# Light and Health in Factory Work Places

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## 1 Abstract

Current standards and guidelines are directed mainly towards visual performance and visual comfort. Biological non-visual effects are not included, although they are well-known for many years. We know that a good illumination increases not only the performance, but also well-being and activity of people.

Light influences important biological functions in human, namely melatonin suppression at night, delay or advance of the circadian rhythm, stabilisation of the circadian rhythm and increase of alertness.

In activation lies a high potential for illumination practice. Unfortunately this effect is hardly investigated for daytime use. At the TU Ilmenau a study is in progress dealing with biological light effects at workplaces in factory buildings.

## 2 Introduction

Light influences important biological functions in human, namely melatonin suppression at night, delay or advance of the circadian rhythm, stabilisation of the circadian rhythm and increase of alertness. New findings show these effects for illuminance levels above 90…180 lx (vertical illuminance at the eye). Higher levels result in more effects. In dark factory buildings, where illuminance levels in this range are likely to be found, more illuminance at the eye could increase activity, alertness and well-being.

The biological effect increases with the use of light that is enriched with blue wavelengths to which the circadian system is most sensitive. The effect also depends on spatial distribution and size of the light sources. Inferior retinal light exposure is more effective than superior retinal exposure. Large area luminaires are also more effective than point sources. Probably dynamic light can cause even more effects.

In activation lies a high potential for illumination practice. Unfortunately this effect is hardly investigated for daytime use. There are many studies for shift work use. Also the stabilisation of the circadian rhythm can be important. It is not known, however, how to implement these findings at workstations reasonably.

Nevertheless, it has not been investigated yet which quantity of light reaches the eye during work. This quantity depends on the lighting system as well as on the movement of the head. In a laboratory pre-test the illuminance level at the eye has been measured.

## 3 Laboratory measurement of the illuminance level at the eye

The biological effect of illumination depends on light quantity, spectral distribution and spatial distribution. For quantification of effects, all these parameters have to be measured. Because this is a very complex task, usually only the vertical illuminance near the eye is being measured, while the line of sight and the motion of the head are ignored. For this reason, a system has been developed which measures the illuminance at the actual eye position. Therefore a sensor is fixed at an eyeglasses' frame (Figure 2).

### 3.1 Measurement System

The measuring system is capable to measure the illuminance and circadian irradiance during several days with a temporal resolution of one second and to save this measured values. Based on this measured values the interrelationship between these ones and the well-being shall be investigated.

The requirements on the measured value acquisition can be summarized as follows:

- The device shall be wearable in everyday life.
- It must be battery-supplied with an operation period of at least one week.
- The data recording shall be made over several weeks with no data loss during power failures (e.g. battery replacement).
- The measurement values must have absolute time-stamps.

