MASTER

Artificial skylights
the benefits of and preference for artificial skylights and sun patterns

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Mariska Stokkermans

Student ID number: 0664142

Supervisors:

Dr. Ir. Yvonne de Kort — TU/e, IEIS, Human-Technology Interaction

Dr. Ir. Antal Haans — TU/e, IEIS, Human-Technology Interaction

Dr. Ir. Pieter Seuntiens — Philips Research, Visual experiences

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Preface

With this thesis I will end my Master Human-Technology Interaction at the University of Technology in Eindhoven. This last project was in combination with the group Visual Experiences of Philips Research. I would like to thank my supervisors, Yvonne de Kort, Antal Haans and Pieter Seuntiens for their feedback and support. Further, thanks to all helping out with the setup and analyses of the experiments.

Summary

Many people have a preference for natural products. This is because people belief natural products are healthier and better than man-made products. These beliefs are also present in the lighting domain. Office employees think daylight leads to less stress and discomfort than electric lighting. This, while daylight is not necessarily superior to artificial lighting. Nevertheless, peoples' self report on many constructs as for instance visual appearance and job satisfaction shows that daylight has positive effects. This is possibly because daylight is much more than just a light source to deliver good quality work. It is dynamic; provides information about the weather; and daylight situations often come with a view out too.

In the present research, artificial skylights were studied. These artificial skylights are based on standard luminaries; however, create the experience of real skylights with blue skies and daylight entering the room. The artificial skylights are being developed by Philips Research to use as a substitution to windowless locations where no windows or skylights are present, or as additional light sources besides windows. Research about artificial skylights and windows is scarce. The few studies regarding virtual (vertical) windows showed that people appreciated the windows. However, effects on physiological measures were not found. Therefore, more research is needed, and the present thesis was a contribution to this.

Two experiments were conducted for this thesis. In the first we investigated the differences between a room with artificial skylights and a room with standard office lighting. Several aspects were measured, namely: appraisal of the lighting (attractiveness, suitability for work, glare), appraisal of the room (attractiveness, atmosphere, visual clarity, uniformity, spaciousness), affect, and perceived naturalness (daylight experience, naturalness of colors). Furthermore, we looked for possible improvements that could optimize the artificial skylights, through a funneled debriefing. The first results of this study showed little significant differences between the artificial skylight room and the standard room. The effects that were found showed that the standard room had a higher visual clarity, was more uniformly lit, and the lighting was more suitable for doing office work. However, the funneled debriefing showed that two distinct groups of people existed. One group recognized the skylight concept immediately, and the other group did not recognize the concept at all. Splitting the groups led to new results. People, who recognized the artificial skylights, had a stronger daylight experience in the skylight room than the people who did not recognize the artificial skylight. Furthermore, this group had a higher daylight experience in the artificial skylight room compared to the standard room. Although an effect was found, the strength of the daylight experience was not very high. The main improvements resulting from the funneled debriefing were that color of the 'sky' had to be less saturated blue, the size of the skylight should be larger and the illumination of the room should be higher. When these improvements will be implemented in the artificial skylight it is likely that the strength of the daylight experience will increase and that more people will recognize the artificial skylight, which will lead to improvements on the other aspects as well.

In the second study sun patterns falling through the artificial skylights were researched. One of the ways to increase the room illumination (as suggested on study 1) is the effect of sun patterns that fall through the skylight on the wall. Preference for different sun pattern attributes (shape, sharpness and CCT) was researched in home and office contexts through a paired comparison method. These attributes contained realistic as well as unrealistic stimuli. Furthermore, possible constructs that could explain this preference

were studied. The results of the study showed that the most preferred sun pattern was a long diagonal pattern with an intermediate CCT (7000 K) and depending on the context a pattern with blurred edges (preferred in homes) or a pattern with sharp edges gradually becoming more blurred (preferred in offices). Besides preference, participants also judged each comparison based on realism, aesthetics, atmosphere, and daylight impression. Results showed that most often realism judgments for different sun patterns were correct. Moreover, also correlation analyses led to interesting results. All constructs correlated significantly with preference, and were therefore important. However certain trends in the data were detected of which conclusions were drawn. Realism seemed to be most important in predicting overall preference. Therefore, the conclusion may be drawn that people seemed to prefer sun patterns that were true-to-nature, and had less preference for unnatural patterns. Furthermore, context effects were also present in the constructs that explained preference. Results showed that aesthetics and atmosphere were very important for both homes and offices, and formed a large part in explaining the preference for a certain sun pattern. However, the main difference was that in offices patterns should represent daylight closely and also be very realistic with respect to other issues, while for homes this seemed to be less important.

In the future, it may be good to repeat the first study, after the suggested improvements are implemented. Then, more positive effects are expected. Further, it may be interesting to also investigate the effects on productivity, health and wellbeing. Of course, combining the sun patterns with the skylight system, and investigating the added value of the sun patterns is also logical step to take. Then, also possibilities for dynamic sun patterns have to be investigated. Sun patterns (dynamic and static) probably make the artificial skylights look more realistic, therefore it is expected that this leads to a higher appraisal.

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1. Introduction

In former times, when there was no electricity in homes and factories, people woke up at dawn and went to sleep after sunset. Humans were completely dependent on daylight, and after the sun set they only had the light of oil lamps or candles. After the invention of the electric light bulb in the late 19th century much changed. Using the light bulb as a substitution for daylight during the evening, people were suddenly able to work and have social events after sun set as well.

However, the way artificial light was being used evolved during the years. It is not a secondary light source next to daylight anymore. Nowadays, people's way of life is dependent on artificial lighting. Although exceptional, whole buildings are built without having one window. More common however, are specific rooms in a building or house were no daylight is present. Examples of these are bathrooms, hallways of hotels, parking garages etcetera. Further, not in all countries offices are required to have windows.

More and more research points in the direction that daylight compared to artificial light is beneficial for health, wellbeing, perception of the environment, (job) satisfaction etcetera. Daylight provides information of time of day, weather, and is dynamic but still subtle. This connection to nature, due to the daylight inside the room, or the view through a window, is highly valuable.

This thesis is about 'artificial skylights'. These artificial skylights are based on standard luminaries; however create the experience of real skylights with blue skies and daylight entering the room. The artificial skylights are being developed by Philips Research to use as a substitution to windowless locations where no windows or skylights are present, or as additional light sources besides windows.

In this thesis, two studies will be conducted. These are related to each other; however, founded on different research areas. The first study is an explorative research where existing prototypes of the artificial skylights will be compared to standard electric light sources. Several questions will be asked. Do people appreciate this new concept? Does it influence other measures as for instance appraisal of the room or pleasure? Do people actually feel a connection to nature?

After these questions are answered, and a general idea of the effects of artificial skylights exists, a second study will be conducted. In this second study, preference for sun patterns (which fall through the skylight) will be assessed. Here, the aim is to research which attributes of sun patterns are preferred. Moreover, the question will be answered what actually explains that something is preferred. Can this be explained by how realistic the patterns are, or is for instance aesthetics more important?

This leads to the following *general* research questions:

1) **"What are the (possible) benefits of artificial skylights compared to standard electric lighting in offices?"**

2) **"Which aspects of sun patterns (within the skylight concept) are preferred, and what factors predict this?"**

Besides these general research questions, both study one and two have more *specific* research questions and these will be presented in respectively chapter four and six. Nevertheless, first, a chapter about necessary background knowledge with respect to lighting and light patterns is given. Thereafter, in chapter three, a theoretical framework will be presented. This will subsequently lead to the research questions of the first study (chapter four). Next, study one (chapter five) will be discussed via a methodology, result and conclusion section. After this first study, the research questions of the second study will be given (chapter six), and these lead to the chapter concerning the second study (chapter seven). This chapter has, like study one, a methodology, results and conclusion section. Finally, chapter eight will present a general discussion section which will reflect on both studies; provide a comparison to existing publications; and discuss possible future research.

2. Background knowledge of lighting and sun patterns

This chapter provides information regarding light and sun patterns. It is not directly related to the research questions of this thesis; however, it is important to understand all details of the present studies. First, a general explanation of lighting characteristics will be given. Thereafter, possible effects of lighting on health are discussed. Lastly, an explanation of how sun patterns exactly look like is given.

2.1 Lighting characteristics

Light is that part of the electromagnetic spectrum to which the human visual system is able to respond. This part is defined by the wavelengths between 380 and 780 nm. These wavelengths are correlated with sensory impression of color. Short wavelengths are violet, long wavelengths red.

Emitted electromagnetic radiation is measured in radiant flux. Luminous flux (specified in lumen; lm), is a measure of light. Luminous flux is radiant flux multiplied by the relative spectral sensitivity of the human eye. It is used to determine the amount of light emitted by a light source in all directions. Luminous flux emitted in a specific direction is called luminous intensity, and specified in candela (cd). Illuminance, is the luminous flux falling on a unit area. This is measured in lm/m^2 or lux. Luminance is the luminous intensity emitted per unit area in a given direction, and measured in cd/m^2 (Boyce, 2003). A graphical overview of these measures is pictured in Figure 1.

Correlated color temperature (CCT) is a way to measure the appearance of a white light source. It is a function of temperature and measured in Kelvin (K). It is based on the emission of a black body (for instance the sun, or incandescent lamp) and defined by Planck's radiation law. The CIE 1931 chromaticity diagram (Figure 2), with a Planckian locus, shows the chromaticity coordinates of black bodies for certain temperatures.

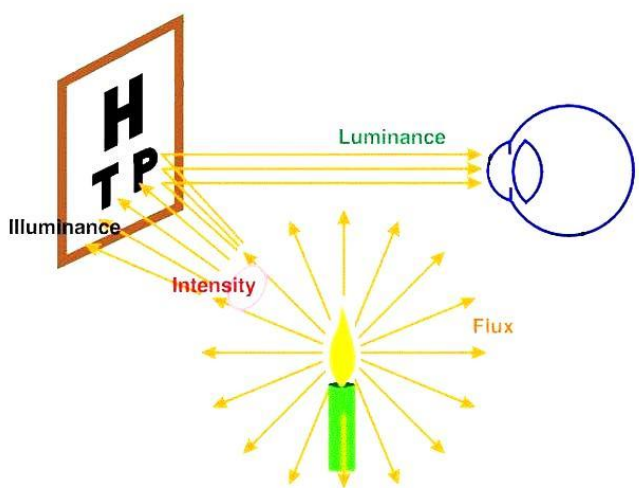

Figure 1: Picture describing relations between Flux, Intensity, Illuminance and Luminance.

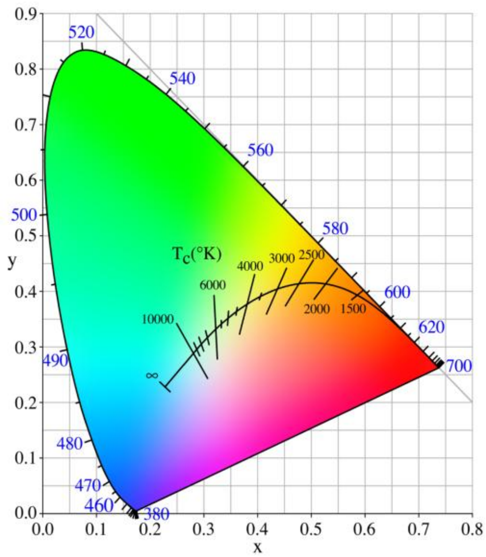

Figure 2: CIE xy 1931 chromaticity diagram including a Planckian locus. The Planckian locus is pictured by the curved black line in the middle of the picture (Wikipedia, 2005).

For other light sources, for instance fluorescent lamps, with chromaticity coordinates that are not exactly corresponding to black bodies, the Planckian locus cannot be used to determine color temperature. This is because the actual color temperature is not aligned with the Planckian locus. For these light sources, the iso-temperature line (the lines perpendicular to the Planckian locus) that is closest to the Planckian locus defines the *correlated* color temperature. This measure, in contrast to color temperature which is only applicable to black bodies, can be used for all white light sources. A lower CCT will have yellowish look and be described as warmer, whereas higher CCTs will look bluish and will be described as cooler (Boyce, 2003).

Color rendering is another characteristic of a light source. The color rendering index (CRI) is a measure of how well the light source renders a color relative to a reference source (CIE, 1995). For instance, color rendering with daylight is better than color rendering with candle light. To calculate this, the positions of a surface color in the CIE 1964 color space under both sources have to be obtained. The best possible quality is a value of 100. The lowest value and most different compared to the reference source is 0 (Boyce, 2003). Therefore, if the color rendering index is high, colors look truthfully in comparison to a natural light source.

Further, the balance between directional and diffuse light plays an important role in lighting. Artificial directional light comes from a directional spot, whereas diffuse lighting comes from a lambertian light source. The difference is in the width of the angle of the light, which is 180° for a lambertian light source, and a smaller beam for directional light sources. For daylight, directional light is provided by sunlight, which creates sharp edges. Diffuse daylight comes from a combination of skylight and light from reflections. The balance between directional and diffuse lighting is very important for the appearance of 3D objects. If only directional components are present, the shades of the object will appear very harsh. If only diffuse components are present, shadows are erased and objects appear dull compared to their environment (Inanici, 2007).

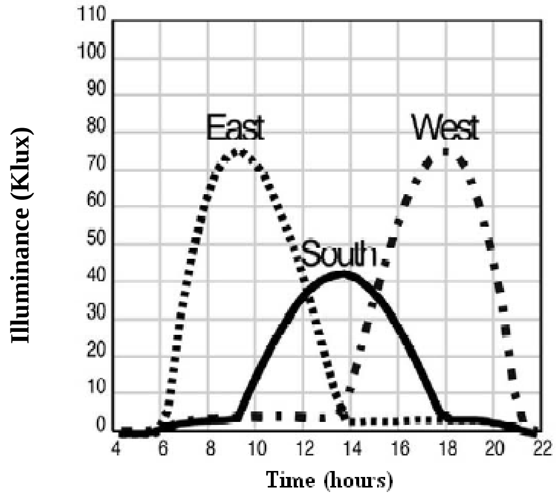

Figure 3: Global vertical illuminances on East-facing, South-facing, and West-facing facades.

Lastly, dynamics is an important aspect of light, and especially for daylight. It is the change of light over time. Daylight has a high variability over the year and over the day. There is a large difference in illuminance between a sunny day and an overcast day. The illumination on building facades can get up to 100000 lux when the sun shines directly on them. However, during an overcast day it can be just a few thousand lux. Also within a day of invariable weather circumstances, illumination varies much. Fontoynont (2002) researched this on a clear day in Lyon, France on June 15. As shown in Figure 3, there is a large variation of illumination over time for each façade. Besides illumination, correlated color temperature is also subject to variation, depending mainly on different sky types. In general, two types of skies can be distinguished. The first type is the overcast sky where CCT is uniform and about 6000K. The second type is the cloudless sky, where CCT is about 7000K near the sun, and up to 20000K at the opposite side (Chain, Dumortier & Fontoynont, 2001). In addition, transmission through windows and reflections indoors changes the CCT of the light. Taking this into account, there will be a variation between 3000 K and 8000 K in an office as a result of daylight (Chain, Dumortier & Fontoynont, 1999).

Perception of light

In contrast to the characteristics described above, perception of light is different under different circumstances. This is because the visual system does not rely only on the stimulus itself, but also on other factors. Firstly, state of adaption is important. Also, a stimulus is not seen as a single item, but as a complex structure of objects. And lastly, perception also involves knowledge from the past, and therefore assumptions are made. An example Boyce gives for these assumptions, is the famous moon illusion. When the moon is low in the sky, it looks much larger, than when it is high, because people assume that it is closer than it actually is (Boyce, 2003). Of course, the moon is in both circumstances equally large. This subparagraph will discuss the perception of brightness. Perceived brightness depends on many factors. "Perceived brightness is an attribute based on the extent to which an object is judged to be emitting more or less light" (Boyce, 2003; p92). Different types of lighting installations for instance can lead to different perceptions of brightness, even though they have the same illuminance on the working plane. Direct lighting, for example, is judged to be brighter than indirect lighting under the same circumstances. Light spectrum can also influence perceived brightness. This is called the Helmholtz-Kolrausch effect. It holds that for two fields of color of the same luminance, the most saturated one will be perceived as brighter. This has been studied among others by Boyce, Hunter and Carter (2002). They compared two light sources with different spectra: the first light source had a high CCT, therefore looking more bluish, and good color rendering (6500K and CRI of 98), the other light source had a low CCT, therefore looking more yellowish and a poor color rendering (3500K and CRI of 82). The results showed that the first light source gave the perception of higher brightness. Also, solely varying color rendering index changes brightness. Light sources with higher CRIs lead to higher perceptual brightness (Boyce, 2003).

2.2 How lighting can affect human health

Light can influence human health in three ways: through radiation, through the visual system and via the circadian system. This paragraph gives a short overview of all these routes.

Radiation

Radiation can have positive and negative health effects. UV radiation on the skin for instance, prevents bone softening and helps cell growth. Further is it used as a treatment for several skin diseases (Boyce, Hunter & Howlett, 2003). However, radiation can also cause tissue damage to the skin and the eye. These effects can be severe and happen acute or chronic. But, since in buildings sunlight will be filtered through glass and the distance of electric lighting to humans is quite large, most UV and IR radiation will not affect the human eye (Boyce, 2010).

Vision system

Incorrect use of lighting can influence health via the visible system pathway. The most common problem is eyestrain. The symptoms of eyestrain range from irritation of the eyes to headaches. Eyestrain can have multiple causes: visual task difficulty, under- and overstimulation, distraction, and perceptual confusion (Boyce, 2010). Several aspects of lighting can cause visual discomfort of which uniformity, glare, veiling reflections, shadows, and flicker are most important (Boyce, 2003). These will be discussed separately.

Glare

Three kinds of glare can be distinguished. The first, disability glare, is caused by light scattering in the eye, which will reduce contrasts of the retinal image and therefore disables the view. The second type of glare is discomfort glare. This has the same physical configuration, but leads to a different effect. Discomfort glare happens when bright light sources distract people and attract their attention. The third type of glare is dazzling glare. Dazzling glare occurs when a bright field of view makes people squeeze their eyes. An example of dazzling glare is bright sunlight. The CIE does not make this distinction and states that dazzling glare is a part of discomfort glare (Vos, 2003).

In the mid-1920s, Holladay made the first quantitative measures for disability glare. The visibility reducing effect was measured as equivalent luminance (L_{eq}) and is written down in a formula as: $L_{eq} = k * E_{glare}/\theta^2$ (Holladay, 1926; in Vos, 2003). It holds that L_{eq} depends on E_{glare}, which is the illuminance upon the eye by a glare source, and the glare angle between the direction of viewing and the direction of the source (θ). If E_{glare} is larger or the angle θ is smaller, then L_{eq} becomes larger. Lastly, age is also important for glare and is included as k (in years). Increasing age will lead to more glare sensation.

Not included in Holladay's formula but known to affect disability glare at large angles is eye color. People with light blue eyes will show more disability glare (Vos, 2003). Discomfort glare is influenced by the luminance of the source, background luminance, source size, and position. A larger contrast between background luminance and light source luminance will lead to a higher sensation of glare. However, this is also related to the size of the light source. Larger sources will lead to more glare sensation (Iwata & Tokura, 1998; Kim & Kim, 2010). Discomfort glare can be measured by the Unified Glare Index. This is a measure used by official European norms which offices have to meet (European Committee for standardization, 2002). Not included in this norm but of interest for glare from windows is the type of view. Different types of view – interesting versus uninteresting, and nature versus urban – can influence the glare sensation. Interesting and natural views lead to less glare than uninteresting and urban views (Tuaycharoen & Tregenza, 2007).

Uniformity

Considering large scale uniformity, Saunders (1969) researched the uniformity ratio horizontal lighting should provide. The study was set in a windowless room, and differences in illumination between two desks were researched. He found that a ratio of 0.7 was acceptable for most people. However, Boyce (2003) adds to this, that when windows are present, people will expect larger differences in uniformity within an office, and do not complain when the illumination ratio is below 0.7. Regulations about uniformity state that in the task area (the workplace in which the visual task is carried out), uniformity has to be equal to, or higher than 0.7 (E_{min}/E_{av}). For the surrounding area (specified as the area of at least 0.5 meter all around the task area) uniformity has to be equal to, or higher than 0.5 (European Committee for standardization, 2002).

Veiling reflections

Veiling reflections are reflections from specular surfaces, like glossy papers. When the angle of incidence the light reflects directly into the eye of the person that reads the paper, it can hinder and lower performance (Boyce, 2003).

Shadows

When light comes from a given direction, and falls on an object, the object creates a cast shadow, and illuminance decreases in that area. Shadows can lead to perceptual confusion and visual discomfort; however, as said before, shadows are also important for revealing three dimensional images (Boyce, 2003).

Flicker

Many electric light sources fluctuate in spectrum and illuminance. If these fluctuations are within a visible frequency, it is called flicker. For people who are sensitive to this, flicker can lead to severe health problems (Boyce, 2003). Besides visible flicker, also unperceivable flicker can cause problems. Flicker of very high frequencies (100-160 Hz) cannot be consciously seen because it is too rapidly changing. Nevertheless it will be processed unconsciously, thereby still impairing visual performance. Other possible health problems related to flicker are less clear at the moment (IEEE, 2010).

Circadian system

Lastly, light operating through the circadian system can influence health. The circadian rhythm is based on two types of oscillators – internal and external oscillators – and the hormone melatonin. Internal oscillators provide time information with a rhythm of slightly more than 24 hours. External oscillators provide information to entrain internal oscillators to exactly 24 hours, and adjust for seasons. This information comes from the light-dark cycle. The hormone melatonin is specifically dependent on the light part of the day, since daylight suppresses melatonin, and as a result makes people feel awake (Boyce, 2010). Recent discovered (non-visual) photoreceptors (ipRGCs) are involved in this and have a peak sensitivity of 470nm, which differs from (the visual photoreceptors) rods and cones (Brainard et al., 2001). The combination of illuminance, CCT, spectrum and duration of light defines the percentage of melatonin suppression during nighttime (Figuero, Rea & Bullough, 2006). Research into high illumination lighting during wintertime showed that systematic exposure of bright light can improve vitality (Patronen & Lönnqvist, 1999).

