Outdoor animals in indoor environments

The influence of (the absence of) daylight on our well-being and performance

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Abstract – Formerly architects embraced the sun, while contemporary architects do not or to a lesser extent. The purpose of this study is to investigate the effects of daylight on human well-being. In addition this thesis also mentions reasons why contemporary architects are not obligated to embrace the sun. In order to achieve this goal, literature is consulted whereby aspects besides the boundaries of architecture are considered. Finally arguments are given why architects should embrace the sun again.

Daylight is able to set and maintain our circadian rhythm, which regulates our whole body. Daylight is also able to provoke the secretion of vitamin D, which, in turn, affects our mood and behaviour. The secretion of endorphins and 'feel-good' hormones are also provoked by daylight, these hormones influence the well-being of humans. The previously mentioned aspects are also able to influence the human performance.

Considering the fact that our society is spending more and more time indoors, architects should apply the available knowledge when designing and embrace the sun again, to provide healthy environments. Regarding the, recently completed, available knowledge, architects should apply this during their designs. In today's world, human inventions such as artificial light and medicines suppress the need to use daylight. Designing sunlit buildings is further suppressed due to energy-based design decisions.

Key words – Sun, Daylight, Human well-being, Human performance, Circadian Rhythm, Vitamin D, Architecture, Indoor environment

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1. INTRODUCTION

> Although we spend most of our time indoors, we are really outdoor animals. The forces, which have selected the genes of contemporary man are found outdoors in the plains, forests and mountains, not in centrally heated bedrooms and at ergonomically designed workstations. (Baker, 2000, p. 1)

Humanity has evolved outdoors throughout a long time. During waking hours, our ancestors spent their time outdoors. During the dark hours, a shelter provided our ancestors with a safe place to sleep. The indoor conditions of these shelters closely tracked the outdoor environment. Our bodies are attuned to the fluctuations during day and night and the seasonal changes, because our ancestors practically always lived outside (Baker, 2000). Even though humanity has evolved outdoors, we now spend 90% of our lives within buildings (Evans, & McCoy, 1998; Andersen, 2014). These indoor environments are not like the shelters of our ancestors; nowadays the indoor environments are strictly conditioned to avoid fluctuations and they form a strict separation between inside and outside.

Several (recent) studies have shown again that daylight is necessary for human well-being. Thereby fluctuations in light intensity and colour as well as direct and indirect exposure to the sun have a major impact on our health (Webb, 2006). Nowadays, most indoor environments are illuminated through two light resources, through natural light and artificial light. The latter compensate for the restricted natural light that is able to enter the building and compensates the absence of natural light during night. The primary task of light in indoor environments is creating, room specific, visual comfort during usage. However, besides creating visual comfort and keeping ourselves healthy, light is also able to affect human psychology, mood and behaviour (Webb, 2006) and is even able to influence human labour productivity (Hameed, & Amjad, 2009; Maarleveld, & De Been, 2011).

The increasing amount of indoor workers is a group which earns extra attention, since they spend more than half of the time that they are awake inside, just by working. Buildings for working organisations are usually designed by architects. In my opinion, they should know how human bodies function and that human bodies need sunlight. Richard Hobday mentioned in his book *The Light Revolution: Health, Architecture, and the Sun* that "over the last 50 years the way in which buildings have been designed, and towns and cities planned, has paid little regard to the health benefits of sunlight. Much that was known on the subject has been ignored or forgotten" (Hobday, 2007, cover page). He is convinced that sun and daylight possess great qualities, not only to higher human well-being, but also increase human performance. In his opinion todays architects pay too little attention to designing with natural light and thus too little attention to the non-visual qualities that it possessions (Hobday, 2007). Personally, I recognize and admit his ideas: during my education, at Delft University of Technology, to become an architect, no tutor ever spoke about using light to improve human health or productivity, nor did a professor. The current Dutch building regulations pay little to no attention to natural light within indoor environments, they only focus on the overall illumination levels and preventing glare (Nederlands Normalisatie-instituut, 2011).

Even though there are indications that leading architects in the Modern Movement and the old Greeks and Romans used the sun and daylight as a leading them in their designs, contemporary architects do not or to a lesser extent. A lot of theories and knowledge are created and provided across the years about the necessity of sun and daylight. However, it seems that contemporary architects are not aware of these facts or even neglect it.

This thesis gives further insight as to how the sun and daylight rhythm behaves, were it consists of and how it affects human well-being. A look back in time is made, to show why former architects did use the sun and to illustrate why today's architects do not. After all is concluded why an architectural change is needed in which the relation with the sun is more important. In addition, there is also concluded why this change must be implemented now.

2. THE DAYLIGHT RHYTHM

2.1 Sunlight, skylight and daylight

Before pointing out which influences natural light has on humans, it is useful to point out what is meant by sunlight, skylight and daylight. Sunlight is the directional solar radiation that reaches the earth surface and cast the recognizable shadows. The solar radiation what is scattered through the ozone layer and atmosphere by water vapour, and by the earth's surface as well, is called skylight. Through this scattering our sky colours blue. The big difference between sunlight and skylight is that skylight does not have a direction, but creates an evenly distributed light (Hobday, 2007). By ecological approaches, skylight is known also as ambient light as the psychologist Gibson mentioned in his book *The Ecological Approach to Visual Perception* (1986). By the infinite reflecting of direct sunlight throughout the sky, he considers the sky also as a light source, because people experiences so (Gibson, 1986). However, within this thesis the physical approach will be followed.
Skylight and sunlight together are called daylight (Hobday, 2007). The quantity and quality of daylight has diurnal and seasonal fluctuations, which is called the daylight rhythm.

