Man's lighting needs in relation to his origin.

Or: Man's evolution to his current light needs and light acceptance.

Modern man evolved some 150,000 years ago around the equator in Africa, where they lived for centuries in almost constant light conditions. The sun would rise in the morning, preceded by a brief twilight period, and it would set 12 hours later, also followed by a brief twilight period, 365 days per year. At that latitude, the number of daylight hours is the same throughout the year (Figure 1). There are changes in daylight throughout the day in regard to light level and colour temperature, but this is a daily recurring pattern, with light levels rising steadily together with colour temperature up to midday and subsequently decreasing up to sunset. The evening light is warm and predominantly in the red side of the colour spectrum.

Natural sunlight was used for daily functioning and survival. The rising sun would wake people up and during the day the food required was gathered and eaten. People made shelters for themselves, beat each other's brains in, take care of their offspring, while at night they would rest. Sometimes the day could be extended with pale moonlight or a little fire. And that was how life was. Man was living according to the natural rhythm of light and darkness, which is deeply embedded in our genes. Serious artificial light only entered our lives around a century ago. For the few generations that grew up with some sort of artificial light, this may be the most normal and natural thing, but seen in the context of the evolution of modern man, this relatively short period is absolutely negligible.

Around 12,000 years ago, humans started to roam the earth and ended up in areas with a totally different natural light situation. Northern Europe for example has almost 24 hours of sunlight in summer but hardly any daylight in winter (Figure 1 and 2). In the thousands of years humans have been living in these northern regions, they still haven't grown used to these different light conditions. There is too much daylight in summer and in winter there is too little in relation to our expectations regarding natural light. The 24 hour rhythm of the human biological clock is directly linked to light expectations. When actual light levels do not match this expectation it can cause problems. The light around the equator seems to be the light we feel most comfortable with. As this has not changed in 12,000 years, it is most unlikely that the next millennia will provide a different picture. If we want to provide good artificial light, we will therefore have to take a good look at the light conditions at the time modern humans evolved. In this article we will call this the "primeval light".

Daylight that differs significantly from the primeval light.

If changes in daylight gradually occur according to the changes of season and are not too extreme, most people will not have too many problems with it. They can handle the lengthening of days towards summer and the shortening of days towards winter. And of course we have aids such as curtains and artificial light. But there is also a large group of people that have problems with these changes in light. That can cause insomnia in summer and depression in winter. But when there are sudden changes in our circadian rhythm, we will see problems in large sections of the population. We notice this when we experience difficulties travelling across several time-zones within a short timeframe, a phenomenon we call "jetlag". We notice the same process when people are forced to change their circadian cycles within a time zone, such as working night shifts. According to standards, we also need a specific amount of light during our night shift to be able to carry out certain tasks. That amount of light however is absolutely not in tune with our expectations for that time of day. And that causes problems.

Figures 1, 2 and 3 show diagrams with respectively primeval light and the light situations in summer and winter in northern regions. The two lines give the approximate range of light that will occur under different weather conditions.

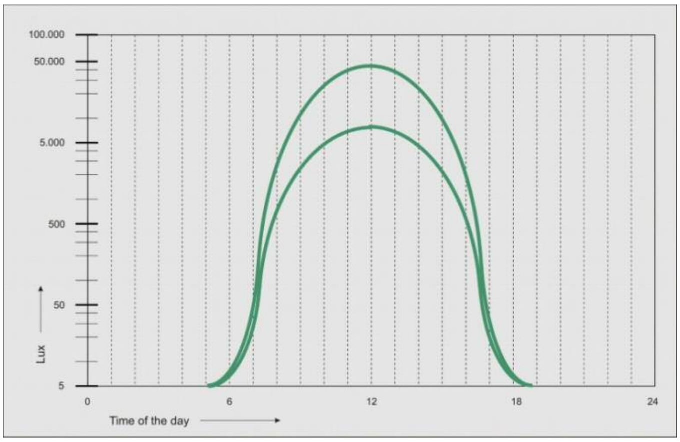

Figure 1. Daylight around the equator: 365 days per year, no difference between summer and winter in regard to light / dark cycles. In this article I refer to this light as the "primeval light". This graphic presents a diagram of the lighting intensity during the day (depending on the weather conditions). The two lines show approximately the differences that may occur due to weather conditions.

