the middle of the ceiling was also on. Both cyan lights initially were presented at maximum saturation, because this showed participants the limited the cyan lights could achieve.

Participants had to tune the saturation of the spot with cyan at high lightness to the same saturation as the spot with cyan at low lightness. This was done once for the cool white light setting and once for the warm white light setting (Table 3.1). The tuning consisted of thirty tuning steps which the participant could choose from, varying from maximum saturation (step 1) to no saturation (white, step 30). The resulting saturations were defined to be the low saturation condition, although for low lightness this was equal to the maximum saturation.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Tuning pilot 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightness</td>
<td>high</td>
</tr>
<tr>
<td>Saturation</td>
<td>tuning</td>
</tr>
<tr>
<td>Hue</td>
<td>Cyan</td>
</tr>
</tbody>
</table>

Table 3.1: Overview of tuning conditions pilot 1.

In total four conditions per participant were tuned in pilot 1. The average across participants was taken to be the saturation level of cyan that is visually equal at both high and low lightness. The results ranged between steps 6 and 10, with an average of 8 (s=2,3).
3.3.3 Pilot 2: Equal saturation for Hues

After the first pilot, the low saturation level of cyan at high and low lightness was set to be the point of reference for the other hues. The hues red, magenta, blue, green and yellow where kept at constant lightness and hue, only the saturation level could be altered.

These coloured lights were, one at a time, presented on the wall opposite to the wall that was illuminated by the cyan spot. Again only the middle spots were on (number 3 and 4, Figure 3.1). All hues were presented at both spots with the references point always on the opposite. The white light (cool or warm) was centred in the middle of the ceiling. The five hues started at the maximum saturation and could be tuned down to the equally perceived saturation as the spot with cyan.

Participants were asked to tune the saturation of the coloured lights, at two different lightness levels (Table 3.2). Again, the tuning consisted of thirty tuning steps for each hue which the participant could tune down from, varying from maximum saturation (step 1) to no saturation (white, step 30). The resulting saturations were defined to be the low saturation condition in the experimental design.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Tuning pilot 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightness</td>
<td>low</td>
</tr>
<tr>
<td>Saturation</td>
<td>max</td>
</tr>
<tr>
<td>Hue</td>
<td>Cyan</td>
</tr>
<tr>
<td>Lightness</td>
<td>high</td>
</tr>
<tr>
<td>Saturation</td>
<td>low (tuned by pilot 1)</td>
</tr>
<tr>
<td>Hue</td>
<td>Cyan</td>
</tr>
</tbody>
</table>

In total forty conditions were tuned in pilot 2 (5x hue, 2x lightness, 2x white light and 2x middle spots). The equally perceived saturation of the hues was calculated by taking the average across participants. Therefore, one can expect that all hues (red, magenta, cyan, green and yellow) are all of equally perceived saturation both at high and low lightness. The results, range, average and standard deviation, of the tunings are presented in Table 3.3.
Table 3.4: Overview results pilot 2.

<table>
<thead>
<tr>
<th>Lightness</th>
<th>Hue</th>
<th>Range</th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warm White light</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td>red</td>
<td>3-7</td>
<td>5</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>blue</td>
<td>1-30</td>
<td>15</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>magenta</td>
<td>7-15</td>
<td>11</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>green</td>
<td>2-13</td>
<td>7</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>yellow</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>high</td>
<td>red</td>
<td>6-14</td>
<td>10</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>blue</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>magenta</td>
<td>11-17</td>
<td>13</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>green</td>
<td>11-15</td>
<td>12</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>yellow</td>
<td>1-3</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Cool White light</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td>red</td>
<td>2-15</td>
<td>7</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>blue</td>
<td>1-30</td>
<td>12</td>
<td>9.7</td>
</tr>
<tr>
<td></td>
<td>magenta</td>
<td>7-16</td>
<td>12</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>green</td>
<td>2-8</td>
<td>4</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>yellow</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>high</td>
<td>red</td>
<td>9-12</td>
<td>11</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>blue</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>magenta</td>
<td>9-12</td>
<td>11</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>green</td>
<td>8-13</td>
<td>10</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>yellow</td>
<td>1-6</td>
<td>1</td>
<td>3.4</td>
</tr>
</tbody>
</table>

3.4 Final design

The final experimental design was shaped after the two pilot experiments were carried out. The selected saturation levels of each hue were transformed into L*C*h values. Together with all other values of each hue the final design was formed (Table 3.4).

Cyan at high lightness had an equally perceived saturation as cyan at low lightness. All other hues were perceived as equally saturated compared to cyan at low saturation both at high and low lightness. Still, some gaps appeared in the experimental design (Table 3.4). To start with, blue could not be of equal low saturation as the other colours because of the wide range and high variance, so blue only appears in the design only at maximum saturation. For yellow, the selected saturation was equal to the maximum saturation yellow could offer. Therefore, yellow appears in the design only at maximum saturation. As mentioned before, cyan at low lightness has the same L*C*h values for both low and maximum saturation.

A white colour condition, where all LED-spots have the same white colour as the white general light, was included into the design as a neutral control factor. But, white light has no saturation, so this white colour condition can be compared with both low and maximum saturated hues.
Table 3.4: Overview of the final experimental design with all L* C* h values, additionally with the saturation (s) values. Cyan (bold) is the results of pilot 1 and the reference point of pilot 2. Note, some colour conditions have the same values for low and maximum saturation.

<table>
<thead>
<tr>
<th>Warm</th>
<th>Saturation Low</th>
<th>L*</th>
<th>C*</th>
<th>h</th>
<th>s</th>
<th>Saturation Max</th>
<th>L*</th>
<th>C*</th>
<th>h</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red</td>
<td>75.9</td>
<td>79.8</td>
<td>37.5</td>
<td>1.1</td>
<td>Red</td>
<td>75.9</td>
<td>119.4</td>
<td>35.5</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Magenta</td>
<td>76.1</td>
<td>164.0</td>
<td>293.9</td>
<td>2.2</td>
<td>Magenta</td>
<td>76.0</td>
<td>296.8</td>
<td>293.8</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>Blue</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyan</td>
<td>77.0</td>
<td>265.8</td>
<td>271.4</td>
<td>3.5</td>
<td>Cyan</td>
<td>76.0</td>
<td>271.4</td>
<td>270.4</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>76.0</td>
<td>66.6</td>
<td>174.9</td>
<td>0.9</td>
<td>Green</td>
<td>76.0</td>
<td>114.2</td>
<td>174.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>Yellow</td>
<td>76.1</td>
<td>38.7</td>
<td>62.1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>76.0</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td>White</td>
<td>76.0</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lightness Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cool</th>
<th>Saturation Low</th>
<th>L*</th>
<th>C*</th>
<th>h</th>
<th>s</th>
<th>Saturation Max</th>
<th>L*</th>
<th>C*</th>
<th>h</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red</td>
<td>75.8</td>
<td>90.3</td>
<td>28.8</td>
<td>1.2</td>
<td>Red</td>
<td>75.7</td>
<td>145.9</td>
<td>29.2</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Magenta</td>
<td>75.6</td>
<td>118.6</td>
<td>322.7</td>
<td>1.6</td>
<td>Magenta</td>
<td>75.7</td>
<td>190.8</td>
<td>322.7</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>Blue</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyan</td>
<td>75.7</td>
<td>119.5</td>
<td>279.2</td>
<td>1.6</td>
<td>Cyan</td>
<td>75.9</td>
<td>118.6</td>
<td>279.0</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>75.7</td>
<td>78.8</td>
<td>156.5</td>
<td>1.0</td>
<td>Green</td>
<td>75.8</td>
<td>120.2</td>
<td>156.3</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>Yellow</td>
<td>75.7</td>
<td>69.1</td>
<td>53.0</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>76</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
<td>White</td>
<td>76</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lightness Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
4 Methods: Main Experiment