2.2 Divisions in daylight

Daylight is created by sun, which is located outside of our atmosphere. Solar radiation passes this barrier before it hits the surface. Due to absorption by water vapour, carbon dioxide and other atmospheric particles the original blackbody waveband is modified before it reaches our habitat. Within sunlight a distinction can be made in visual and non-visual light. The visual region is located between the blue part and the red part of sunlight, from 400 nm to 700 nm. Wavelengths longer than the red light, is called infrared (700+ nm). The wavelengths shorter than the blue light is called ultraviolet (280-400 nm). Shorter wavelengths than ultraviolet are filtered through our atmosphere and will not reach earth at all (Webb, 2006).
As mentioned before, skylight is also a part of daylight. This scattered light is evenly distributed and is coming from all directions. The amount of it depends on the thickness of the atmosphere and the amount of water vapour the atmosphere consist. Skylight is much less intensive than sunlight (Hobday, 2007), as we all experienced once when being outside. Skylight also consist visual and non-visual wavelengths, but in smaller numbers. Instead of sunlight, skylight is always there during day. When sunlight does not reach the surface, through for example a lot of clouds, skylight does. In that case, the intensity of light is lower, due to the high amount of scattering by clouds.

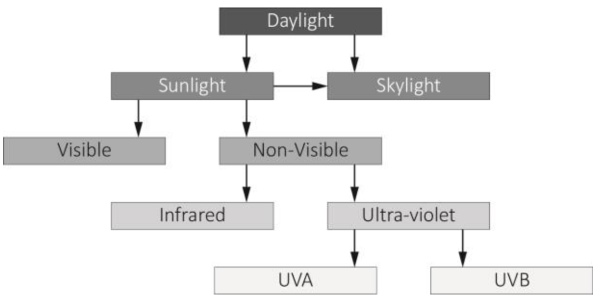

Figure 1: Scheme of divisions in daylight

2.3 Fluctuations

The level of daylight fluctuates during day between sunrise and sunset. If we disregard the amount of clouds, the intensity of daylight is at highest at the middle of the day, when the sun is at his highest. During night the level of daylight is closely to zero (the moon also gives some light). Besides daily fluctuations, the amount of daylight is also different across the year. In winter the sun rises later and sets earlier and the sun does not get as high as in summer. Thereby the intensity of daylight is lower than during summer (Hobday, 2007). The difference in length of days also depends on latitudes; from middle to high latitudes the length differences of days are larger, with its extreme at the polar circles, where sometimes the sun never rises (Webb, 2006). This phenomena is very predictable, actually nowadays there are apps for your smartphone which precisely predict the suns path according your location, like Sun Surveyor Light by Adam Ratana (2012).

Not only the intensity of the light fluctuates over the day and season, but also the waveband and thus the colour of the light does. During day, daylight consists for the biggest part of blue light. The change of colour is caused by the changing amount of moisture in the air, by the changing weather and by the angle of which sunlight has to pass the atmosphere. A more oblique angle, occurring in morning and evening, results in a longer way through the atmosphere, so more light is scattered. That's why in early morning and late evening the sky colours red and yellow; more blue light is scattered around into the sky (Hobday, 2007).

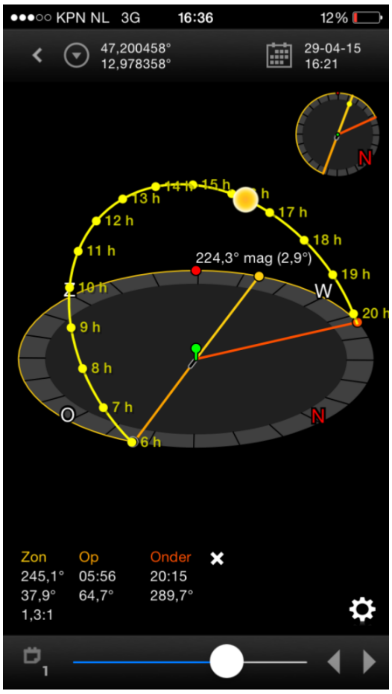

Figure 2: Precise prediction of the suns path by *Sun Surveyor Light*

2.4 Non-visual light

The non-visual part of light consist of infrared (IR) and ultraviolet (UV) light. As already noticed, the longer wavelengths (700+ nm) are IR light, this is experienced as heat. Sometimes this light is especially used as a heat producer (Webb, 2006), like a terrace heater. Besides the 40% of visible light radiated by sun (Andersen, 2014), the most other light is IR. Only about 10% of solar energy is UV light and exists of the shorter wavelengths (280-400 nm). A distinction is made between UVB and UVA. The UVB consist out of shorter wavebands as UVA does (280-315 nm against 315-400 nm). The ozone layer of our atmosphere prevents, in most cases, the shortest UVB wavebands to hit the surface (Webb, 2006).

3. HUMANS AND DAYLIGHT

3.1 From natural to artificial light

People are trying to assign solar rights in a fair and efficient way for at least two millennia (Bronin, 2009). So were the ancient Greeks and Romans aware of the importance of daylight and sun. The Romans had a legislation about right-to-sunlight (Hobday, 2007). These rights were protected by prescriptive easements, government allocations, and court decrees. The Greeks were also aware of the qualities of the sun; they actually designed their land in rigid planning schemes (Bronin, 2009). They used a strict diagonal checkerboard pattern with streets from north-west to south-east and mirrored. In this way, every house is facing south, so the sun has access to heat the houses during winter. Even though the Greeks did design solar cities for saving energy instead of preventing disease, they were aware of the qualities of sun, as well as the Romans were (Hobday, 2007).

