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DEFINITION AND MEASUREMENT OF CIRCADIAN RADIOMETRIC QUANTITIES

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ABSTRACT

Based on the definition of the circadian action function *c(λ)* it is possible to build up a circadian metric and to deviate measuring methods for the evaluation of lighting systems. With the help of the circadian action factor a_{cv} it is possible to derive circadian quantities from photometric quantities. It describes the circadian efficiency of the colours of light. The measurement of a_{cv}-values is possible by different methods:

- by spectroradiometers
- by *c(λ)*-adapted detectors
- as a first approximation with the CIE standard colour-matching function $\bar{z}(\lambda)$

Nowaday modern technologies offer the production of light sources with different circadian action factors. So it is possible to produce lighting systems allowing the specific change of the a_{cv}-value.

Based on this cognitions a special investigation of the circadian light action is possible.

Keywords: circadian action function, circadian action factor a_{cv}, circadian action of light, spectral action, circadian measurement

1. DEFINITION

Based on the experimental findings of BRAINHARD [1] and THAPAN [2] for the action spectrum for light induced melatonin suppression for several wavelengths it is possible to define a circadian action function c(λ) (**figure 1**) [3]. With the help of this circadian action function a circadian radiation quantities X_{ec} can be calculate:

$$X_{ec} = K \int X_{\mathrm{e}\lambda}\, c(\lambda)\, \mathrm{d}\lambda \qquad (1)$$

and $K = 1$

The ratio of the integrals of the circadian and the photometric quantities is called by GALL und LAPUENTE [4] the circadian action factor a_{cv}:

$$a_{cv} = \frac{\int X_{\mathrm{e}\lambda}\, c(\lambda)\, \mathrm{d}\lambda}{\int X_{\mathrm{e}\lambda}\, v(\lambda)\, \mathrm{d}\lambda} \qquad (2)$$

This action factor allows a comparison of different colours of light. The relation between circadian quantities and photometric quantities X_v is as follow:

$$X_{ec} = \frac{a_{cv}}{K_m} X_v \qquad (3)$$

So it is easy to transfer the quantities into each other.

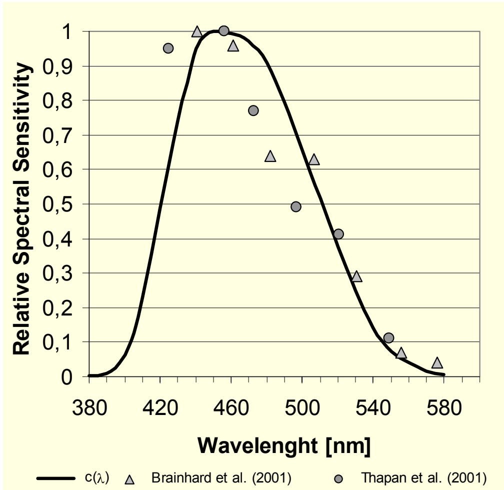

Figure 1: Averaged circadian action function *c(λ)* by GALL [3]

2. MEASUREMENT

The measurement of a_{cv}-values is possible by different methods:

- by spectral measurement
- by integral measurement with *c(λ)*-adapted detectors

2.1 Spectral Measurement

The spectral light distribution can be measured by spectroradiometers. The calculation of the quantities is possible by the equations (1) to (3).

2.2 Measurement with *c(λ)*-adapted detectors

Filters can be used for the adaptation of detectors to special spectral sensitivities. The spectral sensitivity of the blue detection channel of the digital camera of ROLLEI (LMK mobile) [5] is similar to the circadian action function *c(λ)*. The measurement camera LMK color [6] has a special filter which is very well adapted to *c(λ)* (**figure 2**). These devices can measure spatial resolved a_{cv}-values. **Figure 3** shows an example.

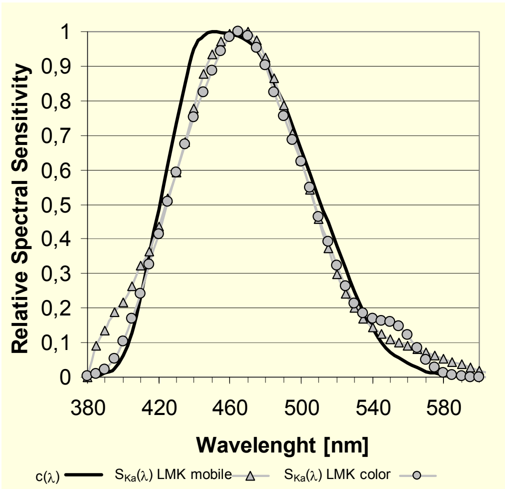

Figure 2: Spectral sensitivity of the blue detector channel of the LMK mobile [5] and of the LMK color with a *c(λ)*-filter [6]