The purpose of this research is to study what are the effects of characteristics of coloured lighting on perceived atmosphere. Several light conditions were presented (Figure 4.1) differing in colour temperature of white light (warm vs. cool), lightness (high vs. low), saturation (low vs. max) and hue (red vs. magenta vs. blue vs. cyan vs. green vs. yellow vs. white) of the decorative light.

![Image of light conditions](image_url)

(a) Colour temperature: Cool and Warm  
(b) Lightness: Low and High  
(c) Saturation: Low and Max.  
(d) Hue: Red, Magenta, Blue, Cyan, Green, Yellow and White

Figure 4.1: Photo examples of the independent factors; (a) CT of white light, (b) Lightness, (c) Saturation and (d) Hue.

Besides perceived atmosphere, the influence of these light conditions on the perception of light characteristics, the preferences of the lighting and the suitability of the lighting for different applications of the space (office and living room) has been studied.

Preferably, this design should be measured as a within-subjects design. However, because this design was too large to evaluate all conditions in one session of a reasonable duration, the design was divided into a between-subject design with colour temperature as a between-subject factor. This meant for the design one group that evaluated all warm white light conditions and one group that evaluated all cool white light conditions. The (main) experiment consisted of one between-subject factor (colour temperature) and three within-subject factors (lightness, saturation and hue).

4.1 Participants

In the (main) experiment, forty native Dutch speaking people participated; twenty women and twenty men. The age of the participants ranged between 21 and 32 years with an average of 25 years. All participants were employed at Philips Research, of which twenty-one students doing their internship. None of them were involved in any atmosphere perception research. Most of the male participants had a technical background and the background of the female participants varied from technology to health and service. According to the Ishihara (1999) test none of the participant had colour perception deficiencies.
**4.2 Experimental Room**

The (main) experiment was performed in a Light Lab, as described in Section 3.1.

**4.3 Light conditions**

In total nineteen coloured light conditions were shown in combination with the warm white light (low CCT of 2800K and 185lux) and nineteen coloured light conditions in combination with the cool white light (high CCT of 6000K and 185lux). An overview is shown in Table 4.1. The coloured light conditions varied in hue, saturation and lightness. The $L^*C^*h^*$ and $s$ values are described in detail in Section 3.4.

Table 4.1: Overview of all the light conditions shown in the experiment. Note, the low saturation of white and cyan is equal to the maximum saturation.

<table>
<thead>
<tr>
<th>Warm</th>
<th>Saturation Low</th>
<th>Saturation Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>Magenta</td>
<td>Magenta</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td>Low</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>Magenta</td>
<td>Magenta</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td>High</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>Magenta</td>
<td>Magenta</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td></td>
<td>Cyan</td>
<td>Cyan</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>White</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cool</th>
<th>Saturation Low</th>
<th>Saturation Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>Magenta</td>
<td>Magenta</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td></td>
<td>Cyan</td>
<td>Cyan</td>
</tr>
<tr>
<td></td>
<td>Green</td>
<td>Green</td>
</tr>
<tr>
<td></td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td>Low</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>Magenta</td>
<td>Magenta</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>White</td>
</tr>
<tr>
<td>High</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td></td>
<td>Magenta</td>
<td>Magenta</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>White</td>
</tr>
</tbody>
</table>

**4.4 Questionnaire**

For each light condition, participants had to complete a questionnaire (Vogels, 2008) (Appendix I). The original questionnaire of Vogels (2008) contained 38 Dutch terms that have been used to describe the perceived atmosphere of an environment. Previous research has shown, by a factor analysis (Vogels, 2008), that those terms can be divided into four underlying atmosphere dimensions; cosiness, liveliness, tenseness, and detachment. For each dimension three items were selected with the highest factor leading on the corresponding factor. For cosiness the terms cosy, safe and intimate were used. Terrifying, threatening and tense were used for tenseness, whereas formal, chilly and detached were used for detachment. At last, lively, inspiring and stimulating made the dimension of liveliness. For each item a seven point unipolar Likert scale was used. The scale used for the atmosphere items ranged from “very well applicable” to “absolutely not applicable”.

To study how people perceive the light in a room two questions were added to the questionnaire that asked about the perceived brightness and perceived temperature of the light. The scale used for brightness was “dim-bright” and for temperature this was “cool-warm”. An additional scale “beautiful-ugly” for preference was added to analyse which light conditions people prefer.

The last question added to the questionnaire was about the suitability of the lighting for different contexts. Participants were asked how suitable the light condition was for a Living room and an Office (on a scale from “not at all suitable” to “very well suitable”).

Before participants filled in the questionnaire, they were asked to give their first impression of the room, which was used to check whether people used a similar terminology as in the questionnaire.
4.5 Procedure

Before starting the experiment, all luminaires were turned on for thirty minutes in order to stabilize the luminance and chromaticity (Van Keersop & Vogels, 2008). A neutral light setting was shown when participants entered the Light Lab. This neutral light setting was either the warm white light (low CCT of 2800K) in the centre or the cool white light (high CCT of 6000K) in the centre of the ceiling, with the LED-spots turned off. The colour temperature was equal to that of all other light settings that were evaluated in that session.

First, all participants were asked to sit down behind a little desk to test for colour deficiencies (Ishihara, 1999). After welcoming the participants, the procedure of the experiment was explained and some demographic questions were asked. During this period, the participants could adapt to the neutral light. Then, four light conditions were shown after each other to get familiar with the type of light condition; the maximum saturated colour blue, the low saturated green, low lightness magenta en high lightness red.

Each coloured light condition was presented by operating the notebook and participants were asked to fill in the questionnaire. Between the switching of the coloured light conditions the neutral light was presented for ten seconds. All light conditions were randomly presented for each participant to control for sequence effects.
5 Results

The experiment consisted of one between-subject factor (colour temperature) and three within-subjects factors (lightness, saturation and hue). As the experiment did not use a complete design, it is not possible to analyse the data with one analysis. Therefore, one experimental design (Table 5.1) and two additional tests were used to analyse the effects of coloured lighting on several aspects: perceived light characteristics, perceived atmosphere, preference of the lighting and suitability of the lighting for different uses of the space (office and living room). In the experimental design, the effect of colour temperature of white light, lightness and saturation for the hues red, magenta, cyan, green and white was investigated. The two additional tests investigated the effect of only colour temperature of white light for blue and yellow at maximum saturation.