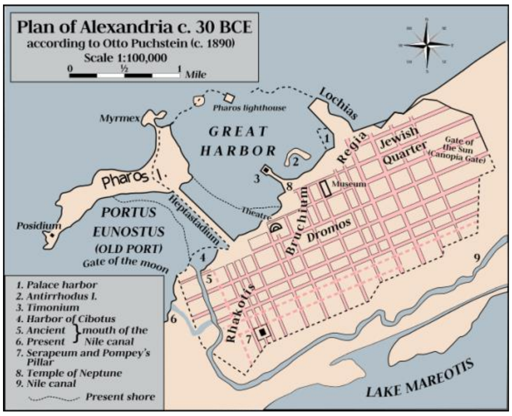

Figure 3: Diagonal checkerboard pattern of Alexandria, c. 30 BCE (Philg88, 2012)

Also the pioneers of the modern movement were aware of the qualities of the sun. So were architects as Mies van der Rohe, Alvar Aalto, Le Corbusier and others familiar with the design of solar houses. Besides gaining energy from the sun, the designs were also focused on preventing disease by giving the sun access to the indoor (Hobday, 2007). Thereby a lot of projects possess a solarium, a place for sunbathing. Le Corbusier gave the solarium of the well-known Villa Savoye (1929, Poissy) a prominent place; at the end of the grand promenade. Le Corbusier experimented with buildings oriented to the sun. In one design he made a big mistake: an overheated building, whose façade had to be redesigned to prevent the overheating again (Cité de Refuge for the Salvation Army, 1933, Paris). Later he started with the Unité d'Habitation projects. Striking is that all these five buildings (1952, Marseille; 1955, Rezé; 1957, Berlin; 1960, Briey; 1965, Firminy) are not facing south at all; at all locations, the block are oriented north-south, regardless the location. All apartments have rooms and a balcony both facing the east side as well as facing the west side. He probably fell back on the theory of the optimum for heliotherapy, whereby east-facing bedrooms are exposed to sun in the morning and west-facing living rooms receive sun in the afternoon (Denzer, 2013). In this way, the apartments are exposed to the sun during the whole day.

Figure 4: Drawing of sunpath Unité d'Habitation, Le Corbusier in 'Le poeme de l'angle droit' (1955) (Denzer, 2013)

Nowadays artificial lighting plays an increasingly larger role in the indoor environment. Since electric lighting has become available, designing sunlit buildings is driven to the background. This tendency was accelerated during the second half of the Modern Movement, when electrical lighting became cheap and easy to use (Hobday, 2007). Thereby the healing effects of daylight were lost out of sight. The use of electrical lighting has increased even more due to the broad application of LED's. Besides this LED-lighting is cheap and easy to apply, LED-lighting is also an efficient way of transforming electricity into light. And they have a long lifespan, which makes it even more attractive to use.

3.2 Circadian rhythm

The major health keepers of our bodies, the nervous system and the endocrine system (Andersen, 2014) are via our pituitary gland and the pineal gland, regulated and stimulated by light (Edwards & Torcellini, 2002). Thereby many aspects of the physiology of the human body are based on the 24-hour rhythm of daylight, this is called the circadian rhythm. Diurnal and seasonal fluctuations in the amount and colour of light are critical factors to set and maintain our 24-hour rhythm. This rhythm plays a key role in the sleep and awake pattern of humans (Andersen, 2014). The circadian rhythm is controlled by the secretion of hormones. Also for these non-visual effects, the eye is the entrance for light to enter the body. Initially scientists were convinced that the photoreceptors for this non-visual effect are the rods and cones in our eyes, which also are responsible for actually seeing the light (Webb, 2006). However other studies showed that mice without rods (Provencio, 1995 in Webb, 2006) and later mice without rods and cones (Freedman et al., 2011 in Webb, 2006), still maintain their circadian rhythm. Also visually blind (Czeisler et al., 1995 in Webb, 2006) and colour blind (Ruberg et al., 1996 in Webb, 2006) humans have working photoreceptors, so these findings imply that there is a third photoreceptor, besides the rods and cones. A later, recent, study by Berson et al. (2002) discovered the third photoreceptor; a light sensitive protein in human ganglion cells in the eye, called melanopsin. The melanopsin innervates the suprachiasmatic nuclei (SCN), located in the hypothalamus, in collaboration with the rods and cones (Webb, 2006). The function of the SCN is to let the rest of the body know which season and which time of the day it is (Hobday, 2007). Out of the SCN many signals go to parts of the nervous system, as well as to the pineal gland. Within the pineal gland high levels of melatonin is secreted during dark periods, while during light periods the melatonin secretion is suppressed. High levels of melatonin, also known as 'hormone of sleep', makes us sleepy. Webb (2006) describes also in her article that melatonin suppression is the