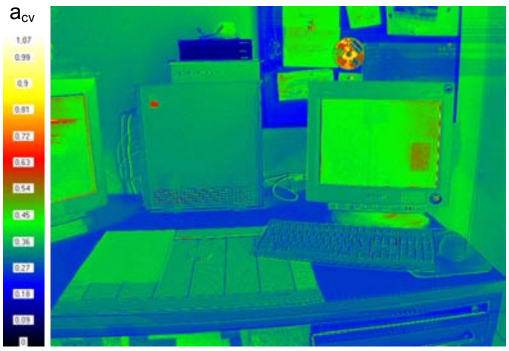

Figure 3: The distribution of a_{cv}-values within an area of measurement

As a first approximation with the CIE standard colour-matching function $\bar{z}(\lambda)$ the circadian action factor a_{cv} can also be measured. Tristimulus colorimeters can be used. The spectral sensitivity of the Z-detector is round about the *c(λ)*-function (**figure 4**). With the Y-detector you can measure the photometric quantity.

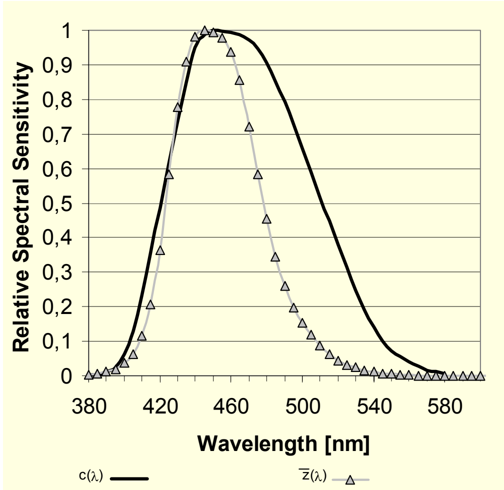

Figure 4: CIE standard colour-matching function $\bar{z}(\lambda)$ of the tristimulus colorimeter HCT-99 [7]

As a first approximation the a_{cv}-value can be calculated by CIE chromaticity coordinates [3]:

$$a_{cv} \approx \frac{\int X_{e\lambda}\,\bar{z}(\lambda)\,\mathrm{d}\lambda}{\int X_{e\lambda}\,v(\lambda)\,\mathrm{d}\lambda} = \frac{z}{y} = \frac{1-x-y}{y} \quad (4)$$

Figure 5 shows lines with similar a_{cv}-values in the CIE standard chromaticity diagram.

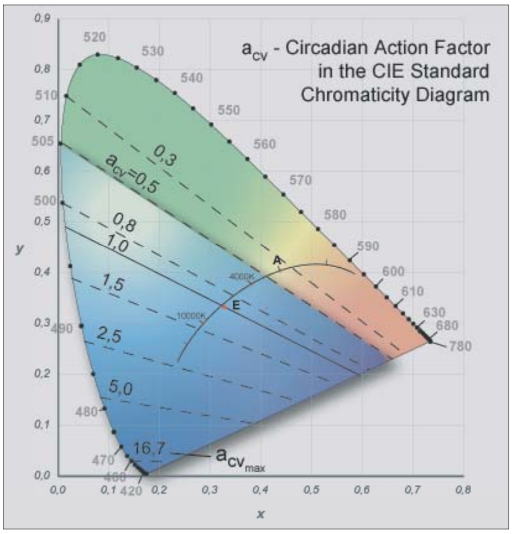

Figure 5: a_{cv}-values in the CIE standard chromaticity diagram [3]

This is a very practicable method of the circadian evaluation of the colour of light of lamps. A description of the a_{cv}-value is also possible with the correlated colour temperature (*CCT*). **Figure 6** shows this correlation.

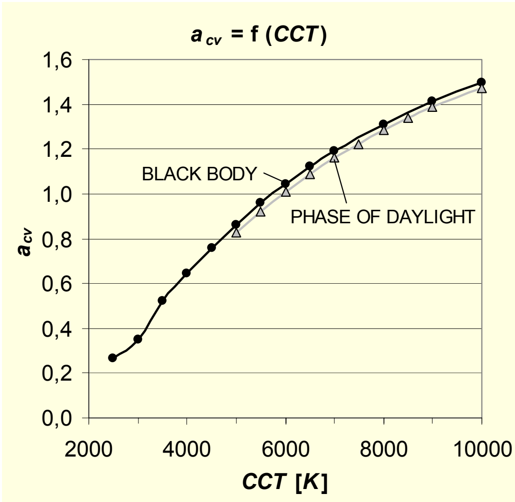

Figure 6: The circadian action factor a_{cv} as a function of the colour temperature (*CCT*) [3]

3. INVESTIGATIONS OF LIGHT SOURCES

Nowadays modern technologies allow to optimise light sources. In order to provide an overview we have selected and measured different light sources. The measured averaged circadian action factors are resumed in table 1. The values are not representative, but they show quantitative differences.