Table 5.1: Overview of the factors used for the experimental design.

<table>
<thead>
<tr>
<th>Experimental Design</th>
<th>Colour temperature of White light</th>
<th>Lightness</th>
<th>Saturation</th>
<th>Hue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1: Blue</td>
<td>warm, cool</td>
<td>low, high</td>
<td>low, max</td>
<td>Red, Magenta, Cyan, Green, White</td>
</tr>
<tr>
<td>Test 2: Yellow</td>
<td>warm, cool</td>
<td>low</td>
<td>max</td>
<td>Blue</td>
</tr>
</tbody>
</table>

As mentioned, the questionnaire consisted of 17 questions that were grouped into 4 categories. All questions were analysed separately, except for the 12 questions on atmosphere, which were divided into the four underlying atmosphere dimensions. Therefore, there were nine dependent variables in total. For each dependent variable a Mixed Models ANOVA (Analysis of Variance) was performed to analyse the results of the nine dependent variables derived from the questionnaire. However, due to the size of the design in this research the data derived from the questionnaires was extensive. This makes it more difficult to keep an overview of the results. Therefore, first an overview of the significant results will be presented. Then, the significant results for all four categories of the questionnaire will be discussed in detail; i.e. light characteristics, atmosphere, preferences and suitability.

A summary of all results is found in Appendix II. In Appendix III the nine variables have been plotted against each other. The variables of the four categories; i.e. lighting characteristics, atmosphere, preferences and suitability have been plotted together.

5.1 Overview significant results

Extensive data was derived from the analyses done in this research. The experimental design with four factors and two tests with one factor were analysed on nine dependent variables. The most important data are the p-values which show the significance of the factors on the variables. Table 5.2 shows the outcome of all p-values in this research.

Table 5.2: Overview of all p-values derived from the experiment.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p&lt;0,001</td>
<td>p&lt;0,001</td>
<td>p&lt;0,001</td>
</tr>
<tr>
<td>CT White light</td>
<td>p=0,280</td>
<td>p=0,017</td>
<td>p=0,004</td>
</tr>
<tr>
<td>Lightness</td>
<td>p=0,108</td>
<td>p=0,159</td>
<td>p=0,035</td>
</tr>
<tr>
<td>Saturation</td>
<td>p=0,547</td>
<td>p=0,035</td>
<td>p=0,001</td>
</tr>
<tr>
<td>Hue: R, M, C, G, W</td>
<td>p=0,444</td>
<td>p=0,299</td>
<td>p=0,017</td>
</tr>
</tbody>
</table>

| CT White light * Lightness | p=0,203 | p=0,307 | p=0,060 |
| CT White light * Saturation | p=0,444 | p=0,289 | p=0,094 |
| CT White light * Hue    | p=0,108 | p=0,178 | p=0,001 |
| Lightness * Saturation  | p=0,547 | p=0,635 | p=0,001 |
| Lightness * Hue         | p=0,444 | p=0,299 | p=0,015 |
| Saturation * Hue        | p=0,771 | p=0,789 | p=0,001 |

| CT White light * Lightness * Hue | p=0,260 | p=0,786 | p=0,300 |
| CT White light * Saturation * Hue | p=0,038 | p=0,872 | p=0,878 |
| CT White light * Lightness * Saturation | p=0,137 | p=0,906 | p=0,117 |

Test 1: Blue

| Colour temperature of White light | p=0,000 | p=0,750 | p=0,098 |
| Test 2: Yellow                    | p=0,081 | p=0,341 | p=0,102 |

Test 2: Yellow

| Colour temperature of White light | p=0,000 | p=0,300 | p=0,098 |
|                                 | p=0,122 | p=0,750 | p=0,300 |
|                                 | p=0,040 | p=0,364 | p=0,090 |
|                                 | p=0,278 | p=0,302 | p=0,035 |
5.2 Perceived Light characteristics

In this section the results of how people perceive the lighting in a room are discussed. In this research people were asked to rate the perceived brightness and perceived temperature of each light condition.

5.2.1 Perceived Brightness

Figure 5.3 shows the results of all conditions for both the warm and cool setting. The scale used for the axis of the plot is equal to the seven point bipolar Likert scale used in the questionnaire (Section 4.4).

![Graphical results of the effects on the perceived brightness.](image)

An effect of CT of white light on the perceived brightness was found ($F(1,38) = 25.19$, $p < 0.001$, $\eta^2_p = 0.399$), were the cool white light setting was perceived are more bright than the warm white light setting. This effect was only found on the hues red, magenta, cyan, green and white, whereas the tests of blue and yellow did not found an effect of CT of white light on the perceived brightness.

Lightness had also a significant effect on the perceived brightness ($F(1,38) = 65.61$, $p < 0.001$, $\eta^2_p = 0.633$). This confirms that a high lightness was perceived as more bright than a low lightness.

Lastly, an effect of Hue on the perceived brightness ($F(4,35) = 2.75$, $p = 0.044$, $\eta^2_p = 0.239$) was found. This means that not all hues at high lightness were perceived as equally bright, as intended. Red was perceived as less bright than magenta, cyan, green and white, whereas cyan was perceived as more bright than red, magenta, green and white. Yellow at high lightness was perceived as bright and blue at low lightness was perceived as neutral bright with a tendency towards bright.

5.2.2 Perceived Temperature

The results of all light conditions for both the warm and cool settings are presented in Figure 5.4. The scale used for the axis of the plot is equal to the seven point bipolar Likert scale used in the questionnaire (Section 4.4).
**RESULTS**

5.4 Figure 5.4: Graphical results of the effects on the perceived temperature. a) Plotted for all light conditions with warm white light. b) Plotted for all light conditions with the cool white light. * Note: this light condition is in front of a light condition with the same outcome value.

Only Hue had a significant effect on the perceived temperature \( (F(4,35) = 32.71, p < 0.001, \eta_p^2 = 0.794) \). Like previous studies have shown, red and magenta were perceived as warm colours, whereas cyan was seen as a cool colours. Green and white were perceived more as a neutral temperature, but with a tendency toward cool. Blue was perceived as a cool colour and yellow was assessed as a warm colour.

5.2.3 Summary

In sum, high lightness was perceived as bright and low lightness as neutral. These results are crucial for the experiment because they confirm that the manipulations in light perception are well chosen. If participants would not have been able to see a difference between low and high lightness, then there would be no use asking about perceived atmosphere. Unfortunately, there was an effect of Hue on perceived brightness, which means that not all hues at high lightness were perceived as equally bright, like intended. Red was perceived as least bright and compared to magenta, cyan, green and white. This could be explained by the Helmholtz-Kohlraush effect which states that when the saturation of an object increases the perceived brightness also increases. This shows the shortcoming of the CIELCH model of which the lightness level used in this research were based on. Also, cool white light was perceived more bright than warm white light, which agreed with the study of Van Erp (2008) and Knez (1995) who found that CT of white light has an influence on the perceived brightness.