2.3 Sun patterns

The second study of this thesis is about sun patterns. In the following chapters preference for sun patterns will be discussed. However, first some information will be provided how sun patterns look like under specific circumstances. Since in this thesis skylights are used, all examples will also be about sunlight falling through a skylight in the ceiling.

All sun patterns, whether they are on the wall or falling on the floor, are formed by the rules of perspective. Therefore the top and bottom of the pattern on the wall will always be in line with the opening in the ceiling. Further, depending on the height of the sun, shape and location of the pattern will be determined. Over a day, the sun is highest during midday, and lowest in the morning and late afternoon. Analyzing a year, the sun is highest in the summer, and lowest in the winter. Of course, these two time periods also interact. Further, location at earth is a factor. At the equator, the sun will be higher at midday than at the poles.

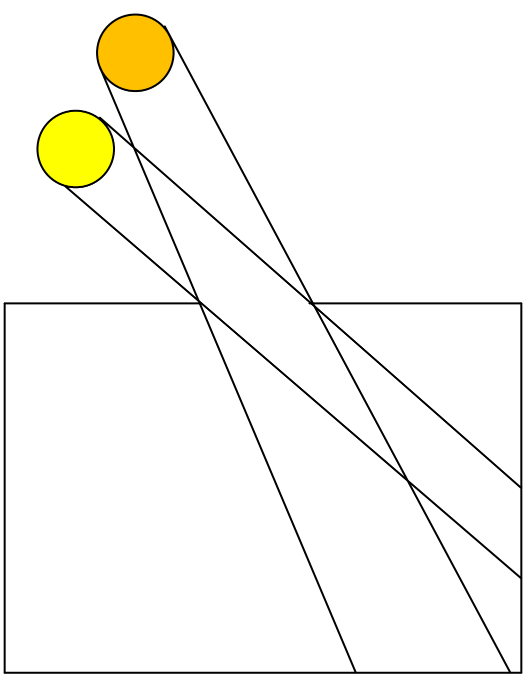

Figure 4: Side view of high and low sun pattern.

Figure 5: Sun pattern rendering.

A high sun will lead to sun patterns low on the wall or floor, while a low sun produces high patterns. Further, patterns low on the wall are longer than high patterns because of the angle of the sun compared to the ceiling. Also, the color temperature for a high sun is higher ('colder') than for a low sun. Moreover, because the earth turns during a day, these patterns also have different places on the wall (horizontally). Figure 4 pictures two sun positions and the corresponding locations of the sun patterns.

Besides the location and size of the pattern, also the sharpness of the pattern is an important factor. When clouds are in front of the sun, light falling through a window is diffuse, and sun patterns will look blurred. Nevertheless if the sky is clear, the sun pattern is still not completely sharp. Because the sun is not a point source but can be seen as a disk with a diameter of 0.5°, the edges of the sun patterns are slightly blurred. Figure 5 shows a rendering of a sun pattern, with slightly blurred edges. This blur is called penumbra, which arises when an extended light source is (partly) occluded by an object (Lotto, Williams, Purves, 1999). Figure 6 shows a rough drawing of a sun pattern with a penumbra from the side and front. Here, the yellow part is fully lit by the sun, whereas the places that are not colored are completely in the shadow (called umbra). The orange part of the drawing is only lit by a part of the sun, and is therefore looking blurred.

Also, the width of the blurring is not the same everywhere. Figure 6 shows that the top part is less blurred than the bottom part. This is because of the angle of the sun and the corresponding distance from the skylight to the wall. Further, the width of the blurring of the diagonal edges is smaller than the width of the horizontal edges. This is because the light pattern does not fall on a horizontal plane but on the wall (a vertical plane). If a small sunbeam would fall on the horizontal floor, it would look like a circle. However, since in this case the sunbeam is interrupted on a vertical wall, it does not look round but like an ellipse. This makes the width of the blurring on the diagonal edge smaller. A drawing of these ellipses is shown in Figure 7.

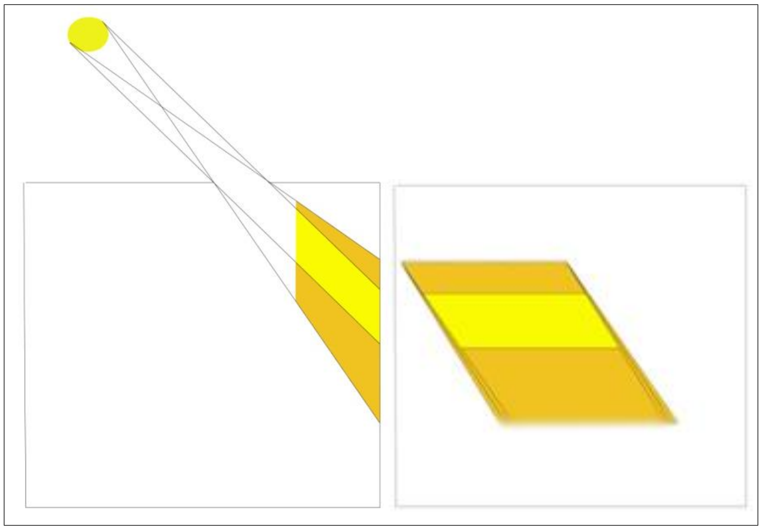

Figure 6: Side and front view of sun pattern.

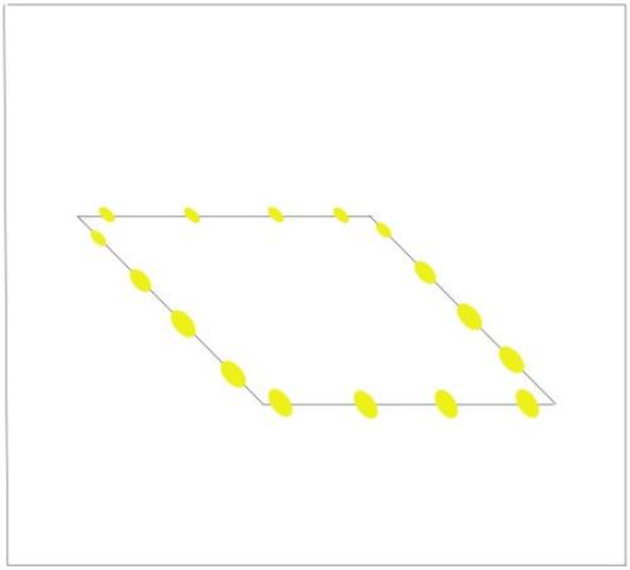

Figure 7: Front view of sun pattern ellipses.

3. Theoretical framework

After the background information with respect to lighting and light patterns, this chapter will contain the theoretical framework for this thesis. In this chapter, first the benefits of windows and daylight compared to artificial light will be discussed, and also some studies researching artificial 'windows'. After that, specific measures that are needed for the studies will be explored. Paragraph 3.2 will be about preferences. Here, preferences of lighting in general, and preference for window size will be discussed. Paragraph 3.3 will discuss environmental appraisal and the last paragraph the effect of lighting on affect. Of course, preceding these topics possible ways to measure these effects will be given. Connected to this chapter, in chapter 4, the research questions for the first study will be given, and thereafter the first study will be discussed.

3.1. Daylight versus artificial lighting

As explained in the introduction of this thesis, humans are becoming more dependent on artificial lighting compared to natural lighting. This change from natural to artificial is not only happening with lighting, but with more aspects of life, like food, consumer products, and medicines. The preference for things that are 'natural' may be a counter effect to this. This preference can be called naturalness bias, meaning that natural products are seen as better and healthier than artificial products. According to Rozin (2005), preference for nature is very clear in the domain of food. The label *natural* appears on as many products as possible, since this is attractive to consumers. Buying natural products has instrumental and ideational reasons. Ideational reasons are related to the innate preference for the environment, and nature. Instrumental reasons for preferring natural products are because it is believed to be healthier, tastier etcetera. However, results of blind food testing showed that organically grown products did not lead to a higher appraisal compared to commercially grown products (Schultz and Lorenz, 1976 in Rozin, 2004). Therefore, despite that there are no hard facts stating that natural products are superior; the belief that they are seems to play a large role in consumers' preferences.

Although up to now, to our knowledge, no actual naturalness biases were researched in the lighting domain, some studies researched preference for, and beliefs about natural lighting. For instance, Cuttle (1983) (in: Galasiu and Veitch, 2006) found that participants believed daylight was superior to electrical lighting. Eighty-six percent of the questioned office employees favored daylight over electric light. This was because they believed it led to less stress and discomfort compared to electric lighting. The authors added that this belief was not so much grounded on the thought that daylight was better for health, but that electric light was harmful.

Furthermore, several studies compared aspects of an office environment in field settings with and without daylight, and found that having windows and daylight led to more positive outcomes on several aspects. A few of these studies will be discussed here. Heerwagen and Heerwagen (1986) researched, through an office environment questionnaire, whether occupants preferred daylight or electric light, and on what aspects. These aspects were: office appearance and pleasantness, psychological comfort, general health, visual health, work performance, fine observation jobs, and color appearance. Results showed that on all aspects participants preferred daylight over electric lighting. Further, the authors compared responses of people working in day lit offices, and people working in offices without direct access to daylight. They found that people working in the offices without daylight valued daylight more than the others. Their conclusion was therefore that deprivation of daylight may increase the need and importance of daylight over electric lighting. Another study, by Finnegan and Solomon (1981) found similar results. Here, a field study was set up to measure work attitudes in windowed versus windowless environments. They found that employees in rooms without windows were less positive on physical work conditions as lighting in general, visual appearance and temperature. Further, job satisfaction was also lower. Moreover, evidence exists that being close to a window can even compensate for negative aspects of offices. Yildirim, Akalin-Baskaya, & Celebi (2007) found that being closer to a window (in an open plan office floor) gave a more positive perception of the space, and also compensated for other negative aspects of an open plan office floor such as lower privacy levels, more interruption and distraction, and decreased performance.

Nevertheless, no evidence exists that correct use of electric lighting is harmful to health (Boyce, 2010). Also, daylight is just electromagnetic radiation that is absorbed by photoreceptors, and is physically not different from electric lighting. Therefore, it is not per se superior to artificial lighting (Boyce, et al., 2003). An example of a study where visual tasks were objectively researched was conducted by Santamaria and Bennett (1981). They assessed whether daylight was superior to electric lighting for visual tasks and did not find any differences. They conducted an experiment for three visual tasks with matched illuminance and directionality of the lighting. Participants did not know if they were in the daylight or the electric light condition. Three performance tests were selected: Needle probing; proofreading; and graph reading. Afterwards they rated how difficult they had perceived the tasks, and aesthetic reactions were measured. Results showed no significant differences for all items measured. The authors therefore concluded that for common visual tasks in workplaces there are probably no differences between daylight and artificial lighting (Santamaria & Bennett, 1981). Furthermore, evidence exists that employees being closer to windows had more problems with glare and heat (Aries, Veitch, & Newsham, 2010).

Then, the question remains why do people belief daylight is better than artificial lighting? And, why in fact does daylight also lead to many positive effects as described above, even though the actual lighting is comparable? This is probably because daylight is more than just a light source to deliver good quality work. The subtle rhythm for instance gives information about the passage of time and weather conditions. Moreover, daylight situations almost always come with a certain view out (Boyce, et al., 2003). Natural views lead to positive feelings, can reduce stressful thoughts, and can lead to restoration from anxiety or stress (Altman, & Wohlwill, 1983 in Ulrich, 1984). A study researching patients' recovery in hospitals from surgery also showed that patients with a tree view were able to leave the hospital earlier than patients looking out to a wall directly behind the window (Ulrich, 1984). Here, the restorative effect of nature was probably to be influential to recovery. Although this comparison of different views is not similar to the comparison of daylight versus artificial lighting, it is possible that this same positive effect may be present for daylight too.

Related to this is research from Heerwagen and Orians (1986). They did not research the effects of lighting directly, but were interested in how people in windowless offices compensated for the lack of windows. The first conclusion they drew was that occupants of windowless offices had consistently more visual materials (as posters and paintings) than occupants of windowed offices on their walls. However, one can argue that windowless offices have more space for hanging these posters. Therefore, the authors computed the mean number of items per wall, and this was also significantly higher. The second hypothesis was that visual materials in windowless offices consisted of more surrogate views. This was not the case; however there were significantly more landscape than cityscape materials. The third hypotheses was linked to this, and held that the visual materials in windowless offices contained more nature than in windowed offices. This was indeed true, since as much as three times as many nature-oriented materials were used in windowless offices compared to windowed offices. The authors concluded that this study showed people's need for contact with nature.

A study with a different method, investigating the role of connectedness to nature also found that both real and virtual nature compared to real urban led to positive results on amongst others affect. For the first study a real life urban area was compared with a real nature area. Among others, affect and the Connectedness to Nature Scale (CNS) were used as measures. The nature condition showed significantly more positive affect and higher ratings on the Connectedness to Nature Scale than the urban condition. The second experiment tested real nature vs. virtual nature vs. virtual urban. The virtual conditions were videotaped and shown on a television. Again affect and CNS were measured. Results showed that the real nature condition created higher positive affect than the two other conditions. Further, participants in the virtual urban condition had more negative affect compared to the others. For the CNS all three conditions were significantly different from each other. In the real nature condition participants felt the strongest connection to nature, followed by the virtual nature participants. The virtual urban participants felt least connected (Mayer, Frantz, Bruehlman-Senecal, & Dolliver, 2009). This study showed that overall, the real condition was better than the virtual condition. Nevertheless, for both virtual and real environments, in the natural condition the connectedness to nature was highest.

Linked to this study investigating virtual nature, are studies using displays as artificial windows. For the present research, studies using displays to replace windows come closest to the design of the first study of this thesis. Not many studies have been done in this research domain, and the different studies also show mixed results. A study that used interviews as a method to research display 'windows', found mainly positive effects. Friedman and colleagues (2008) investigated whether it was feasible to create a technological window to the outside world through a large display. For a period of 6 weeks they installed large displays in employees' offices and provided a real time view by using a webcam. Interviews and surveys were used to collect the data. Interviews showed that participants found the system to have more positive themes than negative ones. Positive themes were: sense of place, psychological wellbeing, activity/experience about technology, social connection, and personal interest. Negatives themes contained mainly ethical issues as privacy and security, and experience with the technology (for instance malfunctioning). After the displays were removed, results showed that 100% of the participants felt less connected to the local area, and also would recommend it to a co-worker. On the other hand, a related study of Kahn and colleagues (2008) measured the physical and physiological effects of so-called 'technological mediated nature'. They compared an HDTV quality real-time view of nature, with about the same view through a real window, and having no window at all. Two hypotheses were researched. The first one held that the rate of heart rate recovery from low level stress would be higher with a glass window than no window. Besides this, they hypothesized that if participants spent more time looking at the glass window, heart rates would decrease more rapidly. The authors had an open question what would happen with a plasma window. Both hypotheses turned out to be correct. However for the open question, the plasma display did not show any difference with the blank wall, and also did not lead to a more rapid decrease in heart rate. A possible explanation for finding no effects may be that the effects of the display were not that large to affect heart rate, but did affect the psychological measures as described in the study of Friedman and colleagues (2008).

In summary, people belief daylight is superior to artificial lighting; however no objective results exist to confirm these beliefs. Nevertheless, studies showed that people report positive effects for many different constructs while being in a day lit room compared to a windowless room. Therefore, only the belief that daylight is healthier than artificial lighting, and vice versa, might lead to these positive effects. The connection to nature, through the daylight itself and the accompanying view out, may play a large part in this. Furthermore, when no real daylight is present, artificial windows may be a good substitution. Studies about virtual windows showed that (although no physiological effects were found) people appreciated these virtual windows over having no windows at all. However, not many studies with respect to this topic have been done, and more research is needed.

3.2. Lighting preferences

After a general discussion about daylight versus artificial light, and the possibility of the substitution of virtual windows with real windows, the next 3 paragraphs will describe the effects of lighting on more specific constructs. In the present paragraph lighting preference will be discussed. This paragraph contains two topics. First preference for lighting settings in general will be explained, and next preference for window sizes will be discussed. Although, these preferences will not be directly measured, this information will indirectly be useful for interpreting the results.

Preference for illumination & CCT

Already in 1941, recommendations about the preferred combination of color temperature and illuminance of a light source were given. These recommendations are pictured in a graph that’s nowadays called the Kruithof curve (Figure 8). It provides a certain range which people prefer. The preferred combination of color temperature and illumination is indicated by the orange area. The combinations in the upper white part produce very colorful and unnatural colors. The ones in the lower white part look very cold. For office lighting that produces illumination of 500 lux on the desk, it holds that the color temperature has to be within the range of approximately 3400 and 6300 Kelvin.

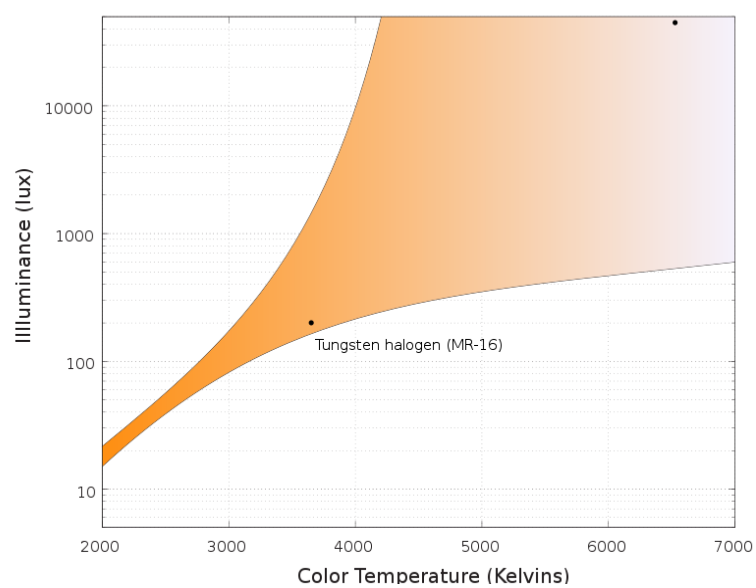

Figure 8: Kruithof Curve (Wikipedia, 2008).

Indoor situations and outdoor light levels play a role in the exact combination of illumination and correlated color temperature. The illuminance and CCT of sun/sky light that reaches the façade of a building is very dependent on such factors as weather, time of day, etcetera. Begemann, van den Beld, and Tenner (1996) studied the effect of daylight on preferred indoor lighting in offices in an experimental setting. Participants worked in an experimental room for a full day and were able to adjust the electric light over a range of 200-2000 lux and 2800-5000 K. In the year 1993, participants added on average 800 lux, measured on the participants' desks, of artificial light to the daylight illuminance. This is averaged for seasons and weather types. However, results of preferred illuminance for overcast days and clear days separated showed that for overcast days the added lighting stayed constant around 1000 lux. For clear days, with increasing daylight levels to 2000 lux, the additional artificial light decreased from 1200 to 500 lux. For preferred correlated color temperature the results showed that for daylight levels of about 500 lux, the preferred CCT of the artificial light was around 3300 K. The CCT increased as the daylight levels outdoors increased. Another finding was that the additional lighting was different for the morning, midday and afternoon. For overcast winter days, the morning and afternoon showed a peak in the addition of artificial lighting, while the midday gave a valley. It has to be noted, however, that large interpersonal differences were also present.

Related to this change in preference for specific times of day, is the study of de Kort and Smolders (2010). They studied the effects of dynamic lighting on office workers in a field study. They defined dynamic lighting as lighting that is not constant, but changes in color temperature and illuminance over a day. In the morning and early afternoon (1:30 PM) higher correlated color temperature and illuminance were given, whereas during midday and late afternoon much lower values were present. The authors researched the effects of dynamic lighting compared to standard electrical lighting on satisfaction, alertness, vitality, subjective performance, and other variables. A significant outcome was found for lighting satisfaction. Employees who worked under dynamic lighting were significantly more satisfied with their lighting compared to other employees. No other significant results were found. A possible explanation for not finding effects on the other measures is that the change in illumination and CCT was too subtle with respect to the environment. Nevertheless, the fact that employees were more satisfied with the system shows that it may be a good to take a daily rhythm into account for lighting.

These studies show that the outside situation can influence the indoor lighting preference. Not only outdoor lux and CCT levels influenced indoor settings, also time of day did. This is especially in the domain of artificial skylights important information, since an artificial skylight will represent outdoor lighting situations, but also has to take into account indoor preferences. These need to be matched. If one of the two is out of people's preference range, it may for instance be either not realistically looking as daylight, or the indoor lighting may not be comfortable anymore. Therefore it is important to take these preferences into account. Moreover, dynamics may be good to use in artificial skylights. This may improve realism of the artificial skylights, and furthermore – according to the present knowledge – also improve satisfaction of the users.

Preference of window and skylight arrangements

The layout of a window affects the amount of light entering a room, and is important for the distribution of the light. However, windows also come with a view, and the layout affects the content of the view. In the present research, vertical windows with a high detailed view are not researched. The main goal of this study is to research skylights, having only a low detailed view towards the sky. However, first – since

more information is known about windows than skylights – some studies researching preferences of vertical window design will be reviewed.
In a field study, Dogrusoy and Tureyen (2007) asked participants how they would change the configuration of their own office window, if they were allowed to change it. In addition, a questionnaire was completed by the participants to determine the motivations behind their choices. Results showed that almost half of the participants preferred a window-wall, followed by a horizontal wall, and finally a squared shaped window. The least preferred layouts were round, rectangular, and vertical band windows. Further, people preferred large size windows of 44 – 100 % of the wall area. The five most important factors for participants' decisions were: natural lighting, sunlight, natural ventilation, spaciousness, and noise control. In another research, participants had to indicate what view they preferred for a window restricted to 20% of the wall. Results showed again that a wide horizontal view (and slightly above and below the horizon) was preferred (Keighley, 1973a). A second experiment of the same author showed that horizontal windows larger than 30% of the wall are preferred most (Keighley, 1973b). Of course, these outcomes are directly related to a certain high detailed landscape view. In a recent study of Philips, skylight configuration was researched in a paired comparison experiment. This was done by simulations on a computer screen, where 20 sky types and skylight configurations displayed in a standard (empty) room were varied. Participants were asked to determine, for the first part of the experiment, which room they thought gave the strongest daylight impression. In the second part, they indicated which room was more appealing. Results showed that large, rectangular skylights gave the strongest daylight impression. Smaller, squared skylight gave the weakest daylight impression. For appeal, similar results occurred, with one exception. Large and rectangular skylights with the longest part perpendicular to the length of the room were thought to be more appealing than the same size skylight with the longest part parallel to the length of the room, while this difference was not present for daylight impression (Seuntiens, van Boven, and Sekulovski, 2011).

