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# **Light and colors – an interaction between daylight and artificial light**

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## **ABSTRACT**

Often a dichotomy between daylight and artificial light is observed, often artificial lighting replaces daylight. In Denmark daylight is characterized partly by being "borrowed" half of the year, partly by having long transitions periods between the light and the dark (nautical and civil twilight). For these reasons artificial lighting does not complement daylight but provides, coupled with the daylight, the total lighting in the indoor environment. Electric lighting is therefore - in a complex interaction with the daylight - of great importance for both our lighting and our wellbeing.

Studying artificial lighting without studying daylight seem to be a common procedure of the practice of today in Denmark and other parts of the industrialized world. As a consequence of this artificial lighting suffers from a quantifying tyranny, a tyranny where the quality of light is measured in quantities. This procedure does not provide a good and sustainable support in the future for the human vision and wellbeing.

Keywords: Daylight, artificial light, ecology, energy, wellbeing

## **1. INTRODUCTION**

Today we face the challenge of future reductions in our consumption of energy, this challenge makes it interesting to look at how we best possible use the artificial lighting. How we optimize the interaction between daylight and the artificial lighting is in this context important for both the perceived brightness and for our general wellbeing. The interaction of spaces and forms with light is essential for the experience of light and can actually help reducing the amount of electric lighting used – form articulating and manipulating both daylight and artificial light. This paper will study architecture as a function of light, the light is thus not only supplied the architecture, but part of it.

This study will reveal two major factors of importance; on one hand the regional differences and on the other hand an insight in our vision and the influence of our vision on what is being seen. Linking these two factors together, this article will give an answer to this fundamental question: Why do Scandinavian

countries prefer a warmer artificial light while southern countries use a cooler lighting? A study of great importance to the aesthetics and colors in architecture, showing that arts and architecture are not absolute, global phenomena, but more likely to be considered regional phenomena, the Mona Lisa in Paris not being the same as the Mona Lisa in Copenhagen. In this paper I will argue against the existing dislocation of light and the separation of light from form in order to create a more human-ecological point of departure for the future architecture in Scandinavia.

## 2. BEFORE GROUND ZERO

The exclusion of the environment dates back to Adolf Loos' *Ornament and Crime* and his 30 years struggle against the eclecticism ending up in Hannes Meyers affect-free architecture in the late 1920s. The fight against the ornament originated from a consensus of fighting for a better world - if only the symbol of the evil - the ornament - was exterminated, all evil would perish with it and a new international architecture would emerge. An architecture which in itself would be good if only it denied using ornament.

Of course this didn't happen, instead we got clean, white rooms stripped of all reflecting and shaping surfaces, an empty holster to be filled with light as the only decoration. But light without form is the same as form without light. So we need to relocate the light and continue this debate and question this development in order to bring us upon a more sustainable course where interplay between daylight and electrical light, between light and form is examined further.

However this functional approach towards light has not always been the norm - actually it is rather recent exception more than the rule - and is derived out of the post First World War's implement of technology in our build environment. With electrical lighting dating only 130 years back, its actual influence on our society and on our way of living and thinking is gigantic and incomprehensible. Before this *revolution of the light*, the sufficient amount of light was measured in candles (candelas) and the perception of brightness was therefore not only a result of the amounts of light, but also on the architectural form, ornament, e.g. on doorways and staircases. One could say that this was a culture where light and form were closely connected. E.g. in the "lysedug" a white tablecloth reflecting a single candlelight out into the entire room, or the ornamented stairway-steps lighting up the darkened steps, reducing the possibilities of falling accidents. Or the stucco shaping of the edges of a room, framing the room. This *location* of the light in the build environment shall be seen in contrast to the *dislocation* of the light mentioned earlier, and the subsequent method of dealing with lux shall be seen in contrast to dealing with candela/sqm or the *perceived brightness* of the surfaces in the room.

From an ecological point of departure, we need to reduce our energy consumption - in Denmark by 4% - which is a new experience. Since we started, we have only used more and more energy each year. Lighting takes up to 20% of our total use of electricity, to challenge our way of using the light is in this sense quite necessary if we look into the future. But how do we do this without reducing the wellbeing of the occupants of the build environment?

In Europe the 130 year old incandescent bulb is being replaced with more energy saving light sources like LED. This change has an impact on our perception of light and indicates that light is a changeable size in our build environment. In Denmark we have had discussions about the EU charter and the end of the incandescent light. With a better light and color rendering it seems strange to take it out of the market -

exchanging it with a poorer light. However these discussions have only taken place in Scandinavia – not in the southern parts of Europe. This fundamental change in lighting therefore also implies a fundamental difference in our perception of light and in our lighting culture.

