

Indoor Workplaces with no Daylight: A Real Problem

Abstract. In general, lighting systems are subjected to verification of photometric parameters after installation what is usually performed by field trial according to lighting project as required by the standard EN 12464-1. Illumination of indoor workplaces is normally based only on artificial lighting without access of daylight through windows or rooflights. To achieve good visual performance for workers, higher illuminance level at the workplace is required. Moreover, in some countries these requirements to photometric parameters shall follow legislative documents which prescribe illuminance level at the workplace. In Slovak Republic the legal requirement for total maintained illuminance is 1 500 lx for indoor workplaces without daylight if any alternative arrangements are not ensured for the workers and long-term stay of persons is declared at the workplace what should reduce health impact of the persons in that space without daylight. This is controlled by the Public Health Authority as one of the requirements for commissioning of the building. More luminaires with appropriate light sources can easily satisfy that illuminance level. But on the other hand, energy consumption for this lighting system is much higher what negatively influences the classification according to the system for energy performance of buildings as requirement of the EU directive 2010/31/EC. Requirements for lighting systems are stated in the document EN 15193. This paper puts focus on workplaces without access of any daylight. Measurements of photometric parameters of lighting systems were performed with respect to the energy performance of building according to requirements of the standard EN 15193. Based on analyses of the results energy performance of lighting systems will be figured out. Suggestions to possible options how to satisfy legislative and normative requirements with respect to lighting systems used in illumination of indoor workplaces will be also presented.

Keywords: Indoor workplaces without daylight, Lighting design, Circadian rhythms.

Introduction

The artificial light is needed for illuminating of indoor lighting purposes to ensure good visual comfort and good visual performance especially for people who perform some work. Therefore indoor workplaces lighting systems should be design to follow these aspects. Historically when the electrical lighting era began most of opinions have governed to replace daylight at workplaces with that artificial lighting without necessity of ensuring of the daylight at the workplace. Nowadays influence of daylight on circadian rhythms of human being has undoubtedly been proven. The daylight is very important for people because the level of it can positively or negatively influence visual comfort, health or mood through the visual system of the observer. In 2007 in the human eye were found third type of the receptors which are not responsible for visual perception, but they are responsible for non-visual aspects of the light on human body through nerves in the eye retina. The ganglion cell layer form neuronal cells. They serve as the output of the optical information via the optic nerve from the retina to the brain. Currently scientists have identified twenty different types of ganglion cells. In the new type which is the third receptor scientists have discovered melanopsin a light-sensitive protein first isolated from the skin of frogs.

Sometimes insufficient of daylight is a real problem in the indoor workplaces where windows are missing or openings are not so large to ensure good daylight access in the day. In that case it is very important to have good artificial lighting compensation. On the other hand higher illuminance level at the workplace has negative impact to the energy consumption. Also it does not matter which lighting system is installed at the workplace. It should follow some rules to ensure good lighting conditions for people. Because inappropriate lighting influences attention and influences the error rate especially in the manual production. Even more also home lighting is very important but this topic is out of scope of this paper. These all facts affects circadian rhythms of the human body what is dangerous for the health of people. The paper is focused about some examples from the practice at the workplaces without or lack daylight where long-term stay of the workers was assumed.

Circadian rhythms

Alternation of day and night – the light and the dark accompanied a mankind from the very beginning of existence. That adapt all their activities, even they are depending on the set of biological „clock“. Beginning an era of electricity with the invention of light bulb meant a huge breakthrough in this regime. The night was no longer an insurmountable obstacle to the work. However, this humiliation of darkness in such a great victory, as it seems? Just think of the impact of light on human beings a little more "light".

At the lighting design should be assumed good lighting conditions of space where people meant to be present. Doing so is often forgotten that light acts on the man, his health and physical and mental well-being. A mismatch between lighting and functions of the body can cause serious health problems. Many human body functions is cyclic. These are divided by the duration as follows

- **Ultradian** – ranging from a few milliseconds to several hours
- **Circadian** – lasting 20 to 28 hours
- **Infradian** – lasting more than 28 hours.