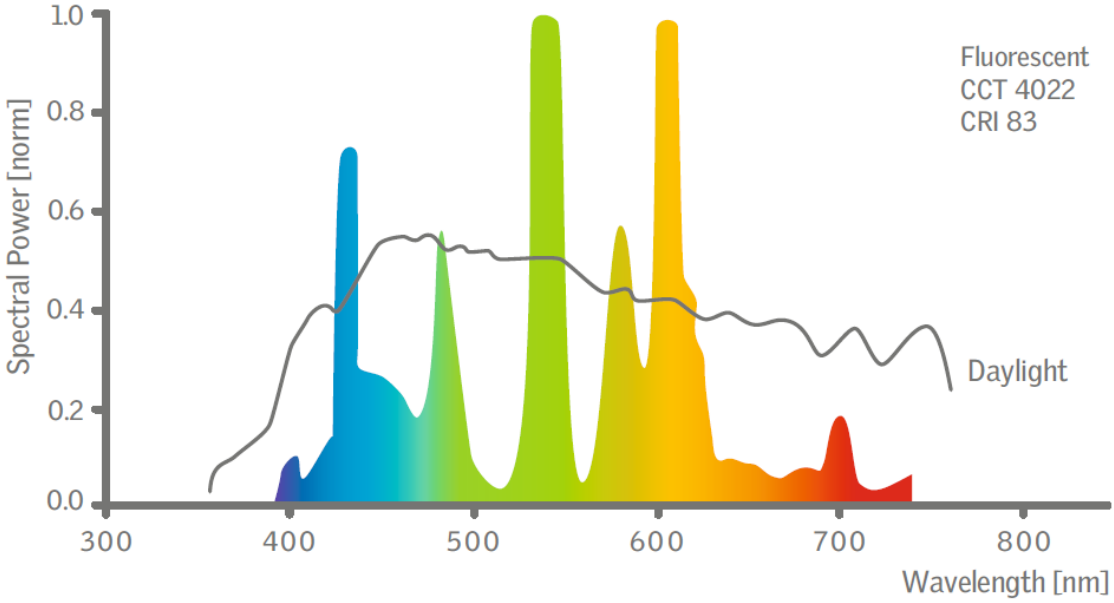

Figure 5: Spectrum of Fluorescent light in comparison to the daylight spectrum (Andersen, 2014)

most sensitive to light with a wavelength region from 446 to 488 nm, with a peak at 464 nm. This wavelength is located in the visible region of blue light (Webb, 2006). Notable is that commonly used artificial lighting, halogen and fluorescent, just radiate a small amount of these wavelengths, which do not come close to the amount that daylight consist of (Andersen, 2014; Webb, 2006). Thereby these lightings do not contain diurnal, seasonal and weather influenced fluctuations to set and maintain our circadian rhythm (Andersen, 2014). By a disturbed circadian rhythm, by for example a night working shift or a jetlag, complications in the sleeping cycle can occur and lead to sleep disruption. "Sleep disruption has been linked", as Andersen listed in *Daylight, Energy and Indoor Climate Basic Book*, "to poor cognitive functions, stress, depression, poor social interaction, metabolic and cardiovascular disease, increased susceptibility to infection – and even cancer" (Andersen, 2014). Hobday (2007) pointed out that too little or too much sleep can have a negative impact on productivity, safety and the quality of life.

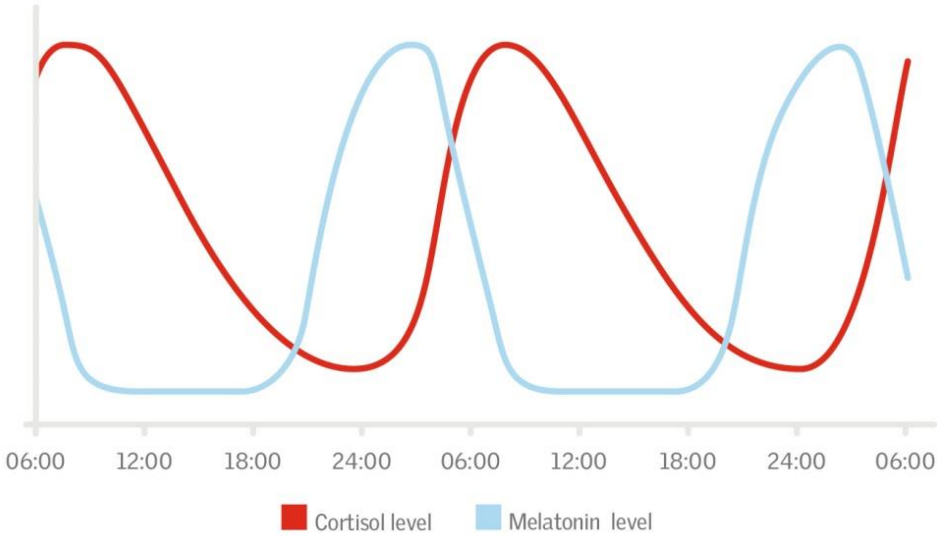

Figure 6: Graph of levels of cortisol and melatonin in a period of two days (Andersen, 2014)

The hormone cortisol is the counterpart of melatonin; the production of cortisol rises during the second half of the night and is at his top just after waking up. The cortisol level decreases during day, and is at his lowest when people should go to sleep (Wirz, 2010). Cortisol is linked to higher alertness, higher activity and more energy and stamina. These aspects are, overall seen, higher in the morning than during the night. This is can be explained, due to the fact that our ancestors had to be watchful for natural hazards during day (Circadian, 2009). Regarding the levels of cortisol, humans should perform at their best during the morning. Since the production of cortisol is dependent on our circadian rhythm, the production of cortisol is also dependent on daylight, because daylight regulates our circadian rhythm. The secretion of cortisol is also dependent on light itself, whether it is artificial or natural does not make differences (Circadian, 2009).

