Educational Lighting and Learning Performance

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Contents

Abstract

The education of our children is one of the most important assignments for society. The facilities where education is conducted have been seen as one important part of a good educational result. In order to create good facilities the lighting situation has for long been seen as one important factor both concerning daylight and electrical lighting. The chapter describes the development of research that initially only could relate to daylight, but with the technological development within lighting was extended to the study of electrical lighting, first the incandescent bulb, then the fluorescent tubes and today the light emitting diodes (LED). The research has for a long time dealt with the visual conditions, but since the late 70s also non-visual aspects has been taken into consideration, not least after the discovery of the ipRGC in the early 21st century. The research in this area has grown very rapidly since and the knowledge has developed. However, much is still to be done. The research is only in the beginning. Results from recent research shows that there is a potential to create better lighting situations with the LED by varying intensity and spectral distribution. Furthermore the distribution of the light should be taken into consideration, and of course the visual aspect must not be neglected. We should also recognize the importance

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of daylight and how daylight and electrical light should work together for creating good lighting environments in the school.

Keywords
Ambient lighting • Daylight • Educational lighting • Nonvisual effects

The education of our children is one of the most important assignments for society. In a world where knowledge is more and more important, the educational levels of the inhabitants of a country become a competitive factor. The facilities where education is conducted have been seen as one important part of a good educational result. But what are the important features? The environment where knowledge and skills are taught has have been an area for research since the modern school system in the Western world was introduced. The communicative factor light has been one important environmental factor. Initially, the focus was on daylight, since it was the only main option. In the UK, a book on school architecture was published already in 1874. Daylight was seen as an important factor, and the advice was 20 % glazing area in relation to the floor area of the classroom. Furthermore, the daylight architecture also pleads for the indirect glare-free northern light (Robson 1877). However, during this period, the development of the electrical light was developing very fast, and in relation to this, the new environmental factor was considered. In this virgin area, the first attempts are benighted and few comments or advises have been found. Even when the development of the electrical lighting took off, the open-air school was the dominant idea during the early 1900s until the 1930s. Still the rule of thumb was the 1 to 5 ratio between floor area and window area. It was not until after the Second World War standards for classroom lighting were formed. The levels started at 100 lux in the 1950s, and in the 1970s, the lighting level on the working plane should be 200 lux in the UK. The lighting levels varied for different countries. For example, in the USA, the recommendations were set to 538 lux for regular class work and 1076 lux for instructions at the chalkboard during the 1980s.

Together with the development of the fluorescent tubes and the increase of their quality, there was a trend in classroom design toward windowless classrooms especially in the USA during the 1960s. From an environmental comfort point of view, the possibility to control the environment was essential. From a pedagogical point of view, some theorists even suggested that windows may distract students' attention. However, empirical studies showed that the environment was perceived as less positive than environments with windows among both students and teachers. The scholastic achievement could be kept, but the level of absenteeism was higher in classrooms without windows (Edwards and Torcellini 2002). Today, a revised view has finalized this discussion. For example, Tikkanen (1979) found that the incidence of eye problem was lower when having a normal side-view window in comparison with skylights. Today, we also know that the view of the outside world has an importance for the general well-being as shown by among others Ulrich, already in 1984. Finally, today, the impact of the nonvisual effects of light has been an integrated part of the research on light and lighting, something we will return to.

As shown above, the main focus has been on the visual aspects of light. However, knowledge about nonvisual effects of light has since the 1970s become an important part of the lighting design. Concerning the impact of daylight and artificial lighting, a study was conducted by my own mentor the late professor Rikard Küller who in an early study became an icebreaker (Küller and Lindsten 1992). The study showed that different types of light have a secondary impact on both children's behavior and physiology concerning circannual levels of cortisol. This study was the first to consider that not only short-term effects of light are important, but long-term nonvisual effects need to be taken into account. The study showed different results concerning the circannual cortisol levels depending on the accessibility to daylight, leading to the conclusion that side-view windows were the best solution since children sitting in the windowless environment show an annual pattern of cortisol that were lower during the whole year than their counterparts in classrooms with side-view windows. Furthermore, the children's behavior was also affected.

Since this early study, the knowledge has been much more elaborated, and today we have knowledge on the impact of qualitative aspects of light such as color temperature, lighting distribution, glare, and spectral distribution for the nonvisual effects of light. The details of this are presented elsewhere in this handbook. Also the knowledge of the visual effects of light in relation to education has been further elaborated. In the next section, the knowledge up to date will be presented.