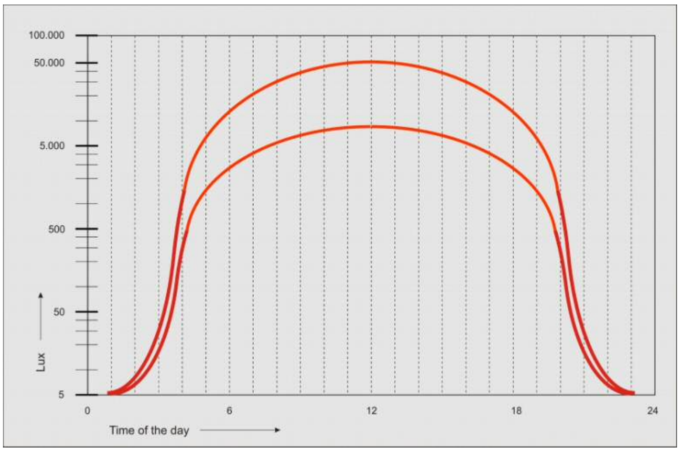

Figure 2. Daylight in northern regions at the end of June.

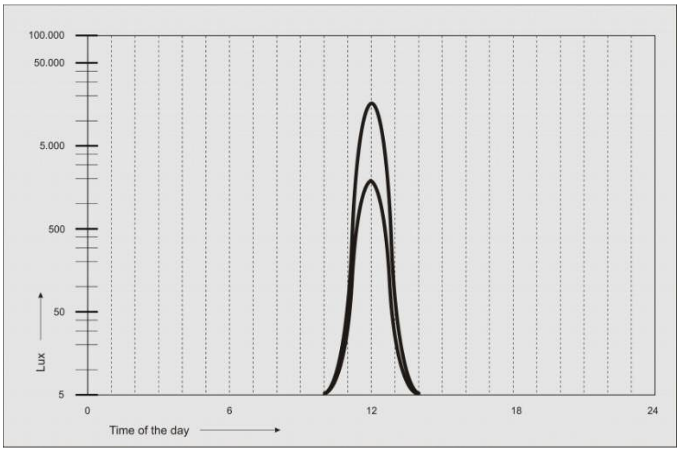

Figure 3. Daylight in northern regions at the end of December.

The closer we get to the geographical poles, the larger the differences in daylight per season. Above the Arctic Circle the sun does not set on the longest day of the year (Figure 2), and does not rise on the shortest day (Figure 3).

Projecting the primeval light onto the winter light in the north reveals two large problem areas (Figure 4). The shaded areas indicate where conflicts may occur. The available daylight only provides the light we need to feel comfortable for a very short part of the day, and sometimes there may even by hardly any light at all, depending on the weather conditions. This can result in "winter depressions".

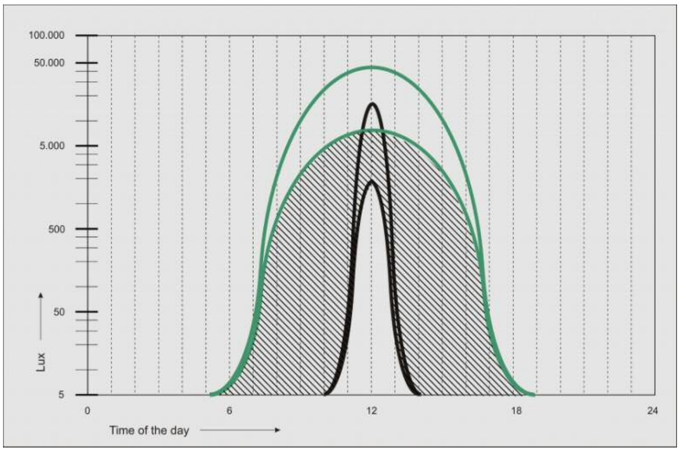

Figure 4: Graph showing "primeval light" (green) projected onto the daylight (black) in winter in northern regions.