As mentioned before, architects of the past were once engaged with the sun. Their designs were completely focused on daylight. Notable is that during those times there was still no striking scientific evidence of the influence of daylight on the human circadian rhythm. For more than two millennia it has been clear that daylight has had a significant influence on our bodies, however only in the last decades has there been enough knowledge to support and explain this theory. The insights of Berson (2002) about the melanopsin is a real breakthrough about understanding the relation between light and our circadian rhythm. The existence of this third photoreceptor had been a missing link for a long time, but now we know that it exists and how it works. Now we know exactly how daylight influences major health keepers in our bodies, we have to apply the knowledge we have within architecture. Architects can no longer close their eyes because of a lack of knowledge, recently all the knowledge is gathered, so now it is time for architects to apply it.

3.3 Secretion of vitamin D

The sun has also influence on the secretion of the well-known vitamin D. Vitamin D is actually not a vitamin, because our body is able to produce it by itself by exposure to sunlight, while vitamins normally cannot be synthesised by our bodies itself. In contrast to the photoreceptors for our circadian rhythm, the receptors for producing vitamin D is our skin. Our skin contains high amounts of cholesterol what is converted by enzymes, to 7-dehydrocholesterol. By exposure to the sun, these molecules convert into vitamin D3 by photochemical conversion. The liver transforms this into the form of vitamin D which actually circulates in our blood, 25-hydroxyvitamin D3. Just some of these molecules pass the kidneys which converts this into 1,25-hydroxyvitamin D3, what is the biologically active form of vitamin D that possess all the beneficial healing characteristics (Hobday, 2007).
The photochemical conversion by sunlight is initiated through the wavelengths within the UVB region. Although too much exposure to these wavelengths are related to damaging our eyes and DNA, photo aging our skin and are linked to skin cancers, UVB also has a crucial role in the conversion of vitamin D. Webb (2006) listed in her article that recent studies have found that vitamin D has positive effects such as lowering blood pressure and lower the onset of autoimmune diseases, such as type 1 diabetes and multiple sclerosis. Vitamin D also has a protective effect against some cancers (e.g. of colon, breast and prostate). Thereby vitamin D is known for a long time as necessary for our calcium metabolism to keep our skeleton healthy (Webb, 2006).
Probably the most worrisome effect of a deficiency of vitamin D is Seasonal Affective Disorder (SAD). This type of depression almost always appears during the winter months, when days are short. A lack of energy, fatigue, feeling low, low levels of interest and concentration are some of the symptoms (Webb, 2006). A research of Rosen et al. (1990) shows that 0.4% to 9.7% of the total world populations might suffer from SAD. Even three times that number are having signs of the disorder, without being classified as a major depression (Andersen, 2014). Rosen et al. (1990) has also shown that at higher latitudes, where days in winter are even shorter, more people are suffering from SAD (Rosen et al., 1990). Notable is that during winter at the higher latitudes, the sun is still strong enough to prevent the symptoms of SAD, when only stay outside for just an hour in the morning (Hobday, 2007). Depressions lead to huge amounts of costs. In 2000 in England the cost due to depression were more than £9 billion, only £370 million were direct treatment costs. All the other costs, £8.1 billion, were accounted for the 109 million lost working days (Hobday, 2007). Unless it is not known how many of these costs are due to SAD, it is likely that SAD has a big share in this, since a lot of people suffer from this or have symptoms of SAD.
The Erasmus University Rotterdam analysed the amount of 25-hydroxyvitamin D in 4167 children at the age of 6 and discovered shocking facts: almost 30% of the children possess deficient or severely deficient concentrations of vitamin D. Children with an African, Asian, Turkish, or Moroccan background have higher vitamin D deficiency than Dutch or other western ethnicities; 54,5% compared to 17,6% (Voortman, Van den Hooven, Heijboer, Hofman, Jaddoe & Franco, 2015). Dark skins produce less vitamin D than white skins, because of the ethnic background; the evolutionary origin of people with dark skin is there where the sun shines more often and with a higher intensity.

Voortman et al (2015) noted also that the amount of playing outside influences the amount of vitamin D deficiency. This recent research shows us how troubling the current situation is among children and provides us also with the importance to change.

We know how vitamin D deficiency affects our well-being and that it is also influencing our psychological condition. The recent research of the Erasmus University Rotterdam has pushed us to face the facts: "Suboptimal vitamin D status is common among 6-y-old children in The Netherlands" (Voortman et al., 2015). This problem is probably not only occurring in The Netherlands but also in other western countries and probably not only children are struggling with a deficiency of vitamin D. A simple change in behaviour or designing sunlit buildings could suppress the deficiency of vitamin D, what results in saving money on treatment costs and, more important, less people feeling unwell. Now we know the facts, architects have to face this problem and have to take these discoveries into account when designing an indoor environment.

3.4 Feel-good hormones

Besides having long-lasting effects, sunlight also affects our body and mind immediately by secreting hormones which affect our mood. Sunlight secretes several endorphins, also called feel-good hormones, which makes us feel better. Besides the secretion caused by sunlight, these hormones can also be secreted by other stimuli, for example, laughing, sporting or orgasms. Endorphins give in the first place a feeling of happiness and euphoria, but endorphins are also pain suppressers. Facing the latter fact, it is not surprising at all that doctors in the first half of the twentieth century recommended sunbathing for healing (Hobday, 2007). Since several researches have shown that when less pain is experienced, the healing process is accelerated.
It goes without saying that humans are able to perform better when they are in a good mood. Also higher alertness and activity increase human performance. These aspects are regulated by endorphins and cortisol levels, which are influenced by direct sunlight and skylight. Since people spend a long time indoor, architecture has to embrace the sun again, to allow people better perform.