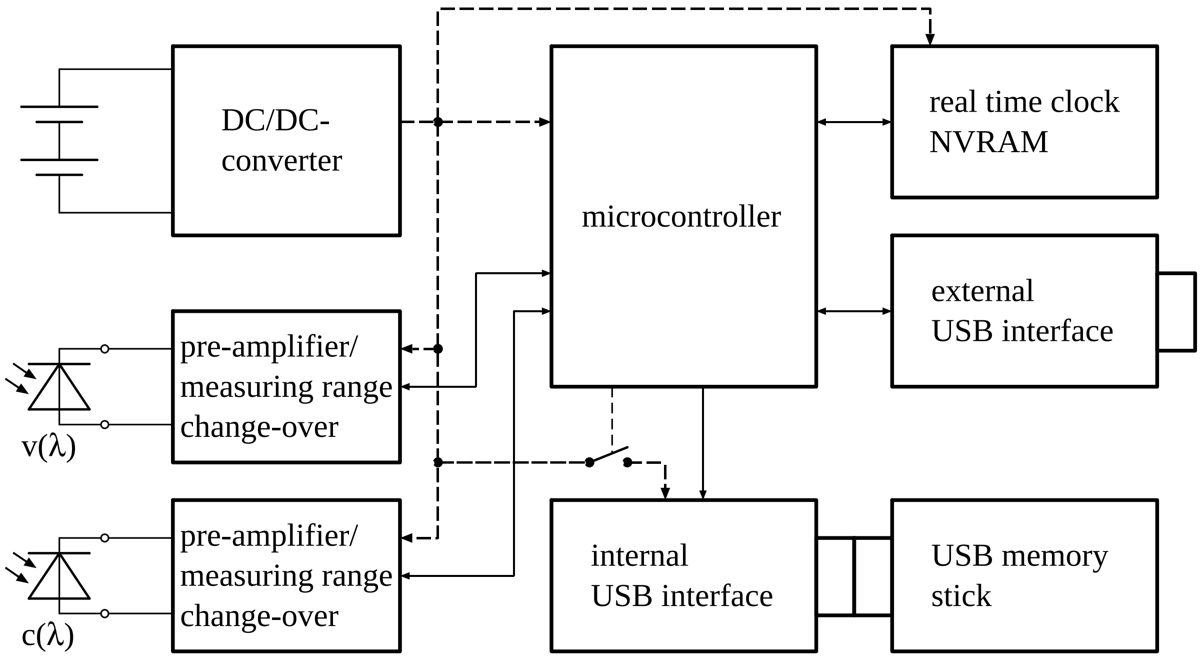


**Figure 1.** Block diagram of the measurement system "LuxBlick"

Figure 1 shows the block diagram of the implemented device. Central part is a microcontroller Atmel ATmega644P controlling all workflows, containing the necessary analog digital converter and putting temporarily the measurement values in a non-volatile memory (NVRAM) located in the real-time clock. These real-time clock also ensures the absolute time-stamps for the measurement data and generates every second an impulse triggering a new measurement. The size of the NVRAM is sufficient to save the measurement data captured during approximatly 7 minutes, then these data must be transferred to to USB-memory.

The intermediate storage of the data in the NVRAM is made because of the power consumption of the USB-memory and the required internal USB-interface. When these both parts would be constantly powered on, the two NiMH-cells supplying the whole device would be empty after few hours. So the data memory with the associated interface is normally currentless and will only be switched on when the NVRAM is filled with approximately 80% of its capacity to transfer the measurement values. For the data memory a commercially available USB memory stick is used in which data captured during several months can be stored per gigabyte of size.

The pre-amplifiers convert the photocurrent generated in the photo sensors to a voltage filtered by a low pass. Furthermore each pre-amplifier is equipped with several measuring ranges which can be selected by the microcontroller. The voltage created in this way is measured by the analog digital converter contained in the microcontroller. The usable metering range runs from 1,0 lx to 40000 lx.

Figure 3 shows an exaple for a measurement with LuBlick System during different light situations in the pretest (chapter 3.2).

