LiTG – Department of Interior Lighting

LIGHTING QUALITY – A PROCESS RATHER THAN A SINGLE FIGURE

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Deutsche Lichttechnische Gesellschaft e.V.

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Lighting Quality – a process rather than a single figure

Method for capturing the requirements of a lighting solution and its assessment for determining lighting quality

36

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Content

1 Introduction

1.1 Problem statement – Experiences in everyday life

Current projects are often affected by specific specifications regarding energy saving and cost optimization. In many cases this may have a detrimental effect on the lighting quality where the standardized criteria regarding lighting are met while the needs of the actual users only play a minor role. The Lighting quality should combine the views of various persons such as lighting designers, end users, architects, operators and investors regarding well designed lighting solutions and should not be confined by the indices for energy efficiency and cost.

We like to use the term »Lighting Quality« whenever we make a statement regarding the subjective »quality« or »excellence« of a lighting solution. Is this assessment adequate in order to objectively capture the lighting quality? Is it sufficient to select a few criteria in order to provide a holistic appraisal of lighting quality?

Various experiences in everyday life illustrate the point:

The architect's office: The space offers a sublime design. The ceiling is dark, the walls are covered in muted colours. The desk made off black timber shows its valence. An individually designed luminaire with a pleasant, curved shape emitting light towards the dark ceiling is suspended above the desk. The illuminance values are not sufficient in order to carry out any work over longer periods of time without suffering from fatigue. The entire ambience aims at representation rather than creating a working environment.

→ The ideas of architect and end user have not been harmonised and thus provided an inappropriate focus when formulating the requirements.

The factory building: The high bay luminaires are suspended in an optimized regular grid across the space. High lumen packages provide even illumination across the entire hall with a comparatively small number of luminaires. Currently the production workplaces are arranged in a regular pattern. In future, part of the hall should be converted to a storage area with high racks while in another area workplaces for packaging shall be installed and in yet another part repair work shall be carried out. What will be missing, are the necessary illuminance levels as well as adequate directional light to cater for these future tasks.

→ In this example the actual purpose of the space and its intended use and thus the user requirements are not known.

The workplace in a university: In the historical buildings of the university there are dozens of similar rooms: They are generous with high ceilings and suitable for many different types of work and study. Some rooms are occupied by IT people working with computer screens whose workplaces are densely packed into the available space, electrical engineers in front of test set-ups as well as a group of architects using large size drawings and 3D mock-ups. The university's department responsible for determining the interior fit-out has arranged for the installation of low brightness office luminaires across all spaces. The latter are a reasonably cheap, energy efficient mass product providing equal illuminance levels and very good uniformity: however, everybody "enjoys" the same lighting but nobody gets the right light for their tasks!

→ In this example the actual purpose of the space and its intended use are known, however, the requirements were "standardized" and the lighting scheme was optimized in the line of cost minimization and energy efficiency.

The piece of artwork The masterpiece is illuminated with state-of-the-art light sources and excellent colour rendering. The painting is lit with perfect uniformity; every little colour hue can be discerned. The question remains: Does this do justice to what the artist intended who actually created the painting in the light of a candle?

→ In this example neither the requirements of the artist nor most likely the intentions of the curator have been considered.

The conference room: Without a doubt this room is very prestigious with a pleasant ambience and an attractive ceiling with a set-back haunch. The indirect lighting installed in the haunch as well as the small spots along the perimeter are an unobtrusive part of the overall appearance. Both lighting systems may be turned on and off by separate switches. Unfortunately the room is simply too relaxing for any serious meeting and not quite suitable for presentations using data projectors, because it is either too bright or completely dark.

→ Here neither the utilisation of the space nor the specific lighting requirements have been fully taken into account; end user and designer are not in tune.

The class room: The pupils enter the class room illuminated by sallow daylight filtering through the windows. Girls and boys sidle to their respective desks. Shortly afterwards the teacher enters the room and turns on the lights. All of a sudden the room is brightly lit. Everything appears evenly illuminated by neutral white light sources providing 500 lx on all desks. The lesson begins: The data projector is turned on and the lights are turned off resulting in sudden darkness. The various lighting scenarios neither support the pupil's different learning phases nor the variety of teaching materials.