4. INDOOR IMPERFECTIONS

4.1 Reducing energy losses

> "The pioneers of the Modern Movement were convinced there was a direct link between town planning, housing, sunlight and health. They designed to prevent disease. Today this no longer applies. In many countries, national policies on health and the built environment have become entirely divorced, and have different aims. As far as buildings are concerned, governments seem more interested in reducing their impact on the environment than on improving the well-being of the people inside them."
> (Hobday, 2007, p. 46)

This section out of *The Light Revolution: Health, Architecture and the Sun* by Richard Hobday perfectly describes the aim of contemporary society. Our economy is focussed on energy and have lost health out of sight, at least regarding architecture and the built environment. A good example of this phenomenon is a frequently heard statement at the Faculty of Architecture located in Delft: Reduce the outer skin of a building, so there is less surface which loses energy. In terms of energy reduction this is a good thought, but in terms of health it is not: reducing the outer skin implies an increase of contiguous floor area. This means less space for windows in the façade per square meter of floor area, what mostly means less sunlit indoor environments. Werner Osterhaus also enhance this thought in *Design Guidelines for Glare-free Daylit Work Environments:*

> "While it appears to be common knowledge that building orientation, layout, floor-to-ceiling-heights, and the placement of daylight openings in the building envelope, as well as the choice of daylighting and lighting technology, have the most profound effect on the daylighting performance of the interiors, other factors such as maximising the available floor area and reducing exterior surfaces for energy reasons at times override the daylighting considerations."
> (Osterhaus, n.d., p. 3)

Another energy aspect is the poor insulated qualities of window glass compared to other insulating materials. To reduce energy it is therefore advisable to reduce glass surfaces. Actually glass surfaces enables daylight to enter buildings and is therefore of great importance to create a healthy and functional indoor environment regarding daylight. Velux (2014) made a study about daylight in deep buildings with several dimensions of windows. In case of a room (8 meters deep, 4 meters wide, 3 meters height), with windows from floor to ceiling at one side, provides only 4,5 meters in depth with sufficient

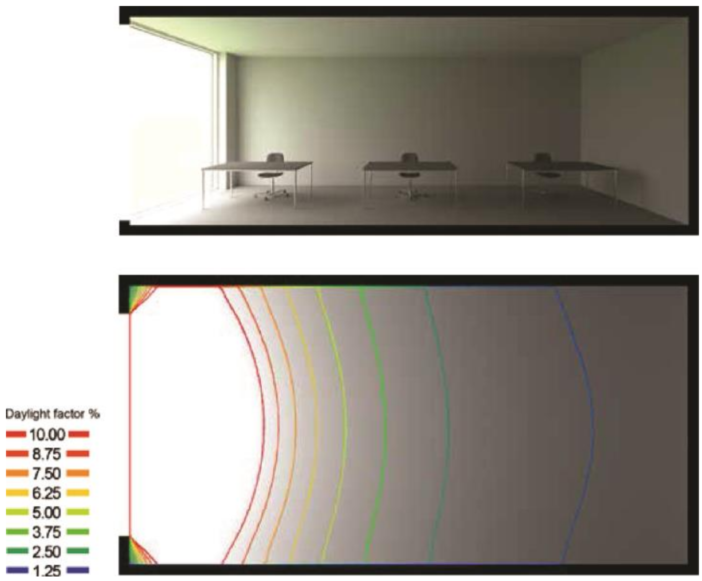

Figure 7: Daylightfactor of office (8m x 4m x 3m) (Andersen, 2014)

daylight for working. Only within the 4,5 meters from façade into the building, a Daylight Factor of 2% is reached, which is adequate for working. Worth mentioning is that Velux uses a visual light transmittance of 78% (Velux, 2014), which is eventually a bit high compared to modern insulating glass types. So out of this study, Velux concluded that only the first 4,5 meters next to a storey height window is appropriate to work. It goes without saying that certainly not everyone is working that close to a window. This assumption is confirmed by the fact that standard office buildings in the Netherlands have a prevailing work floor depth of between 12 and 20 metres; consisting of two rows of offices with a corridor in between (Van Meijel & Bouma, 2013).

4.2 The filtering window glass

Mostly due to windows natural light is able to enter buildings, thereby the amount of light is reduced by window glass as already noticed. Velux uses as a rule of thumb that 80% of the light can enter the building when double glazing is used, while 70 % can enter if triple glazing is used. By using coloured coatings this value can even lower to 20% (Andersen, 2014). Also notable is that window glass filters out UV rays (Hobday, 2007). A short look at a datasheet of triple insulating glass learned us that coatings are able to reduce the UV transmittance to about 10% or even lower, depending on the chosen type. Also the visible light is filtered and its transmittance can be reduced up to 49% by choosing the clear glass type with 3 layers (including two with a coating) of glass and 2 cavities (AGC Glass Company North America, 2014). Large surfaces of glass in a façade will provoke that the building is well sunlit and healthy regarding daylight, but by choosing the wrong glass, lots of the healing qualities of sun and daylight are filtered out. For example, due to coatings UV is filtered out of the entering sunlight, what prevents the secretion of vitamin D.
Nowadays, architects choose more often for highly insulating glass, like HR++ glass or the triple insulating glass of AGC, used in the example. This choice is, again, based on reducing energy losses and loses health issues out of sight.