Overall, all studies concerning vertical windows and the study about skylights show similar results. All indicate that people prefer larger size openings in walls and or ceilings. For the vertical windows, a larger window in the wall often means a more varied view out. For skylights this is also the case, but since the view to the sky is often not very variable, and also people are not looking constant to the sky, this effect may be smaller. A possible explanation valid for both situations is that larger size windows lead to more daylight entering the room. Consequently this may lead to a stronger connection to the outside world.

3.3. Environmental appraisal

After discussing the different preference topics, the next paragraph will be about environmental appraisal. This paragraph does not distinguish between daylight and artificial lighting, but discusses the effects of lighting on the environment in general.

Measuring atmosphere

Besides the effect of the environment on affect – as will be discussed in the following paragraph – the atmosphere of the environment itself is also an important measure. Atmosphere is an affective evaluation of the environment, and might depend on cultural factors, age etc. Atmosphere is related to the *expected* effect on affect, however it is not corresponding to the *actual* effect on affect. "For example, I can evaluate an environment as relaxing, but if I have a lot of things going on in my mind and I would still feel pretty stressed" (Vogels, 2008; p 2).

Vogels (2008) developed a measurement tool to quantify the atmosphere experienced by human observers. Experiments demonstrated that the atmosphere can be described by four dimensions: Coziness, Liveliness, Tenseness, and Detachment. For example, one of the outcomes of a certain study comparing different (real) environments showed that an interior shop was rated high on Coziness, a sport shop on Liveliness, a bank had a high score on Detachment, and finally a casino resulted in a high score on Tenseness.

Another way to research environmental appraisal is via the method of Flynn, Spencer, Martyniuk, and Hendrick (1973)**.** Flynn and colleagues (1973) were the first to measure subjective impressions of the environment. They used three distinct categories, evaluative impression e.g. 'pleasant – unpleasant', perceptual clarity e.g. 'clear – hazy', and spaciousness e.g. 'spacious – cramped'. The different categories give information about the perceived environment.

Not many methods exist that provide information about the environment. We chose to use these two, since both methods provide different information. Vogels (2008) describes the environment according to four dimensions, not giving judgment information. The method of Flynn and colleagues (1973) provides also value judgments.

Effect of lighting on atmosphere

Firstly, the effects of different lighting settings on the appraisal of the environment will be discussed. Thereafter, the possible effect of the color blue on experienced atmosphere will be explained shortly. This is because the (artificial) blue sky, which will be used in the present thesis, can influence atmosphere too. Therefore both in this paragraph as in the paragraph about emotions the effect that blue may have on respectively perceived atmosphere and emotions will be discussed.

Flynn and colleagues (1973) researched the effect of different lighting situations (different illuminances and distributions) on subjective impressions of the environment. For the atmosphere measures of Vogels (2008), the effects of illuminance, correlated color temperature and uniformity were studied (Van Erp, 2008). The study of Flynn and colleagues (1973) showed that for a higher illuminance, the room was rated as more clear and bright; however it did not affect value judgments of the environment. Furthermore, the results for the dimensions of Vogels (2008) showed that for a higher illuminance the room was perceived as more lively and detached while being less tense and cozy for low CCT settings (Van Erp, 2008). For different distributions, Flynn and colleagues (1973) showed that downlighting produced more positive evaluate impressions than diffuse lighting, while diffuse lighting gave a slightly higher spacious impression than downlighting. Results regarding the atmosphere dimensions showed that directional light was found to be cozier, livelier, less tense, and slightly less detached compared to diffuse lighting (Van Erp, 2008).

Further, additional wall lighting was only studied by Flynn and colleagues. Results showed that wall lighting combined with downlighting gave more positive evaluations and increased spaciousness compared to only downlighting. Also, to some extent perceptual clarity was increased (Flynn, 1973). Related to these effects about wall lighting is the study of Han Ishida, Iguchi, and Iwai (2006). Han and colleagues (2006) researched visual impressions when a scale model room was lit by uniform ceiling lighting or by compound lighting (light from the side of the room). Also illuminance was varied (300 lux and 700 lux). Results showed that compound lighting led to a higher impression of *natural* compared to *artificial*, more *active*, more *open* compared to *closed*, and *more clear* compared to *hazy*. No difference was found for: bright/dim, hard/soft, relaxed/not relaxed, quiet/cheerful, dislike/like, unfriendly/friendly, hard to enter/easy to enter, small/large, and complex/simple (Han, et al., 2006). The compound lighting was created by electrical light, however with a correlated color temperature of 5000 K, and was intended to give a feeling of daylight. It is not clear whether it was the distribution of the lighting that explained the results or the effect of having an opening to the outside world.

Lastly, increasing color temperature was only researched by Van Erp (2008). Results showed that a higher CCT led to less coziness, less liveliness, more tenseness, and more detachment.

Bronckers (2009) researched the effects of colored light on atmosphere perception. The author compared different hues and measured the four atmosphere dimensions of Vogels (2008). For the present study the comparison of white and blue is of interest. Bronckers (2009) also researched other colors, but we will only focus on these. For coziness, results showed that red was most cozy while blue and white were the least cozy. Blue light compared to white light was perceived as more lively. For tenseness no specific effects for blue were found. Further, for detachment white was rated as more detached than blue.

These studies showed that changing the distribution of the lighting, illuminance, and CCT led to a different appraisal of the room. For this thesis, it is not intended to change the distribution or illuminance, but solely the effect of having an artificial sky will be researched. Nevertheless, this ‘sky’ might change the perception of the lighting and the room, for instance in a way that it makes the room look more open than close.

3.4. Emotions

After discussing preference and atmosphere, this paragraph will explain different ways to measure emotion, and discuss the effect light can have on emotions. However, first an explanation of what emotions actually are will be given. According to Gray (2007) emotions are subjective feelings which are mentally directed towards some object. They have two components, the feeling and the object. The object (person, thing, or event) is something that is important to the person, and is seen as the cause of an emotion. Feelings associated with emotions are ‘affect’ or ‘mood’. Affect can be classified into a pleasure/displeasure dimension and an arousal dimension. It is a more general term of describing an emotion and not depending on an object. Mood is a longer lasting emotional feeling, and also not necessarily directed to an object. The expressions mood, emotions, and affect are often used interchangeably, but all are about subjective feelings.

Of course, emotions also serve functions. These are linked to the dimensions of pleasure and arousal, and motivate people to approach and avoid objects when needed. This is also accompanied by bodily changes, for instance changes in heart rate, blood pressure, facial expressions.

Measuring emotions

There are many ways to measure emotions. A few well known measures will be discussed in this section. Emotions can be measured through self report, or via physiological measures. In this study we will focus on psychological effects through self report. This is because we do not expect any physiological differences, since besides the blue sky there are no intended differences in the light settings between the experiment conditions. The effect of the blue sky will probably be too small to detect in physiological measures. The methods we discuss underneath are therefore all psychological measures.

According to the theory of Mehrabian and Russell (1974) emotions can be described in a multidimensional space. They provided evidence for three dimensions, based on semantic differential studies. These three dimensions are: pleasure-displeasure, degree of arousal, and dominance-submissiveness (the so-called PAD scales). Pleasure ranges from pain to happiness, arousal from sleep to excitement, and dominance from lack of control to being in control. These factors are independent of each other and therefore all values in one dimension can occur at the same time as values in the other dimensions (Russell & Mehrabian, 1977).

Another method to measure emotions is the Positive Affect and Negative Affect scales (PANAS). This scale consists of 20 items, 10 for Positive affect and 10 for Negative Affect. Examples of Positive Affect are interested and exited, and of Negative Affect, upset and ashamed, all measured by 5-point scales of applicability. The PANAS can be used for several time frames, and therefore measures emotional states, and also more stable emotional characteristics.

According to Mehrabian (1997) Positive Affect (PA) (from PANAS) is similar to the +P+A+D and –P-A-D direction, diagonal in the PAD space. Negative Affect (NA) (within PANAS) is corresponding to the +P-A+D and –P+A-D diagonal in the PAD space. This is pictured (without the Dominance dimension) in Figure 9. However, he compared both scales and found that PA was most weighed by arousal, then pleasure and finally dominance. For NA displeasure weighted most, than arousal and finally submissiveness. Mehrabian (1997) therefore concluded that a valid affect measure would equally weight the different dimensions, and since that is not the case, PANAS would have limited validity. Of course, PANAS is widely used scale, and Mehrabian only compares the PANAS to the PAD scale. Therefore it does not necessarily mean the PANAS in has limited validity on its own.

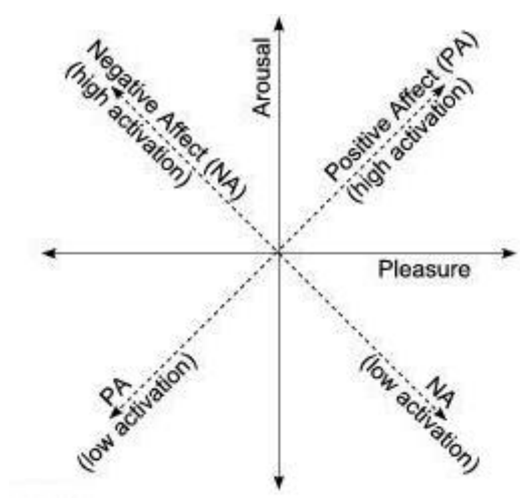

Figure 9: Pleasure & Arousal dimensions with Positive Affect & Negative Affect scales included (Larsen & Diener, 1992)

Another method (derived from the semantic differential scale of Mehrabian and Russell 1974) is a nonverbal judgment of a series of pictures. This is called Self-Assessment Manikin (SAM). It measures pleasure, arousal and dominance in a much shorter time frame than the semantic PAD measure. For each dimension 5 pictures are shown. Participants indicate their emotional state by selecting one of the pictures, or by selecting a position between two pictures. An important factor of SAM is that it can be utilized for non-English speaking cultures, or for example children (Bradley & Lang, 1994).

These three methods are often used ways to measure emotions. All have their advantages and disadvantages. On the one hand, a disadvantage of the PANAS is that according to Mehrabian the dimensions are not equally weighted, and therefore may have limited validity. On the other hand, the dominance dimension of the PAD measure is not always needed or necessary in every experiment. Further, the PAD and PANAS are more time consuming than the SAM. However, a disadvantage of the SAM might be that it is more difficult to understand what is exactly meant by the pictures, which can lead to various interpretations. For the first study of this thesis, the PAD will be used to measure emotions. And, because the dominance measure is for this experiment not necessary to measure, this dimension will be taken out, which reduces the time duration.

Effects of light on affect

After determining how emotions and affect can be measured, the effect lighting can have on affect will be reviewed. Several studies researched the effects of illuminance, CCT and spectral distribution (CRI) on affect. However, many contradicting results were found. First of all, some studies did not find any effects at all. Examples are studies of Baron (1992), Boray, Gifford and Rosenblood (1989), and Knez (2001), where various illuminance and CCT values were varied, and also different affect measures were used.

Baron (1992) studied the influence of illuminance and CRI on (amongst others) affect. Over all three experiments, illuminance (150 and 1500 lux) and correlated color temperature (3000, 3600, 4200, 5000 K) were varied. Affect was assessed in the first experiment by the PANAS measure and in the second and third experiment by the Current Feeling Survey. Results did not show any significant effects in none of the three experiments. Boray, et al. (1989) researched the effects of spectrum (cool white, warm white and full spectrum) on (among others) affect. Illuminance was set at 500 lux. Their measure for affect was the PAD scale from Mehrabian and Russell. In this experiment, again, no significant results were found. Further, Knez (2001) studied the influence of correlated color temperature (warm, cool and artificial daylight white light) on affect (PANAS). Illuminance was set at 500 lux. However, again no significant effects were found.

In contrast to these studies finding no effects at all, other studies did find effects of light settings on affect. Examples of these are studies of Knez (1995) and McCloughan, Aspinall, and Webb (1999). Here, just as in the above described studies, illuminance, CCT and CRI were varied, but also gender was taken into account.

In the study of Knez (1995) illuminance (300 lux and 1500 lux) and correlated color temperature (3000K and 4000K) were varied, and PANAS was used to measure affect. Results showed that females' negative affect decreased in the warm and increased in the cool white condition, whereas males' negative affect showed opposite results. In the second experiment, a lower CRI was used. This time, no effects of gender were found. However in general, positive affect was best maintained in the warm white condition at 300 lux and in the cool white condition at 1500 lux. McCloughan, Aspinall, and Webb (1999) hypothesized a short-term and long-term effect of lighting on affect. They assessed mood (MAACL-R scale) on correlated color temperature (3000 & 4000 K) and illuminance (approx. 300 and 750 lux). The MAACL-R scale measures anxiety, depression, hostility, positive affect, and sensation seeking. Short term effects were measured five minutes after entering the room, and long-term effects after 40 minutes. Results for short-term effects showed that sensation seeking was higher for low than for high illuminance. Besides this, hostility was greater under low rather than high CCTs. An effect of gender showed that generally seen females had significantly higher positive affect than men. For long-term effects, positive affect and sensation seeking were still the same. Negative affect, however, showed complex interaction effects for illumination, correlated color temperature, and gender.

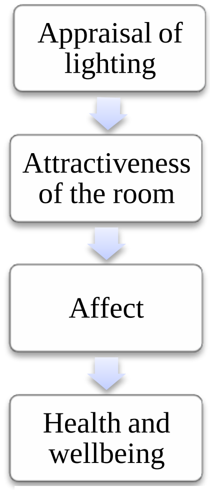

Figure 10: Appraisal pathway

The studies of Knez (1995) and McCloughan, et al. (1999) found effects for affect, however showed complex interaction effects for gender, time duration and spectrum. Therefore, it is difficult to explain the exact cause of the results, and consequently it is difficult to compare to other studies. A study with a completely different method is from Veitch, Newsham, Boyce, and Jones (2008). The aim of this study was not to research independent light settings to find effects of specific illuminance and CCT on affect. The authors researched how lighting in general influences humans, using a model with connected measures.   A significant path in the model (called appraisal path) was from appraisal of lighting to attractiveness of the room, to affect and from affect to health and wellbeing. This pathway is pictured in Figure 10. When people rated lighting as having a higher quality, they assessed the environment (e.g. office) as more attractive, and therefore had a more pleasurable affect (Pleasure from PAD measures). Moreover, even reported visual and physical discomfort decreased, and satisfaction with the work environment increased, when the appraisal of the lighting was higher. This was independent of specific light settings, but only depended on individual appraisal of lighting.

To conclude this section, effects of specific light settings on affect do not show to be very consistent. Some studies do not find any significant differences at all, while others do. However, when effects of light settings were found, it was difficult to explain what caused them. The study of Veitch and colleagues (2008) may be easier to compare to the present study, since we do not use specific light settings. Here, a higher appraisal of the lighting in general led to more positive affect scores.

Effects of the color blue on affect

Lastly, the effects of the color blue of the artificial sky on affect will be discussed. Colors can affect humans through psychological processes, but also via biological or physiological pathways. Psychologically, blue is generally seen as comforting (high pleasure but low arousal; Wexner, 1954 in Valdez & Mehrabian, 1994). Biologically or physiologically seen, blue is often found to be enhancing arousal (Laufer, Lang, Izso, & Nemeth, 2009; Rea, Figueiro, & Bullough, 2002).

Although studies state that in general blue is comforting, this does not have to be the case in all situations. In a recent study of Kuller, Mikellides, and Janssens (2008) two experiments were done, comparing two rooms where one had red colored walls and the other blue. They controlled for lightness, saturation, and luminous reflectance values. In the first experiment, no effect on affect was found. In the second, however, the red room led to more pleasure compared to the blue room. In both experiments, the same model was used to assess affect, however the difference was that it did not contain exact the same words. This may explain why in the second experiment an effect was found, and not in the first. In a study of Valdes and Mehrabian (1994) participants had to assess the color of small cards. Results showed that blue led to the highest pleasure level, while green-yellow was least pleasant. For arousal; green-yellow aroused most, while blue-purple and yellow-red led to the least arousal. Blue led to an intermediate level of arousal, compared to all other hues. Furthermore, Clarke and Costall (2008) set up a qualitative study to research whether earlier (quantitative) findings through experimenting with actual color samples were similar to associations and comments when participants were free to imagine their own examples. They provided participants with a couple of colors, and asked them what emotion, concept or event came into their minds. For the color blue, 69% of the participants made ‘low arousal’ comments.

These studies show many contradicting findings. Possibly people assess colors in different ways when seeing a small card; being in a complete colored room; or when imagining the colors themselves. Furthermore, people can have personal associations with certain colors, and colors can get different meanings in different contexts. In this thesis, the color blue is ‘captured’ in a sky. This experience of a sky can of course influence the effects that were found in previous other studies in completely other way, since it represents a weather situation. Then, besides the effects of the color, (personal) associations with the weather that is represented can influence affect too.

4. Research questions study 1

The theoretical framework showed that the connection to nature that exists when being in a daylight situation and the subtle rhythm of the light seem to be important factors in why daylight leads to many positive effects. Nature is important for restoration, and views to nature can even decrease the length of stay in hospitals. Also, for office situations, employees are generally more positive about their work circumstances when their desk is close to a window. Further, research showed that when people appraised their lighting as good, it led to more positive evaluations of the environment, and increased pleasure. Moreover, being in a daylight situation can even compensate for other negative aspects like lower levels of privacy in an open plan office.

The artificial skylights used in this thesis can be implemented in environments were no real daylight is present. The scarce research about artificial 'windows' showed that people appreciate the virtual connection to the outside world, however more research into this area is needed. The present study will be a good addition to the studies already published. Further, it is also an extension to existing research, since an artificial skylight cannot be completely compared to an artificial vertical window. For instance, differences in the view out may lead to different outcomes.

We will investigate the differences between a room with artificial skylights and a room with standard office lighting. Several aspects will be measured. Of course, the strength of the experience of daylight will be assessed, but also appraisal of the lighting and the room, and affect will be measured. Furthermore, we will investigate possible improvements to optimize the artificial skylights.

The research questions for the first study are formulated as follows:

1. **"What are the differences between artificial skylights and standard electric lighting in offices on appraisal of the lighting (attractiveness, suitability for work, glare), appraisal of the room (attractiveness, atmosphere, visual clarity, uniformity, spaciousness), affect, and perceived naturalness (daylight experience, naturalness of colors)?"**

2. **"How can we optimize the artificial skylights for the best daylight experience?"**

5. Study 1: Benefits of an artificial skylight

5.1. Methodology

Design

The within-subject experiment followed a randomized crossover design consisting of two conditions: one office with artificial skylights and an identical office with standard office luminaries. Both conditions were counterbalanced across participants.

Participants

Twenty-nine participants were recruited for this experiment. All were Philips employees or interns. Only Dutch native speakers were recruited, and all filled out a Dutch questionnaire. Of the 29 participants, 12 were female and 17 male, with a mean age of 29.2 (SD: 8.8; range 20 to 56). Fourteen students, 10 scientists, and 6 secretaries/HR officers were recruited.

Procedure

Participants were welcomed, and brought to the experiment rooms. The experiment consisted out of three sessions. For the first session, participants took a seat behind a desk and LCD screen in one of the two offices. Half of the participants entered the artificial skylight room first, and the other half the standard room. Next, participants read the instructions and signed an informed consent form on paper. They were instructed to look around in the room and to the lighting thoroughly before starting the questionnaire. After that, they completed the first questionnaire on the LCD screen. After completing the questionnaire, the researcher and the participant took a short coffee break in the coffee corner, to readapt to a normal lighting situation. For the second part of the experiment, participants evaluated the remaining room. This second part of the experiment was similar to the first. In the third session, participants were asked to compare both rooms by verbally answering 11 open questions. This always took place in the artificial skylight room, because then participant were able to look at the skylights more carefully. The answers were recorded by the experimenter. In total the experiment lasted for 30 minutes.

Figure 11: Photograph of standard room (left) and artificial skylight room (right).

Setting & Apparatus

Room

The experiment took place in two (more or less) identical rooms. The dimensions of the rooms were: L * W * H = 6.05 *3.72 * 3.00 meters. Photographs of the rooms are shown in Figure 11, and graphical views can be seen in Appendix A. In both rooms, no real daylight was present to avoid changing weather conditions from having a large effect on the perception of the room and lighting. In both rooms all walls were white, and both had grey carpet on the floor. The ceilings were made of squared tiles. The rooms were furnished to resemble offices. Each room had 2 desks, one for the participant and one for the researcher. Appendix A also includes drawings of the room interior. A small difference was present in window covering. In the artificial skylight room, the window was closed by a white role-down shutter, which had a higher reflectance than the painted wooden wall in the standard room. To avoid that this difference would confound with the results, the participants were faced away from the window.

Luminaries

In the standard room, eight Philips Savios (TLS770 6x14W/827/865) were installed. The luminaries were equipped with a Micro Lens Optical plate (MLO), which reduces glare under higher angles. The luminaries were flush mounted with the ceiling. In the artificial skylight room the savios were the same, and placed at the same location in the ceiling. The difference with the standard room was that the luminaries were recessed in the ceiling and were covered by a blue optical structure, resembling a skylight.

Due to the optical structure and the recession, the light distribution of artificial skylight room differed from the standard room. To correct for this difference, the luminaries were set to provide 500 Lux at +/- 4250 K on the desk (measured with a Konica Minolta CL200). Five hundred Lux on the desk was chosen because this is the standard level required in offices in the Netherlands (CEN, 2002). As a result, however, the illumination at other places in the rooms varied. The vertical illumination at eye height, at the place where the participant sat, was approximately 200 Lux in the artificial skylight room, and 300 lux in the standard room. Also, the walls in the standard room had a more uniform light distribution compared to the artificial skylight room. This all together made the impression of the artificial skylight room slightly darker than the standard room.

Others

The temperature of both rooms was measured before every participant arrived. After analyzing the objectively measured temperatures of the rooms, it showed that the artificial skylight room was consistently warmer than the standard room (average temperature difference was 0.6 °C). Since this difference was too high to use for further analyses, none of the temperature assessments will be discussed in the results/conclusion section.