→ In this case the lighting was optimized in order to assure low cost, energy efficiency and functionality. The actual user requirements have hardly been taken into account.

Such experiences clearly show that lighting quality cannot be reduced to a single aspect or just a few parameters. Often the requirements for a lighting solution are not comprehensively recognized, or if so, they have not been weighted appropriately. The scenarios described show that the search for a solution with the user's requirements in mind is often neglected. So far it seems to be common practice to define lighting quality by describing some individual criteria or parameters respectively. Of course, it would be far better to capture and evaluate lighting quality in the form of a process.

1.2 Past practice: Hitherto applied approaches towards a definition of lighting quality

In order to adequately describe a lighting solution, engineers and scientists have always been searching for criteria and parameters. In the past, one attempted to capture the essence of lighting quality by defining and evaluating certain characteristics. Historically the first approaches go back to the introduction of electric lighting.

Selected historical approaches for describing lighting quality:

1912 Illuminating Engineering Society
»Light: Its Use and Misuse«
The IES (Illuminating Engineering Society of North America) composes an initial description of rules for good lighting.

1951 Guth
BCD – Brightness of Source«
S. K. Guth conducts studies related to the luminance distribution at the borderline between comfort and discomfort and deals with discomfort glare as well as the lighting needs of elderly people.

1952 Kelly
»Ambient Light«, »Focal Glow« and »Play of Brilliants«
In the opinion of architect and lighting designer Richard Kelly light shall provide a comfortable ambience and enhance the well-being of the workers. For the purpose of differentiating and describing the lighting components to be employed based on their effect, Kelly developed the three dimensions of light: »Ambient Light«, »Focal Glow« and »Play of Brilliants«.

1959 Blackwell
»Visibility Level (VL)« und »Equivalent Sphere Illumination (ESI)«
These models are based on studies conducted by H. R. Blackwell. The VL describes the ratio between the contrast of the visual task (object) in the current lighting scenario relative to the contrast of the same task (object) that could just be detected with a 50% probability. ESI identifies the equivalent semi-sphere diffuse – illumination where the conspicuity of the visual task is equal – such as under the current lighting scenario. It is quite difficult to implement this model in terms of measurements. The CIE used this model as a template for defining the commonly used parameters »Contrast Rendering Factor (CRF)«, »Disability Glare Factor (DGF)« and »Transient Adaptation Factor (TAF)«.

1970 Hopkinson
Extended base for recommendations regarding lighting quality
Besides glare and flicker limitation and visual performance Hopkinson’s recommendations regarding the lighting quality are based on the additional factors fatigue, light colour, colour rendering and perceived brightness.

1977 Lam
Introduction of a new design criterion for lighting design
According to the lighting designer William M. C. Lam good lighting quality is not just meeting the basic requirements regarding visual perception as well as architectural features. In addition, he introduced the biological-psychological need to be able to orientate oneself in terms of space and time amongst others.

1981 Boyce
Expansion of previous approaches
Boyce adds the aspects of visual comfort and user expectations to the previously known approaches.

1992 Bean and Bell
»Consumer, Satisfaction and Performance (CSP-Index)«
Bean and Bell develop the CSP index. It consists of three co-acting core elements of comfort, satisfaction and performance. They complement the previously existing approaches with the factor called subjective lighting quality.

1994 Baron
New conceptual model
Baron develops a conceptual model describing the relationship between physical factors, personal properties and individual needs.

1996 Veitch and Newsham
»Visual Comfort Probability (VCP index)«
Veitch and Newsham introduce the VCP index. The model predicts the perceived glare by the observer via the photometric data of the luminaires in the observer's field of vision and their geometric arrangement.

1996 Veitch
Additional influence factors
According to Veitch the following influence factors are relevant for good lighting: visual performance, workplace related visual performance, social interplay and communication, mood of the workers, health and safety of the workers, aesthetic aspects.

1998 Kramer
»Eight commandments for good lighting design«
Heinrich Kramer develops the »Eight commandments of good lighting design« representing design recommendations in the architect's language.

2005 Schierz, Dehoff, Tralau
»Ergonomic Lighting Indicator«
Christoph Schierz, Peter Dehoff and Birthe Tralau develop the Ergonomic Lighting Indicator: This indicator relates five characteristics contributing to lighting quality in a radar chart (Kiviatgraph): Visual performance, appearance, visual comfort, emotion, individuality and flexibility.

