# THE BACKGROUND LUMINANCE AND COLOUR TEMPERATURES INFLUENCE ON ALERTNESS AND MENTAL HEALTH

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## 1. Purpose of the study

*"to lay down the appropriate luminance levels at different colour temperatures for ambient lighting within working areas"*

New research in lighting has shown that light is not only influencing the visual system – it also affects the whole body.

For more than 150 years we have considered rods and cones to be the only photo-receptors in the human eye and that these only affect the visual central areas. Four years ago a new 3rd receptor was found by David Berson at Brown University USA which in fact was the missing link in how the human health is influenced by lighting [1] .

It is now shown that light influences different hormones in the brain where the pineal gland plays an important role in controlling the sleep hormone melatonin which is provided to the blood in the body at low light levels or in darkness. At high light levels the stress hormone cortisol is produced by the adrenal cortex which contributes to alertness.

During the last years a lot of studies have been carried out on how the spectrum of the light (daylight and artificial) affects the hormone suppression and how colours and light distribution in the visual field brings emotional effects to the human being [2] [4].

New legislations on the use of energy and findings in research will and have already created new more efficient lighting systems which are optimal for vision as well as for the human health.

Lighting design will in the future be more focused on visual, biological and emotional aspects and future lighting systems must at the same time be energy efficient.

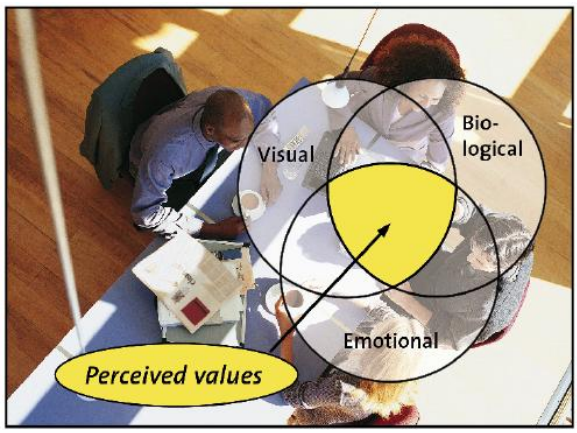
In order to evaluate the need for a sufficient luminance level of ambient light over a working day considering the influence of different colour temperatures from different artificial light sources within the visual field a study has been carried out in cooperation with the Lund University, Fagerhult and the Swedish Energy Agency. The main focus of this study has been the impact of fluorescent light on endocrine and subjective indices of arousal.

36-48 subjects between 18-67 years (m=43) are participating in study. The study is carried out in two equal equipped office rooms where the ambient light in the visual field of view is set to different light levels and colour temperatures (CCT). The study was divided into to parts where the ambient light on different ambient light levels was evaluated using fluorescent tubes at different colour temperatures. .

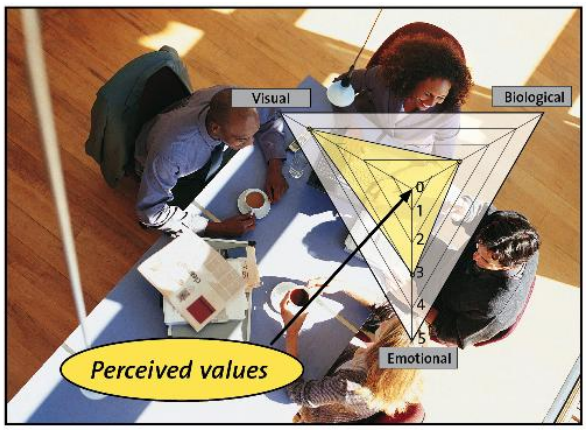
## 2. THE HUMAN ASPECTS OF LIGHT

Lighting design will in the future be more focused on visual, biological and emotional aspects and future lighting systems. In order to describe the design purpose the following evaluation system was used in the study.

### Lighting evaluation of the study




*Evaluation model of a lighting system.*




*Evaluation model of lighting in a working area.*

### Evaluation of a lighting system

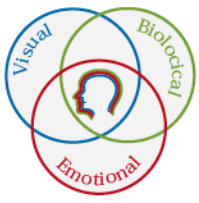
For example in working areas – at task – the visual aspects are of most importance. However, the emotional and biological aspects also have to be considered in order to create creativity and productivity and well-being. In classrooms all aspects could be of equal importance. In another type of application one of the three aspects could of most important.

In lighting design certainly others aspects like energy efficiency and maintenance also has to be considered. These aspects have not been shown in the result of this study.