**Figure 2.** Measurement system “LuxBlick”

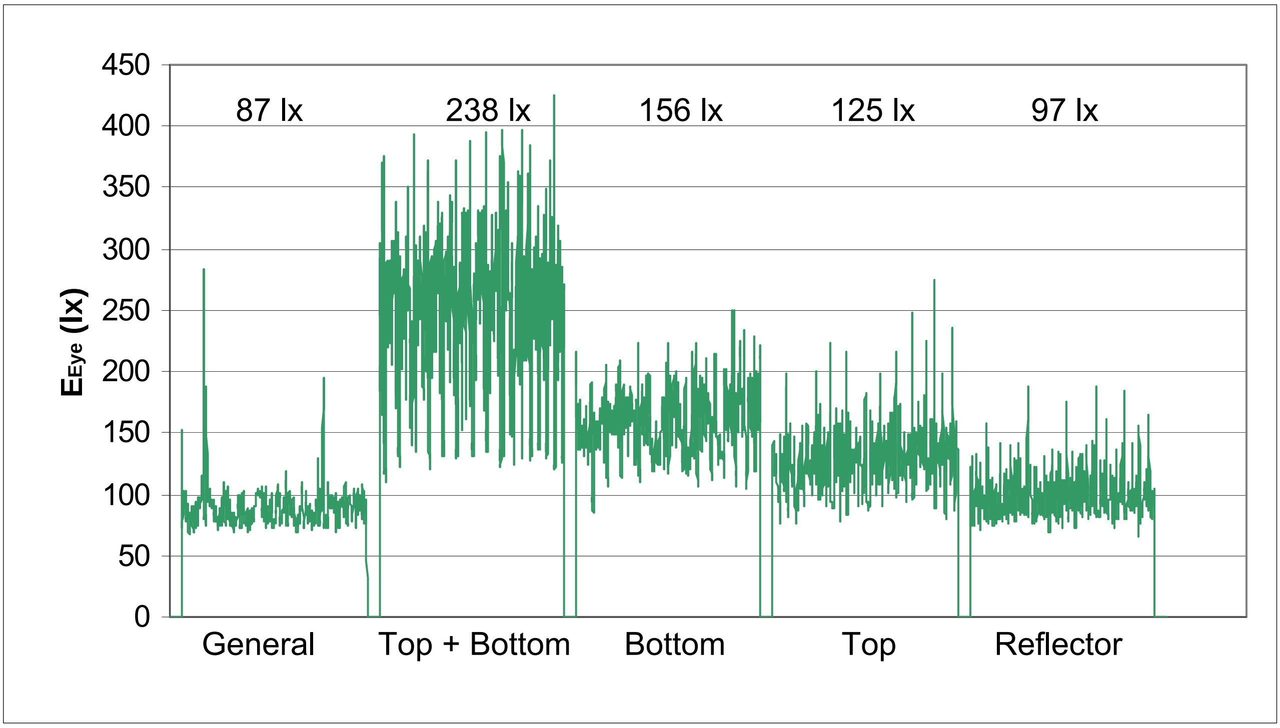


**Figure 3.** Example for a measurement with LuxBlick system

## 3.2 Test work place

In the laboratory, a test work place was installed. Test persons carried out installation work for 10 minutes while wearing the sensor-equipped eyeglasses’ frame (Figure 2). Various illumination systems have been measured (general lighting, vertical luminaires with various sizes and positions while the horizontal illuminance was kept constant (Table 1, Figure 4,

Figure 5)). The measured values have been averaged. The vertical illuminance varied between 60 % (general illumination) and 160% (large scaled luminaire in front of the test person) of horizontal illuminance (Figure 6). The measured illuminance at the actual eye position showed to be only 30 to 40% of the vertical illuminance near the eye (Figure 7), respectively 20% of the horizontal illuminance.

For biological effects a illuminance at the eye caused by large-scale luminaires is important. In the test the lower luminaire and the right and left mounted luminaires produced the same illuminance levels at the eye (Figure 6). So the luminaire position at workstations can vary. This is expedient for installation in the field studies.

The vertical luminaires had a luminance of 1000 cd/m$^2$. Glare ratings assessed an admissible luminance of 1500 cd/m$^2$.

**Table 1.** Dimensions of the Luminaires

| | Top + Bottom | Bottom | Top | Reflect or | Right | Left | Right+ Left |
|---|---|---|---|---|---|---|---|
| Width | 1,30 m | 1,30 m | 1,30 m | 1,40 m | 0,40 m | 0,40 m | 2 x 0,40 m |
| Hight | 1,30 m | 0,65 m | 0,65 m | 0,57 m | 0,58 m | 0,58 m | 0,58 m |
| Distance to the eye | 2,00 m | 2,00 m | 2,00 m | 2,00 m | 0,80 m | 0,80 m | 0,80 m |