The results show that there was an effect of Hue on perceived temperature. Red, magenta and yellow were perceived as warm temperature colours, blue and cyan as cool temperature colours and green and white were perceived as neutral. No significant effect of CT of white light was observed for perceived temperature.

5.3 Results Atmosphere

Twelve items of the questionnaire measured the four underlying atmosphere dimensions which Vogels (2008) found in her research using a factor analysis. This research did not have sufficient participants to perform a factor analyses and therefore the internal consistency of the dimensions was calculated by their Cronbach’s alphas. The Cronbach’s alphas varied from 0.84 till 0.91, which means that for each dimension the three items were consisted with each other. Therefore, the average of these items can be taken. However, the term chilly was left out of the atmosphere dimension detachment, because of a lower consistency.
The results of the perceived atmosphere are described in this section, for each atmosphere dimension cosiness, liveliness, tenseness and detachment separately.

### 5.3.1 Cosiness

All assessed light conditions are plotted in Figure 5.5. The scale used for the axis of the plot is equal to the seven point unipolar Likert scale used in the questionnaire (Section 4.4).

**Figure 5.5**: Graphical results of the effects on cosiness. a) Plotted for all light conditions with warm white light. b) Plotted for all light conditions with the cool white light.

The results showed a significant effect of CT of white light on cosiness ($F(1,38) = 31.21, p < 0.001, \eta_p^2 = 0.617$). This indicates that warm white light was perceived as more cosy than cool white light. No significant effect of CT of white light was found on blue and yellow.

Significant main effects of Saturation ($F(1,38) = 26.62, p < 0.001, \eta_p^2 = 0.412$) and Hue ($F(4,35) = 10.99, p < 0.001, \eta_p^2 = 0.557$) were found on cosiness. Maximum saturation was perceived as less cosy than low saturation and red was perceived as more cosy than magenta, green, cyan and white. Blue was assessed on the negative axis of cosiness, while yellow was evaluated as cosy.

Furthermore, there was a significant interaction effect between Lightness and Saturation on cosiness ($F(1,38) = 16.18, p < 0.001, \eta_p^2 = 0.299$). Figure 5.6a shows that maximum saturation, high lightness was perceived as less cosy than low lightness, whereas at low saturation there is no difference between the two lightness levels.

Also, an interaction effect was found between Saturation and Hue ($F(4,35) = 6.88, p < 0.001, \eta_p^2 = 0.440$), presented in Figure 5.6b. For most hues maximum saturation is less cosy than low saturation, except for cyan and white. This can be explained because white had no saturation and cyan has almost the same values for low and maximum saturation.
5.3.2 Liveliness

Figure 5.7 shows all assessed light conditions for liveliness. The scale used for the axis of the plot is equal to the seven point unipolar Likert scale used in the questionnaire (Section 4.4).

No significant effects of CT of white light and Saturation on the perceived liveliness were found.

Lightness had an significant effect on liveliness \( F(1,38) = 16.01, p < 0.001, \eta^2_p = 0.296 \), which showed that high lightness was perceived as more lively than low lightness.

An interaction effect was found between Lightness and Saturation in liveliness \( F(1,38) = 6.40, p = 0.016, \eta^2_p = 0.144 \). This interaction effect showed that the effect of Lightness is slightly larger at low saturation than at maximum saturation (Figure 5.8a).

Also, the results showed a significant effect of Hue on liveliness \( F(4,35) = 7.96, p < 0.001, \eta^2_p = 0.476 \). White was perceived as least lively compared to red, magenta, cyan and green.

Furthermore, an interaction effect was found between Lightness and Hue \( F(4,35) = 3.58, p = 0.015, \eta^2_p = 0.290 \). The effect of Lightness was larger for white compared to the hues red, magenta, cyan and green (Figure 5.8b).
5.3.3 Tenseness

The results of tenseness are displayed in Figure 5.9. The scale used for the axis of the plot is equal to the seven point unipolar Likert scale used in the questionnaire (Section 4.4).

The analyses revealed a significant effect of CT of white light on tenseness ($F(1,38) = 106.07$, $p < 0.001$, $\eta^2_p = 0.809$). The result showed that cool white light appears to be less tense than warm white light.

Additionally, the results showed an interaction effect between CT of white light and Hue on tenseness ($F(4,35) = 2.92$, $p = 0.035$, $\eta^2_p = 0.250$). Figure 5.10 indicates that the effect of CT of white light was largest for white. The warm white light appears to be more tense than cool white light for magenta, cyan and green, while cool white light appears to be slightly more tense than warm white light for a white spot. Red appears to be equally tense in both white light settings.

However, for the tests of blue and yellow no significant effect of CT of white light was found.
For Saturation a significant effect was found on tenseness (F(1,38) = 36.34, p < 0.001, $\eta_p^2 = 0.489$), which showed that the light conditions with a low saturation were less tense than the light conditions with a high saturation.

Furthermore, an interaction effect between Lightness and Saturation was found (F(1,38) = 6.37, p = 0.016, $\eta_p^2 = 0.144$). Figure 5.11a displays the interaction effect and shows that at maximum saturation the high lightness was perceived as more tense than at low lightness.

Another significant main effect that the results revealed was the effect of Hue on tenseness (F(4,35) = 2.95, p = 0.034, $\eta_p^2 = 0.252$). Red was perceived as more tense compared to magenta, green, cyan and white. Blue was evaluated near the centre of the tenseness axis. Yellow was evaluated on the negative side of the scale of tenseness and was assessed as the least tense hue compared to the other plotted hues (Figure 5.9).

Lastly, an interaction effect between Saturation and Hue was found (F(4,35) = 9.76, p < 0.001, $\eta_p^2 = 0.527$). Figure 5.11b indicates that red at maximum saturation was perceived as most tense in comparison to magenta, cyan and green, whereas at low saturation the effect of Hue was much smaller. The effect of Saturation on tenseness appeared to be the largest for red and negligible for cyan and white. However, this interaction effect could be explained by the fact that in the layout of the design the maximum saturation levels of all hues might differ in perceived saturation.

For Saturation a significant effect was found on tenseness (F(1,38) = 36.34, p < 0.001, $\eta_p^2 = 0.489$), which showed that the light conditions with a low saturation were less tense than the light conditions with a high saturation.

Furthermore, an interaction effect between Lightness and Saturation was found (F(1,38) = 6.37, p = 0.016, $\eta_p^2 = 0.144$). Figure 5.11a displays the interaction effect and shows that at maximum saturation the high lightness was perceived as more tense than at low lightness.

Another significant main effect that the results revealed was the effect of Hue on tenseness (F(4,35) = 2.95, p = 0.034, $\eta_p^2 = 0.252$). Red was perceived as more tense compared to magenta, green, cyan and white. Blue was evaluated near the centre of the tenseness axis. Yellow was evaluated on the negative side of the scale of tenseness and was assessed as the least tense hue compared to the other plotted hues (Figure 5.9).