Much of the explanation to this question is found in two factors:

1) Our vision, as described there seem to be a tendency towards using more and more light in our culture, but taken in to consideration that the eye can only see up to 20 different lighting intensities at a time, it is possible to construct a daylight-artificial light environment where these 20 levels are not exceeded, meaning that the artificial light responds to a given daylight at any time.

2) The geographical latitude, daylight being the background determinant for the *experienced brightness* of the artificial light. Perceived brightness of a room is a complex matter of interaction between daylight and artificial lighting. Again this speaks against any dislocation of the light. Light being related to the daylight of a region, located in a room – not dislocated. This supports the idea that we can abandon the *absolute tyranny* of Lux and instead work with a more *relative, perceived brightness*.

Often the dichotomy between daylight and artificial light relates to another dichotomy: Nature contra technology. Sigfried Giedion traces this dichotomy back to Rousseau's time. With the rising industrialization in the 18<sup>th</sup> century the contradiction between nature and culture is established – and with culture being more and more based on technology – this contradiction today seems more rather to be one between nature and technology. Modern architecture developed after the 1. World war - as a result of social and political revolutions – and driven by technological and engineering developments of new cheap building materials such as steel, glass and machinery. This results in a new way of dealing with daylight. The Crystal Palace by Joseph Paxton and the Great Exhibition of 1851 in London are some of the earliest examples of a new architecture of glass and light. This creating a new aesthetic of openness, light and a healthy and clean physical environment. This healthy and democratic architecture has played a major role in the 20<sup>th</sup> century architecture, bringing light into the buildings – and as we shall later see, forcing a new way of articulating the light – building deeper, with lower room-heights and using UV-filtered and colored glass to protect against overheating, accentuating the use of another kind of light – namely the electrical light:

Until the end of the 19<sup>th</sup> century no efficient artificial lighting was available, the build environment relied upon the natural existing daylight and light from fire, petroleum, etc. In 1879 Thomas Alvin Edison patents the incandescent bulb and starts a network of power-suppliers for electricity worldwide. Making it possible to bring a soot-free, safe and healthy lightsource into the buildings. Developing fast, electrical lighting and illumination becomes one of the main attractions in the Fin de Siècle architecture. Artificial lighting plays a major role in the industrialization, creating an improved visual environment, so to say “prolonging the day”. Perhaps electric lighting expands so quickly, because it is one of the founding stones of the industrialization. There is no doubt that it has an enormous impact on our productivity and on both our physical and psychological development and behavior – making it possible to build larger buildings and creating longer working hours. However this success of the electrical lighting has not only had beneficial effects, it has also drawbacks. One of these drawbacks is the neglect of the use of daylight – along with a neglect of nature itself. This may seem odd, daylight being considered a very precious factor in our build

environment in Scandinavia, in fact in all modernist architecture. But it is none the less rather a rule than the exception that the light in modernistic buildings is being transported into the room without any articulation, reflection and optical efficiency. Let me elaborate on this: Light is in itself invisible to the eye, it is only reflected light that is visible to the eye – and therefore only the meeting of light and form that is determining the optical efficiency. Glass and electric lighting in itself is not enough to provide an experience of brightness. Instead what we have is *a feeling* of brightness and of transparency – based on the presence of so much glass - but actually it provides reduced optical conditions for the eye: As someone recently said to me: *“During the day I shield the daylight, daylight annoys me, especially when I look direct at the windows...”* Glare from the windows cause a feeling of a dim and gloomy lighting in the daytime, all focus seem to be outside of the building, not inside. Much of the present architecture today is like this, squeezed and concentrated – often located on expensive square meters - with many floors. But of what help are all the glass facades when a low room height or a deep-plan building is reducing the natural skylight and the amount of daylight in the room?

Walking in to an average deep-plan office, you have curtain-wall glass on the façade providing a large view, reducing the feeling of a border between indoor-outdoor. However well planned and beautiful articulated this curtain-wall glass provides only little reflection and articulation of the daylight inside the building. Look at the reflecting surfaces adjacent to the glass: Carpets often dark for cleaning purpose, no details around the windows no windowsills. Actually the sills are often dark so that You focus on the view outside – framed by the window. Was it not for the electrical light, it would be an unpleasant experience working in this room, contrast between daylight and darkness being too large, seeing only silhouettes of persons in the room, feeling a gloomy atmosphere.