Two dominating approaches may be extracted:

- Lighting quality is the result of the sum of factors describing a lighting solution without direct connection to illuminance levels (Stein, Reynolds und McGuiness, 1986).

- Lighting quality is part of a holistic approach achieved when the requirements of individual users are met (Veitch, Newsham, 1995, 1998, 2006, 2010). The objective is to create a balance between well-being, economy and architecture in every lighting solution.

Generally it can be said that so far no single parameter predicting the lighting quality from the user's point of view has been found. Too many criteria are necessary in order to adequately describe lighting quality, some of which can be measured while others are not directly quantifiable but only subjectively assessable.

1.3 Objective of this publication

With the knowledge of previous approaches this publication presents a model capturing the requirements of different users and leading to specific measures in lighting design for certain applications and finally an appraisal of such measures. In addition to a pure collection or weighting of quality criteria for good lighting this work introduces a practical process for the holistic description of lighting quality.

The aim of this publication is to create awareness for holistic lighting solutions and quality factors that go beyond normative criteria of lighting quality and that take into account the needs of various project process participants. For this purpose the requirements and descriptive quality criteria are captured and transparently illustrated in implementation measures (means of design). Thus recommendations for the enhancement of lighting quality may be deduced. Finally a range of numerical values for the appraisal of lighting concepts may be found. The participation and co-determination by the user increases his acceptance for a certain lighting solution.

This publication is aimed at ambitious practitioners and lighting designers.

It is not a design guide line and does by no means replace the lighting designer in any project. It serves to better understand lighting quality.

1.4 Structure and utilisation of this publication

This publication provides a comprehensive description of requirements, means of design and attributes for appraising the lighting quality that should be considered when designing a lighting solution for a specific application. The publication serves as an aid for the comprehension of different aspects rather than for providing an obligatory specification. It may be applied by various different persons involved in the design process and covers the following content:

- Up-to-date collection of research, science and application know-how regarding criteria for lighting quality
- Illustration and increasing awareness of ALL quality criteria including those who go beyond the known normative criteria
- Holistic consideration and weighting of requirements subject to the respective application
- Overview on means of design in lighting design
- Catalogue of measures for the implementation of quality lighting solutions with subject to the respective application
- Overview on quantitative and qualitative appraisal factors of lighting quality

The following steps and methods are covered:

- Determining user requirements
- Weighting of requirements with subject to application
- Implementation of lighting solutions bymeans of design and measures for achieving the goals
- Appraisal of lighting solutions against the requirements with the aid of attributes

First, the process consisting of three steps to achieve a light quality is described. In order to illustrate this process, it is presented in simplified form using an example.

The comprehensive weighting, means of design and attributes for the appraisal are listed in the appendix. Appendix A contains the tables for the example. Appendix B explains the individual steps of the process and subdivides them to match the respective applications. With the aid of these tables and the relevant descriptions one can implement the process for achieving lighting quality virtually for any application.

2 Lighting quality – a process rather than a single figure

2.1 Description of the process

Figure 1 illustrates how to understand achieving lighting quality as a process. First the individual steps of the process are implicitly applied in an example. Appendix B provides more detail on the individual steps of the process.

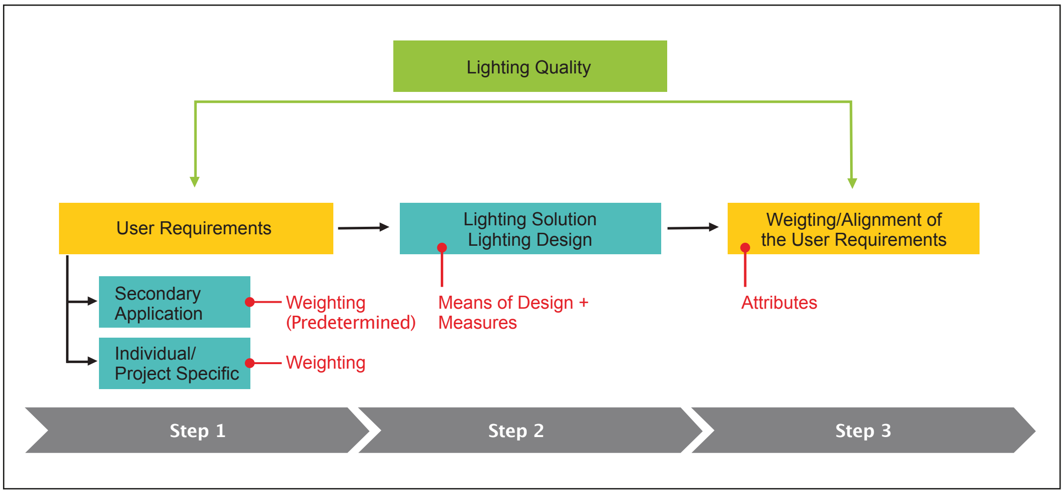
In chapter 3 we propose a definition of lighting quality. Furthermore, we provide an overview of the elements that form the lighting quality of an interior space and show how it distinguishes itself from other factors.