Lastly, an interaction effect between Saturation and Hue was found (F(4,35) = 9.76, p < 0.001, $\eta_p^2 = 0.527$). Figure 5.11b indicates that red at maximum saturation was perceived as most tense in comparison to magenta, cyan and green, whereas at low saturation the effect of Hue was much smaller. The effect of Saturation on tenseness appeared to be the largest for red and negligible for cyan and white. However, this interaction effect could be explained by the fact that in the layout of the design the maximum saturation levels of all hues might differ in perceived saturation.
5.3.4 Detachment

For detachment the results of all evaluated light conditions are plotted in Figure 5.12. The scale used for the axis of the plot is equal to the seven point unipolar Likert scale used in the questionnaire (Section 4.4).

Like the other three atmosphere dimension, detachment also had an effect of CT of white light ($F(1,38) = 39.10, p < 0.001, \eta^2_p = 0.507$). Cool white light was perceived as less detached than warm white light. The blue and yellow tests showed no effect of CT of white light.

A significant main effect of Saturation was found on detachment ($F(1,38) = 7.58, p = 0.009, \eta^2_p = 0.166$). Light conditions with maximum saturated colour were perceived as less detached than light conditions with low saturated colour.

Hue also had an effect on detachment ($F(4,35) = 80.04, p < 0.001, \eta^2_p = 0.901$), which showed that cyan and especially white were perceived as more detached compared to red, magenta and green. Moreover, white was perceived as the most detached followed by cyan, while red was perceived as the least detached hue.

The results indicated that a significant effect between Lightness and Hue on detachment ($F(4,35) = 3.50, p = 0.017, \eta^2_p = 0.286$). Figure 5.13 shows that low lightness was perceived as slightly more detached than high lightness except for white where the opposite occurred.

A trend was found on detachment between Saturation and Hue ($F(4,35) = 2.60, p = 0.053, \eta^2_p = 0.229$). This trend showed an effect for cyan and white in comparison to red, magenta and green, but this was due to the equality in saturation for cyan and white.
5.3.5 Summary

In sum, the results for CT of general white light revealed that cool white light was perceived as less *cosy*, less *tense* and less *detached* compared to warm white light. For *liveliness* no effect of CT of white light was found. Intuitively, one would find the opposite effect of CT of general white light on *tenseness* and *detachment* more probable, which is supported by the studies of Moors (2009) and Van Erp (2008).

The results for Lightness showed only an effect on *liveliness*, where low lightness was perceived as less *lively* than high lightness.

For Saturation the results showed that, low saturated light conditions were perceived as more *cosy* and more *detached*, while maximum saturated light condition were perceived as more *tense*.

The results for Hue revealed a significant effect on the four atmosphere dimension. For *cosiness* the results of Hue revealed that red compared to magenta, blue, cyan, green and white was perceived as the most *cosy*. Blue and white appeared to be the least *cosy*. The result of Hue on *liveliness* showed that white, especially white at low lightness, was perceived as the least *lively*, followed by cyan, compared to red, magenta, blue, green and yellow. For *tenseness* the results of Hue showed that red, in particular red at maximum saturation, was found to be perceived as the most *tense* compared to the other hues. On the other hand, yellow appeared to be evaluated as the least *tense*. The results for the last dimension *detachment* showed that white was perceived as the most *detached*, whereas red was perceived as the least *detached* compared to magenta, blue, cyan, and green.

Overall, Red was perceived as most *cosy*, but also most *tense* and least *detached* compared to magenta, blue, cyan, green and white. Yellow was evaluated as equally *cosy* as red and appeared the least *tense*. White was perceived as most *detached* and least *lively* in comparison to red, magenta, blue, cyan, green and yellow.
5.4 Results Preference

Figure 5.14 shows all light conditions for preference. The scale used for the axis of the plot is equal to the seven point bipolar Likert scale used in the questionnaire (Section 4.4).

For CT of white light no significant effects were found on preference.

A significant effect on Lightness was found on preference (F(1,38) = 5.03, p = 0.031, $\eta^2_p = 0.123$), which showed that high lightness was more preferred than low lightness.

Saturation also revealed an effect on preference (F(1,38) = 6.58, p = 0.015, $\eta^2_p = 0.154$). These results revealed that low saturation was more preferred than maximum saturation.

Moreover, a significant interaction effect between Lightness and Saturation was shown (F(1,38) = 11.49, p = 0.002, $\eta^2_p = 0.242$). The results indicate that at low saturation high lightness was more preferred than low lightness whereas at maximum saturation the effect of Lightness was negligible (Figure 5.15a).

The effect of Hue on preference was significant (F(4,35) = 8.05, p < 0.001, $\eta^2_p = 0.494$). These results revealed that cyan was preferred more compared to red, magenta, green and white. Yellow was evaluated high on preference, comparable to cyan.

In addition, an interaction effect was found between Saturation and Hue on preference (F(4,35) = 3.00, p = 0.032, $\eta^2_p = 0.267$). This result is displayed in Figure 5.15b and indicates that the effect of Saturation was largest for red, smaller for magenta and green, and negligible for cyan and white. This could be due to equality of saturation for cyan and white and the fact that the maximum saturation of the hues might differ in perceived saturation.
Figure 5.15: a) Graphical result of the interaction effect of Lightness and Saturation on preference. b) Graphical result of the interaction effect of Saturation and Hue on preference. Note; the error bars show the 95% confidence intervals of the means.

A trend between Lightness and Hue was also shown on preference (F(4,35) = 2.54, p = 0.058, $\eta_p^2 = 0.235$). The effect of Lightness was most pronounced for white (Figure 5.16).

Figure 5.16: Graphical result of the interaction effect of Lightness and Hue on preference. The error bars show the 95% confidence intervals of the means.

5.4.1 Summary
In sum, Cyan and yellow were the most preferred hues in comparison to red, magenta, blue, green and white, especially for high lightness. In general, low saturation appeared to be more preferred than maximum saturation.
5.5 Results Suitability

In this section the results are shown for the suitability of lighting for different uses of the space. The results of the questionnaire were divided into the suitability of a living room and the suitability of an office.

5.5.1 Suitability of Living room

The results for suitability of a living room are displayed in Figure 5.17. The scale used for the axis of the plot is equal to the seven point unipolar Likert scale used in the questionnaire (Section 4.4).

![Graphical results of the effects on suitability of a living room. a) Plotted for all light conditions with warm white light. b) Plotted for all light conditions with the cool white light. * Note; this light condition is in front of a light condition with the same outcome value.](image)

CT of white light had a significant effect on suitability of a living room (F(1,38) = 12.52, p = 0.001, $\eta^2_p = 0.248$). Cool white light was evaluated as less suitable than warm white light.

An effect of Saturation on the suitability of a living room was significant (F(1,38) = 20.30, p < 0.001, $\eta^2_p = 0.348$). The results showed that low saturation was evaluated as more suitable for a living room than maximum saturation.

Additionally, an interaction effect between Lightness and Saturation on the suitability of a living room was found to be significant (F(1,38) = 7.54, p = 0.009, $\eta^2_p = 0.166$). Figure 5.18a indicates that at low saturation high lightness was evaluated as more suitable for a living room than low lightness, while at maximum saturation the effect is reversed.