Deficiency of the daylight causes the characteristic symptoms, such as sleepiness, fatigue, apathy, reduced activity and performance, headache, reduced ability, weak bones and teeth due to lack of vitamin D, increased aggressiveness, cancer etc. These aspects is called as syndrome SAD (Seasonal Affective Disorder), known as seasonal disorders of the body. These symptoms can be eliminated by appropriate usage of the artificial light with high intensity what causes higher illuminance level for long enough. They are recommended to use light sources with a balanced spectrum which CRI is the closest natural daylight i.e. with CRI equal to 100 light sources or with more than 95 CRI is currently possible to obtain. Usually these light sources are used as compact fluorescent lamps or linear fluorescent lamps with higher CCT. At the present these traditional lights are replaced by the modern LED lighting systems which can be better controlled by the user and also it can be changed CCT in the time of the day. Incandescent bulbs with its dominance of the red part of the spectrum

causes constant stress, lack of blue and purple spectrum is responsible that human vision system is stressed at high level. The importance of light for the human body, we see very clearly on the treatment methods commonly used in practice. In newborns it has long been successfully used for the treatment of neonatal diseases, e.g. jaundice irradiation of special light sources. Treatment method based on so-called photodynamic therapy, operates by the specific action of the light of the tissue which the light remove or prevent unwanted cell growth. It is used in treatment of cancer, skin diseases, arteriosclerosis and in ophthalmic surgery.

Lighting design requirements

By means of many research works has been found that the human body is influenced to illuminance values less than 1 lx. This results in a significant decrease in the production of melatonin. In other experiments scientists have proved negative effects on the human body at illuminance level between 0,25 lx to 300 lx task lighting at disrupting darkness light during sleep. As an example of an adverse effect on children of preschool age is when their parents at bedtime allowed lighted up the night light luminaire. To avoid these negative effects should be at the design used luminaires in the street lighting with appropriate spectral power distribution. It is recommended to use light sources with a wavelength close to that ganglion cells perceive the least. Since ganglion cells are the most sensitive to a wavelength of 464 nm which belongs to the blue color should be used luminaires or lamps that do not contain the blue component. Therefore using of low pressure sodium is good light source for public lighting although CRI is equal to 0.

On the other hand lighting design at the indoor workplaces i.e. at the work time of people was proven that blue content of spectra of light sources is undoubtedly desirable due to stimulation of human body processes. Furthermore other aspects should fulfill lighting system design to ensure both visual comfort and visual performance. For the biologically effective lighting design should respect as follows

- illuminance level
- luminance distribution (uniformity)
- directionality of light
- correlated colour temperature (CCT)
- colour rendering CRI and colour appearance
- variability of light

Aspects listed above should be combined in right way to reach good visual condition at the workplace. The appropriate combination of illuminance level, directionality and quality of light at the workplace can positively influence activity of the workers.

The first of all as it is listed above is illuminance in workplace. Generally the daylight factor is the measure of sufficient daylight at the workplace. Based on this factor should be assessed if daylight access is sufficient or not. In some countries when natural daylight is missing at the workplace is regulated by law what illuminance level should be ensured. In Slovakia this requirement is level of illuminance stated at 1500 lx when long-term period of persons in workplace is assumed. Therefore it is question if higher illuminance is sufficient for people which are present at the workplace. Some studies have shown that illuminance level positively influence activity of human brain. It was done by investigation of level EEG waves [1] in the brain which are present when people are sleeping i.e. they are responsible for tiredness. If level of EEG waves is

lower then persons are more active and attentive. This is shown in the picture Fig.1. People were tested in office workplace.

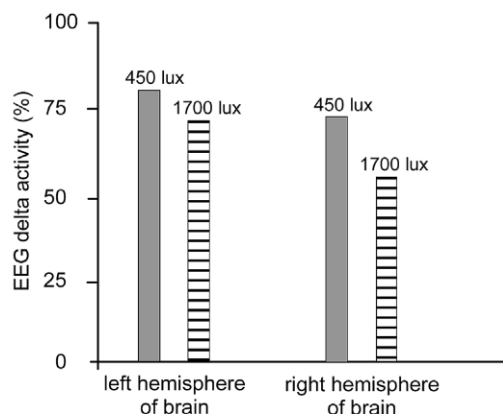


Fig.1. EEG delta activity dependent on illuminance level [1]

Another study was performed with people who work at different shift work schedule [2]. Also results of this research work has proven that higher illuminance level is better for workers and even more has shown dependence brain activity in time i.e. dependence on work shift during the day or during the night (Fig. 2).