**Visual**
- Task area lighting
- Visual performance
- Contrast
- Glare

**Biological**
- Ocular light
- Circadian effects
- Mental health
- Alertness

**Emotional**
- Comfort
- Dynamics
- Colours
- Colour of light



## 3. METHOD

The main focus of the study is the impact of fluorescent light on endocrine and subjective indices of arousal.

Four types of fluorescent T5-tubes were used – 3000K / 4000K – and 8000K / 17000K each at three different luminance levels of the ambient vertical luminance levels– 20 cd/m$^2$, 100 cd/m$^2$ and 350 cd/m$^2$. The light spectrum was kept constant for all luminance levels for the different colour temperatures (CCT).

The vertical luminance was kept uniform within ±30° of the horizontal line of sight.
The horizontal illuminance was kept at 500 lux within the working area /task area for each ambient luminance level.

Exposure lasted for one whole day for each of the six combinations. The rooms were designed as ordinary office rooms. In a pilot study the luminance levels was checked to be reasonable. Thereafter the final luminance levels were decided. The subjects were randomly assigned to start at different levels of luminance.

Measurements concerning the endocrine indices (cortisol and melatonin) were obtained in the morning, at noon and in the afternoon on the day of light exposure, but also in the afternoon on the day preceding the experiment.

The morning samples were collected by the subjects around seven o'clock, which means that the obtained values will reflect the amount of melatonin excreted during night, as well as the pronounced diurnal rise in cortisol taking place in the early morning. The samples from the afternoon were taken around four o'clock, showing the suppression of melatonin during the day as well as the levels of cortisol.

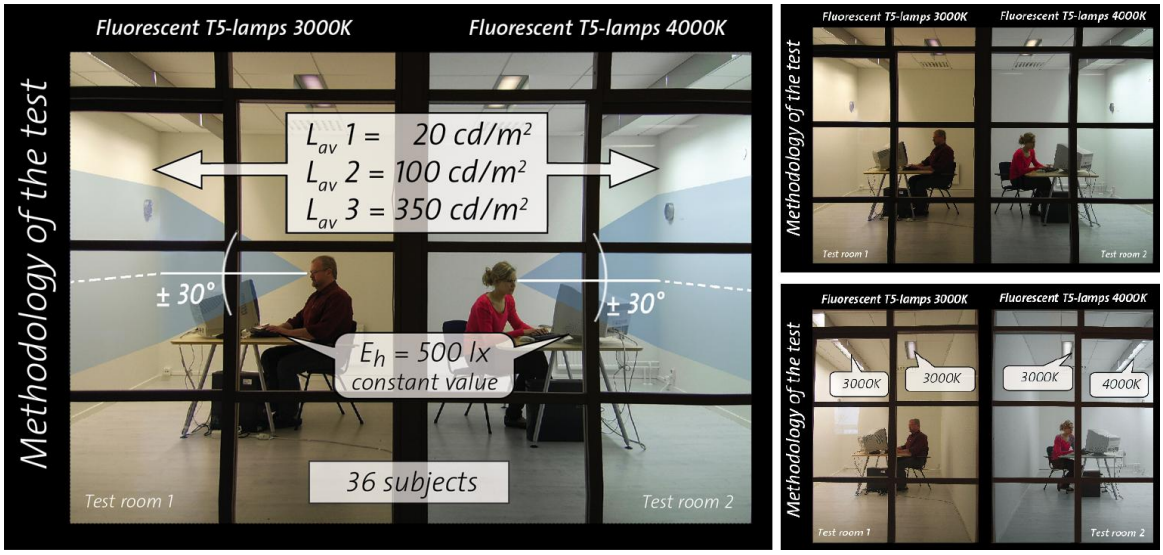
Furthermore, the visual discomfort, subjective assessment of lighting quality was assessed by different forms shown on a VDU connected to a computer in the office room.

The affective state of the subjects described as general well-being, level of sociability and activation was also measured.

Additional measurements concerning personality and diurnal rhythm were also conducted by means of questionnaires and interviews.

The data were treated by means of ANOVA, repeated measures where every subject acted as their own control.

## 4. DESIGN OF THE STUDY



**Time Schedule**

**Day 1 PM**

14:45 Saliva – Cortisol / Melatonin test 1

For each light setting endocrine indices on Cortisol and Melatonin levels was measured 5 times. Subjective and emotional tests of the different light scenes were also carried out during the test as shown in the enclosed test schedule beside.