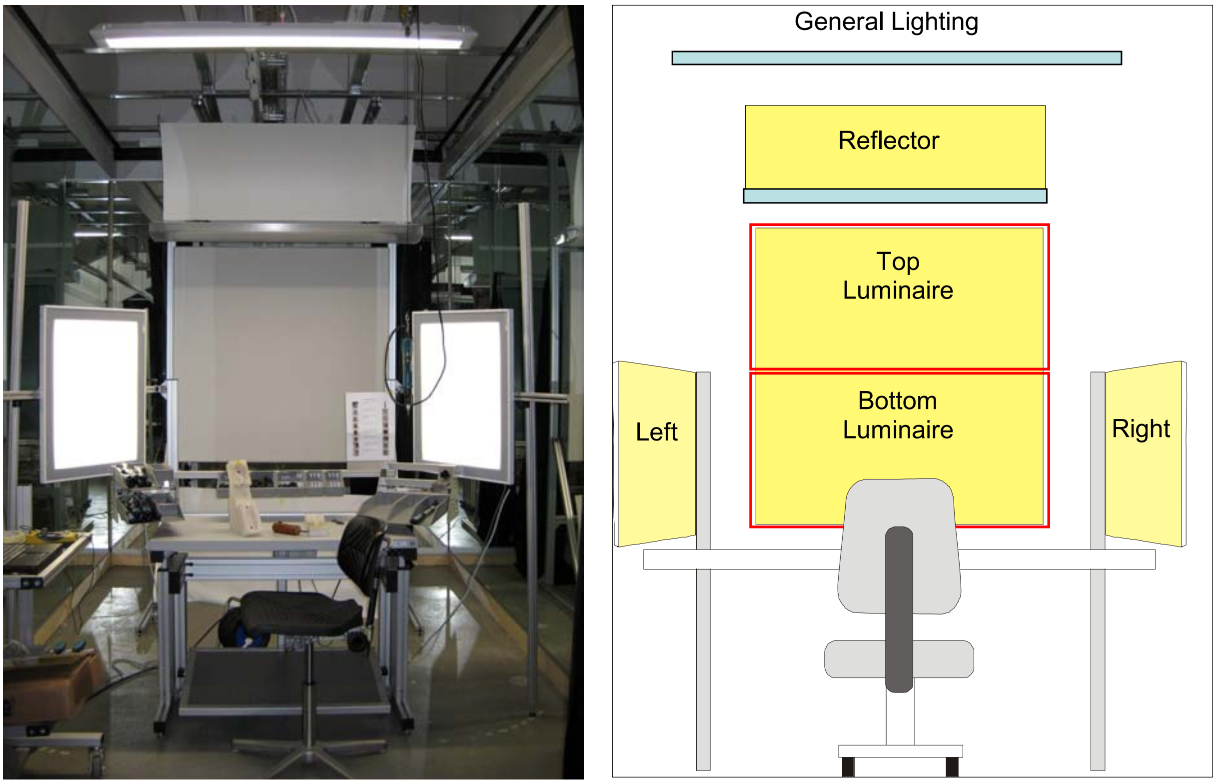


**Figure 4.** Positions of the Luminaires

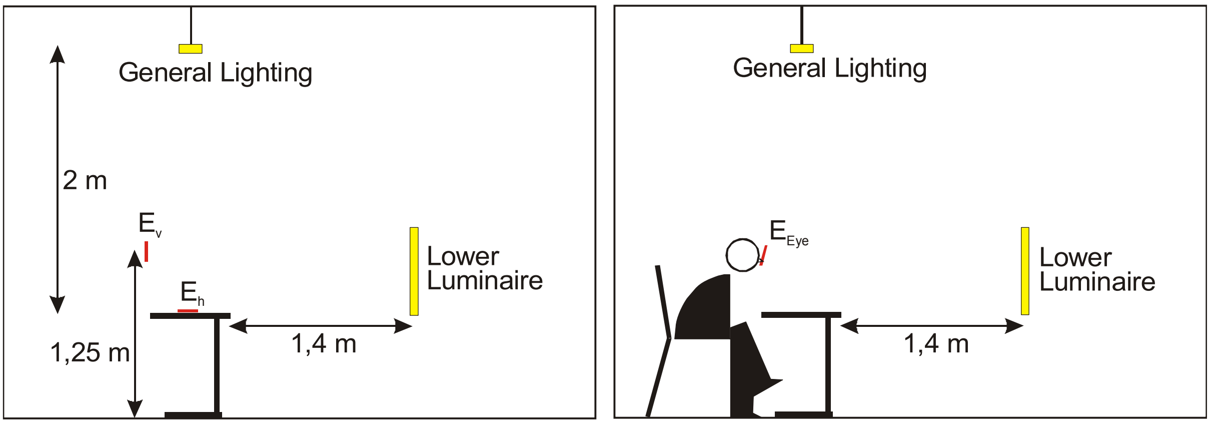


**Figure 5.** Position of the metering points

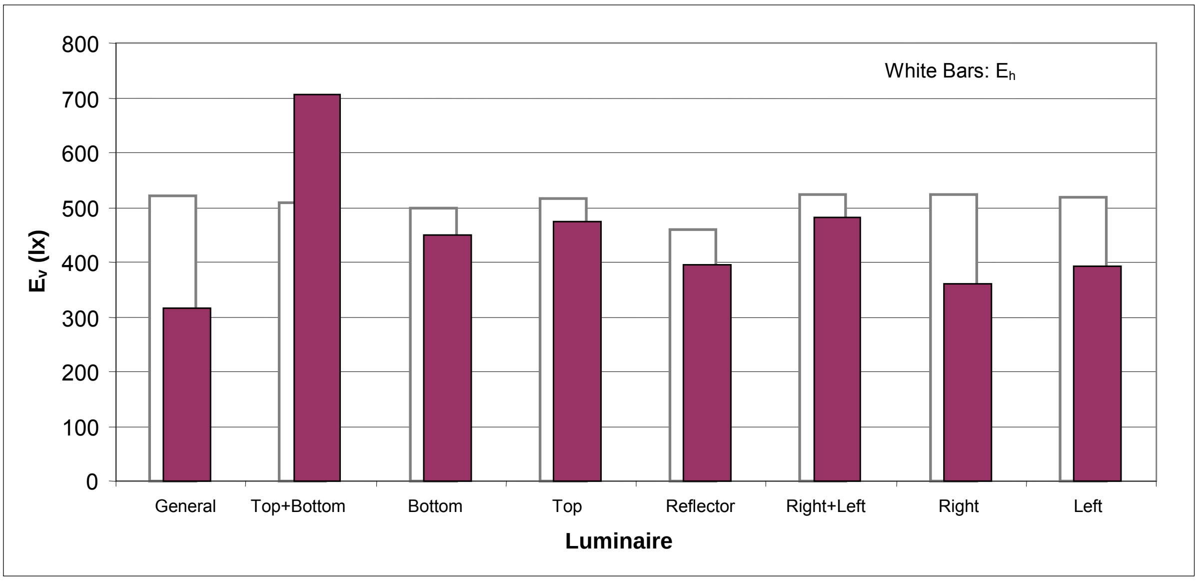


**Figure 6.:** Vertical illuminance $E_v$ near the eye

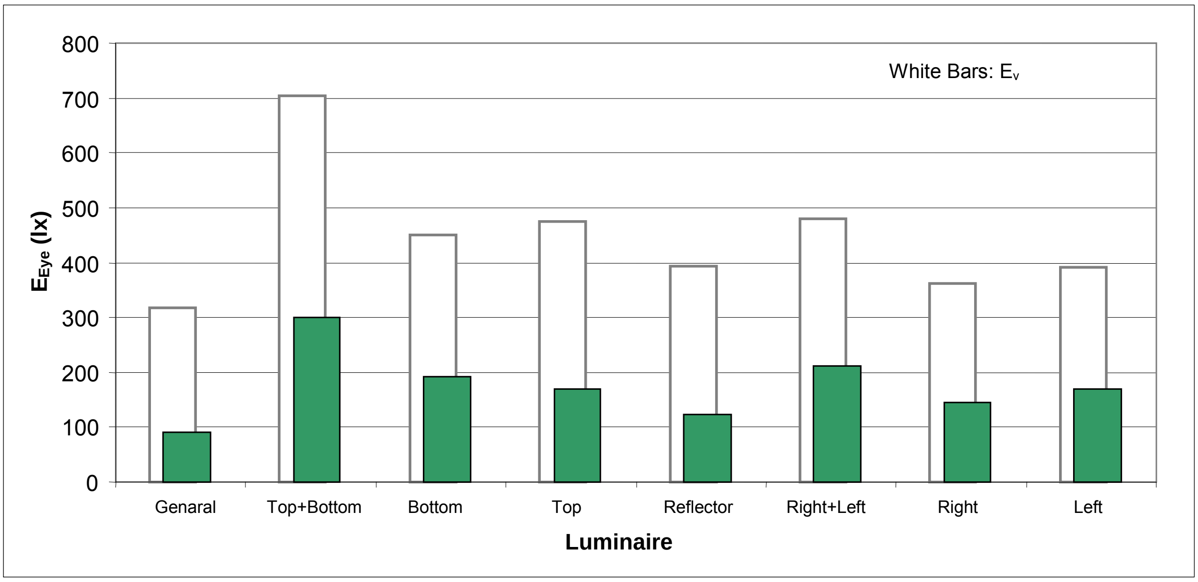


**Figure 7.** Illumination $E_{Eye}$ at the eye

## 4 Field study in factory buildings

Based on the results of the laboratory tests, 41 workstations in factory buildings have been set up with vertical large-scale luminaires. The rooms have dark walls and little daylight. The vertical luminaires have a luminance of 1500 cd/m$^2$ and are installed in front of the user. So we have much more vertical bright areas in the field of view. The colour temperature of the luminaires can be varied between 3000 K and 8000 K. Tabele 2 gives an overview of lighting situations tested in the field study.

Every situation was being tested for at least 4 weeks. The test person rated well-being, activity, sleep quality and light quality. Correlations between light situations and peoples' ratings are expected. Therefore, illumination parameters as well as circadian values for each light situation were evaluated. Figure 8 exemplifies a work station , in table 3 and 4 the metering data's are presented.