When we project the graphs of the primeval light onto the daylight in summer in northern regions (Figure 5), we notice two conflicting areas. We address the shaded area on the left by using curtains that keep the daylight out in the morning hours and thus prevent us from waking up too early. The shaded part on the right usually causes few problems; actually, we rather enjoy the long summer nights. The natural light steadily loses its strength, becomes warmer in colour and as such fits our natural lighting needs. The day is extended with a type of light that is warm and weak, comparable to a small fire. However, we don't want this to go too far, as we prefer it to be dark when we go to sleep and we again draw the curtains.

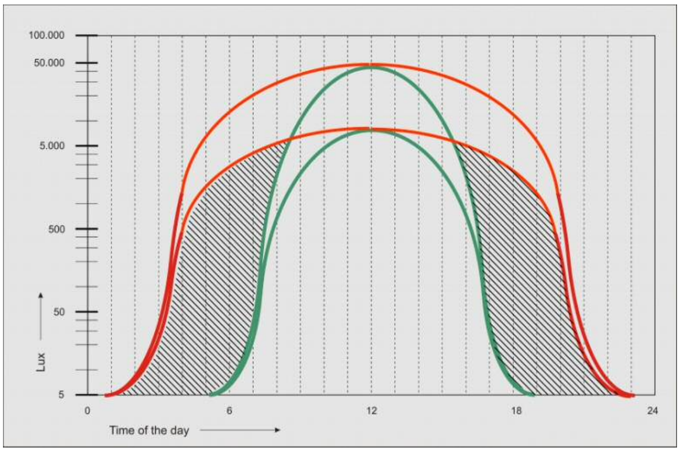

Figure 5: "primeval light" curve (green) combined with the summer daylight curve (red) in northern regions.

As the primeval light is probably or possibly the basis for our lighting needs, maybe it is time to draw the conclusion that this light should be a very important source for creating a functional light design instead of just maintaining current standards. The focus here should be on people. In other words: maybe the standards don't apply as they are based on the amount of light people need to carry out certain tasks. That does not seem right. The correct light is a combination of the functional light required together with man's current biological rhythm. If we stick to this rule, we shall see that the amount of functional light will often conflict with man's natural lighting needs at that time. The correct level of light cannot be provided at that time. The final conclusion could be that most people are for example not suited to carry out most types of night work, but that is common sense, I think. Good light design will meet human needs at any time of day and is therefore by definition not static but adjusts to, or is adjusted by the time of day.

Colour temperature in relation to light intensity

In addition to light intensity, the colour temperature is an important feature of light in relation to the influence it has on humans. The Kruithof curve (Figure 6) from 1941 indicates the relationship between light intensity (lux) and colour temperature (Kelvin) people generally experience as comfortable. We highly appreciate the warm light colour from a small wood fire providing little light. Full sunlight during the day has a colder lighting pattern. People experience a low light level combined with cold light as unpleasant, just think of the first generation LED lights with their cold, blue light. The Kruithof curve shows which combinations of light intensity and colour temperature are experienced as pleasant, but it does not take the biological time into account. A light level of 10,000 Lux with a colour temperature of 5,000 K is fine light, but not in the middle of the biological night. Therefor the Kruithof curve should be combined with the factor (biological) time. I'll come back to that at the end of this article. One remark according to Kruithof; when we look at the curve, we notice that the light of the moon, with a colour temperature of around 4000 K combined with a very low light level does not fall within Kruithof's "pleasant" area, while we experience this light as very pleasant at night.

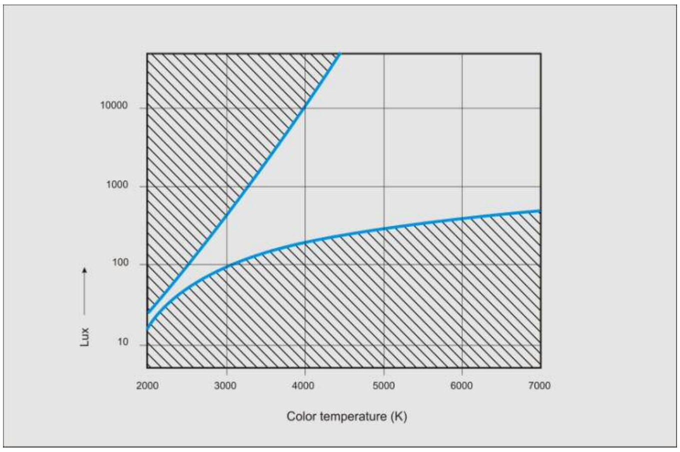

Figure 6: The Kruithof curve: The unshaded part marks the comfort zone.