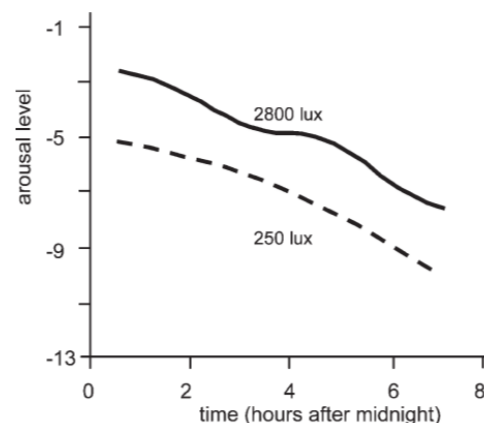


Fig.2. Activity dependent on illuminance level at shift work [2]

The CCT in connection with CRI of light source is further important parameter after illuminance level. Both of them influence the mood,

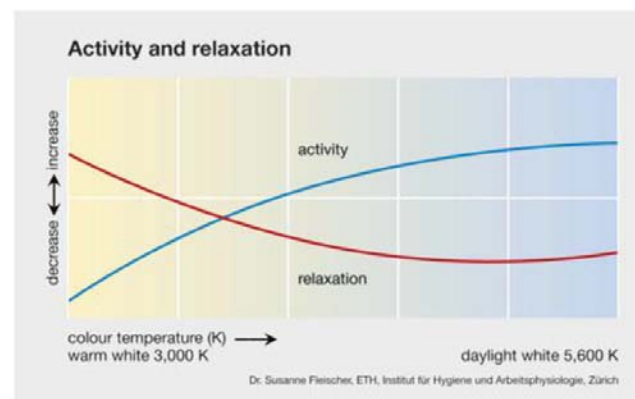


Fig.3. Activity dependence on CCT [3]

From the graph in picture Fig.3 is shown at higher CCT values people are more relaxed than lower CCT values of light source installed into the luminaires. Some studies also shown dependence activity on CCT changes during the day. Therefore it is good when it is possible also changing CCT of light sources during period of work shift.

As another aspect of quality of the light is CRI of the light source or luminaire. As it was written at beginning of this chapter that at the night time when usually people sleep is better CRI approaching to 0 in opposite way it is desirable for higher activity in the night higher values of CRI with emphasis on rich blue spectra region should be present in the spectral power distribution because blue light is responsible raises activity of human brain.

The last very important main aspect which should be regarded in lighting design is directionality of light in respect with position of light source and eye retina to be illuminated. Also in this field some studies have shown influence of directionality of the light on human body biological process. One of the studies based on changing of illumination of eye retina by light source has proven the fact that production of melatonin is changing due to this fact [4]. Biological changes of production of this so-called "sleeping" hormone are depicted in the picture Fig.4.

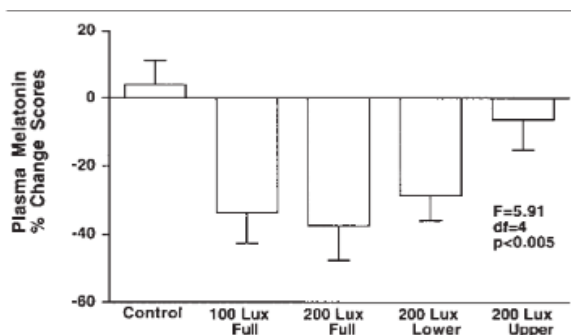


Fig.4. Melatonin change production dependence on illuminance of eye retina area [4]

However illumination of eye retina is positive for higher activity on the other hand it should be avoided uncomfortable glare of the person being at the workplace what undoubtedly is counterproductive for activity and performance of the staff. Other aspect of directionality of light at the workplace is luminous uniformity of the workplace. If uniformity is inappropriate it can cause also uncomfortable glare to the employee due to the big contrasts at the working plane and surrounding area.

Main aspects were mentioned above for lighting designers what should respect in their designs to ensure good lighting environment in the indoor workplace. Also the results of these studies should be followed especially at the workplaces without access of natural daylight where people are more sensitive. These situations occur for example at night shifts at production lines where no access of daylight can be ensured. Therefore by appropriate lighting system can be reduced these all negative impact on the working stuff visual system to ensure good lighting environment at the workplace.

Results

In this section are presented some cases from the practice of workplaces without daylight where different lighting systems were investigated by field measurement. The illuminance level was measured by illuminance meter Class L according to DIN standard and it was properly

metrologically calibrated with traceability to SI standards. The field measurement was focused on illuminance level and uniformity at the workplace. The other parameters as CCT, CRI etc. were obtained from catalogue list of luminaire producers.

The first workplace was placed in the manual production area of automotive industry where employees have night shifts. Therefore it is desirable to have enough light to ensure secure and visual comfort for them. It was ensured by local luminaire over the head of workplace. The workplace is shown in the picture Fig.5.