To conclude, we must acknowledge the impact of lighting in the school environment. Light has an impact, as a part of the physical environment, but how big it is, is an often put question. Research within environmental psychology exemplified by a study of my own may shed some light on the issue. The impact of different physical environmental factors on children's well-being was assessed, together with other parameters such as the social environment, individual differences, and activities. One conclusion was that about 15–20 % of the total variance could be attributed to features in the physical environment. Some may say that this is a low figure, but the lighting conditions are a factor that gets the cup run over (Laike 1997). Furthermore, many studies show that young people are more sensitive to physical environmental factors than older people, and this is also of importance (Refs). I will argue that creating good and healthy school environment will gain the society as a whole. Today, we have the means, and the knowledge is growing.

State of the Art

As been described above, the daylight has an immense impact on the physical environment of schools. In the thorough review by Wu and Ng (2003), the growing understanding of the relation between man and daylight is clearly described. It could be concluded that the daylight is the source of light that functions best, even though it could also cause problems such as glare. The distribution of daylight in a room is of outmost importance.

When looking at the international literature in the field of education and lighting, there is an impressive amount of literature. However, the quality of the works varies

a lot, and rigorous studies are few. Furthermore, there is quite a big disagreement among researchers in the application of the presented research results, often due to imprecise descriptions of the design and methods. However, some facts are more clear and undisputed (Higgins et al. 2005).

Regarding visual perception, we know that with increasing illuminance, vision improves and this enhances the ability to perceive (van Bommel and Van den Beld 2004). Another important aspect is the impact of light on the developing visual apparatus. Myopia is on the rise in many countries, especially in developing countries, and studies show that increasing the illuminance level will reduce the incidence of myopia (Chen et al. 2007; Lee et al. 2013). In relation to this, it has been shown that light from LED is perceived brighter than the light from other light sources (Govén et al. 2014). From an application point of view, it could be argued that good LED light sources raise the possibility to arrange educational environments with sufficient amount of light to a low-cost of energy. Looking in a worldwide perspective, research in developing countries shows that access to artificial light not only in school but also in the home environment enhances the possibility for good school results. The implementation of LED together with solar-driven luminaries makes this possible. Interestingly, there is a parallel related to the lighting development in the Western countries for more than hundred years ago when the electrical lighting became more common. Some authors argue that the electrical lighting had an immense impact on the societal development toward a more equal and prosperous society because of the access to cheap electrical lighting (Garnert 1993).

Artificial light needs energy and we need to act sustainable in relation to energy use, and therefore, excessive use of artificial lighting is never a solution. It is necessary to look at the optimal lighting levels. The risk by using a figure for horizontal illuminance is that it will not cover the complete issue of good lighting (Boyce 2004; Rea 2012). Turning to alternatives, relations between the ambient lighting and the horizontal illuminance levels have been used to describe the lighting conditions in classrooms. One study (Govén et al. 2002) assessed the preferred levels of surrounding light when the horizontal illuminance level was fixed. The result showed that with an illuminance level of 500 lux in the horizontal work plane, the most preferred levels in the vertical plane were between 80 and 100 cd/m^2. This relation has been discussed with practitioners that often use this as a rule of thumb. When using LED light sources, it could be of importance that the luminaries have the possibility to give an indirect light toward the ceiling and the walls with the abovementioned ratio.

The impact of color temperature (CCT) has also been subject to research and shows some clear results indicating that at higher illuminance levels cooler color temperatures (17,000 K) have an arousing effect, and studies even show that the concentration ability goes up. It should be noticed that this research has mainly been carried out with fluorescent tubes which have a very different spectral distribution pattern and not all studies have been conducted within school environments (Viola et al. 2008; Mills et al. 2007). In the same way, lower illuminance levels together with lower CCT seem to have a calming effect (Baron et al. 1992; Knez and Enmarker 1998).

According to Barkman et al. (2012), the research on artificial lighting in schools may be divided into three groups relating to the type of light sources used in the studies. First, early studies using full-spectrum lamps, not used anymore, hypothesize that the complete color spectrum was needed in the school situation in order to reach positive effects. However, the results were never clear-cut, and according to McColl and Veitch (2001), the relation between visual, perceptual, and cognitive effects of the full-spectrum fluorescent tubes was very weak. Other researchers reached the same conclusion (Boyce 1994; Gifford 1994). One reason for this may be that the spectral distribution of those lamps was not comparable to the daylight they were supposed to simulate. Another type of studies was comparing modern fluorescent tubes with different color temperatures together with the impact of daylight (Küller and Lindsten 1992). The results indicated that the cool light (4000 K) resulted in higher ability to concentrate and the warmer (3000 K) light may enhance communication.

Colored filters have also been used to facilitate reading among pupils. Results indicate that using such filters reduces symptoms of visual stress and headache and speeds up the ability to read (Wilkins 2003).