Step 1:
a) The user requirements are described in Appendix B1. Thereupon the requirements are either listed according to their importance for a specific application or are allocated to a specific project. The weighting results from experience and statements by experts for predetermined main applications and some specific secondary applications. In case none of the general profiles may be applicable the weighting can also be conducted individually.

b) The weighting indicates how »important« respectively how »relevant« each particular requirement is. Requirements with a higher weighting must be met in order to achieve a high degree of lighting quality (also refer to chapter 2.2 and Appendix B2).

Step 2:
In this step of the process the actual lighting design begins. In order to design a lighting solution, the means of design and the measures to meet the requirements are first presented.Some attributes for appraising lighting quality are already assigned (Appendix B3).

Figure 1: Process steps and methods for describing lighting quality



Step 3:
The process is only completed once the existing or planned lighting solution is being appraised with regard to the originally defined requirements. This appraisal is based on quantitative and qualitative attributes (Appendix B4). Quantitative parameters can be calculated and aligned to predetermined normative requirements. The appraisal of the qualitative attributes results from the degree to which they meet the requirements.

The magnitude of the attributes is determined by an expert who considers relevant guidelines, standards, codes of practice and experience.

The primary relevant guidelines, standards and codes of practice are listed.

The appraisal of the lighting solution is valid at any time of day or night. This may imply that the artificial lighting is assessed differently in conjunction with natural light during the day and the night. In the case of a dynamic lighting situation, the lighting quality may be assessed variously at different stages because the appraisal is always related to a momentary real lighting scenario.

Table 1 shows a total overview. The means of design (Appendix B3, top line) are available for meeting the requirements (Appendix B1, left column). Relevant combinations are shaded grey. A grey field stands for a weighted requirement for a specific application (Appendix B2) as well as measures (from Appendix B3, Tables 12 through 20) and attributes for appraisal (Appendix B4).

Table 1: Overview over the aspects of lighting quality: grey field = relevant means of design for the requirements as well as attributes for the appraisal (refer to Appendix B4)

Requirements (see appendix B1)		Means of design (see appendix B3): Luminous flux of the light source	Relative size of the light emitting area	Number, arrangement and position of source(s)	Light colour	Light distribution	Spectral distribution of the light source	Dimmability of the lighting system	Operating the lighting system
Functional requirements									
F1	Seeing and identifying details	*E* *Fl*		U_o B_{Re} *CRF* *SS*		*Uo* *Bal* B_{psy} B_{phy} *SS*			
F2	Seeing and identifying shapes			*SS* *Mod*		*Bal* *Mod*			
F3	Seeing and identifying colours				R_a *CCT*		R_a		
F4	Speed of perception and identification	*E* *Fl*				*Bal* *Mod*			
F5	Seeing and identifying over a period of time							*Q*	
F6	Directing attention	*E*	*Q*	*HK* *Q*	*FK*	*Q*		*Q*	
F7	Order/ability to differentiate	*E*		*HK* *Q*	*Q*				
F8	Physical safety	*E*						*Q* *Fl*	
F9	Physical protection	*E* H_{dm}					H_{dm}		
Biological requirements									
B1	Activation	*E*	*Q*	*Q*	*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B2	Relaxation	*E*			*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B3	Circadian rhythm	*E*		*Q*	*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B4	Protection against radiation						H_{dm} *Q*		
B5	Physiological effects of radiation						*Q*		