Fig.5. Workplace in the production area of automotive industry

In the picture Fig.5 is depicted workplace area where lighting system consists from LED luminaire above the workplace and general lighting consists highbay luminaires with metal halide discharge lamps 300W uniformly spread around the workplace at height 8,1 m. It should be noted that workplace was reconstructed by owner of the company. The former lighting system consisted halogen luminaire placed directly into the workplace area what was absolutely unsatisfactory for the work. The survey was done among employers where they were asked simple questions about improvement of lighting environment at the workplace. Although by measurement was proven illuminance level over 1500 lx and uniformity over 0,70, CRI was over 80 and CCT around 4000 K over 90% percent answers were negative i.e. expressed disappointment that new lighting system after reconstruction is uncomfortable and feel tired after the work. During the investigation it was found out that disappointment is due to huge contrasts between task area, immediate surrounding (about 300 lx) and background area (around 150 lx) because the line of the sight of workers is constantly changing due to the work. Because of that fact visual system of employees was steadily strained i.e. well-balanced luminance distribution at the workplace was not ensured. The power consumption of workplace with 4 pcs general lighting luminaires was Furthermore also directly glare from the luminaire was found due to bad optics in the luminous part.

The second workplace was situated in the building without daylight in company which deals with production of credit or debit cards. Therefore focus on big attention and concentricity of the employees is very important at the workplaces. The photographs of the workplaces are



shown in the picture Fig.6.

Fig.6. Production hall of credit and debit cards company with layout of workplaces

The general lighting consists linear LED luminaires with LED retrofit tubes T8 2x27W with aluminium grid at height 3,5 m uniformly spread over the ceiling of the production hall. Each of the task area of workplace was illuminated by LED luminaire 30,5W mounted above the head of employee in the height around 2,0 m with appropriate optics due to directionality of the light on the task area and immediate surrounding. Also in this case it was reconstructed lighting system by the owner of the hall because they did not satisfied laws in Public Health in Slovakia. In this case the survey revealed satisfaction most of the employees with lighting system and feeling good after the work even more some of them checked improvement of the feeling after the work. By the measurement was proven that contrasts between task area, immediate surrounding and background area were much more balanced than in the first case. Illuminance level on the task area was 1686 lx, in the immediate surrounding area 1280 lx and in background are 621 lx what is balanced according to EN 12464-1 standard and comply law requirements of lighting environment of workplace in Slovak republic. Uniformity on the task area was 0,88 what is evidence of good luminance distribution on it. CRI of light sources was over 85 and CCT was 4000 K. The power consumption of lighting system was 4,8 kW.

Third working place (Fig.7) which is demonstrated in this paper is very often solved problem and it is shops in the big shopping centres. Namely in these centres are places which are without daylight and employees are working at that places whole day between 8 to 12 hours. Furthermore these areas should follow requirements of the law i.e. 1500 lx with uniformity 0,5 as general illuminance level in the area if any alternative arrangements are not ensured by the employer.



Fig.7. Store in the shopping centre area without daylight

In this store area was general lighting consisted LED spot luminaires 30W and 40W unevenly spread over the ceiling to illuminate each part of the store differently due to goods to be sold in the store. By the measurement was found out that overall general illuminance level of the illuminated store area was 1565 lx with uniformity 0,50 what complies Public Health law requirements. CRI of light source were over 85 and CCT was 3000 K. The power consumption of lighting system was around 5 kW. The survey among employees after furnishing was made. Although lighting environment follow the law requirements the results also from other similar workplaces have proven over the half of answers satisfaction with lighting system. On the other hand less than half asked employees expressed disappointment with lighting system outlining "lot of light in the area". It can be caused by CCT 3000 K used in the lighting system due to lack of blue spectra is missing or the different work is performed in the store than in production area.

Conclusions

In the paper was presented problematic of workplaces without daylight. It was found that lighting system requirements are undoubtedly very important in designing of workplace. All of the aspects as illuminance level, uniformity represented by luminance distribution on the task area, directionality of light, colour of the light and colour rendering should be followed by designers because it was proven by surveys among employers in each working area presented in the paper. In the first was problem with contrasts what is shown as negative also for feeling employees at that workplace in comparison with second work place where balance of all aspects of lighting system was good proven by survey. Third one working area was different than two presented workplace. It was situated in shopping centre area as store of goods. There disappointment of part of employees can be caused due to colour of light where 3000 K light sources were used. In further work should be investigated more workplaces with other types of lighting system and different work performed by employees.

Acknowledgments



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