4.3 Dynamic lighting

Humans invented electrical lighting to create light when the sun does not accomplish our satisfaction. Electrical lighting is a cheap and easy way and is often used to lighten badly sunlit indoor environments, since the industrial revolution. Common used electrical light does not cover the whole light spectrum as natural light does (Webb, 2006; Andersen, 2014), and does not have the fluctuations over day and year. There are actually developments in dynamic artificial lighting, which try to mimic daily fluctuations of natural light, but these are still not covering the whole spectrum of daylight (Andersen, 2014). Due to the fluctuations, the circadian rhythm of people exposed to the light are maintained. At the other side, there is still missing an essential part; the radiation of UV, which is responsible for the secretion of vitamin D. Overall seen I have to admit that dynamic lighting is a better solution than conventional artificial lighting for lighting bad sunlit areas, but it cannot be seen as a replacement for natural light, because of the spectra differences.

4.4 Consequences of indoor imperfections

As already mentioned, people spend nowadays 90% of their lives indoors (Evans, & McCoy, 1998; Andersen, 2014). Because of a lack of sunlight, low levels of feel-good hormones are secreted within our bodies. Our skins are not exposed to UV, since sun is mostly not able to enter the building in the first place and window glass is filtering UV out in the second place. This lead to low levels of vitamin

D within our bodies. The absence of this hormones and vitamin D increases the risk of SAD and other depressions. The absence of diurnal and seasonal fluctuations of daylight causes disorders to our circadian rhythm. In this way the SCN is not able to communicate to crucial organs how they have to act and react. An unstable circadian rhythm is linked to many diseases, including some forms of cancer. In short, our whole body is based on the daylight, and we, as designers, have to be aware of this. As Andersen (2014) mentioned: "The amount of daylight in our homes or workplaces can be of considerable significance – though the effective value of daylight will depend on the architectural design of a room and the facade" (Andersen, 2014, p. 28).

Since all the knowledge about the effects of light on our bodies is there, we have to take them into account during a building design. The decisions which architects have to make nowadays are mostly based on reducing or even producing energy. The healing capacities of light are driven to the background; after all we invented drugs to keep people healthy. In my opinion it is better to prevent diseases and disorders by designing healthy buildings, instead of designing energy efficient buildings and cure people later with the use of drugs. I am also wondering if the production of medicines and the treatments of people, is not more damaging to the environment as building healthy buildings is. However, health is the most important aspect of our lives. So architects have to base their decisions on this aspect first, thereafter they should focus on energy reduction or production.

4.4 Outdoor animals outdoors

Actually, the best solution to overcome the imperfections of the indoor is to spend more time outdoors. We prefer to perform the most processes, for example at work, at school or at home, indoors. In these indoor environments are conditions precisely designed for these processes. But what if architects design specific outdoor area's for some of these processes? For example if people have to read documents at work from paper or a laptop. This could be done outdoors, if the wind is not too cold and if we are protected from rain. By designing an attractive outdoor area, easy accessible from the normal workplace, architects can trigger people to spend more time outdoors. To revert to the example of Le Corbusier; he designed places to trigger people to spend more time outdoors. In the well-known Villa Savoye (1929, Poissy) the prominent positioned solarium is an attractive place for spending time outside. The two curved walls, on top of the building provide privacy and protection against wind. Unless they are facing north, the sun is still able to enter, mainly during morning and evening.

Figure 8: Roof plan of Villa Savoye, with solarium (Betablogueur, 2009)

In my opinion architects should not only focus on creating sunlit indoor environments, but they also have to pay attention to designing attractive outdoor areas. Areas where people are able to perform processes they normally perform indoors. Off course not all processes can be performed outside, but some are, and architects have to support this. Related to the example of reading documents, architects should provide outdoor areas with primary (protection against wind and rain) and secondary (electricity, access to internet, etc.) needs of users.

5. HUMAN PERFORMANCE AND DAYLIGHT

5.1 Overall productivity of organisations

Lots of people are working indoors nowadays. One could think of people who work in offices, but also of people who work for example as metallurgist in industrial buildings. Although these places are completely different, these working places all have one important aspect in common; the indoor environment is separated from outside influences, such as rain, wind and daylight. Especially the latter has major impact to our overall well-being, as pointed out in the previous chapters. Besides the well-being of employees, reaching the highest possible productivity is important for employers as well, since gains and losses are to a large extend dependent on the productivity. The overall productivity of organisations is dependent on several aspects, at one side there is productivity of machines and the production line, and at the other hand there is labour productivity. As Hameed and Amjad (2009, p. 2) defined productivity of organisations: "productivity is a ratio to measure how well an organization (or individual, industry, country) converts input resources (labor, materials, machines etc.) into goods and services". Since we learned that light is able to influence humans behaviour and well-being, the focus point in this section is labour productivity.