The main effect of Hue had a significant result on the suitability of a living room (F(4,35) = 3.72, p = 0.013, $\eta^2_p = 0.299$). The result revealed that red and white were more suitable for a living room than magenta, cyan and green. Blue was evaluated as the least suitable hue for a living room while yellow was evaluated as a suitable hue for a living room. Yellow is even the most suitable hue for a living room.

A significant effect interaction was found between Saturation and Hue (F(4,35) = 5.25, p = 0.002, $\eta^2_p = 0.375$), which indicates that the effect of Saturation was largest for red, smaller for magenta and green, and negligible for cyan and white. Again, this could be due to equality of saturation for cyan and white and the fact that the maximum saturation of the hues might differ in perceived saturation (Figure 5.18b).
RESULTS

Figure 5.18: a) Graphical result of the interaction effect of Lightness and Saturation on the suitability of a living room. b) Graphical result of the interaction effect of Saturation and Hue on the suitability of a living room. Note: the error bars show the 95% confidence intervals of the means.

5.5.2 Suitability of Office

Figure 5.19 shows the evaluated light conditions for the suitability of an office. The scale used for the axis of the plot is equal to the seven point unipolar Likert scale used in the questionnaire (Section 4.4).

![Graphical results of the effects on suitability of an office. a) Plotted for all light conditions with warm white light. b) Plotted for all light conditions with the cool white light.](image)

The results on the suitability of an office had a significant effect of CT of white light ($F(1,38) = 41.62$, $p < 0.001$, $\eta^2_p = 0.523$). Cool white light was evaluated as less suitable for an office than warm white light. The test for blue revealed also a significant effect of CT of white light ($F(1,38) = 4.79$, $p = 0.035$, $\eta^2_p = 0.112$), which indicates that blue in the cool setting was evaluated as less suitable for an office than blue in the warm setting.

Furthermore, a significant effect of Saturation on the suitability of an office was found ($F(1,38) = 16.63$, $p < 0.001$, $\eta^2_p = 0.304$). Maximum saturation was evaluated as less suitable for an office than low saturation.
An interaction effect between Lightness and Saturation was found on the suitability of an office (F(1,38) = 6.26, p = 0.017, η² = 0.141). Like the suitability of a living room, Figure 5.20a indicates that at low saturation high lightness was evaluated as slightly more suitable than low lightness, while at maximum saturation the effect was reversed.

Hue had also a significant effect on the suitability of an office (F(4,35) = 56.96, p < 0.001, η² = 0.867). The results indicated that white was evaluated as the most suitable hue for an office followed by cyan compared to red, magenta and green, whereas red and magenta were evaluated as the least suitable hues for an office.

Lastly, an interaction effect of Saturation and Hue was found on the suitability of an office (F(4,35) = 6.52, p < 0.001, η² = 0.427). The results indicate that the effect of Saturation was largest for red, smaller for magenta and green, and negligible for cyan and white. This could be due to equality of saturation for cyan and white and the fact that the maximum saturation of the hues might differ in perceived saturation (Figure 5.20b).

Figure 5.20: a) Graphical result of the interaction effect of Lightness and Saturation on the suitability of an office. b) Graphical result of the interaction effect of Saturation and Hue on the suitability of an office. Note; the error bars show the 95% confidence intervals of the means.

5.5.3 Summary

In sum, warm white light appeared to be most suitable for both spaces. Low saturation was found to be less suitable for a living room and an office than maximum saturation. For the living room the most suitable colours of the coloured decorative light were red, white and yellow compared to magenta, blue, cyan and green. The least suitable colour was magenta, especially at maximum saturation. For the office, cyan appeared to be more suitable than red, magenta, blue, green and yellow. White was found to be the most suitable for an office, whereas red and magenta were the least suitable for an office.
5.6 Correlations

Some of the results found on the nine dependent variables had similar effects of the independent factors. Therefore a correlation analyses was preformed on the variables to see if they correlated. Table 5.3 shows the results of this correlation analyses.

Table 5.3: An overview of correlations between variables.

<table>
<thead>
<tr>
<th>Correlations</th>
<th>Perceived Brightness</th>
<th>Perceived Temperature</th>
<th>Cosiness</th>
<th>Liveliness</th>
<th>Tenseness</th>
<th>Detachment</th>
<th>Preference</th>
<th>Suitability Living room</th>
<th>Suitability Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceived Brightness</td>
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<td>0.07</td>
<td>0.09</td>
<td>0.36</td>
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<td>0.14</td>
<td>0.29</td>
<td>0.21</td>
<td>0.23</td>
</tr>
<tr>
<td>Perceived Temperature</td>
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<td>1</td>
<td>0.55</td>
<td>0.33</td>
<td>-0.20</td>
<td>-0.34</td>
<td>0.22</td>
<td>0.42</td>
<td>-0.08</td>
</tr>
<tr>
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<td>0.57</td>
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<td>-0.18</td>
<td>0.54</td>
<td>0.61</td>
<td>0.07</td>
</tr>
<tr>
<td>Liveliness</td>
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<td>1</td>
<td>0.24</td>
<td>-0.05</td>
<td>-0.42</td>
<td>0.63</td>
<td>0.40</td>
<td>0.15</td>
</tr>
<tr>
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<td>1</td>
<td>-0.06</td>
<td>-0.42</td>
<td>-0.41</td>
<td>-0.23</td>
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<tr>
<td>Detachment</td>
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<td>-0.18</td>
<td>-0.34</td>
<td>-0.18</td>
<td>1</td>
<td>0.15</td>
<td>0.05</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>Preference</td>
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<td>0.54</td>
<td>0.63</td>
<td>-0.42</td>
<td>0.15</td>
<td>1</td>
<td>0.57</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Suitability Living room</td>
<td>0.21</td>
<td>0.61</td>
<td>0.40</td>
<td>-0.41</td>
<td>0.05</td>
<td>0.57</td>
<td>1</td>
<td>0.37</td>
<td>1</td>
</tr>
<tr>
<td>Suitability Office</td>
<td>0.23</td>
<td>-0.08</td>
<td>0.07</td>
<td>0.15</td>
<td>-0.23</td>
<td>0.73</td>
<td>0.35</td>
<td>0.37</td>
<td>1</td>
</tr>
</tbody>
</table>

Several correlations between variables were found. Strong correlations exist between perceived *temperature*, *cosiness*, *liveliness*, *preference* and *suitability* of a living room. The effect of Hue appeared to have the same results on these variables. Red and yellow were perceived as *warm* colours, but also as *cosy* and *suitable* for a living room, especially for warm white light. In addition, a strong relationship between preference and suitability of a living room existed, where yellow was *preferred* the most and was evaluated as the most *suitable* hue for a living room. Furthermore, the effect of Hue was correlated for *cosiness* and *liveliness*. Yellow was perceived as *cosy* and *lively*, while white was perceived as less *cosy* and least *lively*. Also a correlation of *liveliness* and *preference* existed. The results showed that the effect of Lightness correlated to both variables. High lightness was found to be more *lively* and *preferred* over low lightness.