**Day 2 AM**

07:00 Wake-up time – SalivaCortisol/Melatonin 2
08:45 Saliva Cortisol/Melatonin 3
09:00 PC-Computer welcomes
09:15 Subjective experience of lighting 1
09:30 Subjective emotional experience 1
10:00 Visual stress 1
10:30 Daily rhythm (subjective experience)
11:00 Subjective experience of lighting 2
11:30 SMB (subjective conception of the room)
11:45 Saliva – Cortisol/Melatonin 4
12:00 Lunch at site

**Day 2 PM**

13:15 Subjective experience of lighting 3
13:30 Subjective emotional experience 2
14:00 Visual stress 2 (eye strain – due to glare)
14:30 SQM (SAD-test questionnaire)
14:50 Personality test type AB
15:10 SIGH Revised (depressive ability)
15:30 Subjective experience of lighting 4
15:45 Subjective emotional experience 3
15:50 Saliva – Cortisol/Melatonin 5
16:00 Debriefing

## 5. RESULTS

The results on the visual, biological and emotional indices measured in the afternoon at 03.50pm when subjects had been exposed for a whole working day are shown below.
Other measurements were made (see time schedule) but are not shown in this paper.

### Study Part 1 – Comparison between 3000K and 4000K

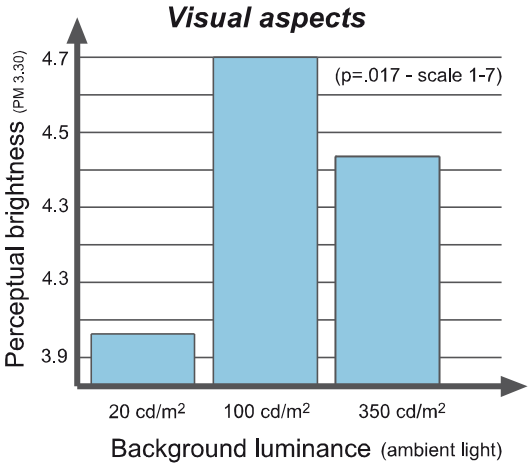
### Visual Aspects

**Perceptual experience** – Subjects sitting in the 4000K room experienced the room significant more cool than their counterparts in the 3000K room. The visual perception of brightness also showed a significant difference between the three lightness levels. However, the subjects experienced the 100 cd/$m^2$ situation as the brightest, followed by the 350 cd/$m^2$. The 20 cd/$m^2$ situation was perceived as the least bright environment (**Figure 1**).

This result may be caused by the fact, that when the lightness of the ambient light was higher than the lightness of the working area (desk lightness ~140 cd/$m^2$) the eye is adapted to a higher level which results in a lower brightness of the desk. (see figure). However no significant differences were found between 3000K and 4000K.

Previous studies on preferred luminance distribution has shown that ambient light levels around 80 cd/$m^2$ at a horizontal illuminance level within the task area of 500 lux when using a general lighting systems [3].

*Figure 1*




## Emotional Aspects

**Subjective arousal** – The alertness showed a significant difference between the three lightness levels (**Figure 2**). The subjects showed more arousal when the ambient luminance was higher.

**Subjective feelings** – However concerning emotional feelings the subjects displayed significantly most positive feelings when the ambient luminance level was 100cd/$m^2$ and least at the 350cd/$m^2$. The negative emotional feelings at 350cd/$m^2$ may indicate an emotional stress effect (**Figure 3**).

No significant differences were found between 3000K and 4000K concerning these aspects.

*Figure 2*

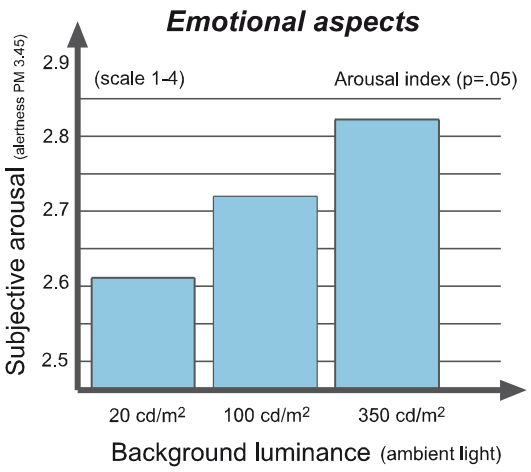
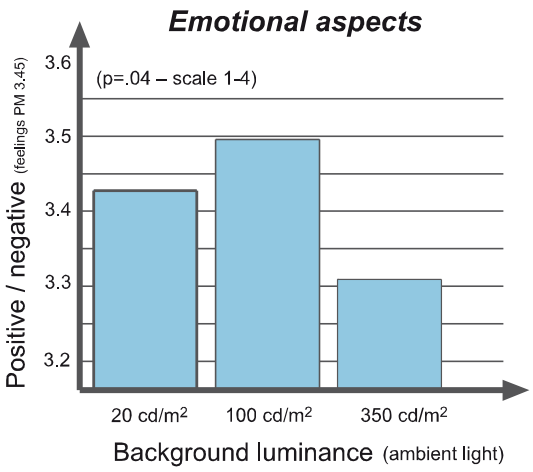