In this way the electrical lighting causes a negligence of daylight. The electric lighting being the excuse for building deeper room-depths with lower room-heights and lower daylight factors. Leaving the electric light on all day. However it was not always like this, ventilation along with electrical lights – and medicine - has been the driving power for reducing this room-height to the minimum of 2.5 m today. With modernist architecture engaging with technology since the 1920-30 both ventilation and electrical lighting became a common mechanization of the building, replacing the earlier tall - but expensive - 3.0 m ceiling heights, and reducing the window-height. The window loosing the original meaning of the word: *wind* and *ow* - wind and eye - fresh air and light.

From 1930 – 1950 almost 95% of all electricity in Denmark was used for lighting<sup>1</sup>. At this time there was a limited access to electricity and electricity was quite expensive. From the 50s and up the power-supply all in all were improved and the electricity costs were stepwise reduced. Hence a big leap is observed from the early '60s where both the use of electricity and the available electric equipment doubles within a short period of 5 years. The following reductions in electricity costs only accelerated the use of more electricity in this period and very symptomatic for this change is the exceeding use of artificial lighting in the buildings. In Denmark a final step further away from nature and natural daylight is taken in 1977 building legislation (BR77). Due to the energy crisis the window area is reduced to 15% of the wall-area. This means that heating energy is saved, but more electrical lighting is required. In reality making us independent of the daylight and thereby creating a whole new building-culture in Denmark - this being a *Ground Zero* for the lighting in Denmark.

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<sup>1</sup> Source: ELFORSK, *“Boligers elforbrugsfordeling på slutanvendelsesgrupper 1946 – 2030”*

So, all in all light seem to be a very changeable size. Causing a problem seem to be that light, being an immaterial building stone in our built environment, takes a very liquid shape in our design-vocabulary. It has an invisible material – photons – takes no specific form in itself and is articulated through the meeting with form. Therefore, since form is the major theme for the aesthetics up until now, giving form to light is a complex and challenging task and reducing it to Lux and measurable numbers only an escape from facing the real *experienced light*. In this way light seem to suffer from what can be called the dichotomy between *the aesthetics of the objects versus the aesthetics of the perception* - as stated by Boehme. This being an aesthetic tradition since the antics and up to Kant and Adorno, where dealing with beauty merely seems to be a matter of dealing with form and proportions. Boehme sees a development in the aesthetics away from this *expression of the object* towards an *impression* - from object to subject. Light is hence not only “out there” rather inside ourselves and to deal with practice we need to look more closely at our perception, focusing more on *experienced brightness* and less on the physical Lux.

### 3. HOW TO MOVE ON FROM GROUND ZERO?

Why do we need to bring the light out of this shadow of functionalism? Because we are forced to do so. We are in a situation where we need to reduce our consumption of artificial lighting and this being said we need to use the existing daylight. In short we need to spend the light more intelligently and to look more closely at the interaction between daylight and artificial light. Not only for the sake of the environment but also for the sake of our general wellbeing when we keep in mind that we spend most of our time – up to 90% of the time - in the indoor environment.

To improve the chances of practice to create a better and more sustainable environment I see two important keystones. In the following, give a closer study of these two factors of importance; a) The vision and b) The use of regional lighting conditions.

#### a) The vision:

The eye always adjusts to a given light-level, only being able to perceive *momentary* differences in brightness. At a given time the eye can approximately distinguish up to 20 different lighting intensities. This makes seeing *a relative sense* - not *an absolute sense* – and *a momentary sense* due to the inability of the eye to remember absolute brightness and color.

That is why light is a changeable size. In the 1930s in Denmark we had a standard saying that 30 lux on the desk was sufficient for reading, today in Denmark we have 400 Lux and in Sweden 500 Lux. In future engineers plan for even more Lux – I recently heard 1.200 Lux! This is of course a result of technical development but increasing the level to 1.200 Lux will not solve a problem of our perception of brightness nor of darkness. Light being *a relative factor*. Only using more light will therefore not result in a better physical environment.

I will flesh this out by this example: In Aarhus I have passed through a certain passage hundreds of times over the years and found the existing electrical lighting in these passages, very sufficient and very well designed. But then, this autumn, when I returned an evening, a new passage-way had been build and added to the existing one prolonging it through to another building complex. The new lighting in this new corridor all of a sudden made the existing passage look gloomy and insufficiently lit, appearing completely different. Though it had not changed at all! This explains the following question: Why do our physical

lighting environment change from 30 Lux to 1.000 Lux? The answer to this question is that we don't observe this change. As the earlier city major of Copenhagen Ritt Bjerregaard, recently said at Earth Hour 2009: *We get used to the light – the more light we use the more light we need!* Now to argue to what extend a recent amount of light (lux) is, is a very interesting and complex matter. But this observation means for sure that there seem to be no absolute figures, no foundation for absolutism in terms of lighting!