Measures

The content and purpose of the questionnaire measures and the funneled debriefing are explained beneath. Appendix B contains the whole questionnaire (in Dutch).

Appraisal of the lighting

Appraisal of the lighting contained the measures ‘attractiveness of the lighting’, ‘suitability for work’, and ‘glare’. These will be explained below, one by one.

Attractiveness of the lighting

The measure ‘attractiveness of the lighting’ consisted out of the items ‘like lighting’, ‘lighting pleasant’, ‘lighting interesting’, ‘lighting comfortable’, and ‘lighting beautiful’. The items ‘like’, ‘pleasant’, and ‘interesting’, came from Flynn (1973). ‘Comfortable’ and ‘beautiful’ were added to these. All items were provided on a 7-point scale ranging from not at all applicable (-3) to very applicable (+3), through zero. The average of these five items (for all participants) was taken to compute the measure ‘attractiveness of the lighting’. Reliability (Cronbach’s alpha value) of this aggregated measure was 0.82 for the artificial skylight room, and 0.86 for the standard room.

Suitability of the lighting for work

The measure ‘lighting suitable for work’ consisted out of the two items ‘lighting hinders my work’ and ‘lighting suitable for offices’. All items were provided on a 7-point scale ranging from not at all applicable (-3) to very applicable (+3), through zero. Both these items contained one similar outlier which influenced the data, and was therefore taken out of the dataset. This brought the number of participants for these items to N = 28. The average of these two items was taken to compute the aggregated measure ‘lighting suitable for work’. Before the averaging; the item ‘lighting hinders my work’ was reversed. The reliability (Cronbach’s alpha value) of this aggregated measure was 0.80 for the artificial skylight room, and 0.92 for the standard room.

Glare

Three glare items were assessed: perceived ‘glare on paper’, ‘on screen’, and ‘directly from the light source’. These were presented on a 5-point scale ranging from not noticeable (0), noticeable but not annoying (1), slightly annoying (2), annoying (3) and very annoying (4) (ITU, 2000). These items were not aggregated into one measure, since the reliability (Cronbach’s alpha values) was too low.

Appraisal of the room

Appraisal of the room contained the measures ‘attractiveness of the room’, ‘atmosphere of the room’, ‘visual clarity of the room’, ‘uniformity of the light in the room’, and ‘spaciousness of the room’.

Attractiveness of the room

For the measure ‘attractiveness of the room’, items ‘like room’, ‘room interesting’, and ‘room pleasant’ from Flynn (1973) were used, and the item ‘room beautiful’ was added to this. These items were provided on a 7-point scale, and participants had to indicate to what extent the words were applicable to the room (ranging from -3 to +3, through zero). The average of these items (for all participants) was taken to compute the measure ‘attractiveness of the room’. Reliability (Cronbach’s alpha value) of this aggregated measure was 0.82 for the artificial skylight room, and 0.83 for the standard room.

Atmosphere of the room

The atmosphere dimensions of Vogels (2008) were used to assess the atmosphere of the room. Atmosphere consisted out of the dimensions, ‘liveliness’, ‘coziness’, ‘tenseness’ and ‘detachment’. Table 1 shows the Dutch items that were used for each dimension. For each of the 12 words, participants indicated to what extent the word was applicable to the room on a 7-point scale ranging from not applicable at all (-3), through (0), to very applicable (+3). The average scores of the three items of every dimension were used to compute the four dimensions. Reliability (Cronbach’s Alpha) of these aggregated measures ranged from 0.57 to 0.93. Individual Cronbach’s alpha values are reported in Appendix C.

Table 1: Dimensions of Atmosphere

Atmosphere Dimensions	Items
Liveliness	Levendig
	Stimulerend
	Inspirerend
Coziness	Behaaglijk
	Geborgen
	Intiem
Tenseness	Beangstigend
	Bedreigend
	Gespannen
Detachment	Formeel
	Kil
	Zakelijk

Visual clarity of the room

The average of the items ‘clear-hazy’, ‘bright-dim’ from Flynn (1973) were used to measure ‘visual clarity’. These items were semantic differentials, and had 7 spaces for each pair (ranging from +3 to -3, through zero). The aggregated measure ‘visual clarity’ had an internal consistency of alpha = 0.81 for the artificial skylight room, and alpha = 0.83 for the standard room.

Uniformity of the light within the room

One item was used to measure the uniformity of the lighting within the room. This was the semantic differential ‘uniform-non uniform’, with 7 spaces (ranging from +3 to -3, through zero).

Spaciousness of the room

Spaciousness of the room was assessed in three ways. Firstly, the average of the items ‘spacious-cramped’, ‘large-small’ (from Flynn, 1973) were used to computed the measure ‘spaciousness of the room’. These measures were semantic differentials, and had 7 spaces for each pair (ranging from +3 to -3 through zero). The aggregated measure spaciousness had an internal consistency of alpha = 0.84 for the artificial skylight room and alpha = 0.93 for the standard room. Secondly, participants estimated the size (length, width, and height) of the first room in meters. The estimations of the single dimensions were later multiplied into cubic meters. Lastly, in the second room, the participants indicated whether they perceived that room as ‘larger’ or ‘smaller’ than the previous.

Perceived naturalness

Perceived naturalness contained the measures ‘daylight experience’ and ‘naturalness of colors’.

Daylight experience

The aggregated measure ‘daylight experience’ was the average of the items ‘looks like daylight’, ‘feels like daylight’, ‘daylight experience’, ‘relationship with outside’, ‘relationship with the weather’, ‘relationship with nature’, and ‘naturalness of the light’. ‘Naturalness of the light’ was assessed on a 7-point scale ranging not natural at all (-3), to very natural (+3), through zero. All other measures were assessed on a 7-point scale ranging from very weak (-3) to very strong (+3), through zero. The reliability of this measure (Cronbach's alpha values) was alpha = 0.95 in the artificial skylight room, and alpha = 0.93 in the standard room.

Naturalness of colors

Further, the aggregated measure 'naturalness of colors' was the average of the items 'naturalness of skin tone' and 'naturalness of color of furniture'. Both items were assessed on a 7-point scale ranging from not natural at all (-3), to very natural (+3), through zero. Reliability (Cronbach's alpha values) was alpha = 0.83 for the artificial skylight room and alpha = 0.81 for the standard room.

Table 2: Dimensions of Affect

Affect dimensions	
Pleasure	annoyed – pleased
	unsatisfied – satisfied
	despairing – hopeful
	melancholic–contented
	bored – relaxed
	unhappy – happy
Arousal	relaxed – stimulated
	calm – exited
	sleepy – wide awake
	unaroused – aroused
	sluggish – frenzied
	dull – jittery

Affect

To measure affect, we used a Dutch translation of the pleasure and arousal dimensions (Mehrabian and Russell 1974; Brengman, 2000). The items of 'Pleasure' and 'Arousal' are provided in Table 2. To compute the pleasure dimension, the average of the items was taken, and similarly for the arousal dimension. All items were semantic differentials and participants could respond on a seven point scale (ranging from -3 to + 3, through zero). Reliability (Cronbach's alpha values) of the pleasure dimension was alpha = 0.88 for the artificial skylight room and alpha = 0.93 for the standard room, and for arousal alpha = 0.75 in the artificial skylight room, and alpha = 0.71 in the standard room.

Funneled debriefing

After completing both questionnaires, a short verbal questionnaire (with open ended questions) was held to get more insights into the reasoning behind the answers, and to ask for possible short comings of the skylight system. The questions were arranged in a funneled debriefing method. It started out broad and gradually became more specific, to not 'push' the participants in a certain direction. All questions can also be found in Appendix B.

Analyses

The aim of the experiment was to compare the artificial skylight room with a standard room equipped with normal lighting. Two different kinds of analyses were needed, one for the quantitative data and one for the qualitative debriefing. IBM SPSS Statistics version 19.0.0 was used to analyze all quantitative data. More specifically these were analyzed by related samples (artificial skylight and standard room), nonparametric tests (Wilcoxon Signed-Rank test). Related samples tests were done because of the within subjects design, which meant that all participants assessed both rooms. This analysis detected possible differences between the rooms per participant. Nonparametric tests were needed because most of the measures were not normally distributed. This was assessed by the Kolmogorov-Smirnov test ($p < 0.05$). The reason that the data was not normal was probably because many measures were assessed at the low end of the scale. For instance, the rooms were not decorated, which led to very low evaluations for for instance attractiveness measures. Nonparametric tests are less powerful than parametric tests as for instance an ANOVA, and this leads to higher chances of Type 2 Errors (Field & Hole, 2003). Two exceptions to the general data analysis were needed for the measures 'size estimation in m^3', and 'room larger or smaller than the previous room'. These were only asked in one room. Therefore these were analyzed with a between group, independent samples, non parametric test (Mann-Whitney test).

Based on the funneled debriefing we could distinguish two separate groups of people. The first group recognized the concept of an artificial skylight right away. The second group did not see this at all, and thought it was just a new/special type of armature, but had completely no association with daylight. Since this could influence the analyses, it was decided to also analyze these two groups separately. This was done by related samples non parametric tests (Wilcoxon Signed-Rank test) and independent samples non parametric tests (Mann-Whitney test). The Mann-Whitney U test tested differences between the two groups of people, in both rooms separately. The Wilcoxon Signed-Rank test was the same as for the whole group of participants, and used to analyze possible differences between the rooms and in this case for both groups of participants separately. We did not correct for capitalization on chance.

Test statistics with **$p < 0.05$** are considered significant. Besides test statistics, means and standard deviations will be presented. Furthermore, since non parametric tests have been done, and these tests are based on differences between ranks, medians represent the data better than means (Field & Hole, 2003). Medians were therefore also calculated and reported in Appendix C.

The qualitative data was used to explore for short comings to the skylight concept. Also, extra information about the reasons why participants disliked something was gained. This information was quantified using Microsoft Office Excel 2007 by counting the number of participants with related opinions, and counting the number of related comments.

In Figure 12: Overview of data analyses an overview of the data analyses is given.

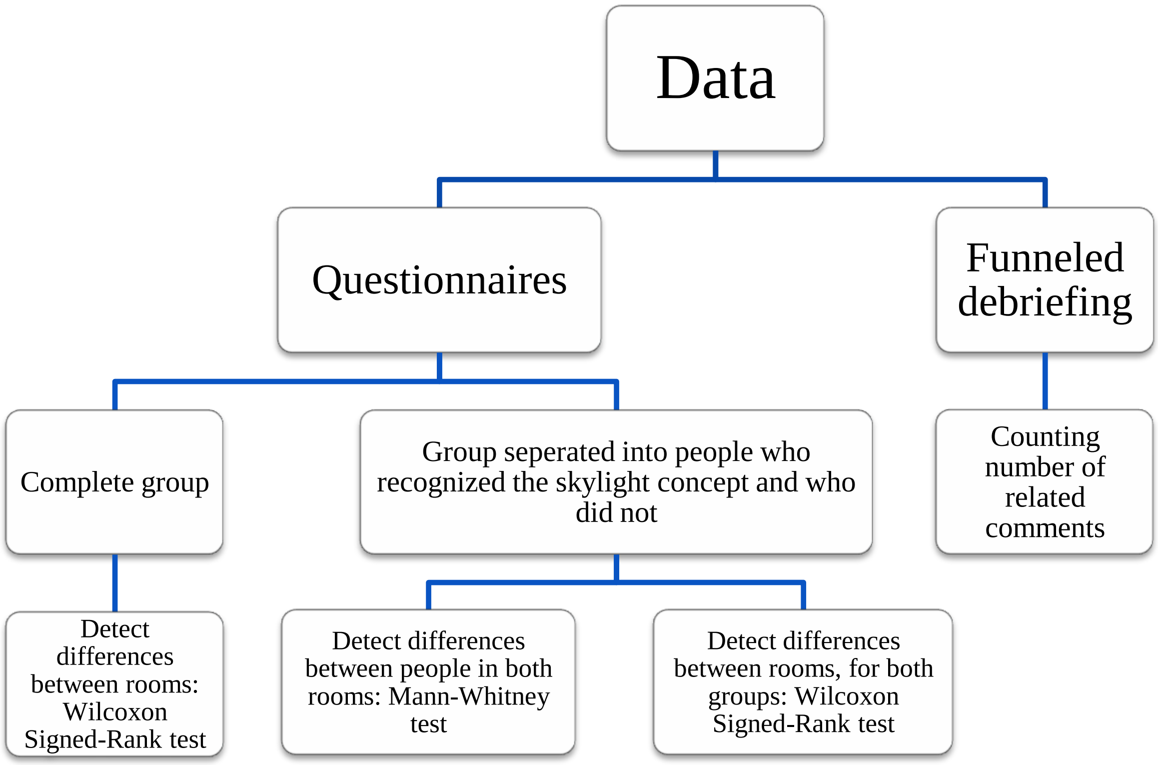

Figure 12: Overview of data analyses

5.2. Results

Analyses of the two conditions (artificial skylight versus standard room) in general will be discussed first. The analysis of the two distinct subgroups will be explained afterwards.

Artificial skylights versus standard luminaries

Related samples non parametric tests (Wilcoxon Signed-Rank test) were used to compare the artificial skylight room with the standard room. Means and SDs are provided in Table 3. A complete overview of all statistical results is provided in Appendix C. In this result section the most important effects will be described. When all participants were included in the analysis (N=29), three measures differed significantly. These were: 'lighting suitable for work' **($T = 46.0$, $p = 0.03$)**; 'visual clarity of the room' **($T = 32.5$, $p < 0.00$)**; 'uniformity of the light in the room' **($T = 10.5$, $p < 0.00$)**.

The data showed that the participants thought the lighting in the standard room was more suitable for office work compared to the artificial skylight room. Further, the standard room was found to have a higher visual clarity and was more uniformly lit than the artificial skylight room.

We found no significant differences on the remaining measures (see appendix C).

Artificial skylights versus standard luminaries – 2 distinct subgroups

As described above, when all participants were included, only a few differences regarding measures of the light, and the impression of the room were found. However, the verbal debriefing showed that there were two distinct groups of people. Therefore, the sample was split in people who recognized the skylight concept right away (N=16), and people who did not (N=13). This resulted in new effects, and they will be discussed per measure. Analyses were done to detect differences between the two different groups of people, for each room. Also, analyses within the two groups were done (in each group), to detect differences between the rooms. If there were no differences between the groups of people, possible within group effects are only discussed shortly, however all outcomes are shown in Appendix C.

Perceived naturalness

Results showed no significant differences on the measure 'daylight experience' for the complete group; however, for the subgroups significant differences did exist. The two groups differed significantly in the artificial skylight room **(U=21.5, p = 0.00)**, whereas for the standard room the groups did not differ significantly **(U=92.5)**. The group who did recognize the skylight concept had a higher daylight experience in the artificial skylight room than the group who did not. In addition, the group who did recognize the skylight concept had a higher daylight experience in the artificial skylight room than in the standard room **(T = 7.5, p = 0.003)**. In contrast, the group of people who did not recognize the skylight concept had a higher daylight experience in the standard room than in the artificial skylight room **(T = 13.0, p = 0.023)**. A graph of the two rooms versus the two groups of people is shown in Figure 13. Further, no significant differences were found for the measure 'naturalness of colors'.

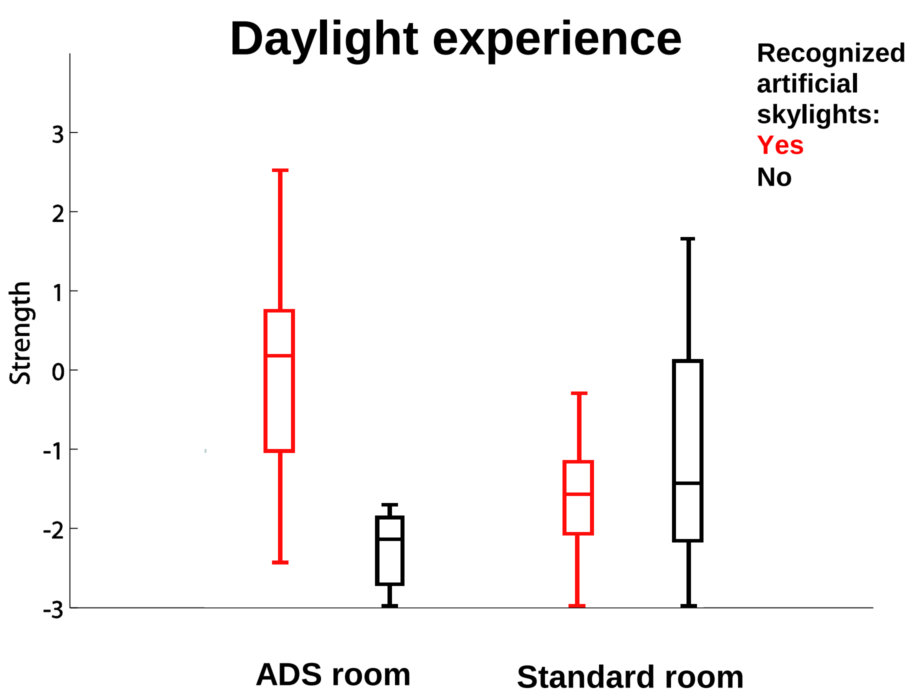

Figure 13: Boxplot (with median and 25% quartile ranges) picturing two rooms versus two groups of people.

Appraisal of the lighting

For the measure ‘lighting suitable for offices’ a between group effect was found for the artificial skylight room **(U=52.0, p = 0.037)**. The group who recognized the daylight concept assessed the artificial skylight room as significantly better suited for office work than people who did not recognize the concept. Further, no significant effects were found for the measure ‘attractiveness of the lighting’ and on any of the three glare items.

Appraisal of the room

For the two measures, ‘uniformity’ and ‘visual clarity’, the standard room was perceived as more uniform and had a higher visual clarity when the complete group was analyzed. When the two groups were split, this same effect was found again for both groups. For ‘visual clarity’ the standard room scored higher in the group of people who recognized the skylight concept **(T = 6.0, p = 0.009)** and also in the group who did not recognize the concept **(T = 10.0, p = 0.023)**. Further, the standard room was perceived as more uniform by the group who recognized the skylight concept **(T = 0.00, p = 0.003)**, and by the group who did not recognize the concept **(T = 4.5, p = 0.006)**. For the measures regarding the perceived size of the room: ‘spaciousness of the room’, ‘size estimate in m^3’, and the question ‘is this room larger or smaller than the other room’, no effects were found at all. Furthermore, no significant differences were found on the measure ‘attractiveness of the room’ and on none of the ‘atmosphere’ dimensions.

Affect

No significant differences were found on the measures ‘pleasure’ and ‘arousal’.

Table 3: Means (M) and Standard Deviations (SD) for all measures (for different groups, and different rooms).

	All participants together			Group who recognized skylight concept			Group who did not recognize skylight concept		
	N	Skylight room Mean (SD)	Standard room Mean (SD)	N	Skylight room Mean (SD)	Standard room Mean (SD)	N	Skylight room Mean (SD)	Standard room Mean (SD)
Daylight experience	29	-0.97 (1.53)*[2]	-1.17 (1.36)	16*[1]	-0.05 (1.36)	-1.33 (1.29)	13*[1]	-2.10 (0.79)	-0.97 (1.47)
Naturalness colors	29	0.48 (1.28)	0.91 (1.17)	16	0.81 (1.25)	1.13 (1.27)	13	0.08 (1.24)	0.65 (1.00)
Lighting attractive	29	0.28 (1.08)	-0.01 (1.15)	16	0.54 (1.20)	0.01 (0.95)	13	-0.05 (0.83)	-0.03 (1.40)
Lighting suitable for work	28*[1]	0.88 (1.48) *[2]	1.66 (1.22)	16	1.34 (0.61)	1.94 (1.06)	13	0.16 (1.53)	1.00 (1.76)
Room attractive	29	-0.67 (1.19)	-0.61 (1.17)	16	-0.33 (1.33)	-0.61 (1.06)	13	-1.10 (0.85)	-0.62 (1.34)
Room visual clarity	29*[1]	0.71 (1.48)	1.95 (0.90)	16*[1]	1.06 (1.33)	2.06 (0.68)	13*[1]	0.27 (1.59)	1.81 (1.13)
Room uniform	29*[1]	-0.14 (1.60)	1.83 (0.93)	16*[1]	0.12 (1.50)	1.81 (1.11)	13*[1]	-0.46 (1.71)	1.85 (0.69)
Room spacious	29	0.34 (1.31)	0.83 (1.26)	16	0.38 (1.40)	1.00 (1.22)	13	0.31 (1.25)	0.62 (1.31)
Glare on paper	29	0.66 (1.11)	0.59 (0.98)	16	0.75 (0.93)	0.50 (0.82)	13	0.54 (1.33)	0.69 (1.18)
Glare on screen	29	0.24 (0.58)	0.21 (0.56)	16	0.31 (0.70)	0.19 (0.54)	13	0.15 (0.38)	0.23 (0.60)
Glare from light source	29	0.52 (0.69)	0.31 (0.54)	16	0.69 (0.79)	0.38 (0.62)	13	0.31 (0.48)	0.23 (0.44)
Arousal	29	-0.21 (0.81)	-0.12 (0.80)	16	-0.05 (0.65)	0.07 (0.68)	13	-0.41 (0.96)	-0.36 (0.89)
Pleasure	29	0.92 (0.95)	0.99 (1.15)	16	1.09 (0.92)	1.08 (1.01)	13	0.71 (0.98)	0.87 (1.34)
Lively	29	-0.63 (1.36)	-0.25 (1.50)	16	-0.25 (1.47)	-0.23 (1.42)	13	-1.10 (1.07)	-0.28 (1.65)
Detached	29	0.76 (1.10)	1.09 (1.00)	16	0.67 (1.22)	1.17 (0.97)	13	0.87 (0.98)	1.00 (1.05)
Tense	29	-1.38 (1.44)	-1.76 (1.04)	16	-1.42 (1.48)	-1.69 (0.93)	13	-1.33 (1.45)	-1.85 (1.19)
Cozy	29	-0.75 (1.12)	-1.00 (0.88)	16	-0.67 (1.17)	-1.06 (0.95)	13	-0.85 (1.09)	-0.92 (0.82)

***[1] Significant difference between rooms;**

***[2] Significant difference between groups of people (recognized / did not recognize skylight concept) in the artificial skylight room**

Qualitative Measures

After completing both questionnaires, a short funneled debriefing was done to get more insights into the motivations behind the participants' answers, and to ask for possible improvements to the artificial skylights.