The third type of studies has been assessing how dynamic or variable lighting affects school children in various ways. We will return to this question in a later part of this article. Before we go to this, let us look at the other side of the coin, namely, the discomfort of light in the school environment.

Studies have been conducted where different adverse effects of lighting have been investigated and their potential impact on children's school performance. However, one problem with these kinds of studies is that they vary quite a lot in design and sometimes the number of subjects has been small which make it difficult to generalize from the results. With this in mind, nevertheless, there have been results pointing in directions that certain factors may hinder. One such factor is discomfort glare. In a study by Winterbottom and Wilkins (2009), the luminance from whiteboards was so high that it may induce discomfort. The results fit well in with findings about students' complaints about visibility of data-projection screen (Hall and Higgins 2005; Smith et al. 2005). Another problem is the flicker from the light sources. Having lamps operated with AC supply (50 Hz in Europe, 60 Hz in the USA), there will be a modulation in light output twice the supply frequency. With incandescent bulbs, this modulation is very small due to the fact that the filament will not cool down, but with fluorescent tubes, there may be a modulation in illuminance between 9 % and 90 %. The 100 Hz modulation affects humans both perceptually and cognitive. Studies have shown that young people are more sensitive to these effects than older people (Küller and Laike 1998) and that children diagnosed with autism are extremely sensitive, for example, in one study, the repetitive behavior decreased and communicative behavior increased when using flicker-free lighting (Coleman et al. 1976). Concerning LED, there are indications that especially when dimming, there is a modulation of this kind, depending on the technique used for dimming and because of the ballasts used. However, studies using LED are few. A recent study by Govén et al. (2014) didn't find any adverse effects of this type in a school setting with high school students. On the contrary, the perception of the

lighting conditions was much more positive concerning the LED solution. However, more studies are needed and clear definitions of the concepts of flicker and light modulation must be developed.

In a study where the total physical environment of schools was investigated, it was found that concerning lighting, the schools differed quite a lot. More interesting was also that the behavior concerning the use of lighting was that normally it was switched on in the morning and then on during the whole day, despite changes in the visual conditions (De Giuli et al. 2012). The control of the lighting seems to be a factor that could be handled in different ways. Today's general knowledge about physical environments points that the physical environment should not be too static, if so the environment will not be stimulating, and a boredom will occur. On the other hand, it is important that the environment is not too chaotic or complex, which will lead to overstimulation. However, it seems that concerning lighting, the first mentioned situation seems to be the most common (Küller 1991). As mentioned above, the dynamic or variable light has been one recent topic for study. Several studies have been presented and are based on the assumption leading back to earlier research that preferences for certain light are dependent on situational factors and individual needs. Besides this psychological assumption, also the knowledge about different levels of light for handling human circadian rhythms has brought attention.

The factors that often have been varied are the illuminance levels and the color temperature (CCT). This may be done through certain preprogrammed schemes or preprogrammed scenarios that are chosen by the teacher. A German study compared two classrooms in two separate schools with variable lighting with two control classrooms. The variable lighting scenarios were set to seven different variants, standard, focus on board, board only, concentrate, activate, relax, and extreme relax. The teacher in the classroom was supposed to handle and chose the alternatives. The study went on for 9 months, and the results showed first of all that the students and the teachers were satisfied with the variable light. Furthermore, the result showed that under the variable light variant "Concentrate," the students displayed better attention than on the other solutions. The students also displayed a higher reading speed, and reading comprehension was also improved. On the other hand, the achievement motivation and the atmosphere of the classroom did not change with the variable lighting solution. The light source used in this study was fluorescent tubes (Barkmann et al. 2012).

In a Dutch study comprising of three different studies, Sleggers et al. (2013) compared different vertical illuminance levels (350–1000 lux) and different correlated color temperatures (3000 and 12,000 K). Two of the studies were quasi-experimental field studies using a dynamic lighting system, while the third study was conducted in a simulated school setting in a windowless laboratory setting. The aim of the two field studies was to investigate a lighting system with the possibility to address different needs in the classroom situation such as activation, attention, and calmness. The same aim was the target for the third study but under a controlled situation. The focus of the study laid on the cognitive performance as in the former presented German study. The results affirm that the lighting conditions have an impact on the children's performance. However, the results are not completely

clear-cut, since there are differences between students from grade four, where positive results were found, which not the case was for students from grade six. One explanation suggested by the authors is, as been mentioned earlier in this chapter, that younger children are more affected by environmental stimuli, than their older counterparts. The older children have learned to handle environmental factors in a better way. Furthermore, the controlled laboratory study did not confirm the results from the field studies. Concerning this result, the authors suggest that the reason may be the time of the year the studies were conducted. The two field studies were carried out during the winter season, and the laboratory study was conducted in spring. The seasonal effects should not be neglected. As Küller and Lindsten (1992) showed in their study, the reaction, both physiological and behavioral, varies over the year in countries far from the equator where big differences in the length of the day are at hand. The impact of daylight will be larger during the spring and summer season in comparison to the winter season. To summarize, the dynamic solution based on different settings aimed for different demands seems to have an effect, but to a relatively moderate amount.