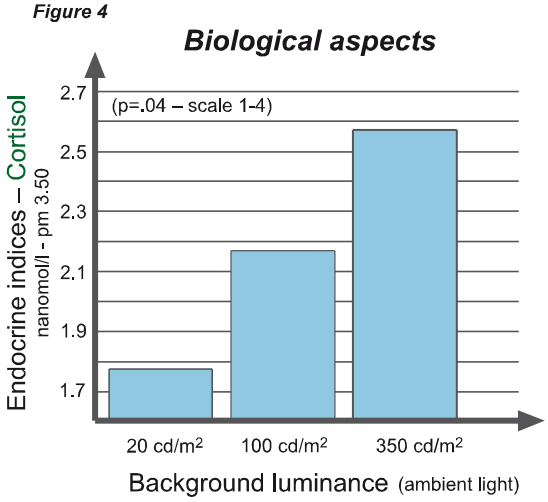

*Figure 3*




## Biological aspects

**Hormone analyses** – The cortisol levels showed a significant increase when the ambient light (background luminance) was increased (**Figure 4**). No significant differences were found regarding the melatonin concerning the ambient light levels. Due to the fact that cortisol is a stress hormone one may consider the high levels of 350cd/$m^2$ as a negative stress factor. This must however be further analysed for the final report.

*Figure 4*




**Influence of colour temperature (CCT)** – No significant differences where found when comparing 3000K and 4000K at the different ambient light levels. However when only comparing the groups entering the 3000K room with the group entering the 4000K room significant differences were found for both cortisol and melatonin. Higher levels of cortisol and lower levels of melatonin were found in 4000K concerning aveage values of 100cd/m$^2$ and 350cd/m$^2$ (**Figure 5 & 6**).

*Figure 5*

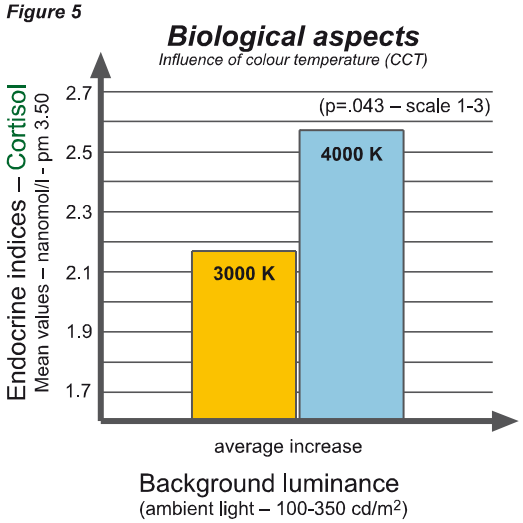
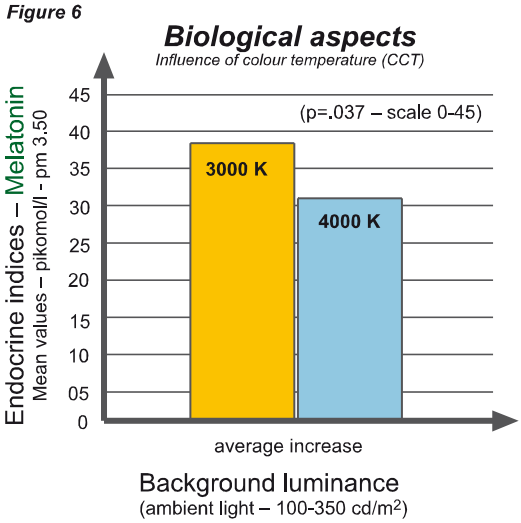



*Figure 6*




Since no main effect was found these results must be interpreted with caution. For example just a few subjects in our sample showed an extreme sensitivity to the higher colour temperature (4000K), but we were not able to find any relation to the background variables such as age, gender etc. In the future one aim is to define these sensitive groups.