**Table 2.** Situations in the field study

| Situation | General lighting | Additional vertical large-scale luminaires |
|---|---|---|
| S1 | Current situation 3000 – 4000 K | -- |
| S2 | Current situation 3000 – 4000 K | 8000 K |
| S3 | Current situation 3000 – 4000 K | luminaires change the colour temperature from 8000 K to 3000 K during a working day |
| S4 | Current situation with 8000K lamps | |

**Figure 8.** Example for a workstation (left: S4, right: S2)

**Table 3.** Illumination at the eye (example figure 8) measured by LuxBlick system (mean and standard deviation)

| Situation | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| $E_{eye}$ (lx) | 129,8 ± 26,6 | 378,5 ± 82,2 | 311,4 ± 84,6 | 304,9 ± 47,9 |
| $E_{ms}$ at the eye $(mW/m^2)_{eff}$ | 80,2 ± 7,4 | 254,5 ± 72,0 | 159,4 ± 44,86 .... … 254,5 ± 72,0 | 252,8 ± 47,7 |

**Table 4.** Horizontal and vertical illumination at the desk (example figure 8)

| Situation | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| $E_h$ (lx) | 2007,3 | 2187,5 | 2223,8 | 2163,9 |
| $E_v$ (lx) | 873,7 | 1120,0 | 1145,4 | 991,0 |

**Table 5.** Illumination and colour temperature at all workstations (mean and standard deviation)

| Situation | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| $E_h$ (lx) | 1010 ± 570 | 1120 ± 550 | 1040 ± 560 | 1185 ± 700 |
| $E_v$ (lx) | 360 ± 300 | 575 ± 360 | 490 ± 295 | 405 ± 320 |
| Colour temperature (K) | 4000 | 4200 | 3900 | 6300 |

Table 3 and Table 4 show the metering data of an investigated working station. The positions of the metering points are corresponding to figure 5. $E_{ms}$ is the irradiance weighted with relative spectral responsivity curve $s_{ms}(\lambda)$ for suppression of melatonin (DIN, 2009). This example shows the increase of illumination level at the eye in situation S2 and S3 by additional luminaires. Changes in daylight level, task pattern or arrangement of material around the work station influence the metering data remarkable.

Table 5 shows the mean of the metering data of all investigated working stations.

Contrary to the expectations the test series are not completed until deadline. Therefore the results will presented at the poster.

## 5 Results

The test person accepted the changed situations. In S2 und S3 glare was a little bit higher.

Activation and parameters of sleep quality were higher in S2, S3 and S4 compared to S1, but often not significant.Exaples are shown in figure 9, 10 and 11.

Significant effects of age, chronotype and daylight were found. They mask the light effects.