Psychological requirements									
P1	Spatial orientation	*E* *HK*		*HK* *Q*	*CCT* *Q*				
P2	Chronological orientation	*E*			*CCT* *Q*	*Bal*		*Q*	
P3	Orientation regar-ding proceedings	*E* *HK*							
P4	Privacy	*E* *HK*		*HK* *Q*		*Bal* *Q*			*Q*
P5	Personal territory	*E* *HK*	*Q*	*HK* *Q*		*Bal* *Q*		*Q*	*Q*
P6	Self-expression/ presentation	*E* *HK*		*HK* *Q*		*Bal* *Q*		*Q*	*Q*
P7	Feeling of savety	*E*				U_o *Bal* *Q*			
P8	Self monitoring							*Q*	*Q*
P9	Mental activation	*E*	*Q*		*CCT*	*Bal*	$a_{mel,v}$	*Q*	
P10	Mental relaxation	*E*	*Q*		*CCT*	*Bal*	$a_{mel,v}$	*Q*	
P11	Familiarity	*E*		*Q*	*CCT*	*Bal* *Q*			*Q*
Architectural requirements									
A1	Structuring the room according to its form		*Q*	*Q*					
A2	Structuring the room according to rhythmicity		*Q*	*HK* *Uo* *Q*	*FK* *Q*				
A3	Structuring the room according to zones		*Q*	*HK* *Uo* *Q*	*FK* *Q*				
A4	Supporting the character of the architecture	*E*	*Q*		*CCT* *Q*	*Bal* *Q*		*Q*	
A5	Emphasizing architectural – creative – features		*Q*	*Q*	*CCT* *Q*	*Q*			

Evaluation parameters are listed in Appendix B4

2.2 Conducting the process on the basis of an example

This chapter exemplifies the process steps for determing lighting quality.

2.2.1 Short description of the project example and of the general framework

The group office is located on a level about half way up in the office building. This office is occupied by several administrative assistants, some department heads, the managing director and secretaries.

The company is active in the fashion industry and employs mainly young people as well as a few older fashion designers. Most workplaces are continually occupied. Most of the work is done with computers but also using pencil and paper. Most people start late, enjoy an extended lunch break but work long hours in the evening. The furnishings are modern: some areas are designated for meetings and for creative work. Therefore it is intended to change the furniture arrangement as shown in Figure 2.

2.2.2 Overview outlining the necessary steps for assessing the lighting quality

So how do we design the lighting in order to meet the client's requirements, achieve high acceptance by the workers and thus a high degree of lighting quality? As introduced in Chapter 2.1, three steps are necessary to assess lighting quality. Step 1 serves for establishing project-specific and individual user requirements. This results in a weighting of the requirements for the project which may differ from the standard requirements for offices. The relevant means of design for planning the lighting solution are selected on the basis of the above requirements.

Figure 2:
Group office prior to conducting a lighting design

The relevance of the previously defined requirements results in a weighted catalogue of measures, which helps to focus the lighting design on the most important requirements.. This is step 2 in the process. Step 3 covers the appraisal of one or more lighting designs respectively lighting solutions with the aid of the evaluation parameters as well as for the alignment of the defined requirements at the beginning.

Step 1: Determination project specific (individual) user requirements

A high degree of lighting quality can only be achieved in a project if the client's and the user's requirements are fully known. Ideally the requirements are defined jointly with the client. In order to capture lighting quality comprehensively, *biological, psychological* and *architectural* factors should be considered besides the purely *functional* requirements.

In our example we are dealing with a company from the fashion industry. Visual tasks such as high-gloss magazines are viewed, fabrics compared or models developed both on computer screens and by drawing sketches. Thus *seeing* and *identifying shapes and colours* represent a fundamental functional requirement and should therefore be weighted with higher priority compared to general office environments. Employees occasionally work very long hours in the office and often work late in the evenings before submitting a project.It is fundamentally important that light supports the *circadian rhythm of the personnel* and provides a solid foundation for a stable "wake-sleep-cycle" even in case of flexible working hours. Besides *activation* it is also necessary to provide *relaxation phases* in order to facilitate long focused working hours. Light should also serve as indicator for chronological orientation while *representing* this fashion outfit as a young, dynamic and creative *enterprise*. The furnishings are selected with a focus on design while the architectural elements are minimalistic. The lighting should be an integral part of the interior and should enhance space and architecture.