Lastly, a strong correlation occurred for *detachment* and *suitability* of an office. Several effects correlated to these variables. The effect of CT of white light showed that warm white light was evaluated as more *suitable* for an office and perceived as more *detached*. For saturation the results indicated that low saturation was perceived as more *detached* and evaluated as more *suitable* for an office. Cyan and white were hues found most *suitable* for an office and most *detached*. 
6 Discussion

The goal of this research was to study the effects of coloured light characteristics on the perception of light characteristics, atmosphere, preferences and suitability. These light characteristics varied in CT of general white light and Lightness, Saturation and Hue of coloured decorative light. This section will discuss the findings of this research for each of the four categories separately and will provide recommendations for future research.

6.1 Perceived Light characteristics

The perceived light characteristics were divided into perceived brightness and perceived temperature. The result for perceived brightness showed that people were able to discriminate between high and low lightness. This confirms previous research which shows that the perceived brightness is influenced by changing the illuminance. Unfortunately, the results showed also an effect of hue on the perceived brightness. This means that not all hues were perceived as equally bright while the lightness level of all hues was identical. This result might be related to the Helmholz-Kohlraush effect, which states that when the saturation of an object increases the perceived brightness also increases. Apparently, the manipulations used for lightness were not entirely well chosen.

The results of this research showed an effect of hue on the perceived temperature, which divides coloured light into warm coloured light and cool coloured light. Red, magenta and yellow were perceived as warm colours, blue and cyan as cool colours and green and white were perceived as neutral. These results are in agreement with earlier studies on perceived temperature of colours (Kawamoto & Soen, 1993; Kaya & Epps, 2004; Manav, 2006).

The perceived temperature of the light was not affected by the CT of white light. This could be explained by the fact that for CT a between-subject design was chosen and therefore participants might have used the cool or warm white light as a neutral reference light. When both the warm white and cool white settings were presented to a participant, the two white lights can be compared to each other. Also the effect of hue might have dominated the perception of temperature. Studies have shown that when only white light was presented a high CCT was perceived as “cool” whereas a low CCT was perceived as “warm” (Van Erp, 2008; David & Ginther, 1990). Moors (2009) used both white and coloured light and found a significant effect on the perceived temperature.

In the questionnaire questions about perceived brightness and perceived temperature were asked, but no questions about perceived saturation and perceived hue were asked although these variables could be considered useful for the perception of lighting characteristics. During the pilot experiments participants were specifically asked about perceived saturation. In the main experiment it would have been interesting to see if the results of the pilot experiments could be confirmed.

6.2 Perceived Atmosphere

Besides studying the perception of the light, the effects of coloured lighting characteristics on the perceived atmosphere were studied. The perceived atmosphere was divided into four dimensions: cosiness, liveliness, tenseness and detachment.

A significant effect of CT of general white light was found on several atmosphere dimensions. The results showed that warm white light appeared to be perceived as more *cosy*, more *tense* and more *detached* than cool white light. Van Erp (2008), on the other hand, found in his study on general white light that warm white light was perceived as more *cosy*, less *tense* and less *detached* than cool white light. Moors (2009) used both white and coloured light and found that warm white light was perceived as more *cosy*, more *lively*, less *tense* and less *detached*. The fact that for this research a between-subject design was chosen might explain the differences on *tenseness* and *detachment* in comparison to the other studies. However, an interaction effect showed that the effect of CT of white light depends on the hue of the spot: warm white light in combination with (warm) white spots was less *tense* compared to cool white light with (cool) white spots. In addition, the effect of CT of white light on *detachment* was mainly caused by only one hue: green.
The results revealed that Lightness had an effect only on *liveliness*, which showed that low lightness was perceived as less *lively* than high lightness. This result is in agreement with the results found by Van Erp (2008) for general white light and Moors (2009) for decorative light. However, Van Erp and Moors found an effect of brightness on more atmosphere dimension. There were significant interaction effects between Lightness and Saturation and between Lightness and Hue and on the other atmosphere dimensions. The results showed that at maximum saturation the high lightness was perceived as less *cosy* and more *tense*. Furthermore, low lightness was perceived as slightly more *detached* than high lightness except for white where the opposite occurred.

The effect of Saturation on the perceived atmosphere was also studied. The results showed that low saturated light conditions were perceived as more *cosy*, more *detached*, and less *tense* compared to maximum saturated light conditions. Moors (2009) found that a low saturation was perceived as less *lively* and less *tense* than maximum saturation. The difference in results for *cosiness* and *liveliness* could be explained by the fact that Moors only used two hues (red and blue) and did not explicitly check if the saturations levels of the hues were perceptual equal.

Several interaction effects between Saturation and Hue were found on atmosphere perception. These effects showed that a difference in saturation occurred for red, magenta and green, while no difference in saturation was found for cyan and white. This is in fact not a strange result because white has no saturation level and cyan had a low and maximum saturation level that was practically similar.

Consequently, these results were mostly based on the hues red, magenta and green, because blue and yellow were only presented at maximum saturation and white and cyan did not differed in saturation level. Therefore, it could be interesting to change the saturations levels of blue, yellow and cyan as well and see if the same results will occur.

The results for Hue revealed a significant effect on the four atmosphere dimension. For *cosiness* the results of Hue revealed that red compared to magenta, blue, cyan, green and white was perceived as the most *cosy*. Blue and white appeared to be the least *cosy*. The result of Hue on *liveliness* showed that white, especially white at low lightness, was perceived as the least *lively*, followed by cyan, compared to red, magenta, blue, green and yellow. For *tenseness* the results of Hue showed that red, in particular red at maximum saturation, was found to be perceived as the most *tense* compared to the other hues. On the other hand, yellow appeared to be evaluated as the least *tense*. The results for the last dimension *detachment* showed that white was perceived as the most *detached*, whereas red was perceived as the least *detached* compared to magenta, blue, cyan, and green.

Overall, Red was perceived as most *cosy*, but also most *tense* and least *detached* compared to magenta, blue, cyan, green and white. Yellow was evaluated as equally *cosy* as red and appeared the least *tense*. White was perceived as most *detached* and least *lively* in comparison to red, magenta, blue, cyan, green and yellow.

The results of Hue on the perceived atmosphere suggest that people are capable of matching colour to atmosphere. The results are in agreement with other studies on atmosphere. Red was found to be more arousing, more *cosy*, more *lively* and less detached than blue (Moors, 2009; Dijkstra et al., 2008; Kwallek et al., 2007).

In this research only single hues were used for creating atmosphere while in reality environments are often defined by colour combinations. Seuntiens and Vogels (2008) found that professional designers would use the colours orange and blue for creating a *cosy* atmosphere.

### 6.3 Preferences

In general, high lightness was more preferred than low lightness and low saturation appeared to be more preferred than maximum saturation, except for cyan. This could be due to small perceived differences between low and maximum saturation for cyan.

The results for Hue on preference of the lighting showed that cyan and yellow were the most preferred hues in comparison to red, magenta, blue, green and white, especially for high lightness.