### Study Part 2 – Comparison between 8000K and 17000K

#### Visual aspects

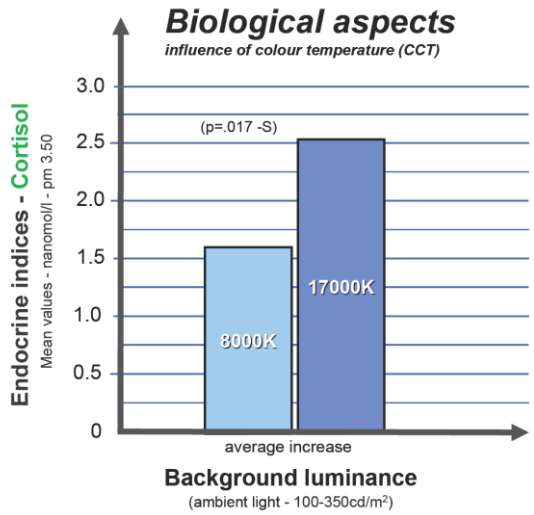
No differences were found between the luminance levels and nether between the different coulor temperatures.

#### Biological aspect

No differences were found between the luminance levels. However a difference was found between the different colour temperatures. The higher colour temperature 17000K gave from a general point of view a higher effect on cortisol. (**Figure 7**)

Cortisol levels on 8000K = 1.58 nmol/l and on 17000K = 2.54 nmol/l. Significance p = .017

***Figure 7***

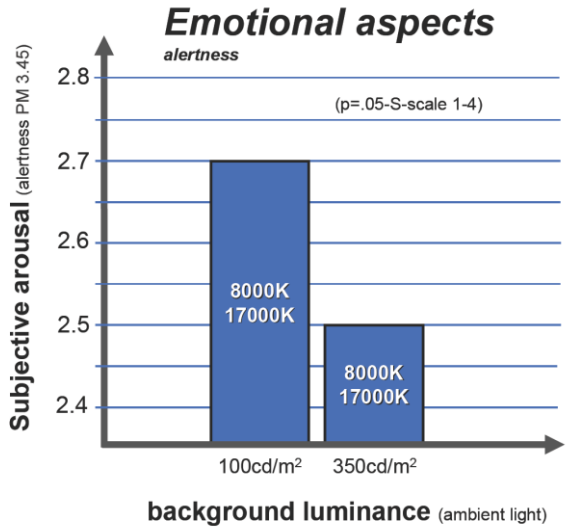



## Emotional aspects

**Subjective arousal** – The alertness showed a small but significant difference between 100cd/m$^2$ and 350cd/m$^2$. The subjects felt most activated at an ambient luminance level of a 100 cd/m$^2$. (**Figure 8**).

Subjective arousal levels on a scale 1-4; 2.7 (100cd/m$^2$) and 2.5 (350cd/m$^2$)

***Figure 8***




## 6. CONCLUSION

*Part 1 – Comparison between 3000K and 4000K*

Our alertness is increased on a scale when we increase the ambient light. It also has the same effect on the stress hormone cortisol. Regarding emotional feelings there was a negative response at the highest ambient luminance level 350cd/m$^2$, and the subjects also perceived the environment in the room as brightest at 100cd/m$^2$.

We found most positive reactions at 100cd/m$^2$ concerning visual and emotional aspects. For future lighting applications we therefore recommend an ambient luminance level of around 100cd/m$^2$.

*Part 2 - Comparison between 8000K and 17000K*

The differences between the two colour temperatures were minor. Due to the higher colour temperatures the impact of the different luminance levels is smaller. Only a significant difference on emotional aspect was found. Subjects felt more activated at 100cd/m$^2$.

Both studies show that the level of background luminance has an influence on visual, emotional and biological aspects. We found most positive reactions at 100cd/m$^2$ concerning visual and emotional aspects. In both studies we the cortisol levels increased by the ambient light level. However the emotional feelings were most negative most aspects on the highest ambient light level. Whether this is caused by negative stress is to be evaluated in a final report.

Based on this study we can not draw a conclusion that fluorescent tubes with higher colour temperatures between 8000K and 17000K should be better impact on the aspect of the subject's wellbeing when having a fixed illuminance level of 500lux at the horizontal work plane.

However both studies showed that 100cd/m$^2$ gave the most positive reactions concerning the ambient light on visual and emotional aspects. For future office lighting applications we therefore recommend an ambient luminance level of around 100cd/m$^2$.

## REFERENCES

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