The funneled debriefing showed, when asking participants to their first impression of the artificial skylight room, two distinct groups of people. It should be noted that the participants were not informed in any way about the aim of the experiment. The first group immediately said something regarding daylight or the blue sky (55 %), while the second group did not see any relationship with daylight or the sky at all (45 %).

Also, questions about possible improvements were asked (in both groups). Answers were given in Dutch and were translated by the author. Most comments were about the sky color of the luminaire. Many people thought it was *"too blue to be natural for the sky in the Netherlands"*, or the color difference between the white parts (when looking up straight) and the blue parts (when looking further away) was too large. Further, the brightness of the room was too low. People thought it would be better if *"the light had the same brightness as the other (standard) room"*. Further comments as, *"had no daylight experience because the light did not match the feeling of real daylight"* and *"the light is too dark for the representation of the weather"* were given. The last major part of the comments was about the size of the

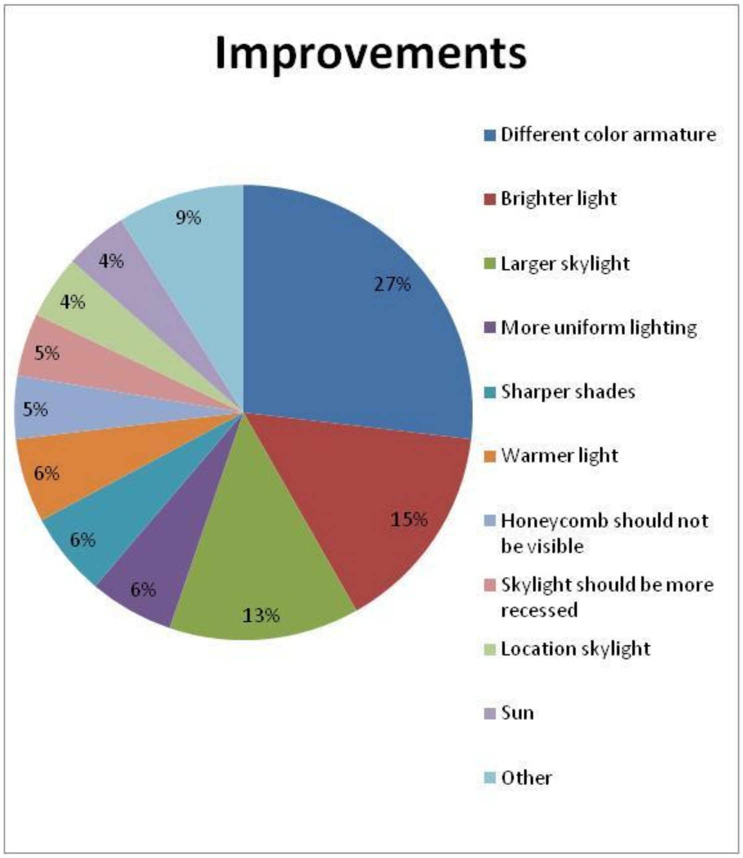

Figure 14: Possible improvements to the artificial skylights that evolved out of the funneled debriefing. (Percentages are the amount of times a specific remark was made compared to the total amount of remarks).

skylight. People thought that *"if the skylight was larger, the daylight experience might be larger too"*. Further, *"a larger size, maybe a large square in the middle of the ceiling, as more often with skylights, would be better"*. And lastly, *"the skylight should not have a standard luminaire size"*. Additional, smaller, improvements could be made if the uniformity of the lighting in the room would be higher; the sharpness of the shades would be higher; the light warmer; the optical element not visible; the skylight more recessed; the location of the skylight different; and an effect of the sun included in the skylight. A graphical overview of all improvements and percentages is depicted in Figure 14.

Besides, a general question asking for possible improvements to the skylight, participants were asked whether they thought the skylight should be more dynamically. To this question 68% answered that they wanted the skylight to be dynamic in some way. These answers varied from *"yes, if it is more dynamic, it might be more realistic"* or *"yes, it would be stimulating"*, to *"yes if it is optionally, and very subtle"*. Thirty-two percent of the people answered that they did not want to make the skylight more dynamically, because *"it would distract too much"*, or *"it would be nice for at home, but not for in an office"*.

Next, two questions were asked about whether the skylight should match outdoor weather circumstances, or not. To the first question (asking if it should match, if there was no real window present), 43% of the people thought it should match, and 25 % of the people thought it did not need to match. One specific group of people thought that as long the skylight represented sunny weather it did not need to match (32 %). When people were instructed to imagine that there was a real window besides the skylight, 77 % thought it should match, against 8 % who thought it did not need to match. Here, 15 % thought it did not need to match as long as the skylight represented sunny weather.

The last question was which room – artificial skylight room or standard room – they would choose if one of them could be their office. Forty-one percent preferred the artificial skylight room directly, and 28 % preferred the standard room. The group who preferred the artificial skylight room was not necessarily the same as the group who comprehended the daylight concept. Another 28 % preferred the artificial skylights in the future if improvements were done. The last 3 % did not have an opinion.

5.3. Conclusion and discussion

The overall comparison of the artificial skylight room and standard room showed little differences. Almost all measures were not significantly different. Differences were present for the suitability of the lighting for office work, visual clarity and uniformity. The lighting in the skylight room was judged to be less suitable for office work, the artificial skylight room had less visual clarity, and was lit less uniformly.

The distribution of the light in the artificial skylight room was different due to the blue optical element of the luminaire, and its recession in the ceiling. As a result, vertical illuminance was lower, and the walls were lit less uniformly in the artificial skylight room. This led to a lower perceived visual clarity and uniformity of the artificial skylight room. This may be related to the 'suitability for office work' too. Officially the office lighting norms were met, however because the lighting was different compared to normal offices – due to the lower vertical illuminance and lower uniformity – people may have perceived it as less suitable for doing work.

No further significant differences appeared between the two rooms. People's attractiveness for the lighting and attractiveness for the rooms were similar. The rooms were assessed as equally spacious, and no effect appeared on the direct size comparison of the two rooms. Atmosphere of the two rooms was also perceived as similar. A positive remark about finding no effect for atmosphere is that even though the artificial skylight room had a lower visual clarity and uniformity, both rooms were rated as equally cozy, lively, detached and tense. This is in contrast to earlier research. Van Erp, (2008) & Bronckers, (2009) demonstrated that the atmosphere dimensions of Vogels (2008) depended on illuminance, spatial distribution, and hue. Therefore it would be expected that when visual clarity and uniformity decreased, atmosphere dimensions were perceived differently too. For affect, the time duration in the room might have been too short to have an effect. Possibly, if people would be in the rooms for a whole day, or longer, a difference might exist. Lastly, daylight experience was also assessed as equally strong in both rooms.

When the groups (according to the outcomes of the funneled debriefing) were split into people who recognized the skylight concept immediately and people who did not recognize the concept at all, it led to new interesting findings.

People who recognized the artificial skylight had a stronger daylight experience in the skylight room than the people who did not recognize the artificial skylight. Also, this group had a higher daylight experience in the artificial skylight room compared to the standard room. In contrast, the group who did not recognize the artificial skylights had a higher daylight experience with the standard luminaries. In the absence of their perception of the luminaries as daylight simulators, they may have based their assessment on the higher uniformity, brightness, and higher vertical illuminance. One question that remains is whether a stronger daylight experience requires that people recognize the skylight concept or, the other way round, that people do not recognize the artificial skylights without a strong daylight experience.

An additional interesting finding resulting from the distinction between those who did and did not recognize the luminaries as artificial skylights, relates to the perceived 'suitability of the lighting for offices'. When analyzing the data of all participants together, the standard room lighting appeared to be more suitable for office work than the lighting in the artificial skylight room. However, a between group effect emerged, showing that the group that did recognize the skylights rated the suitability of the artificial skylight room as higher than the group who did not recognize the skylight concept. A possible explanation for this finding is that when people recognized the skylight concept, the daylight experience compensated for instance for the lower brightness of the lighting.

The funneled debriefing led to insights for improving the artificial skylights. The main factors mentioned were the color of the optical structure, the size of the skylight, and the brightness of the room. The color of the optical structure was too saturated and therefore too unnatural. Most people thought that it would be better if it was of a less saturated blue color. Further, the size of the skylight should be larger. Lastly, the lighting should have a higher illuminance.

As discussed in the theoretical framework, literature showed that people have an innate preference for natural things over man-made (Rozin, 2005), and also belief that daylight is superior to electric lighting (Cuttle, 1983). Moreover, interviews done by Friedman and colleagues (2008) showed that people appreciated artificial display windows over having a blank wall. Therefore, actually more benefits could have been expected from the artificial skylights compared to standard office lighting. Nevertheless, we were able to demonstrate that when people recognized the artificial skylight, their daylight experience was stronger in the artificial skylight room than in the standard lit room. The fact that almost half of the people did not recognize the artificial skylights influenced the findings strongly. Therefore, it is important that more people recognize the skylight concept. Also, generally the strength of the daylight experience has to be increased. The average scores of the daylight experience measures were not particularly high, indicating that the strength of the experience was not very strong. The present study suggests several ways how this strength can be increased. If the artificial skylight would be larger; would have a less saturated blue 'sky'; and, would provide a higher room illumination, it is likely that the strength of the daylight experience would increase and that more people would recognize the artificial skylight. One of the ways to increase the room illumination within the skylight concept, is the addition of sun patterns that fall through the skylight on the wall. These will increase the room illumination. Besides this, they may also increase naturalness of the skylights. However, before it will be possible to implement them into the artificial skylights, people's preference of how these sun patterns have to look like, has to be investigated. This will be the topic of the second study, which will be discussed in the following chapters.

6. Research questions study 2

Sun patterns can influence the appearance of the room. The dynamic patterns of light and shadows are also important for sense of time, orientation and wellbeing (Evans, 1981). As already discussed in the theoretical framework, nature is good for restoration. In a study of Kaplan (1995) the question was asked how nature relates to restoration. One of the topics was that nature exists of various ‘soft fascinations’, namely clouds, sunsets, snow patterns and the motion of leaves in a breeze. Soft fascinations are good restorative environments, and provide an opportunity for reflection. According to the author these factors in nature will hold attention, but leave enough space for thinking about other issues. Although in the study of Kaplan (1995) ‘real’ nature was researched, this theory might be applicable to sun patterns indoors as well.

A recent simulation study of Philips – as discussed in the theoretical framework chapter for the preference of skylights – also researched preference of sun patterns. In this study, renderings of skylight configurations and different sun patterns (depending on the sky condition) were presented on a computer screen. Participants indicated which picture (skylight and sun patterns together) they preferred in general, which picture gave the strongest daylight impression, and which one was most appealing. Results of the oral debriefing showed that when participants were asked what aspects they considered being important for their overall preference, 29% of the comments made were related to the skylight, and 28% to the light pattern. When asked to what was important for daylight impression, the course of results was the same. The skylight itself was most often named (38%), and the amount of comments about the light pattern on the wall / floor was 36%. Thirdly, participants were asked what aspects they considered most important when judging appeal of a light condition. Again, the skylight was named most often with 38%. The patterns were again named secondly, however with a slightly lower percentage (25%) compared to the daylight impression question. The direction of these results may indicate that light patterns are more important for daylight impression than for appeal. Further, participants were asked to indicate which aspects of the pattern they thought were most important. For all three questions, sharpness of the edges and CCT were the most important elements for the overall pattern. In general, warmer patterns with sharp edges were preferred most (Seuntiens, et al., 2011). The set up of the room in this study was made neutral: there was no furniture and also no context information was given to the participants. When this information would have been given, it may have led to different results. A slightly related study of Park, Chang, Kim, Jeong, Choi (2010) researched the effect of context for preference of standard luminaries. Here, preference for CCT showed to be dependent on the room the participants had to assess. This study varied CCT (3000 K, 4000 K, 5000 K, and 6000 K) and different spaces (office, living room, and bedroom) in a photo-image test. Participants had to choose which photograph they preferred most for every space. The results of the living room and the bed room were corresponding. Preference in CCT for both rooms was 3000 K > 4000 K > 5000 K > 6000 K. However, this was different from the assessment for an office environment. In an office environment preference for CCT was 4000 K > 5000 K > 3000 K > 6000 K. Although these assessments concerned artificial light sources, it may also have some relation to sun patterns, since sun patterns may also affect the perception of environment, and people may subsequently prefer different settings in different spaces.

In the study explained above, Seuntiens and colleagues (2011) investigated overall preference, daylight impression and appeal for different skylight configurations and different sun patterns. However, the effect of daylight impression and appeal on overall preference was not researched. The following study will investigate four possible predictors of preference. Furthermore, different attributes of sun patterns will be researched. These are sharpness, CCT, and shape. Seuntiens and colleagues (2011) showed that certain CCTs and sharpness's affect people's preference for sun patterns. We decided to add the attribute shape to these, because we assumed that people's preference would also depend on the shape of the sun pattern. Furthermore, all attributes (shape, sharpness, CCT) will contain one level that is not realistic. The constructs that will be used in this experiment to explain peoples' preference for sun patterns are realism, daylight impression, aesthetics, and atmosphere. The study of Seuntiens and colleagues (2011) used daylight impression, and appeal, and we added realism and atmosphere to these because we thought these would improve the explanation of preference. We are interested how these constructs predict preference. Also will be investigated how the attributes affect judgments for each construct. For example, it is possible that a sun pattern can be found very beautiful, however not realistic at all. Then it is interesting to research which construct will explain preference most. Furthermore, we can study whether the unrealistic sun patterns are also perceived as unrealistic, and whether this realism judgment also affects overall preference. Lastly, context (office and home) will be manipulated to research differences in preference for sun pattern attributes, and overall relations between the constructs for different contexts.

The research questions of this second study are as follows:

1) **"What kind of sun patterns, varying in shape, sharpness and CCT, do people prefer?"**

2) **"What is the weight of aesthetics, atmosphere, realism & daylight experience in predicting preference for sun patterns?"**

7. Study 2: Preference for sun patterns

7.1. Methodology

Design

The experiment followed a within-subjects paired comparison design for the sun pattern stimuli (with five dependent measures), and between-subjects context (office and home) manipulation. Two sun patterns were projected side-by-side on the wall using high end beamers, and participants indicated which pattern they preferred (with respect to the context). Further, all sun patterns were presented in a random order, and random side (left/right) on the wall.

Participants

Thirty participants (13 male, 17 female) were included in this study, with a mean age of 28 (SD: 7.5, range: 20-55). All participants were Philips research employees (students, researchers, and administrative employees). The first fifteen participants were situated in the context of an office; the last fifteen were in a home environment.

Stimuli & manipulations

The sun pattern attributes shape (4 levels), sharpness (3 levels) and CCT (3 levels) were varied in this experiment. For shape, a short diagonal pattern, a long diagonal, a short rectangle, and an unnatural pattern (trapezium) were used. Short patterns will appear in a skylight configuration when the sun is very low, for instance in the morning and the late afternoon. Long patterns appear during mid day. The short rectangular pattern occurs once a day, when the sun is exactly in line with the skylight. The unnatural pattern was chosen to investigate whether people noticed that it was not realistic, and to research how this influenced preference. For sharpness, a pattern with blurred edges, a pattern with gradually blurred edges from top to bottom, and a pattern with completely sharp edges were used. The pattern with blurred edges occurs when clouds are in front of the sun. The pattern with gradually blurred edges from top to bottom represents a clear sky condition where the sun directly shines at the skylight. Further, the pattern with completely sharp edges is not realistic. For CCT, a high CCT (7000 K), a low CCT (5500 K) and an unnaturally high CCT (8500 K) were chosen. The high CCT represents a noon and/or a partly cloudy situation. The low CCT occurs during the morning and the late afternoon. Further, the very high CCT represented an unrealistic situation. An overview of all attributes and levels is shown in Table 4 and Figure 15.

Table 4: Attributes of sun patterns

Attributes	Levels
Shape	Short, rectangle
	Short, diagonal
	Long, diagonal
	Trapezium (unnatural)
Sharpness	Completely sharp (unnatural)
	Blurred
	Gradually blurred edges
CCT	Low (5500 K)
	High (7000 K)
	Very high (8500 K) (unnatural)

When combining these attributes and levels, it led to 4 * 3 * 3 = 36 different patterns, which are all shown in Appendix D. For this paired comparison study, one attribute of the sun pattern was varied per comparison, while the others were kept constant. By this, main and interaction effects could be analyzed without necessarily doing a full design. In total, 126 comparisons were done to assess one dependent measure. Five dependent measures were assessed in this experiment, which led the total amount of paired comparisons in the design per participant to 5 * 126 = 630.

The dependent measures overall preference, aesthetics, atmosphere, realism and daylight impression were used. Since preference is based on underlying constructs, it is important to know which constructs can explain preference. For sun patterns, we thought these measures would capture preference completely. Nevertheless, it was chosen to assess preference first – without informing the participants about the other measures – and thereafter all four other measures in a counterbalanced order. Therefore, it was possible to analyze if these measures predicted preference completely or only partially.

Also, context was manipulated. Participants were asked to imagine being either at home sitting at their couch, or being in their office behind a desk. To enhance this, we made the setup of the room to represent the correct context.

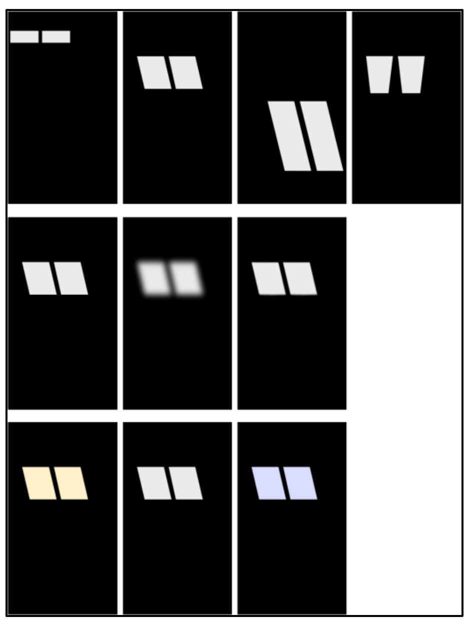

Figure 15: Overview of sun pattern attributes and levels.

From left to right, and top to bottom:

Shape: Short rectangle; short diagonal; long diagonal; trapezium (unnatural).

Sharpness: Completely sharp (unnatural); blurred; gradually blurred edges.

CCT: 5500 K; 7000 K; 8500 K (unnatural).

Procedure

The participants were welcomed, and sat down on a couch / chair at approximately 3 meter from the wall, in the middle of the two projections. They received written instructions and signed an informed consent form. After that, all five dependent measures were assessed. Participants were instructed to press the left arrow key if they preferred the left sun pattern, and the right arrow key for the right sun pattern. Per measure, it took on average 5 minutes to complete all 126 paired comparisons. The total time of the experiment, including instructions, was 30-40 minutes.

Figure 16: Top left figure shows photograph of home setup. Top right figure shows photograph of office setup. Bottom left figure shows graphical representation of setup. Bottom right figure shows photograph of projected (small rectangular) sun pattern.

Setting & Apparatus

Room

The experiment took place in the artificial skylight room, as described in study 1. The dimensions of the room were: L * W * H = 6.05 *3.72 * 3.00 meters. The window was closed by a role-down shutter. For the first part of the study, the set-up in the room was to represent an office. In the second part of the study, the set up of a home environment was made. A photograph of both set-ups, a photograph of one skylight with sun pattern, and a graphical picture of room is shown in Figure 16.

Luminaries

Four Philips Savios (TLS770 6x14W/827/865) were installed, left and right, in pairs of two. The luminaries were recessed in the ceiling and covered by an optical element creating a blue sky appearance.

Projectors and patterns

Two Sanyo WUXGA projectors (PLC ZM5000L) were installed at both sides of where the participants sat. They were placed line with the skylights. The size of the total projection on the wall was W * H = 1080 *1920 pixels and 1.85 m * 3.29 m. The aim of the experiment was to make the location on the wall, the length and the angle of the pattern as realistic as possible (with a few deliberate exceptions), as if it looked like the sun patterns came from the sun, falling through the skylight. The room and skylight openings were implemented in Google Sketch-up. It was chosen to use Casablanca, Morocco (33.63 N; 7.583 W) on the 13th of August at 3 moments in time (08:08, 10:00, and 11:05 AM). Casablanca was used because the height of the sun was high enough to provide short and long sun patterns, without the distance between the patterns being too far away from each other. This was necessary because otherwise the size of the projection was too small, and also since it was better for participants to compare patterns at locations close to each other. The exact size, angles, and sharpness of the patterns as shown in Google Sketch-up were measured and reproduced in Adobe Photoshop CS4. The CCT of the sun patterns was determined differently. Here, the projections of the beamer (with a white point of 6500 K) were used to determine the RGB values that were corresponding with the intended CCTs. For the low CCT of 5500 K, the color point was x: 0.33, y: 0.38, and the luminance was 98 cd/m^2 (RGB values: 255, 240, 200). For the high CCT of 7000 K, the color point was x: 0.30 and y: 0.35, with a luminance of 95 cd/ m^2 (RGB values: 235, 235, 235). Lastly, for the unnaturally high CCT of 8500 K the color point was x: 0.29 and y: 0.33, with a luminance of 86 cd/ m^2 (RGB values: 218, 220, 252).

Dependent measures

The dependent measure 'overall preference' was assessed first. Here, the question asked to the participants was: "*Which of the two patterns (left or right) do you prefer most, i.e. which would you like to have on the wall?"*

Afterwards, the possible predictors of preference were assessed in a counterbalanced order. The measure aesthetics was used to assess which pattern participants thought was the most beautiful. This was assessed via the question: "*Which of the 2 patterns (left or right) in your opinion is the most beautiful one?"* Atmosphere was assessed by asking for the most pleasant atmosphere. This was questioned as follows: "*Which of the 2 patterns (left or right) in your opinion creates the most pleasant atmosphere in the room?"* Further, participants assessed daylight experience by the question: "*Which of the 2 patterns (left or right) in your opinion comes closest to a daylight experience?"* Lastly, realism was assessed. This was done by the question: "*Which of the 2 patterns (left or right) is in your opinion most realistic compared to what you normally see with real skylights?"*

Analyses

To answer the research questions, three different analyses were executed. First, main effects for the patterns were analyzed. Second, interaction effects between context and the attributes. And thirdly, interaction effects among the attributes themselves were analyzed. Lastly, correlation analyses were done, to research the importance of the predictors with respect to preference. Also, for the correlation analyses context will be taken into account.