That cyan is the most preferred hue corresponds to earlier research, the preference of yellow is contradicting several studies (Valdez & Mehrabian, 1994; Granger, 1955; Eysenck, 1941) which...
found that yellow was the least preferred colour. However, these studies used coloured patches instead of a coloured light source which was used in this study. This could make a difference because yellow light is often associated with sunlight and people prefer sunlight, while a yellow colour patch might appear unpleasant and therefore is not preferred.

6.4 Suitability

The last dependent variable studied was the suitability of the lighting for a living room and an office. The results showed no considerable effects of Lightness on the suitability of a living room or office. However, the results showed an effect of CT of general white light and Saturation and Hue of decorative light.

For CT of general white light the effect on suitability showed that warm white light appeared to be most suitable for both spaces. The effect of Saturation on suitability showed that maximum saturation was found to be less suitable for a living room and an office than low saturation. The effect of Hue showed that, for the living room red, white and yellow were more suitable colours compared to magenta, blue, cyan and green. The least suitable colour was magenta, especially at maximum saturation. For the office, cyan appeared to be more suitable than red, magenta, blue, green and yellow. White was found to be the most suitable colour for an office, whereas red and magenta were the least suitable colour for an office.

All light conditions that appeared to be most suitable for the living room had a high correlation with cosiness. Living rooms are found to be related to warm colours and low saturation (Dijkstra, 2008; Kwallek et al. 2007), which are similar to the results found on cosiness.

For the office a high correlation with detachment was found. Offices or functional environments are found to be related to cool colours and high illuminance (Van Erp, 2008; Kwallek et al. 2007), which are similar to results found on detachment.

6.5 Future research

The findings in this study give insight into the relationship between characteristics of coloured light and the perceived atmosphere. It was shown that Lightness, Saturation and Hue have effects on the perception of the lighting, perceived atmosphere, the preferences of the lighting and suitability. However, there are some suggestions for further research.

In this research a diffuse white light source was combined with LED-spots which provided the coloured lighting. Research has shown that the spatial distribution of light influences the perceived atmosphere (Van Erp, 2008). Non-uniform white lighting appeared to be more cosy, more lively and less tense compared to uniform white lighting. Therefore, it would be interesting to investigate the effects of non-uniform white lighting combined with decorative lighting (uniform or non-uniform) on the perceived atmosphere. Unfortunately, no physical measure has been found yet that can describe the brightness impression of a room (Van Erp, 2008). Therefore, studying the effect of spatial distribution of coloured lighting on the perceived atmosphere, while keeping room brightness constant, could be quite challenging. In addition, dynamic lighting could also influence the atmosphere, for example to create exciting atmospheres (Seuntiens & Vogels, 2008).

Like discussed before, environments rarely use a single coloured. Therefore, colour combination, like used in the study of Seuntiens and Vogels (2008), could enhance or reduce the perceived atmosphere. Furthermore, additional hues besides the primary and secondary colours, such as tertiary colours like orange, pink and aquamarine colour could be used. For example, orange reminds people of sunsets and aquamarine gives people a relaxed feeling (Kaya & Epps, 2004).

Additionally, it would be interesting to see if daylight or moonlight have an influence on the perceived atmosphere but also on the suitability of a space. In this experiment there was no light from outside, while daylight is a common factor (especially in offices) in everyday life. However, daylight is uncontrollable and therefore it could be wise to fake daylight to control influences of outside variables like cloudiness or extreme sunlight.
This research did not take in consideration the effect of age and gender on perceived lighting characteristics, due to an insufficient number of participants. Knez and Kers (2000) found that younger people evaluated an illuminated room as brighter than older people. For gender effects, it was found that males evaluated an illuminated room as more dim than female participants (Knex & Enmarker, 1998). The same effects of age and gender occurred on perceived temperature (Knez & Enmarker, 1998; Kenz & Kers, 2000). Younger participants evaluated an illuminated room are more cool than older participants. Furthermore, female participant were found to be less sensitive for high CCT values than male participants. The age effect was explained by the reduction of light sensitivity for illuminance when becoming older, but no explanations for the differences in gender were given. The participants of the experiment for this research were equally distributed into females and males and the age difference was limited from 20 to 35 years old. However, if the number of participants had been larger if would be interesting to take these effects into consideration.

Overall, this research is a valuable start in the study of coloured lighting characteristics on the perceived atmosphere.
References


Kwallek, N. K., Soon, K., & Lewis, C. M. (2007). Work week productivity and visual complexity and individual environmental sensitivity in three offices of different color interiors. *Journal of Color Research and Application, 32*, 130-143


Appendix I

**Naam:**

**Nr.:**

Beschrijf je **eerste indruk** in maximaal 3 woorden.

Geef voor elk woord uit de onderstaande lijst aan in welke mate dit woord van toepassing is op de **sfeer** van de ruimte, op een schaal van absoluut niet van toepassing tot zeer goed van toepassing.

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<th>Neutraal</th>
<th>Zeer goed van toepassing</th>
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</table>
Geef uw mening over het licht in deze ruimte door bij elk van de onderstaande woordparen een vakje in te vullen dat het meest van toepassing is op het licht.

Donker  ☐ ☐ ☐ ☐ ☐ ☐ ☐ Helder
Koud    ☐ ☐ ☐ ☐ ☐ ☐ ☐ Warm
Lelijk  ☐ ☐ ☐ ☐ ☐ ☐ ☐ Mooi

Hoe geschikt vindt u dit lichtscenario voor de volgende ruimtes?

Woonkamer
Ongeschikt ☐ ☐ ☐ ☐ ☐ ☐ ☐ Geschikt

Kantoor
Ongeschikt ☐ ☐ ☐ ☐ ☐ ☐ ☐ Geschikt

Hebt u nog op- of aanmerkingen?

Bedankt!
### Appendix II

Table II.1: A summary of all main effects found in this research.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Characteristics of the lighting</th>
<th>Perceived Atmosphere</th>
<th>Preference of the lighting</th>
<th>Evaluated Suitability</th>
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Appendix III

Perceived light characteristics

Figure III.1: a) Perceived brightness against perceived temperature plotted for all light conditions with warm white light. b) Perceived brightness against perceived temperature plotted for all light conditions with the cool white light.
Perceived Atmosphere

Figure III.2: a) Perceived liveliness against perceived cosiness plotted for all light conditions with warm white light. b) Perceived liveliness against perceived cosiness plotted for all light conditions with the cool white light.

Figure III.3: a) Perceived detachment against perceived tenseness plotted for all light conditions with warm white light. b) Perceived detachment against perceived tenseness plotted for all light conditions with the cool white light.
**Preference of the lighting**

*Warm White light*

*Cool White light*

*Figure III.3:* a) Preference against perceived temperature plotted for all light conditions with warm white light. b) Preference against perceived temperature plotted for all light conditions with the cool white light.

**Evaluated Suitability**

*Warm White light*

*Cool White light*

*Figure III.4:* a) The suitability for an office against the suitability of a living room plotted for all light conditions with warm white light. b) The suitability for an office against the suitability of a living room plotted for all light conditions with cool white light.