Another way to look at the lighting system is to investigate the lighting distribution in the room. Research suggests that the surrounding light may be important, not least for the nonvisual effects of light. In a study where four classes were compared according to daylight and lighting distribution, pupils from grade three in a school in the UK were studied (Govén et al. 2011). Two classrooms had a large degree of surrounding light (75 % on walls and ceiling), while two control classrooms had (45 % on walls and ceiling, standard solution). In all classrooms, the light sources were changed in order to minimize the Hawthorne effect. Furthermore, in one experimental and one control room, the daylight factor was around 1.5 %, and in one experimental and one control classroom, the daylight factor was around 4.5 %. The pupils were followed during one school year at five different occasions with measurement of the children's subjective experience of sleep and emotional status together with measurements of the children's cortisol and melatonin levels at different occasions. The children's school performance was also rated. The results indicated that the two rooms with the highest amount of daylight described similar results, while the rooms on ground floor with lower daylight contribution, an effect during the darkest season was found, on both regarding arousal as measured by the morning cortisol and on the school performance, showing that the pupils in the experimental classroom displayed better results in school than their counterparts in the control room. The cortisol pattern revealed that the children in the experimental room displayed higher arousal during the dark season (November to February) indicating that the mere difference of the distribution of the light may have an impact on the children.

The knowledge from this study was brought to a second study where the idea was to compare LED light sources with fluorescent T5 tubes where the light distribution was as identical as possible. The study was conducted in southern Sweden with high school students. These students were followed for one school year, and the measurements conducted were the same as in the English study, with the exception that melatonin was not measured in this study. The student's activity during the measurement days was also checked.

The details of the study were as follows: in one conventional T5 fluorescent tubes with 4000 K and in the other a LED solution, also with 4000 K. The lighting level on the work plane in both situations was 500 lux (the standard in Sweden). In the study, both subjective experience of lighting conditions and the results of chronobiological marker (cortisol) were measured during three occasions during 1 day, at five consecutive times over the school year. The results concerning the experience were quite clear, that even though the conventional solution was good, the LED solution was experienced as brighter and the visibility displayed a higher rating. However, regarding the chronobiological marker, the results did show small differences between the two kinds of solutions; rather, daylight has an immense impact on the circadian rhythm. In Sweden, as other countries far from the equator, there is a large difference in the length of the day over the year, and this fact was clearly manifested in the results. In March, when the length of the day became longer, the results were clear. However, a small trend toward a more stable circadian rhythm was seen in November within the classrooms equipped with LED. Taken together, one could conclude that using LED is at least as good as using conventional fluorescent tube solutions, but it is important that the luminaire is taking care of all the possibilities for glare (Govén et al. 2014).

Conclusions

The overall results from different studies show that, with the new light source LED, there is a potential to produce better lighting solutions, both concerning the intensity, but also in relation to the spectral distribution. However, our knowledge is still limited and we need to know more about the impact of light from different wavelengths, especially in the long wavelength band. Based on today's knowledge, the intensity and the positive effects of short wavelength light in the morning hours are something that could be introduced relatively easy in the school environment. At the same time, it is important not to forget the impact of daylight, that the school environments need to use daylight in a proper way as much as possible. The artificial light should be seen as a complement to that should be used when the daylight could not fulfill the demands of the pupils. We must also remember the basic quality needs such as glare problem and enough light. Those two aspects are, as have been clearly shown, also very important when describing high-quality educational lighting.

What is the future for the lighting of schools? This question is difficult to answer since the development goes fast, but in environments where additional light is needed, the future may lay in a light that could mimic the daylight, a light that is free from glare, has the same properties as daylight, and are changing in line with the daylight. When working during evenings and nights, one must take this into account and have information on when the person should go to sleep and relate this to the total amount of radiation needed for a good solution that is both healthy and stimulating. Another thing may be to have lighting solutions that could be helpful for different activities in the school environment. The teacher may change the ambient lighting depending on the work conducted, if it is to work in group or to

work individually. The most important thing is that we create lighting environments that go together with the human needs. We are today in the beginning of the understanding of this, and there is still much to learn, but with the development of technology as well as the understanding of the impact of light on psychological responses, there is much to come.

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