Artificial light in addition to the primeval light.

Extending the day with incandescent light bulbs is in line with the natural light expectation at that time. This light bulb offers us warm light that even gets softer when we dim the light. This light can be compared to the light of a fireplace, a type of artificial light modern man has always been familiar with. The shaded section in Figure 7 marks the theoretical problem area. In practice this addition to natural light does not create any problems as the light offered is in line with the natural light at the time of sunset and the light of a flame. Light bulbs and candles extend the time between the transition from day to night in a natural way.

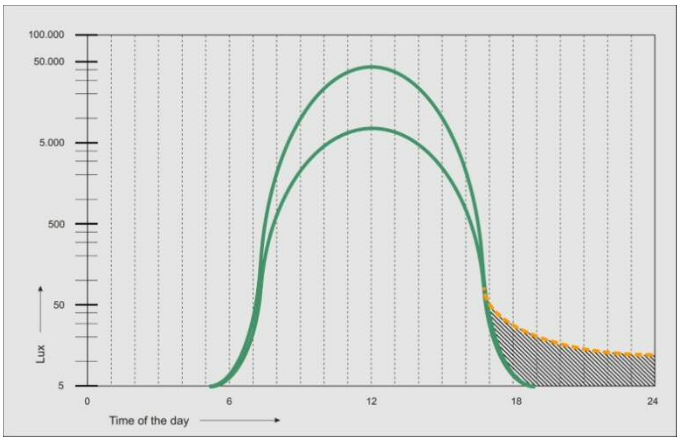

Figure 7: "primeval light" plus a low level artificial light at night

During the day fluorescent light is useful as a possible addition to, or replacement of, daylight, but at the level of 500 lux it will definitely differ substantially from our lighting expectations later during the day. When dimming a fluorescent light source, the colour temperature will not change. A substantially dimmed fluorescent light will therefore not fall within the margins of the Kruithof curve

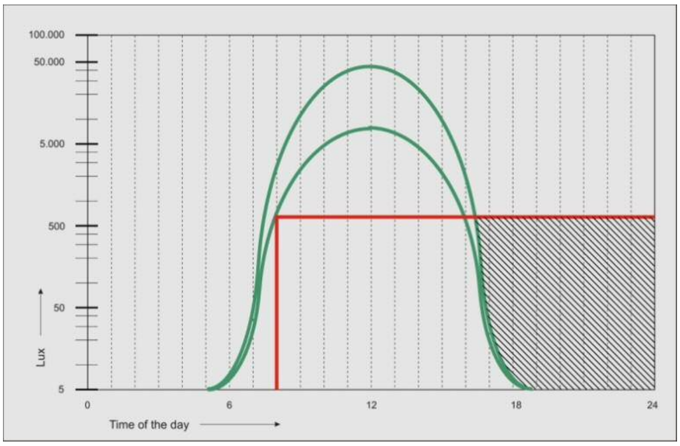

Figure 8: The "primeval light" graphic combined with fluorescent artificial work light: the shaded part clearly indicates where problems occur. During the day the situation is fine with 500 lux of fluorescent light but at night the nature of the light differs too much from our light expectations.

The incandescent light bulb was developed as a universal light source, and the same applies to fluorescent light sources. The properties of both light sources differ substantially in technological terms, but in developing them this was not an aim in itself. In practice, both light sources actually complement one another very well. Fluorescent lights are very well suited to supplement the lack or shortage of natural light during the day; they provide a lot of light together with a colour temperature of your choice. In offices and factories, a colour temperature of 3000 or 4000 K is most popular. That is warmer than the light of the sun, but colder than light bulbs. Fluorescent light is not very well suited to extend the day into the night; light bulbs would be the preferred choice here. Nobody complains about fluorescent light at the office during the day, but at the same time nobody will have this as their preferred light source at home at night. Until now we mainly used light bulbs as our light source at night and in winter, when we want to add some atmosphere, we often use candles. Both candles and light bulbs provide a light that suits our light expectations at that time of day. A low light level combined with a low colour temperature, with red being the dominant colour in the spectrum. A fireplace definitely indicates a return to primeval times. It provides warmth and light but neither in a very efficient manner. Apparently we don't specifically want a fireplace for warmth or for light. Fluorescent light or turning up the central heating are much more efficient in this respect. It looks like we are still seeking our fireplace from 150,000 years ago; the fireplace is the centre of attention in the room and we are all looking at it. A specific kind of light apparently creates the atmosphere we are looking for. On the other hand, nobody is trying to create an atmosphere at the office during the day by lighting a candle. Apparently, the combination of light and the time of day decide whether or not we like a specific light, or at least accept it.