The human vision is a quite complex matter. Also when it comes to distinguish color. Electrical light appears warmer on a background of daylight, daylight influencing both the experience of brightness and color. The electrical light is being like "*an artificial sunbeam*" striking the room and creating bright and warm colors on the faces we see. Therefore we use artificial light as a way of providing *artificial sunshine* in our environment. We do not use artificial light only as a mean of getting *more* light but also of getting a *warmer* light! To explain this further we need to talk about the Purkinje-effect or the relationship between the *photopic* day vision and the *scotopic* night vision. This effect describes that the relative sensations for various colors alter as the brightness values are reduced to a lower intensity. The Purkinje effect operates *only within* the eye, creating this change of color by changing from day vision to night vision. For example a reddish purple will be seen to vary from reddish purple to a more blue violet. Sensitivity to color changes along with the sensitivity towards light, from a yellow-green peak-sensitivity (555 nm) and to a more blue-green peak-sensitivity (507 nm) explaining the change of color.

This could be the answer to a very essential question: Why do we in Scandinavia tend to like a warm electrical light compared to the cool daylight? New lighting technologies like LED and CFL make it possible to change to any color you would ever like, breaking the existing restricting technology of the incandescent bulb with its characteristic warm color (K 2700). Yet we don't observe any change in preference – actually the new technology is only miming the old incandescent light color.

So why this warm color? Because it evokes a feeling of an electric "sunbeam"? As human beings we have developed a unique color vision, color vision is defined as: *The capability of discriminating lights (scattered light as well as light sources) on the basis of the spectral content of the light, even when those lights are of equal subjective brightness.* Now picture the rainbow: What you see appearing to have discrete bands of color is not a physical phenomenon, it is not out there arisen from the radiation in the sky. If you measure the radiation with a spectrophotometer, you find that the wavelength of maximum intensity as a function of the radial distance across the rainbow decreases smoothly and monotonically from the outside to the inside of the bow. The apparent discreteness is an artifact of our photo-pigments (chromophore and opsin) and the neural processing of our photoreceptors' output to our brain! The brain is creating what we see, actually what we see is not what is actually there, but what the brain interprets from the incoming signals in the eyes. The specifics of our unique color vision are still somewhat mysterious. One thing however is clear: The best known predictor of what sort of pigments will be expressed by any given animal, is the pigments expressed by its nearest living relatives. In our case this means the color red because of the color of our skin – not quite accidentally also bearing a lot of synaesthetics, or as by Goethe a *Sinnlich-Sittlich*<sup>2</sup> effect, like warm, near, erotic. To an evolutionary biologist this makes a lot of sense because we as primates developed in a our own way in the Mesozoic age, from small rodent-like mammals that were most probably nocturnal to the evolution of a unique vision - our tri-receptor color-vision. In this evolution from mammals, segments of color vision were lost, only to be regained for some species of primates, by gene-

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<sup>2</sup> J.W.Goethes Zur Farbelehre, 1810

duplication. Therefore other mammals like for example dogs and cats generally only have two-receptor color perception systems, which can distinguish blue and green—but not the reds. In other words we use three types of chemical photoreceptors with red as a *new* color. This adaptation to see reds is particularly driven by its importance for our survival, since it leads to identification of potential mating partners.

This is one good reason why we love the warm color of light – it affects our limbic system and our deepest emotional instincts because it supports our very survival and wellbeing. It is important to note that it is not as much the light itself, but more its effect on the faces we meet or the inventory we see, etc. If we combine 1) The fact that our vision actually only can see the warm colors on a background of daylight with 2) The fact that we are evolved as *creatures of light* and even more precisely as *creatures of sunshine*, we derive an explanation of why the southern culture of light is different from ours: Simply because they switch from the day vision to the night vision in a relative short period of time due to their regional environment. When adapted to the night vision the yellow light appears all of a sudden white because of the light-adaption of the eye, this goes for any color of white – cold or warm - since any color in the darkness seem “white”. Southern countries are therefore not as dependent of the warm color of light than we tend to be in Scandinavia, because they don't have the same long transitions between darkness and light, no background of daylight when they use the artificial light.