Table 1: a_{cv}-values of different types of light sources (examples) [8], [9]

Light Sources	a_{cv}-Value
direct sun 5081 *K*	0,76
blue sky 19963 *K*	1,49
cloudy sky 5924 *K*	0,88
incandescent lamp 2800 *K*	0,35
HMI 3640 *K* neutral white, ceramics	0,39
high-pressure sodium lamp 2770 *K*	0,28
Fluorescent Lamps	
warm white 2827 *K*	0,31
neutral white 3678 *K*	0,52
Basic DAYLIGHT 765 6750 *K*	0,85
LUMILUX DAYLIGHT 865 6400 *K*	0,80
DELUXE BIOLUX 965 6500 *K*	0,94
LUMILUX SKYWHITE 880 8000 *K*	1,00
“Truelite” 5600 *K*	0,76
Light-Emitting Diodes	
LED blue λ_{max}= 468 *nm*	6,9
LED white	1,05 .. 2
Maximum (monochromatic 460 *nm*)	26,3

4. INVESTIGATIONS OF REAL WORKING ENVIROMENTS

Circadian action factors were investigated in real work environments (offices and industrial tasks) [8], [10]. The a_{cv}-values were measured in the task areas according to the typical line of sight horizontal or vertical. The a_{cv}-values we have found are typical in the range between 0,35 and 0,45. The illuminance in the task area was in minimum 320 lx and in maximum 1640 lx.

Important for the circadian effect are not only the a_{cv}-values and the illuminance in the task area, but the radiation absorbed in the eyes can cause a circadian effect. This means the illuminance and the a_{cv}-value on the eye are important. They are influenced by the reflectance behaviour of the environment (**figure 7 to 9**). The investigations show circadian efficient irradiances in the range between 0,06 *W/m²* and 0,24 *W/m²* ($c(\lambda)$-weighted – equation (1)).

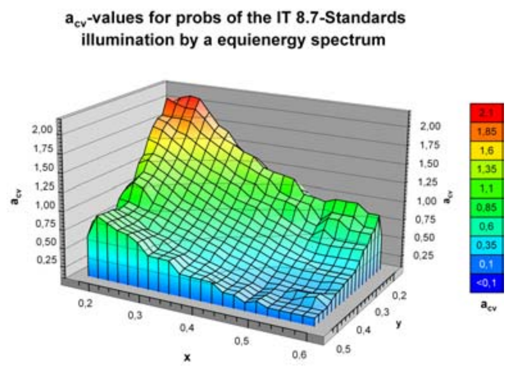

Figure 7: Variation of the circadian action factor a_{cv} in dependence on CIE chromaticity coordinates x, y by illumination with a equienergy spectrum, a_{cv}: 0,86; *CCT*: 5484 *K*

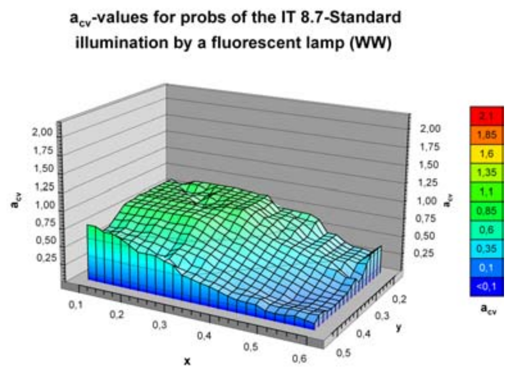

Figure 8: Variation of the circadian action factor a_{cv} in dependence on CIE chromaticity

coordinates x, y by illumination with a fluorescent lamp ww, a_{cv}: 0,34; *CCT*: 3075 *K*

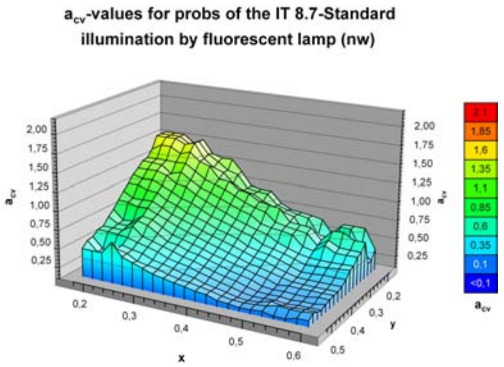

Figure 9: Variation of the circadian action factor a_{cv} in dependence on CIE chromaticity coordinates x, y by illumination with a fluorescent lamp nw, a_{cv}: 0,55; *CCT*: 4708 *K*

5. SUMMERY

By definition of the circadian action function $c(\lambda)$ it is possible to determine the circadian effect of different types of light sources. The circadian action factor a_{cv} is able to describe this effect. It is possible to deviate it from photometric quantities. Based on this it is possible to investigate the effect of lighting systems and to find out useful dosis rates. In the future it is necessary to include not only photometric quality criteria, but also circadian effects in order to provide an optimal lighting systems. So the measurement of the circadian action factor a_{cv} for lamps, luminaries and lighting systems will be essential.

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