Light intensity and light colour are important properties of artificial light, but there is more. There are fluorescent lights available that offer light with the same light stream and colour temperature as a light bulb. As mentioned above, consumers still don't consider these light sources as being equal to the light bulb. If we take a look at the spectral composition of the light, we see that the light bulb has a very different structure to fluorescent light and apparently we do experience this difference. LED lamps also have a different spectral composition to the light bulb. The spectral composition of a light source defines the colour rendering (CRI), this index indicates how 15 reference colours are rendered on average. This index is important; the higher the CRI, the better the colours are rendered. The CRI of a incandescent light bulb is 100. Still, colour temperature and colour rendering don't provide any certainty about the usefulness and lighting quality of the light. Two different light sources with an equal light stream, an equal colour temperature and an equal colour rendering index (as long the CRI is not 100) can still provide a very different light.

The incandescent light bulb, which also includes the halogen lamp is due to legislation on its last legs. The energy-saving electric bulb, which has been around since the 80th from the last century, and the recently introduced LED lamp were placed on the market as its replacement. The energy-saving electric bulb I talk about is the compact fluorescent light bulb. Still we cannot say that this energy-saving electric bulb has replaced the incandescent light bulb over these past decades. That in itself is remarkable. When consumers still had a choice, they apparently chose the old light bulb, especially in places where a warm atmosphere was required, despite the fact that the energy-saving electric bulb is much cheaper to use than the original bulb. When it comes to energy saving, we do invest in double glazing and other types of insulation or in the installation of solar panels, but apparently we do not invest in cheaper artificial light. Is this because we do not like the light of energy-saving electric bulbs and we don't mind spending a bit more on energy to be able to continue using the incandescent light bulb? It does indeed look like we don't mind paying a bit more for good lighting. That option has now disappeared with the ban on the light bulb. LED lamps are improving but technically speaking, they are still not equivalent to the light bulb.

Artificial light in the near future

It looks like LED will become a very important, if not the most important light source over the coming decades. Existing light sources such as the light bulb (replacement of which is compulsory) gas-discharge lamps such as fluorescent lamps, but also other sources like sodium lamps will likely be replaced by LEDs. With regard to the light bulb; these days many retrofit LED lamps are placed on the market, and these lamps are designed to fit into fittings for light bulbs we already have in the home. Some of these are reasonably good, but others are sub-standard in terms of imitating a light bulb. We still consider many of these retrofits as energy-saving light, the type of light that has not been able to get a strong foothold in the market over the past years, which shows our dissatisfaction with this type of light.

The new LED-technology however, offers us many opportunities. Dimming a light bulb makes the lighting warmer, but this is not the case for an LED. However, we can create this effect though by mixing several colours of LEDs within one lamp. The light bulbs and the different types of gas-discharge lamps that will be replaced each have their own specific properties and in creating a lighting design, designers look at those properties and for each design they choose from the available light sources. The low pressure sodium lamp has a very bad colour rendering, but due to its 1800 K colour temperature, can work very well at night as façade lighting in historic cities, while a much colder standard LED lamp would be out of place here. Fortunately LEDs allow us to create many types of light, it is up to the industry to offer designers the light fittings and light sources required to create optimal lighting designs. Ultimately, it is important that we can use good artificial light which makes it possible to see things clearly while at the same time answering our light expectations. Both in- and outdoors, both during the day and during the night, both in summer and in winter, both in the city and in the country, and in museums, offices, factories, theatres and at home.

(Artificial) light; the combination of luminous properties and the biological clock.