There is the explanation for why you do not find the warm light when you look at countries nearer to the Equator.

*b) The use of regional lighting conditions:*

In Europe the 130 year old incandescent bulb is being replaced with more energy saving light sources like LED. This change has an impact on our perception of light and indicates that light is a changeable size in our build environment. In Denmark we have had discussions about the EU charter and the end of the incandescent light. With a better light and color rendering it seems strange to take it out of the market – exchanging it with a poorer light. However these discussions have only taken place in Scandinavia – not in the southern parts of Europe. This fundamental change in lighting therefore also implies a fundamental difference in our perception of light and in our lighting culture, which I will try to elaborate here.

In Denmark and Scandinavia we have very long transitions between the day and the evening. While near the equator the diurnal daylight is followed by the nocturnal darkness in an extremely short period of only 15 minutes all year, we have the dusk period of approximately 4 – 7 hours of the total 24 hours cycle, with large variations during the year. This being the result of our latitude at 55<sup>th</sup> meaning that the sun has to travel a smaller distance compared to near the equator in the same span of time, e.g. 1 hour at the equator equals 1/24 of 40.000 km, while 1 hour at 55<sup>th</sup> latitude only equals approximately 1/24 of 31.500 km, this together with the decline of the axis of rotation by 23.5 degrees explains the differences in the rhythm of daylight. So duration of the twilight period between dawn and sunrise varies greatly depending on the observer's latitude, from a few minutes to many hours. At the North Pole there is little or no difference between day and night, while a big difference is observed between summer and winter. Moving to the equator reverses this fact: Little if no difference is observed between summer and winter, while a big difference is observed from day to night. In Denmark this means that electrical lighting during a large part of the day is used *on a background of daylight*.



This interaction between daylight and electric light has a great impact on the aesthetics. In practice changing both our perception of light and of color. In Scandinavia we can neither neglect the use of artificial light nor neglect the importance of sufficient daylight. We cannot just pour artificial light in the building where there is not enough daylight and we can't base the lighting on daylight alone. I believe Alvar Aalto is a good example of this pragmatic relationship between daylight and electrical light, using the daylight in his buildings *together* with the artificial light. He realized the fact that in Scandinavia we can't live with only daylight nor with only artificial light. Aalto was one of the first to break with the modernist thoughts of creating an international style, turning away from a functional international architecture. Working with the local experience as a function equally important as the more physical functions, Aalto combined daylight and artificial light, working with light-zones, and so forth. He understood that light and wellbeing is a result of daylight and artificial light working together, not just replacing each other, but reinforcing each other. Aalto designed several lighting fixtures for his buildings working with the limited amount of regional daylight as an inspiration rather than a limitation.

#### 4. CONCLUSION:

Light is not only "out there" rather it is also inside ourselves and to deal with practice we need to look more closely at our perception, focusing more on *experienced brightness* and less on the physical Lux. From a human-ecological point of departure, light is - only visible because of the dark. If everything is illuminated equally, then we might as well be blind or blinded. We find ourselves in generally surrounded by more and more artificial light. We see this today in the cities, where focus on "Dark Skies" attempts to limit the amount of artificial light we emit out into the space. This light is preventing us from seeing a starry night and neglecting the ever so poetic moonlight. We also see it when we are driving cars in full daylight with the lights on. Apparently based on the ground that this is more secure, something that can't be justified from a professional lighting point of view, perhaps in reality rather challenged as car lights provide glare and disadvantage compared to other more vulnerable road users? Have we come too far into our artificial and excited use of artificial light, so that we are incapable of even seeing it? Are we - quite literally - blinded by the light?

In order to reestablish our consumption of energy it is necessary to investigate how regional differences in light affect the vision and how the artificial lighting adapts to the regional challenge of the daylight. Our build environment is at its best a reflection of the conditions: location, orientation and activity. Light is one of the important factors revealing space, activity and focus. *Locating* the light is of great importance for this. Our part of the world is former known as *ihibitabilis*, meaning it was not able to house human beings! Electrical lighting has however, along with other new technologies, made this possible. This mechanization and the lack of sunlight and use of electrical light has created a special culture and architecture in the Northern countries – an interaction between daylight and artificial light. In the future this lack of daylight can be used as an inspiration, and is rather than a restriction, a possibility to revise our way of living and to use the electrical light in a more human-ecological way in the future, as a *response* to the existing daylight and activity. As an interaction between the regional daylight and the artificial light.