5.2 Labour productivity and daylight

Overall labour productivity consists of several processes on several levels in organisations. Maarleveld and De Been (2011) made a distinction between individual labour productivity, team labour productivity and organisational labour productivity. This research has shown that individual productivity is far more important than team and organisational productivity, which contributes the overall labour productivity relatively little (Maarleveld, & De Been, 2011).
Productivity of machines is easy to measure, for example by produced units per hour. Measuring labour productivity does not have these clear measuring units. Labour productivity is dependent on divergent aspects. Maarleveld & De Been (2011) mentioned, inter alia, aspects as openness, noise, lighting, temperature, layout, spatial arrangements and climate control as influencers of productivity. These technological aspects are stabbing against the psychological approach of Bakker in *De Breinwerker* (2010). Bakker points out that intrinsic characteristics of employees are more important than all technological aspects. Surely, if an employee intrinsically wants to reach a goal, the employee will work more productive than when the employee intrinsically does not care about what he or she is doing. Besides the intrinsic motivation, also the extrinsic motivation plays a role, in terms of appreciations of colleagues or the boss, rewards or an extra bonus (Bakker, 2010). However, productivity is a very broad term with lots of influencing aspects. Hameed & Amjad (2009) pointed out that the time that employees do not, or cannot, work also affects productivity. The amounts of breaks, the amount of employees leaving early and the amount of absenteeism are therefore also influencers of productivity (Hameed & Amjad, 2009). Especially the latter has a major impact, since this has the largest timespan of non-working employees. Absenteeism is directly linked to increasing cost losses by a research of Halbsleben, Whitman & Crawford (2014). Absenteeism is often caused by illness or (longstanding) disorders. In previous chapters is explained how a lack of daylight can cause (longstanding) disorders. This is for example caused by a disrupted circadian rhythm, an insufficient amount of vitamin D or due to a lack of feel-good hormones. In chapter 3 is mentioned that endorphins are able to higher concentration and enables us to perform better due to feeling more happy, which also may affect labour productivity. So besides the direct

influence of sun on our labour productivity in forms of feel-good hormones, the sun is able to influence productivity by preventing us from getting ill.

Proper daylighting is thus not only able to increase employees' well-being, but is also economical attractive for employers since it is able to reduce losses. In today's working society daylighting is therefore of invaluable worth. 100 years ago daylighting was not a large point of attention, since people were working a lot more outdoors as people nowadays do. The majority of today's population in western countries are actually working indoors. And the amount of indoor workers will even raise, according to the predictions. People spend a lot of time within these work environments, up to 8 hours a day, so work environments plays a major role in giving humans enough daylight and direct sunlight. Therefore, architects should focus on the sun when designing a work environment, then the sun is able to keep our society healthy.

5.3 Learning and daylight

Previous sections are focused on working environments specifically, but daylight affects off course not only our working performance. Due to the daylight humans are healing faster (Hobday, 2007) and also learning better (Heschong, 2002). A research by Heschong (2002) investigated the relation of daylighting to scores at a standardized test in several districts in the USA. Because normal windows in a classroom should cause complicating factors (the quality of view might influence the scores as well), the research also includes classrooms with only a skylight. In this way the pure effect of daylight on scores could be investigated. Finally Heschong concluded that "students in classrooms with the most window area or daylighting were found to have 7% to 18% higher scores on the standardized test than those with the least area or daylighting". Point of discussion is that the focus group of this research are children of the elementary school and it is still not proved that this phenomenon also is valid for adolescents. Besides that, the results are striking; daylight is able to influence the learning capabilities of humans.

6. CONCLUSION

This thesis explains how our bodies reacts to sun and daylight and how these reactions take place. A lack of exposure to sun can lead to vitamin D deficiency (Voortman, 2015; Webb, 2005) and a deficiency of feel-good hormones. A lack of daylight can also disturb the human circadian rhythm, which can have a variety of consequences; from sleep disruption to increased risk of several cancers (Webb, 2005). The knowledge about how light enters the suprachiasmatic nuclei had been a missing link for a long time. Since Berson et al. discovered melanopsin in 2002, a light sensitive protein in human ganglion cells, the mystery was solved and all the knowledge was acquired. Even though all the knowledge about daylight and how it affects human bodies is known, contemporary society is more focussed on saving energy within the built environment (Hobday, 2007; Osterhaus, n.d.). This results in buildings which are designed to reduce energy losses, which is often accomplished by keeping the sun out of the building. If this tendency continues, our society will be exposed to sun and daylight even less, with all its consequences. Especially given the fact that our society is living indoors for an increasingly longer time, this problem is growing. Nowadays we spend 90% of our lives indoors, where it is difficult to expose ourselves to direct sunlight and skylight (Evans & McCoy, 1998; Andersen, 2014). This high percentage can be explained by the fact that an increasing amount of people are working indoors. The majority of the population have jobs that oblige them to work inside. Due to proper daylighting, not only the health of workers can be improved, but also the productivity can be raised and losses can be decreased. Regarding the fact that working indoor predominates in the future as well, work environments play a major role in keeping our society healthy.

Not only does work oblige people to be indoors, but also learning, healing and living do. It is a challenging task for architects to create attractive outdoor areas where people can fulfil processes which they normally should fulfil indoors.

Striking is that famous historical architects did use the sun as a main focus point during designs. Even the old Greeks and Romans did. A little information about how the sun affects human bodies was known, but definitely not as much as it is nowadays. It also was less important to design sunlit buildings, because people worked and lived more outdoors than nowadays. Energy consumption was no hot item at that moment, so they were able to use glass a lot. The designs of the great architects from the beginning of the 20th century are well sunlit buildings, which allow the sun to reach our bodies. In this way the healing properties of the sun are able to reach human bodies, in contrast to most buildings architects are designing nowadays.

Thereby inventions have pushed the necessity of designing with the sun even more to the background. Artificial light is a cheap and easy replacement for creating visual comfort. Medicines and drugs are a replacement for the natural secretion of some vitamins and hormones. Though, not all qualities of the sun are replaceable yet.

Considering our society is conducted indoors, it is time for architects to change their point of view regarding the sun. The sun has to be the central focus during designing, just like the architects in the past did. Only when we embrace the sun again is it possible to let outdoor animals work and live in indoor environment in a proper and healthy way.

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