A pair wise comparison design was used for this study. Participants indicated which pattern (right or left of each pair) they preferred. In total 126 pairs, per dependent measure, per participant were assessed. Thurstonian scaling was used to analyze the data. For every level within one attribute a Z-score was calculated, and the level which was preferred the least got a Z-score of 0. The delta Z-scores could then be easily interpreted and calculated into percentages that one attribute is preferred over another. As a general indication, a delta Z-score of 0, 0.5, 1, and 1.5 corresponds respectively with the percentages 50%, 70%, 85%, and 93%. For example, when the first level has Z-score of 0.5 and the second a Z-score of 1.0, the delta Z-score is 0.5. This means that 70% of the people preferred the second level over the first.

To make it possible to detect significant significance when interpreting graphs more easily, error bars of this method were altered. Unaltered, it was only possible to calculate an error bar for the comparison of levels A with B, A with C, and B with C. However, it was not possible to calculate the error for level A, B and C separately. To calculate these error bars for each level we used Montag's method. Further, since in the present research every time more than two levels are compared, a correction for multiple analyses was made. Therefore, a significant difference ($p<0.05$) is present when the mean of the error bar of one attribute is outside the error bar of another attribute.

Interaction effects between all attributes, and between context and the attributes, were analyzed by a parametric bootstrap analysis. Bootstrapping can be used to calculate confidence intervals without knowing the sampling distribution.

After analyzing main effects and interaction effects, correlation analyses were done to determine the weight of the predictors of preference. For the correlation analyses, Z-scores for all 126 comparisons were taken. For each comparison, the Z-values for preference, aesthetics, atmosphere, daylight experience, and realism were compared. Also two analyses were done for the two contexts separately. Furthermore, besides correlations, R-squares were calculated to determine how much the four constructs – aesthetics, atmosphere, realism, daylight impression – contributed in predicting preference. These were calculated with regression analysis. We decided not to include the other regression outcomes, because of possible multicollinearity problems between the predictors of preference.

These analyses were all executed in MATLAB 7.11.0., except for the correlation (and R-square) analyses where the data was transferred into IBM SPSS Statistics 19.0.0.

7.2. Results

After analyzing the data, we found distinct effects for the different stimuli. Main effects were present for all attributes (shape, CCT, and sharpness); however interaction effects between the attributes and context (office-home) were only detected for sharpness. Therefore, first shape and CCT will be discussed, and afterwards the more complex results for sharpness.

Table 5 and Table 6 show averages of the Z-scores (M) and Standard Errors (SE) for all measures and all patterns. Table 5 shows the results for the measures not having an interaction effect between the attributes and context. Table 6 shows the results for home and office separately, since for these an interaction effect of the attribute with context was found. Further, no interaction effects at all were detected among the different attributes themselves. Lastly, also correlation analyses will be discussed for overall data, and home and offices separately.

Table 5: Z-scores Means (M) and Standard Errors (SE) for the measures without any interaction effects between attributes and context.

Attributes	Preference Z-score M (SE)	Atmosphere Z-score M (SE)	Aesthetics Z-score M (SE)	Daylight impression Z-score M (SE)	Realism Z-score M (SE)
Shape 1	0.24 (0.10)	0.00 (0.11)	.01 (0.11)	0.08 (0.10)	0.53 (0.11)
Shape 2	0.53 (0.10)	0.79 (0.11)	.57 (0.11)	0.80 (0.10)	1.03 (0.11)
Shape 3	0.48 (0.10)	1.13 (0.11)	.68 (0.11)	1.15 (0.10)	1.15 (0.11)
Shape 4	0.00 (0.10)	0.14 (0.11)	.00 (0.11)	0.00 (0.10)	0.00 (0.11)
CCT 1	0.00 (0.10)	0.19 (0.10)	.00 (0.10)	0.00 (0.10)	0.00 (0.10)
CCT 2	0.40 (0.10)	0.34 (0.10)	.35 (0.10)	0.46 (0.10)	0.31 (0.10)
CCT 3	0.16 (0.10)	0.00 (0.10)	.13 (0.10)	0.15 (0.10)	0.02 (0.10)
Sharpness 1	-	-	-	0.00 (0.10)	0.00 (0.10)
Sharpness 2	-	-	-	0.08 (0.10)	0.17 (0.10)
Sharpness 3	-	-	-	0.43 (0.10)	0.51 (0.10)

Table 6: Z-scores Means (M) and Standard Errors (SE) for the measures showing an interaction effect between sharpness and context.

Context	Attributes	Preference Z-score M (SE)	Atmosphere Z-score M (SE)	Aesthetics Z-score M (SE)	Daylight impression Z-score M (SE)	Realism Z-score M (SE)
Home	**Sharpness 1**	0.00 (0.13)	0.00 (0.14)	0.00 (0.14)	-	-
	Sharpness 2	0.99 (0.13)	1.39 (0.14)	1.41 (0.14)	-	-
	Sharpness 3	0.76 (0.13)	0.98 (0.14)	0.75 (0.14)	-	-
Office	**Sharpness 1**	0.38 (0.13)	0.00 (0.13)	0.00 (0.13)	-	-
	Sharpness 2	0.00 (0.13)	0.07 (0.13)	0.17 (0.13)	-	-
	Sharpness 3	0.34 (0.13)	0.22 (0.13)	0.23 (0.13)	-	-

Effects for shape, CCT, and sharpness

Analyses regarding overall preference showed a significant main effect for shape. Figure 17 shows the graph for preference of shape. The diagonal patterns (2 and 3) were preferred most, and the unnatural pattern (4) least. The ΔZ of approximately 0.5 between the diagonal patterns and the unnatural pattern indicated that 69% of the participants preferred the diagonal patterns over the unnatural pattern. Furthermore, 60% preferred the diagonal patterns over the short rectangular pattern. No significant difference was detected between number 2 and 3. Contrary, when looking at the other dependent measures – realism, daylight impression, aesthetics, and atmosphere – differences between the diagonal shapes were present. For all these measures the long diagonal pattern scored highest. Further, an interesting result was that for daylight impression, atmosphere and beautiful, the small rectangular pattern had the lowest scores. Only for preference and realism, this small rectangular pattern scored slightly higher.

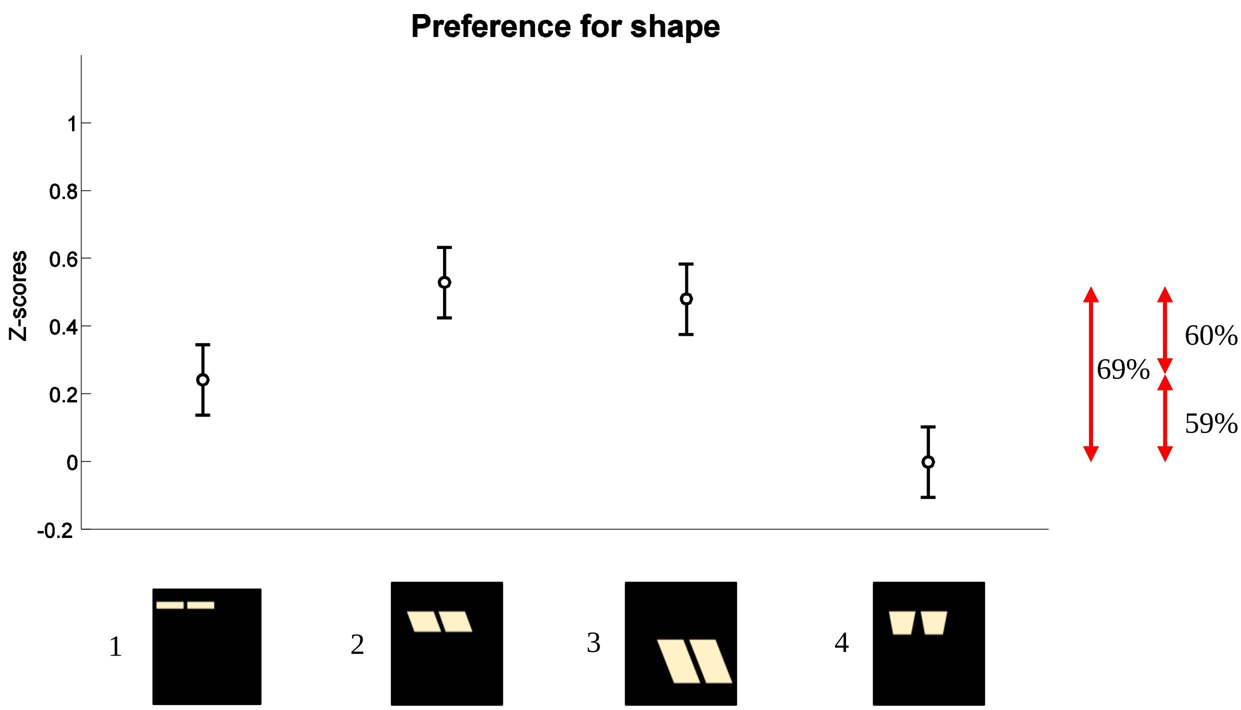

Figure 17: Preference for shape

For CCT, results showed that the pattern of 7000 K was significantly preferred above the patterns of 5500 K and 8500 K. Figure 18 shows a graphical overview of these results, where CCT number 1, 2 and 3 respectively represent 5500 K, 7000 K and 8500 K. Approximately 66% of the people preferred the middle CCT over the lowest, and 60% over the unnatural high CCT. Also a significant difference between the lowest and the highest CCT existed. Fifty-six percent preferred the highest CCT over the lowest. For the other dependent measures the same results were found, except for atmosphere. For atmosphere, the lowest CCT was preferred more than the highest CCT.

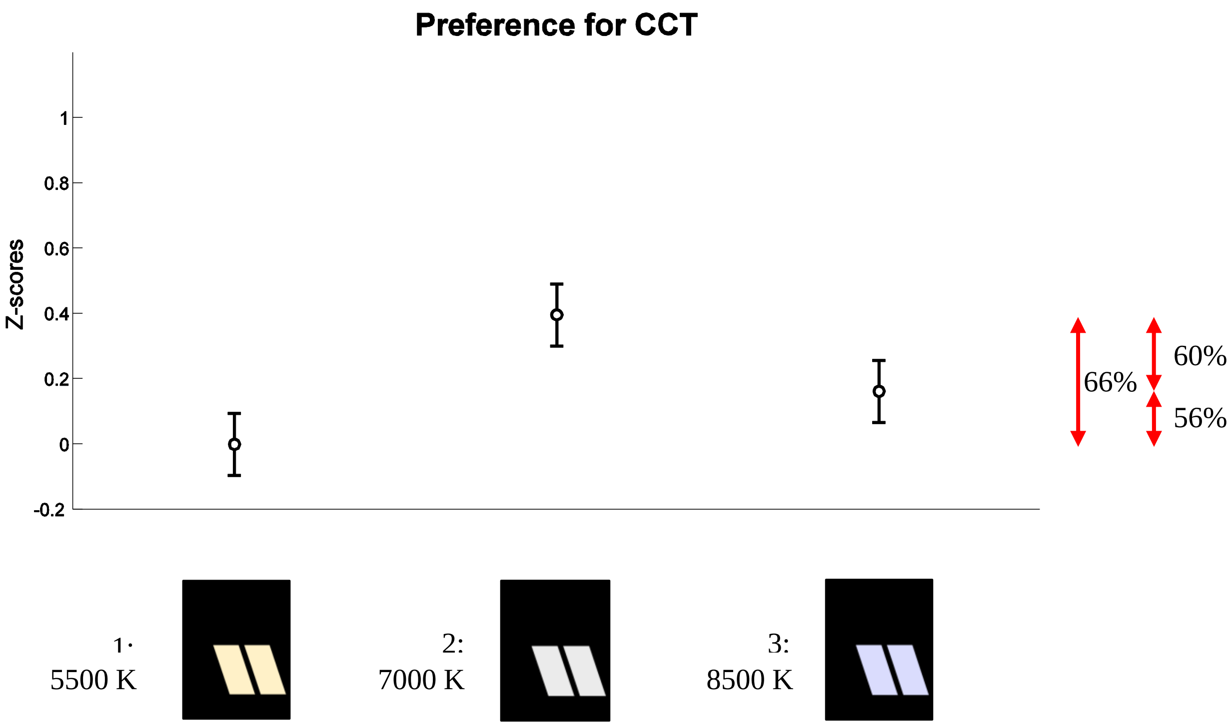

Figure 18: Preference for CCT

The main effect of sharpness on preference was analyzed separately for offices and homes, since we found a very strong interaction effect between context and sharpness ($p < 0.01$). As shown in Figure 19, approximately 64 % of the participants preferred the pattern with sharp edges (pattern 1) and the pattern with gradually blurred edges (3) over the blurred edge pattern (2) for an office environment. No significant difference existed between the pattern with completely sharp edges and the pattern with gradually blurred edges. Contrary, in home environments the pattern with blurred edges scored highest in terms of preference. For homes, 84 % of the participants preferred the pattern with blurred edges over the pattern with completely sharp edges, and 59% preferred this pattern over the pattern with gradually blurred edges. Also, a significant difference existed between the gradually sharp pattern and the completely sharp pattern.

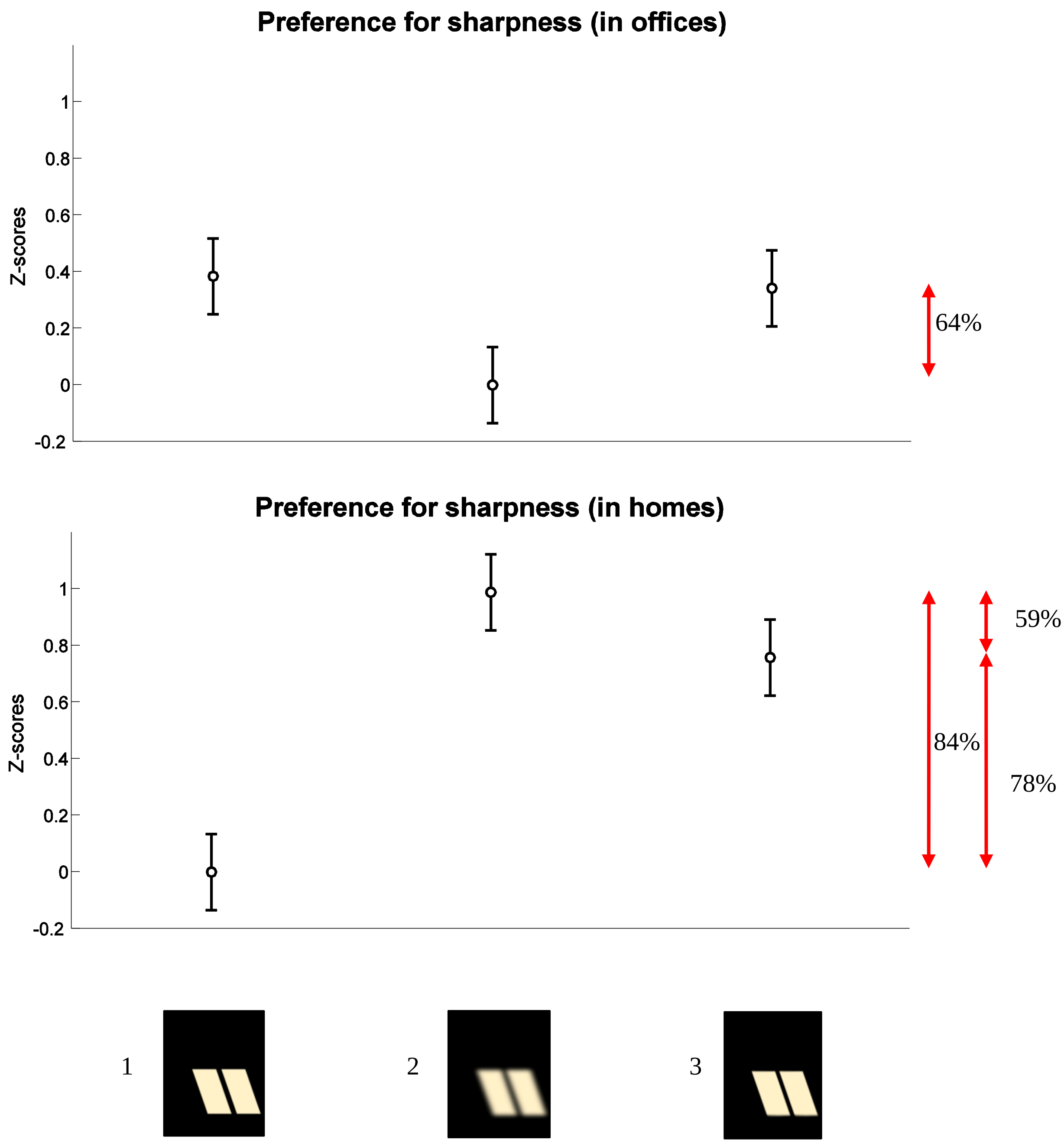

Figure 19: preference for sharpness in offices (top graph) and homes (bottom graph).

The other dependent measures regarding sharpness showed much variation. Firstly, no interaction effect between context and sharpness existed for both the dependent measures daylight experience and realism. For both measures the pattern with gradually blurred edges scored highest, and the pattern with completely sharp edges lowest. For realism, 70% thought that the pattern with gradually blurred edges was more realistic than the pattern with completely sharp edges. Also, the other effects were significantly different. The graph for realism is shown in Figure 20. The daylight impression graph is not depicted because of the large similarity with realism.

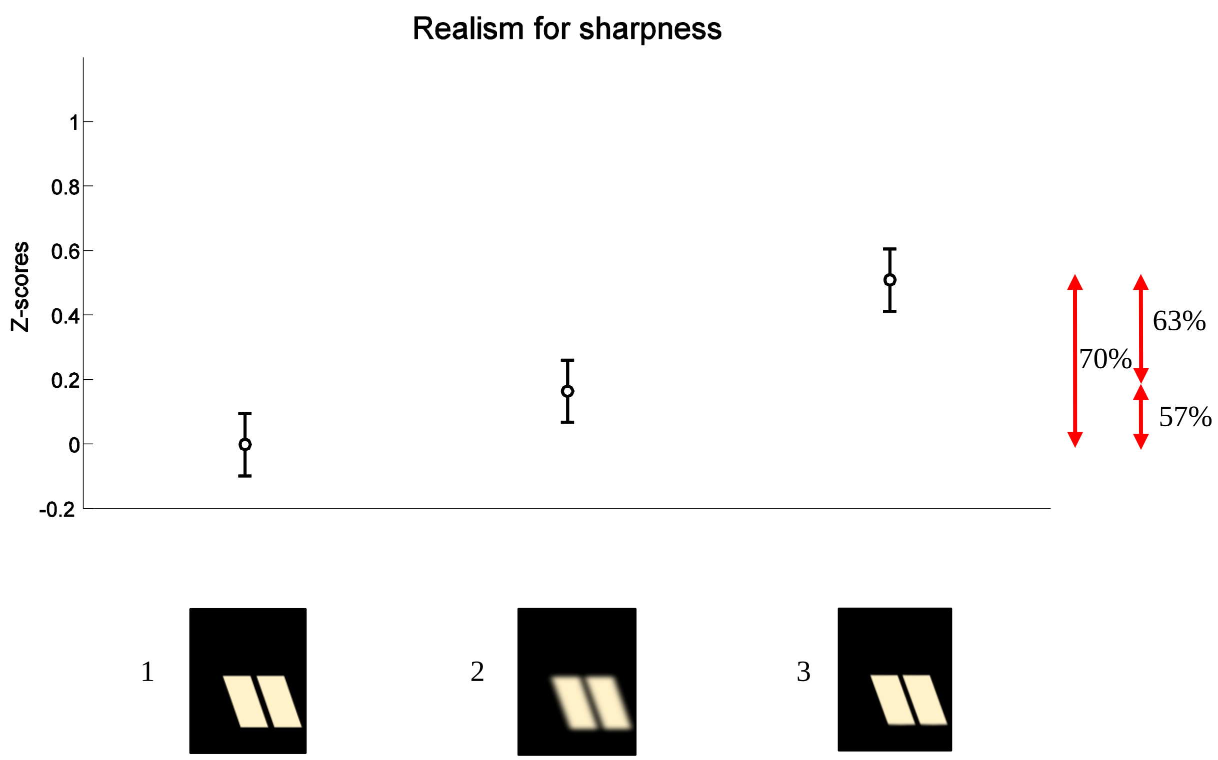

Figure 20: Realism with respect to the aspect sharpness.

Aesthetics and atmosphere showed an interaction effect between context and sharpness ($p < 0.01$). Also for these measures the similarity between them was very high. For homes, all three levels were significantly different from each other, and the patterns with blurred edges scored highest on both aesthetics and atmosphere measures. Aesthetics and atmosphere judgments in an office context were less explicit. Here, although a very small effect was shown, it might be best interpreted that for offices all sharpness patterns were equal to each other. Both graphs for aesthetics are shown in Figure 21, and it should be noted that the results for atmosphere were approximately similar, and therefore not depicted.