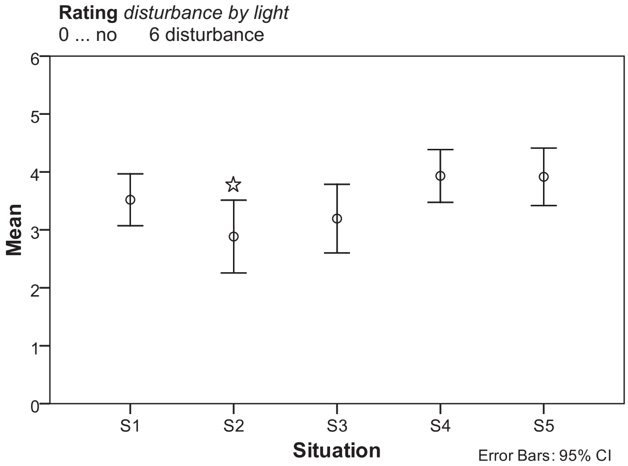


**Figure 9.** Rating of Disturbance of light, Situation S2 differs significantly from situation S1

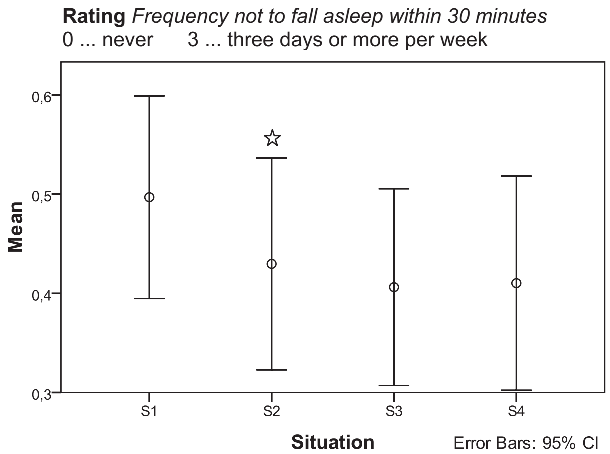


**Figure 10.** Frequency not to fall asleep within 30 minutes, Situation S2 differs significantly from situation S1

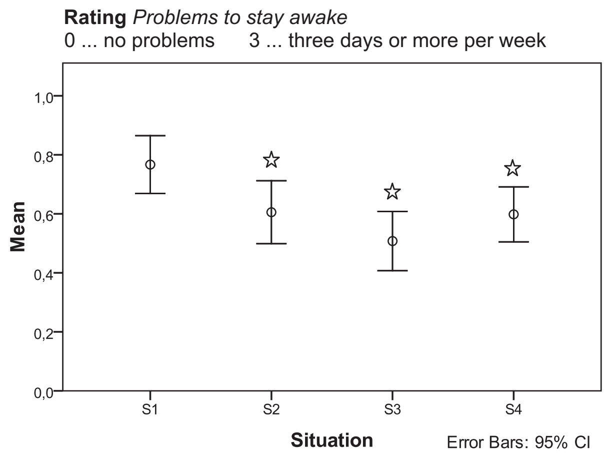


**Figure 11.** Problems to stay awake, all situations differ significantly from situation S1

At the end of the study, subjects were asked in conclusion. 36 subjects participated. Of these, six subjects (17%) were aware that a good illumination increases their influence of light quality on their well-being, their awareness and their sleep quality (Figure 12).

The results of the questionary are shown in Figure 13. They show that there were no significant differences in scores between the existing lighting at the work places S1 and the lighting situation S4. The lighting situations with additional vertical large-scale luminaires S2 and S3 were rated slightly worse. At the lighting situation S4, the volunteers have felt most comfortable. They would prefer this lighting situation for their jobs. The change of the luminous colour of the lamps within the existing lighting system to higher correlated color temperature was positively perceived by the subjects.