As mentioned before, man's light requirements and acceptance not only depend on his current activities or the tasks needed to be carried out, but also on his biological clock. The amount of light required to execute a specific task is laid down in standards and we can assume that practice has created those standards. The acceptance of light is, as stated above, very much related to mans internal biological clock. According to the Kruithof curve, the lighting levels match certain colour temperatures of the light. According to the "evolution light acceptance theory" the right light is determent by the biological clock. The graph below is a first attempt to combine the principle of the Kruithof curve with the biological time, while not focussing too much on absolute values. The shaded sections mark the unpleasant light according to Kruithof. When projecting the graphs of the primeval, the summer, and the winter light we see where the natural light in the summer and winter graphs fall into the unpleasant area, while the primeval graph stays within the comfort zone of Kruithof. This seems to correspond with the earlier presumptions and findings in this article.

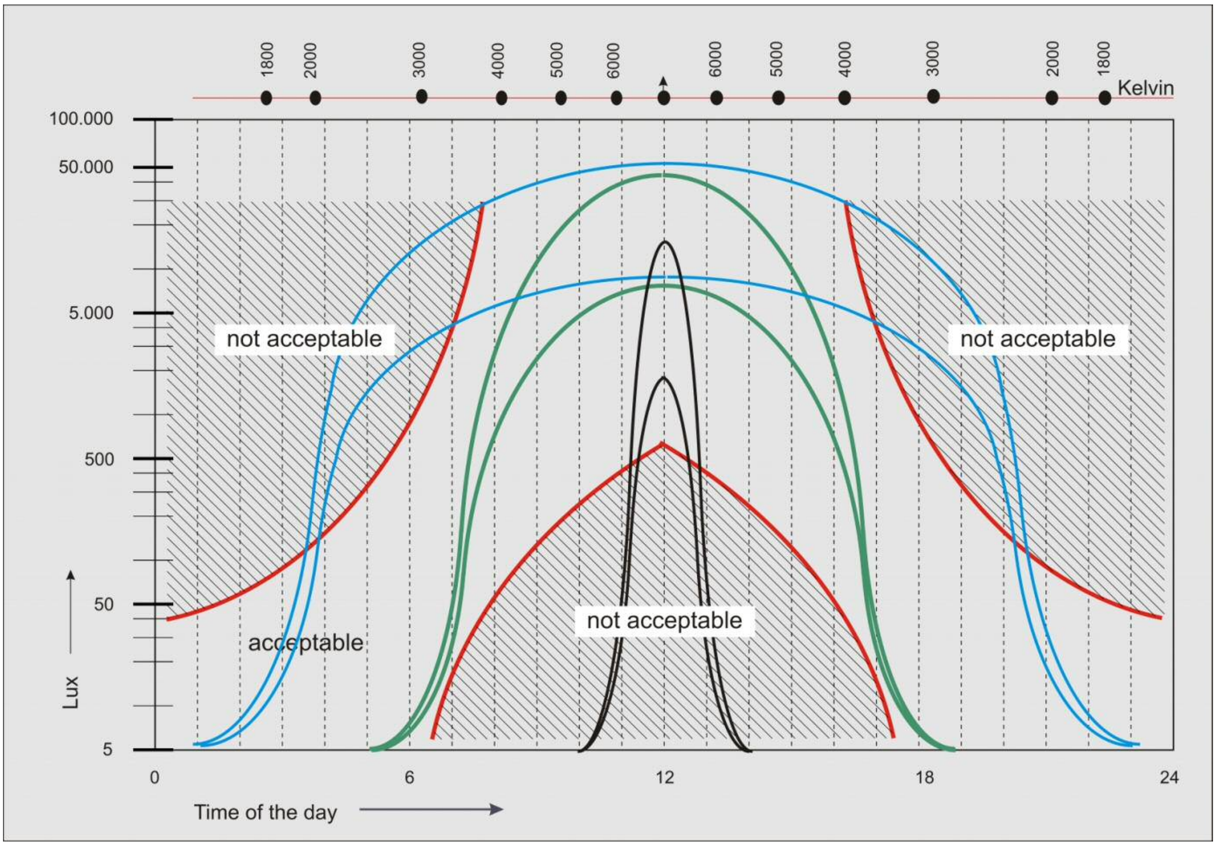

Figure 9: Kruithof curve (red) combined with biological time and primeval light (green), summer (blue) and winter (black)

Rob van Beek, June 2014