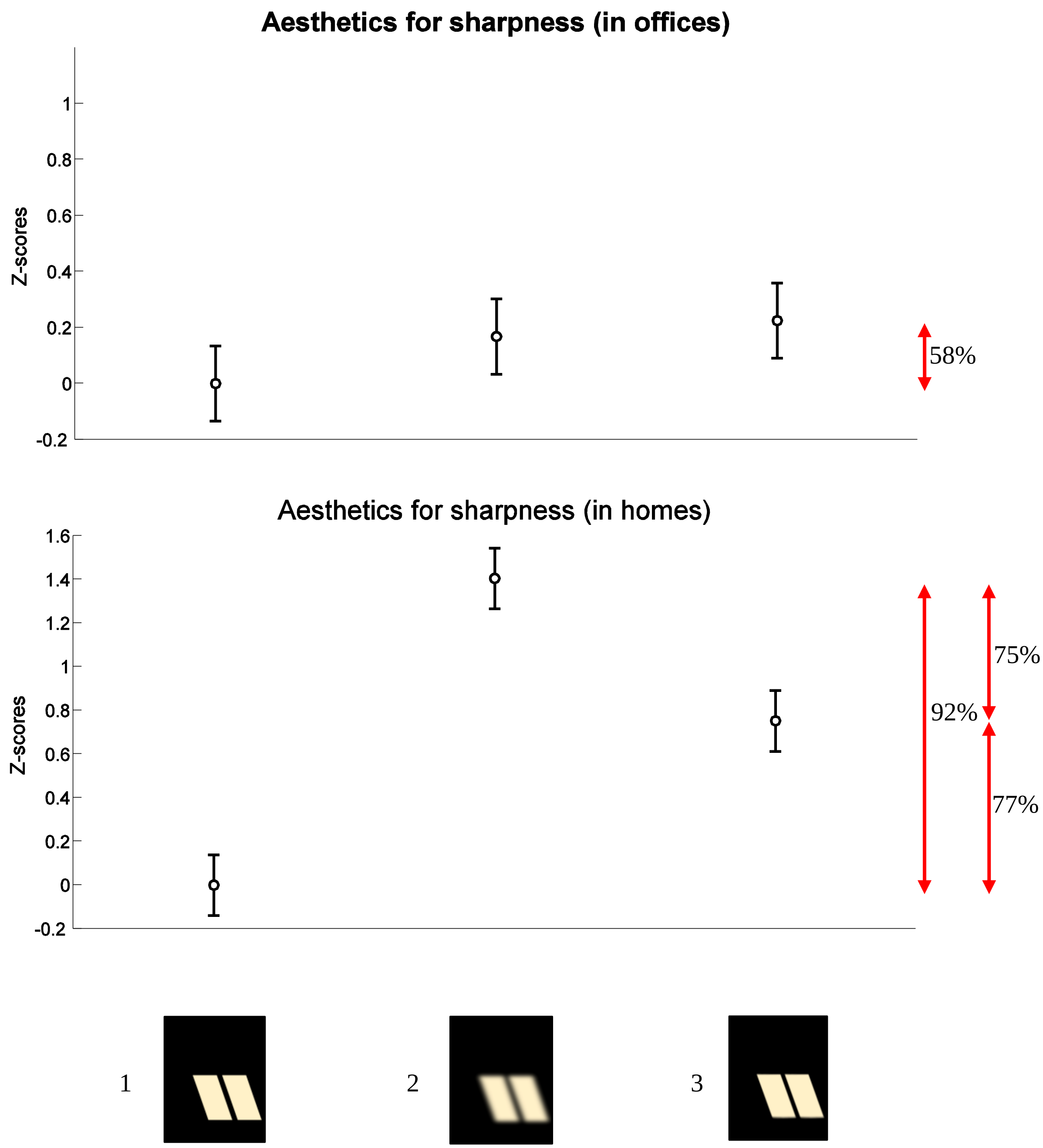

Figure 21: Aesthetics for sharpness in offices (top graph) and homes (bottom graph).

Correlation analyses

The results of the interaction effects between sharpness and context pointed already in the direction that possibly different predictors were important for homes and offices. This was more thoroughly researched through correlation analyses. Here, firstly overall correlations (for the whole group) were analyzed, and afterwards home and office were analyzed separately.

Table 7: Correlations between preference, daylight impression, realism, atmosphere, and aesthetics.

OVERALL**	Preference	Daylight Impression	Realism	Atmosphere	Aesthetics
Preference	1	0.72*	0.78*	0.66*	0.73*
Daylight impression	-	1	0.87*	0.81*	0.73*
Realism	-	-	1	0.75*	0.74*
Atmosphere	-	-	-	1	0.86*
Aesthetics	-	-	-	-	1

*p < 0.05 **R-Square = 0.66

Table 8: Correlations office context.

OFFICE**	Preference	Daylight Impression	Realism	Atmosphere	Aesthetics
Preference	1	0.68*	0.68*	0.56*	0.64*
Daylight impression	-	1	0.84*	0.86*	0.82*
Realism	-	-	1	0.80*	0.79*
Atmosphere	-	-	-	1	0.82*
Aesthetics	-	-	-	-	1

*p < 0.05 ** R-Square = 0.53

Table 9: Correlations home context.

HOME**	Preference	Daylight Impression	Realism	Atmosphere	Aesthetics
Preference	1	0.42*	0.53*	0.63*	0.73*
Daylight impression	-	1	0.72*	0.58*	0.41*
Realism	-	-	1	0.57*	0.58*
Atmosphere	-	-	-	1	0.77*
Aesthetics	-	-	-	-	1

*p < 0.05 **R-Square = 0.54

The overall correlation analysis showed that the correlations between the predictors and between the predictors and preference were moderately high to high (and all significant). Therefore one could argue that they all had an equal piece in predicting preference. However, a certain trend in the results was found. Amongst the predictors results showed that aesthetics correlated highly with atmosphere, and daylight impression correlated highly with realism. It also seemed to be that realism was somewhat more important in predicting preference and atmosphere slightly less. The R-Square of all predictors together was 0.66. All correlations are depicted in Table 7.

Next, the results of the correlations for home and office separately will be reported.

For offices, daylight impression, atmosphere, realism and aesthetics predicted preference in an approximately equal way. Possibly one could say that atmosphere had a slightly lower part in the total prediction. The R-Square of all predictors was 0.53. All correlations for offices are presented in Table 8.

In homes, all measures had a slightly different weight in predicting preference. When looking at the correlations of these predictors with preference, it showed that aesthetics and atmosphere had the highest correlation with preference. Further, the lowest correlations were for realism and daylight impression. The R-Square of the predictors within a home context was 0.54. All correlations are depicted in Table 9.

7.3. Conclusion and discussion

The second study of this thesis gave insight into what kinds of sun patterns were preferred, and which predictors determined preference. Firstly, a short conclusion and discussion will be given regarding preference for the sun patterns themselves, and afterwards the relationship of preference with the other predictors will be discussed. Of course, the effects for context will also be deliberated on.

For shape, this study showed that most people preferred diagonal patterns. People had no explicit preference for the small or the large diagonal pattern. Nevertheless to optimize aesthetics, atmosphere, daylight impression and realism, the largest diagonal pattern should be used. Participants were able to detect that the unnaturally shaped pattern was indeed not realistic, and also had no strong preference for this pattern. Preference for CCT was very unambiguous. The patterns with a CCT of 7000 K were preferred most, secondly, the patterns of 8500 K, and the lowest scores were for the patterns of 5500 K. Also for aesthetics, daylight impression and realism this same order of CCTs occurred. One exception was that for atmosphere, the lowest CCT scored higher than the very high CCT. Further, interestingly enough, the most unnatural CCT was not found to be least realistic.

Contrary to shape and CCT, sharpness showed more complex interaction effects with context. Here the environment was a very important factor for preference. For homes, the patterns with blurred edges were preferred most, while in offices these were the least preferred. In offices, patterns with sharper edges were preferred. When subsequently aesthetics, daylight impression, atmosphere, and realism were researched, a specific pattern occurred. In living rooms at home, people had a clear opinion about atmosphere and aesthetics, which led to the high scores for the pattern with blurred edges. In offices, no distinct effects within the patterns for aesthetics or atmosphere could be detected. This indicated that the participants did not favor a certain sharpness pattern which would lead to the most pleasant atmosphere or aesthetics in an office. Further, daylight impression and realism were similar for the office and the home situation; and besides this showed once more that participants were able to tell which pattern was not realistic.

Seuntiens and colleagues (2011) mentioned that participants preferred patterns with sharper edges. This is difficult to compare to the present study. Sharper patterns are indeed preferred for offices, however not at all in a home context. Seuntiens and colleagues (2011) did not use any context, and presented patterns in an empty room. However, if any relation would be expected between an empty room and an office/home environment, then probably the office would make more sense, which would confirm the present results. Furthermore, Park and colleagues (2010) researched preference for CCT of lighting in different environments. They concluded that in living rooms different CCTs were preferred than in offices. This appears in contrast to our findings in such a manner that in the present study no difference was detected. A possible explanation for this is that two different methods are being compared. Park and colleagues researched standard indoor lighting that did not need to represent daylight. In the present study preference for projections of sun patterns was investigated. This preference might, contrary to indoor room lighting, not necessarily differ between contexts, since in the present study the representation of daylight was important. Lastly, for shape, preference could (partially) be based on size and possibly luminous intensity. The largest (diagonal) shapes were preferred most, while the small rectangular shapes were preferred to a lesser extent. This was, even though participants' judgments showed that they were aware that both shapes were not completely unrealistic. Another explanation can be that since the diagonal patterns occur more often in real life, these were perceived as more realistic, and also stronger preferred.

Correlation analyses were performed to investigate relationships (regardless of specific shapes, sharpness's, and CCTs) between aesthetics, atmosphere, daylight impression, and realism with preference. Aesthetics, atmosphere, daylight impression and realism all correlated significantly with preference. Nevertheless, a certain trend was found. Aesthetics and atmosphere proved to be very similar to each other. Also, daylight impression and realism were correlating highly. Further, if a strongest predictor of preference had to be selected, it would be realism. Besides these 'overall' conclusions, the differences between homes and offices were also very interesting. We can conclude that for office situations, aesthetics, daylight impression, realism and atmosphere were all approximately equally important in predicting preference. However for homes, aesthetics and atmosphere were more important for preference than realism and daylight impression. Furthermore, when investigating the differences between the contexts, it shows that the correlations of aesthetics and atmosphere with preference are not very different for both contexts. The correlations of realism and daylight impression, on the other hand, differ more between the two environments. Consequently, the conclusion can be drawn that aesthetics and atmosphere were very important in both contexts, and formed a very large part in explaining the preference for a certain sun pattern. However, the main difference was that in offices patterns should represent daylight closely and also be very realistic with respect to other issues, while for homes this seemed to be less important.

The set up of this second study also had some limitations. The most important drawbacks were due to the settings of the beamers used to project the sun patterns. Firstly, the luminance levels were not high enough to represent real daylight patterns Also, luminance levels of the patterns were all approximately equal, which could have led to an unnatural combination with the different CCTs. For instance, one would expect a 'sunny' pattern to have a higher luminance level than a pattern representing a cloudier situation. This was not the case, and could have influenced the results. Furthermore, for setting the CCTs, although they were very close, it was not possible to match the values exactly with the Black-body. These discussion points together may explain why participants were not able to detect the CCT that was least realistic. Lastly, the general representation of home and office, and the fact that two beamers were present in the room may have led to less convincing results. Nevertheless, the instructions were very clear, and differences between contexts were found in some cases.

Despite these limitations, this study led to interesting conclusions. Overall, the most preferred sun pattern was a long diagonal pattern with an intermediate CCT (7000 K) and depending on the context a pattern with blurred edges (homes) or a pattern with gradually blurred edges (office). Further, except for CCT, participants were able to tell which patterns were least realistic. Moreover, these the unnatural patterns never scored highest on overall preference and on aesthetics, atmosphere, and daylight impression judgments. Lastly, although all measures predicted preference quite highly, a certain pattern could be detected. Aesthetics and atmosphere seemed to be important for preference in all circumstances. However in offices, contrary to homes, realism and daylight impression seemed to play a larger role in preference. Possible explanations for these findings will be discussed in the next chapter.

8. General discussion

Two studies were conducted in this thesis, the first explored the benefits of artificial skylights, and the second was a more specific study about preference for sun patterns (falling through the artificial skylight). The research questions that were formulated for this thesis were: *"What are the (possible) benefits of artificial skylights compared to standard electric lighting in offices?"* and *"Which aspects of sun patterns (within the skylight) are preferred, and what factors predict this?"* The answers to these questions were extensively discussed in the previous chapters. Nevertheless, a short recap of the findings and a general discussion will be given. Afterwards, possible future studies will be discussed.

The importance of realism

The main conclusion with respect to the first study was that most people did not assess the artificial skylight room more positively than the standard lit room. The most important reason behind this finding was probably that approximately half of the participants did not comprehend what the special lighting in the skylight room was about. These people did not 'see' the resemblance with a sky, but thought it was just a new designed luminaire. Nevertheless, the people that did recognize the skylight concept had a stronger daylight experience in the skylight room than in the standard room. To increase the amount of people recognizing the artificial skylights, it is necessary to make them seem more realistic. This would mainly comprise a more natural sky color, size of the skylight and light level of the room. The second study formed a direct connection to this increase of the light levels, since the sun patterns theoretically led to a brighter room. This was not investigated; however the focus was on what kinds of sun patterns were preferred, and which constructs predicted this preference. First of all, contrary to the first study, strong statistical effects were found. This could be partly due to the forced choice study design, but also because a strong preference existed in favor of specific sun patterns. Also, unrealistic patterns were included in the design. Perceived realism judgments showed that most of the time participants were able to detect these unnatural patterns. This was interesting information since some of the variations – for instance in sharpness – were very subtle. Therefore, even though sun patterns are observations that people do not give a moment's thought on a daily base, people were able to discriminate between realistic and unrealistic. Moreover, a certain trend was found in the direction that the unnatural patterns were not very often preferred and also were not very positive for aesthetics, daylight impression and atmosphere. Stated differently, patterns that were 'perceived' as realistic also were preferred strongly. Interpreting the overall correlations, realism was also an important predictor for preference. Although all predictors were correlating significantly with preference, and conclusions therefore have to be drawn with a certain caution, realism did have the highest correlation with preference. Therefore, the conclusion can be drawn that people seemed to prefer sun patterns that were true-to-nature, and had less preference for unnatural patterns. It is noteworthy that solely the fact that a pattern looks realistic can predict a large part of preference. Moreover, perceived realism and judgments of aesthetics also correlated with each other. Therefore, we may conclude that besides a preference for realistic looking patterns, these natural looking patterns are also perceived as more beautiful. These findings have some similarity to the study of Rozin (2005). The authors stated that – regardless of the topic – people have an innate preference for nature. People believe that 'nature' is superior over 'artificial'. More specifically, people believe natural things to be healthier and better than manmade things.

For the comparison of windows and daylight with electric lighting, realism also showed to be important. For office environments, daylight and windows are preferred over artificial light for several aspects (Heerwagen & Heerwagen, 1986; Finnegan and Solomon, 1981; Yildirim, et al., 2007). Furthermore, also for artificial windows, although no physiological effects were found, people seemed to appreciate them over a blank wall (Friedman et al., 2008). Taking this all together, more positive outcomes could have been expected of the first study. However, since the second study showed that even for subtle things as sun patterns realism is important, the artificial sky in the first study – although quite realistic – not looking realistic enough, was probably the main disadvantage. This also corresponds closely to the participants' feedback that the skylights need to look more true-to-nature.

Offices versus homes

As explained, most studies found that office employees preferred daylight over artificial light. The second study showed that also for sun patterns realism and daylight experience tended to be important for preference. This means that sun patterns have to look like there is real daylight entering the room. However, a trend in the results showed that daylight impression and realism seemed to be more important for preference in offices than in homes, and vice versa. Interesting to know is why? A few possible explanations can be provided. Firstly, the effects of daylight being positive for wellbeing and other aspects may be more appreciated in an office environment than at home. When being in an office there is probably less freedom to go outside for a while, or walk around. When people are at home, it is much easier to go to a place where daylight is available. Therefore, the need for sun patterns looking like daylight may be stronger in offices. Contrary, one can argue that in homes there is less need for realism of sun patterns, because aesthetics might play a larger role in homes. For instance, sun patterns may be seen as a piece of art on the wall, which as long as it fits in the environment, and creates a nice atmosphere, it does not need to be true-to-nature. Whether these explanations are legitimate or not, for these specific participants it was the case that they are more often in an office during daytime than at home. This could, regardless of the specific route, have influenced their preference for sun patterns.

Future research

The results of these studies provided direct information for future studies. For the second study the outcomes were quite clear. Preference for sun patterns correlated highly with aesthetics, atmosphere, daylight experience, and realism. It would be sensible to see if these predictors are similar for real sun patterns (or pictures of them). In this case also the difference between office and home would be interesting to investigate, and possibly stronger effects could be detected. Moreover, the question can be raised if preference for other topics with respect to lighting can be predicted in a similar way?

The predictors used in this study were all important. However, although the R-squares were already quite high, they could have been higher. This means that aesthetics, atmosphere, realism, and daylight impression were not completely explaining preference. The addition of constructs is necessary to fully predict preference. It is advisable for future studies to take this along, and search for more possible predictors.

In the first study, participants gave the recommendation to make the artificial skylights look more realistic. Therefore, after these improvements are implemented, it may be good to repeat this study. Then, more positive effects are expected. Unfortunately, this was not possible to do in the short time-span of a Master's thesis. Further, it may be interesting to also investigate the effects on productivity, health and wellbeing. Another possibility for future studies is to compare the artificial skylights with a real skylight, and investigate if there are any differences. Although the artificial skylights are not meant to be a replacement for windows, comparing them with real skylights might give additional interesting information. Of course, combining the sun patterns with the skylight system, and investigating the added value of the sun patterns is also logical step to take. Sun patterns probably make the artificial skylights look more realistic, therefore it is expected that this leads to a higher appraisal. Then, however, also user studies regarding long term effects of these static sun patterns on the wall are necessary to investigate.

Besides this, it would also be good to investigate possibilities for having dynamic sun patterns that change very subtle over for instance a day, an hour, or minute. In the funneled debriefing of the first study, the question was asked whether the sky itself should be dynamic. Sixty-eight percent of the people thought this was a good idea as long as it would be subtle. Dynamic sun patterns were not questioned, but possibly the direction of the results would be similar. Nevertheless, also for dynamic patterns a long term user study of the effects of the sun patterns would be advisable.

A last general question mark can be placed by the question: when is it realistic enough to be preferred? Or even more important, when will it lead to positive effects for health and wellbeing? The second study showed that for very obvious unnatural patterns, preference scores were very robust, and in the same direction. For the more subtle differences, also more subtle differences occurred for preference. Although in this study only one unnatural factor per attribute was used, it would also be interesting to investigate in future studies where certain boundaries are.

9. References

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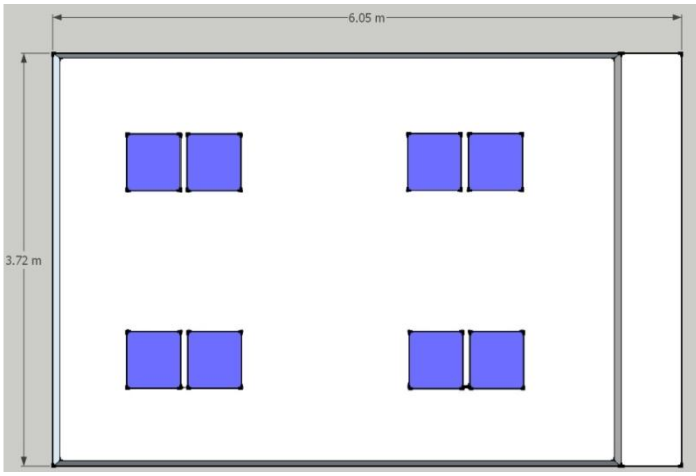
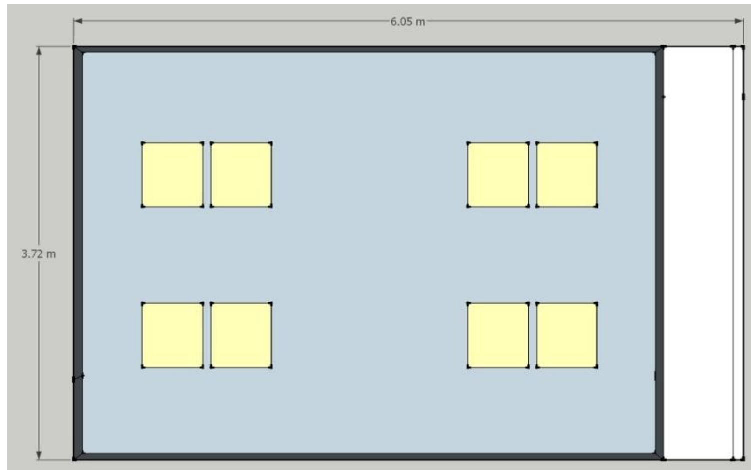
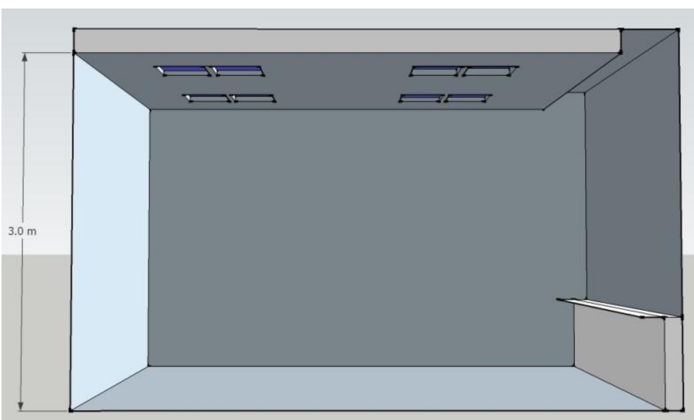
Appendix A: Experiment rooms



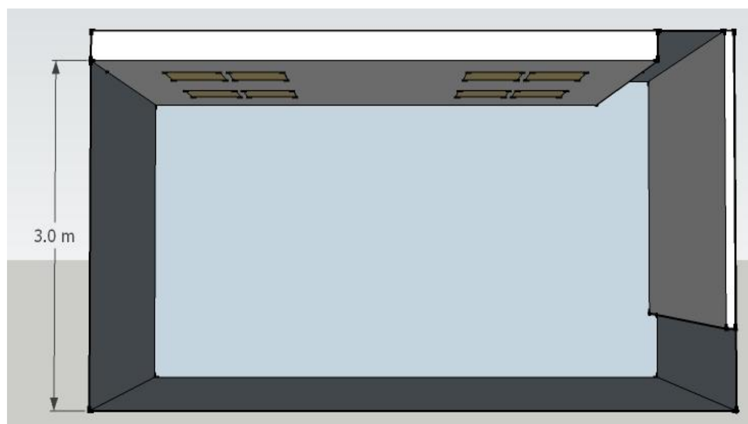
Ceiling plan artificial skylight room



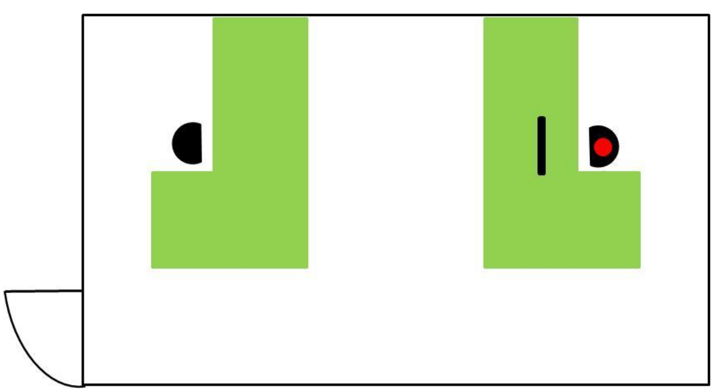
Ceiling plan standard room



Front view artificial skylight room



Front view standard room



Left: Floor plan of the artificial skylight room. In the room are two desks, and chairs. The chair with the red dot was for the participant. The other one was for the researcher. The floor plan of the standard room was the mirror image of that of the artificial skylight room.