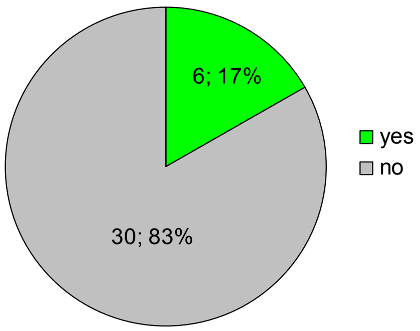


**Figure 12.** Perception of the influence of light quality on well-being, awareness and Activates sleep quality (N = 36)

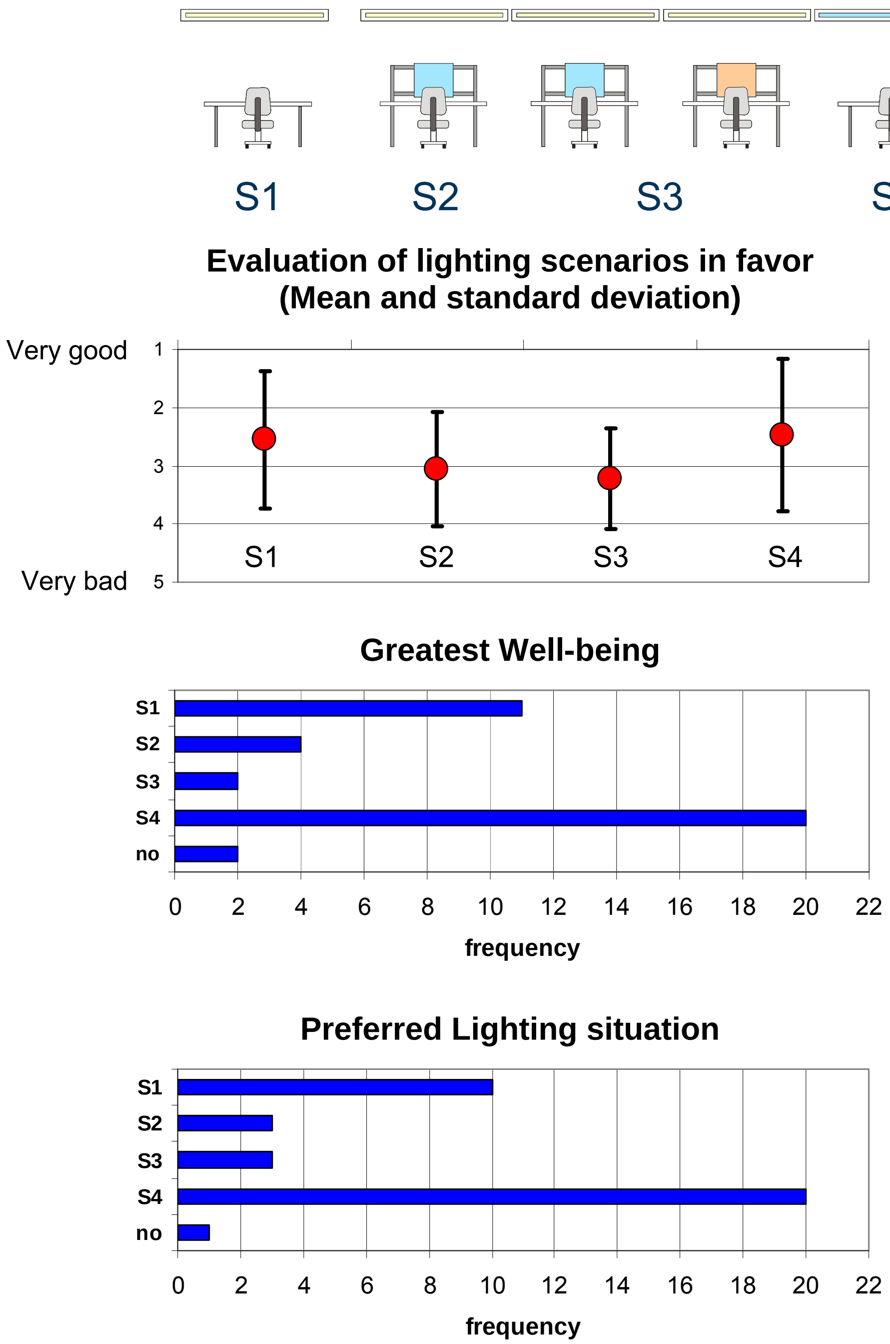


**Figure 13.** Evaluation of lighting scenarios (N = 36), frequency of naming for largest well-being and preferred choise

# 6 References

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