Appendix B: Questionnaire study 1

Persoonsgegevens

Geslacht *

( ) Man ( ) Vrouw

Leeftijd *

[ ]

Beroep *

[ ]

Atmosfeer van de ruimte

Geef aan in welke mate de onderstaande woorden van toepassing zijn op de ATMOSFEER VAN DE RUIMTE, op een schaal van "absoluut niet van toepassing" tot "zeer goed van toepassing". Dus als voorbeeld: Als je het woord behaaglijk absoluut niet van toepassing vindt op deze ruimte kruis je het meest linkse vakje aan. Als je het zeer goed van toepassing vindt, dan kruis je het meest rechtse vakje aan.

	Absoluut niet van toepassing	Nauwelijks van toepassing	Niet zo van toepassing	Neutraal	Enigszins van toepassing	Goed van toepassing	Zeer goed van toepassing
Behaaglijk *	( )	( )	( )	( )	( )	( )	( )
Levendig *	( )	( )	( )	( )	( )	( )	( )
Beangstigend *	( )	( )	( )	( )	( )	( )	( )
Formeel *	( )	( )	( )	( )	( )	( )	( )
Geborgen *	( )	( )	( )	( )	( )	( )	( )
Stimulerend *	( )	( )	( )	( )	( )	( )	( )

Bedreigend *	○	○	○	○	○	○	○
Kil *	○	○	○	○	○	○	○
Intiem *	○	○	○	○	○	○	○
Inspirerend *	○	○	○	○	○	○	○
Gespannen *	○	○	○	○	○	○	○
Zakelijk *	○	○	○	○	○	○	○

Evaluatie van de ruimte

Geef aan wat je vindt van de RUIMTE.
De vragen zijn zo opgesteld dat beide woorden elkaars tegenstelling zijn.
Kruis aan wat je het meest van toepassing vindt op deze ruimte.
Je kunt alle 7 opties aankruisen.
Als voorbeeld: als je deze ruimte heel erg scherp vindt overkomen,
kruis je het meest linkse vakje aan.
Als je deze ruimte daarentegen heel erg vaag vindt overkomen,
dan kruis je het meest rechtse vakje aan.

Scherp	○	○	○	○	○	○	○	**Vaag**
Helder	○	○	○	○	○	○	○	**Donker**
Uniform	○	○	○	○	○	○	○	**Niet uniform**
Ruimtelijk	○	○	○	○	○	○	○	**Nauw**
Groot	○	○	○	○	○	○	○	**Klein**

Evaluatie van de ruimte (questionnaire 1)

Geef een schatting van de lengte, breedte en hoogte van deze ruimte.

De lengte (in meter) *

De breedte (in meter) *

De hoogte (in meter) *

Evaluatie van de ruimte (questionnaire 2)

Vind je deze ruimte groter of kleiner lijken dan de eerste ruimte?

○ **Groter** ○ **Kleiner**

Evaluatie van de ruimte

Geef aan in welke mate de onderstaande woorden van toepassing zijn op deze RUIMTE, op een schaal van "absoluut niet van toepassing" tot "zeer goed van toepassing".

	Absoluut niet van toepassing	Nauwelijks van toepassing	Niet zo van toepassing	Neutraal	Enigszins van toepassing	Goed van toepassing	Zeer goed van toepassing
Leuk *	○	○	○	○	○	○	○
Interessant *	○	○	○	○	○	○	○
Prettig *	○	○	○	○	○	○	○
Mooi *	○	○	○	○	○	○	○

Verlichting van de ruimte

Geef aan in welke mate de onderstaande woorden van toepassing zijn op de VERLICHTING in deze ruimte, op een schaal van "absoluut niet van toepassing" tot "zeer goed van toepassing".

	Absoluut niet van toepassing	Nauwelijks van toepassing	Niet zo van toepassing	Neutraal	Enigszins van toepassing	Goed van toepassing	Zeer goed van toepassing
Leuk *	○	○	○	○	○	○	○
Interessant *	○	○	○	○	○	○	○
Comfortabel *	○	○	○	○	○	○	○
Prettig *	○	○	○	○	○	○	○
Mooi *	○	○	○	○	○	○	○
Hindert mijn werk *	○	○	○	○	○	○	○
Geschikt voor kantoor *	○	○	○	○	○	○	○

Verlichting van de ruimte

Geef aan in welke mate je verblinding of hinderlijke schittering (glare) ervaart vanwege reflecties op het papier en op het beeldscherm, of direct van de lichtbron.

	Niet waarneembaar	Waarneembaar, maar niet storend	Een beetje storend	Storend	Zeer storend
Op het papier *	○	○	○	○	○
Op het beeldscherm *	○	○	○	○	○
Van de lichtbron *	○	○	○	○	○

Temperatuur van de ruimte

Geef aan in hoeverre je de TEMPERATUUR in deze ruimte comfortabel vindt, op een schaal van "absoluut niet van toepassing" tot "zeer goed van toepassing".

	Absoluut niet van toepassing	Nauwelijks van toepassing	Niet zo van toepassing	Neutraal	Enigszins van toepassing	Goed van toepassing	Zeer goed van toepassing
Comfortabel *	○	○	○	○	○	○	○

Temperatuur van de ruimte

Geef aan wat je vindt van de TEMPERATUUR in deze ruimte.
Je kunt alle 7 opties aankruisen.

Koud ○ ○ ○ ○ ○ ○ ○ **Warm**

Temperatuur van de ruimte (Questionnaire 2)

Vind je deze ruimte warmer of kouder dan de vorige ruimte?

○ **Warmer** ○ **Kouder**

Hoe je jezelf voelt

Geef aan, aan de hand van onderstaande woorden, hoe je JEZELF op dit moment VOELT.
De vragen zijn zo opgesteld dat beide woorden elkaars tegenstelling zijn. Je kunt alle 7 opties aankruisen.
Als voorbeeld: als je je op dit moment heel erg geërgerd voelt kruis je het meest linkse vakje aan.
Als□je jezelf daarentegen op dit moment heel erg behaaglijk voelt, dan kruis je het meest rechtse vakje aan.□

Geërger	○	○	○	○	○	○	○	**Behaaglijk**
Slaperig	○	○	○	○	○	○	○	**Wakker**
Verveeld	○	○	○	○	○	○	○	**Ontspannen**
Ontspannen	○	○	○	○	○	○	○	**Gemotiveerd**
Loom	○	○	○	○	○	○	○	**Uitzinnig**
Wanhopig	○	○	○	○	○	○	○	**Hoopvol**
Ongelukkig	○	○	○	○	○	○	○	**Gelukkig**
Futloos	○	○	○	○	○	○	○	**Zenuwachtig**
Ontevreden	○	○	○	○	○	○	○	**tevreden**
Bedrukt	○	○	○	○	○	○	○	**Aangenaam**
Rustig	○	○	○	○	○	○	○	**Opgewonden**
Niet geprikkeld	○	○	○	○	○	○	○	**Geprikkeld**

Ervaring van het licht

Voor de volgende vragen wordt je ervaring met bepaalde onderwerpen gevraagd. Voor de eerste vraag kun je hiervoor je mening geven op een schaal van "helemaal niet" tot "heel erg". Voor alle overige vragen op een schaal van "zeer zwak" tot "zeer sterk". Ook de 'onbenoemde' vakjes hiertussen in kun je aankruisen.

Geef aan in welke mate je het licht vindt lijken op daglicht

	Helemaal niet			Neutraal			Heel erg
Lijkt op daglicht *	○	○	○	○	○	○	○

Geef aan hoe sterk je het gevoel hebt dat je in een daglicht situatie bent.

	Zeer zwak			Neutraal			Zeer sterk
Daglicht gevoel *	○	○	○	○	○	○	○

Geef aan hoe sterk je een daglicht ervaring voelt op dit moment.

	Zeer zwak			Neutraal			Zeer sterk
Daglicht ervaring *	○	○	○	○	○	○	○

Relaties

Voor de volgende vragen wordt je relatie met bepaalde onderwerpen gevraagd. Voor alle overige vragen op een schaal van "zeer zwak" tot "zeer sterk". Ook de 'onbenoemde' vakjes hiertussen in kun je aankruisen.

Geef aan hoe sterk je relatie met .... is op dit moment.

(vul de onderstaande woorden op de stippellijn in)

	Zeer zwak			Neutraal			Zeer sterk
Buiten *	○	○	○	○	○	○	○
Het weer *	○	○	○	○	○	○	○

De natuur *							

Natuurlijkheid

Geef aan of je de volgende dingen natuurlijk vindt overkomen in deze ruimte. Je kunt hiervoor je mening geven op een schaal van "helemaal niet natuurlijk" tot "heel erg natuurlijk". Ook de 'onbenoemde' vakjes hiertussen in kun je aankruisen

Geef aan hoe natuurlijk je .... vindt in deze ruimte.

(vul de onderstaande woorden op de stippellijn in)

	Helemaal niet natuurlijk			Neutraal			Heel erg natuurlijk
Het licht *							
Je huidskleur *							
De kleur van meubels en objecten *							

Funneled debriefing

- Wat was je eerste indruk van deze kamer?
- Wat vind je van het licht in beide kamers?
- Wat vind je van het verlichtingssysteem in beide kamers?
- Wat vind je van de blauwe kleur in het ene systeem?
- Wat vind je van de inbouwdiepte in het ene systeem?
- Wat vind je van de lichtverdeling?
- Wat zou je aan het daglicht systeem willen verbeteren/wijzigen?
- Dient het licht zich als kantoor verlichting of als buiten verlichting te gedragen?
- Wat vind je van de impressie van het weer?
- Dient de impressie van weer overeen te komen met het echte weer van buiten?
- Welke kamer zou je geschikter vinden als kantoor, en waarom?

Appendix C: Chronbach's alpha values, Medians, and non parametric tests study 1

Cronbach's alpha values for aggregated measures.

Composite measures	Items	Cronbach's alpha value artificial skylight room	Cronbach's alpha value standard room
Pleasure	Pleasure 1 to 6	0.883	0.925
Arousal	Arousal 1 to 6	0.749	0.707
Lively	Levendig Stimulerend Inspirerend	0.867	0.828
Detached	Formeel Kil Zakelijk	0.656	0.566
Tense	Beangstigend Bedreigend Gespannen	0.934	0.713
Cozy	Behaaglijk Geborgen Intiem	0.687	0.597
Daylight experience	Daylight experience 1 to 3 Relationship 1 to 3 Naturalness of light	0.945	0.934
Naturalness of colors	Naturalness of skin tone Naturalness of colors of objects and furniture	0.829	0.810
Room spacious	Room large Room spacious	0.841	0.929
Room visual clarity	Room clear Room bright	0.808	0.832
Lighting attractive	Lighting beautiful Lighting like Lighting interesting Lighting comfortable Lighting pleasant	0.818	0.857
Lighting suitable for work	Lighting hinders work Lighting suitable for offices	0.801	0.924
Room attractive	Room like Room interesting Room pleasant Room beautiful	0.824	0.826

Medians for the whole group, and for the separate groups, per room.

	All participants together			Group who recognized skylight concept			Group who did not recognize skylight concept		
	N	Median artificial skylight room	Median Standard room	N	Median artificial skylight room	Median Standard room	N	Median Artificial skylight room	Median Standard room
Daylight experience	29	-1.57	-1.57	16	0.21	-1.57	13	-2.14	-1.43
Naturalness colors	29	0.50	1.00	16	1.00	1.00	13	0.00	1.00
Lighting attractive	29	0.40	0.20	16	0.80	0.10	13	-0.20	0.20
Lighting suitable for work	28	1.25	2.00	16	1.50	2.00	13	0.50	1.50
Room attractive	29	-0.75	-0.75	16	-0.25	-0.88	13	-1.00	-0.75
Room visual clarity	29	1.00	2.00	16	1.25	2.00	13	0.00	2.00
Room uniform	29	0.00	2.00	16	0.00	2.00	13	-1.00	2.00
Room spacious	29	0.50	1.00	16	0.25	1.00	13	0.50	1.00
Glare on paper	29	0.00	0.00	16	0.00	0.00	13	0.00	0.00
Glare on screen	29	0.00	0.00	16	0.00	0.00	13	0.00	0.00
Glare from light source	29	0.00	0.00	16	0.50	0.00	13	0.00	0.00
Arousal	29	0.00	-0.67	16	0.00	0.00	13	-0.17	-0.17
Pleasure	29	1.00	1.33	16	1.33	1.25	13	0.83	1.33
Lively	29	-0.67	-0.33	16	-0.50	-1.67	13	-1.00	-0.67
Detached	29	1.00	1.00	16	1.00	1.33	13	1.00	1.00
Tense	29	-1.67	-2.00	16	-1.67	-2.00	13	-1.67	-2.00
Cozy	29	-0.67	-1.00	16	-0.67	-1.00	13	-1.00	-1.00

Wilcoxon signed-rank test, to detect differences between rooms, for the whole group, and the separate groups.

	All participants together			**Group who recognized skylight concept**			**Group who did not recognize skylight concept**		
	N	**Artificial skylight vs. standard room**		**N**	**Artificial skylight vs. standard room**		**N**	**Artificial skylight vs. standard room**	
		Wilcoxon T	Sig.		Wilcoxon T	Sig.		Wilcoxon T	Sig.
Daylight experience	29	172.0	p = NS	16	7.5	p = 0.003	13	13.0	p = 0.023
Naturalness colors	29	92.0	p = NS	16	25.0	p = NS	13	21.0	P = NS
Lighting attractive	29	162.5	p = NS	16	38.0	p = NS	13	44.5	p = NS
Lighting suitable for work	28	46.0	p = 0.03	16	23.0	p = NS	13	12.0	p = NS
Room attractive	29	142.0	p = NS	16	35.0	p = NS	13	20.0	p = NS
Room visual clarity	29	32.5	p = 0.00	16	6.0	p = 0.009	13	10.0	p = 0.023
Room uniform	29	10.5	p = 0.00	16	0.0	p = 0.003	13	4.5	p = 0.006
Room spacious	29	101.0	p = NS	16	30.0	p = NS	13	26.5	p = NS
Glare on paper	29	18.5	P = NS	16	2.5	P = NS	13	3.5	P = NS
Glare on screen	29	9.0	P = NS	16	1.5	P = NS	13	2.0	P = NS
Glare from light source	29	19.5	P = NS	16	4.0	P = NS	13	6.0	P = NS
Arousal	29	106.5	p = NS	16	36.5	p = NS	13	21.0	p = NS
Pleasure	29	132.5	p = NS	16	45.0	p = NS	13	24.5	p = NS
Lively	29	133.0	p = NS	16	51.5	p = NS	13	21.5	p = NS
Detached	29	155.0	p = NS	16	40.5	p = NS	13	33.5	p = NS
Tense	29	87.5	p = NS	16	34.0	p = NS	13	15.0	p = NS
Cozy	29	151.5	p = NS	16	36.5	p = NS	13	41.0	p = NS

Mann-Whitney U test, to detect between subject differences, per room.

		Artificial skylight room		Standard room	
		Recognized skylight concept vs. did not recognize concept		Recognized skylight concept vs. did not recognize concept	
	N	Mann-Whitney U	Sig.	Mann-Whitney U	Sig.
Daylight experience	29	21.5	p = 0.00	92.5	p = NS
Lighting suitable for work	28	57.5	p = 0.04	65.5	p = NS
Naturalness colors	29	71.0	p = NS	81.0	P = NS
Lighting attractive	29	72.0	p = NS	99.0	p = NS
Room attractive	29	64.0	p = NS	103.0	p = NS
Room visual clarity	29	77.0	P = NS	95.5	P = NS
Room uniform	29	82.5	p = NS	103.5	p = NS
Room spacious	29	100.0	P = NS	89.0	P = NS
Glare on paper	29	81.5	p = NS	97.5	p = NS
Glare on screen	29	98.5	p = NS	101.0	p = NS
Glare from light source	29	78.0	p = NS	94.0	p = NS
Arousal	29	78.5	p = NS	77.0	p = NS
Pleasure	29	78.0	p = NS	102.5	p = NS
Lively	29	70.0	p = NS	101.0	p = NS
Detached	29	97.5	p = NS	92.5	p = NS
Tense	29	101.0	p = NS	90.0	p = NS
Cozy	29	97.0	p = NS	94.5	p = NS

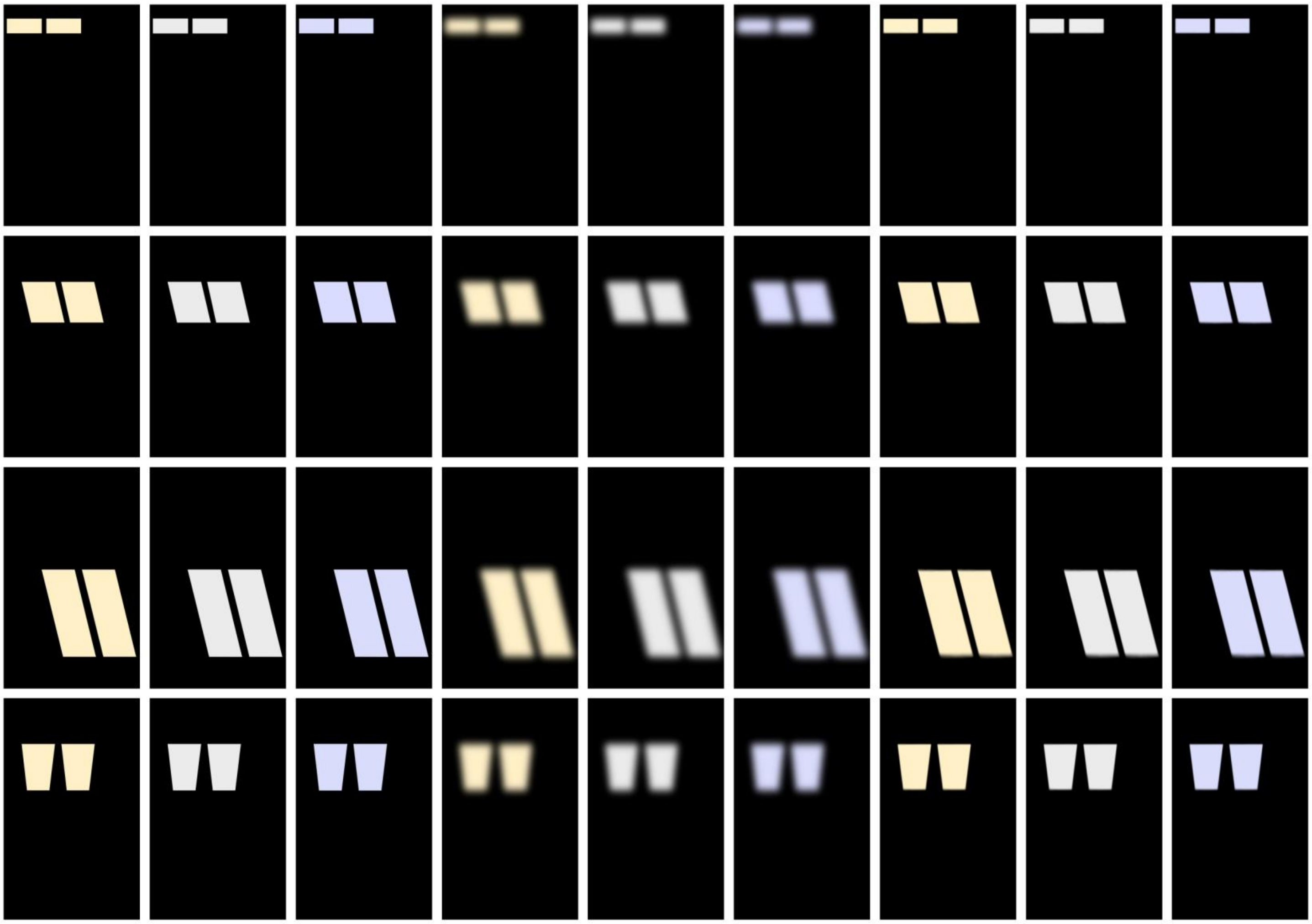
Median, Mean, Standard Deviation, and Mann-Whitney U test to compare perceived room sizes.

	Artificial skylight room			**Standard room**			**Between room test**		
	N	Median	Mean (SD)	N	Median	Mean (SD)	N	Mann-Whitney U	Sig.
Perceived size room (m^3)	15	72.0	76.4 (27.0)	14	78.0	80.5 (32.0)	29	95.0	p = NS

Percentages and Binomial test to test which room is perceived as larger.

	N	**Artificial skylight room larger**		**Standard room larger**		**Binomial test**
		N	Percentage	N	Percentage	
ADS or standard room perceived as larger	29	13	55%	16	45%	P = NS

Appendix D: Sun patterns study 2



From left to right: low CCT & sharp; middle CCT & sharp; high CCT & sharp; low CCT & blurred; middle CCT & blurred; high CCT & blurred; low CCT & gradually blurred; middle CCT & gradually blurred; high CCT & gradually blurred.

From top to bottom: small rectangular pattern; short diagonal pattern; long diagonal pattern; trapezium pattern.