The most important project specific requirements are listed in an orange field in table 2.

The functional, biological, psychological and architectural requirements as well as their typically assumed relevance in various application fields are generally explained in Appendix B1 and B2. Details with specific requirements for an enterprise in the fashion industry are shown in Table 5 in Appendix A1.1.

Step 2: Lighting design with the aid of means of design and measures for meeting the requirements

Now the more important requirements are known prior to commencing the lighting design process. Therefore one can select the relevant means of design for planning a lighting solution.

The following means of design are available to the designer:

- Luminous flux of the light source
- Relative size of the light emitting area
- Number, arrangement and position of the light source(s)
- Light colour (colour appearance)
- Light distribution
- Spectral distribution of the light source
- Dimmability of the lighting system
- Operating of the lighting system

Table 2: Overview on individual requirements and means of design to be used: orange field = individual requirements; black square in orange field = means of design to be applied

		Means of design (see appendix B3)							
Requirements (see appendix B1)		Luminous flux of the light source	Relative size of the light emitting area	Number, arrangement and position of source(s)	Light colour	Light distribution	Spectral distribution of the light source	Dimmability of the lighting system	Operating the lighting system
Functional requirements									
F1	Seeing and identifying details	■		■		■			
F2	Seeing and identifying shapes			■		■			
F3	Seeing and identifying colours				■		■		
F4	Speed of perception and identification	■				■			
F5	Seeing and identifying over a period of time							■	
F6	Directing attention	■	■	■	■	■		■	
F7	Order/ability to differentiate	■		■	■				
F8	Physical safety	■						■	
F9	Physical protection	■					■		
Biological requirements									
B1	Activation	■	■	■	■	■	■	■	
B2	Relaxation	■			■	■	■	■	
B3	Circadian rhythm	■		■	■	■	■	■	
B4	Protection against radiation						■		
B5	Physiological effects of radiation						■		

Psychological requirements									
P1	Spatial orientation	■		■	■				
P2	Chronological orientation	■			■	■		■	
P3	Orientation regarding proceedings	■							
P4	Privacy	■		■		■			■
P5	Personal territory	■	■	■		■		■	■
P6	Self-expression/presentation	■		■		■		■	■
P7	Feeling of savety	■				■			
P8	Self monitoring							■	■
P9	Mental activation	■	■		■	■	■	■	
P10	Mental relaxation	■	■		■	■	■	■	
P11	Familiarity	■		■	■	■			■
Architectural requirements									
A1	Structuring the room according to its form		■	■					
A2	Structuring the room according to rhythmicity		■	■	■				
A3	Structuring the room according to zones		■	■	■				
A4	Supporting the character of the architecture	■	■		■	■		■	
A5	Emphasizing architectural – creative – features		■	■	■	■			
Measures for fulfilling the requirements		Tab. 21	Tab. 22	Tab. 23	Tab. 24	Tab. 25	Tab. 26	Tab. 27	Tab. 28

In Table 2 one can see which means of design is relevant for which application (fields with black squares) and provides a clue to Tables 21 through 28 that show the concrete measures for implementation. The individual means of design are listed in Appendix B3.

In case of the fashion enterprise the most important factors are the correct *number, arrangement* and position *of the luminaires* as well as the *luminous flux of the light source*, in order to make shapes and details easily discernible. *light colour, light distribution* and *spectral distribution* have a major influence on identifying colours. In order to meet the biological requirements a combination of various means of design is necessary: these are a *large light emitting area* as well as *light colour* and *light distribution* adjustable according to the time of day by means of a *lighting control system*. In addition, *personal adjustment of the light scenes* should be possible, which helps to »representatively stage« the work places and the entire business. The lighting system should be unobtrusive and enhance the architecture and the design language of the company.

Catalogue of measures: A list of measures of the selected means of design for meeting the requirements

Once the relevant means of design have been selected the specific catalogue of required measures can be established. Generally the measures for every combination of means of design and requirement can be found in Tables 21 through 28 in Appendix B3. In our example the first means of design »Luminous flux of the light source« results in the following catalogue of measures:

Luminous flux of the light source
- Increasing the illuminance level enhances activation of the human body (B1 activation).
- Low illuminance levels help to relax the human body (B2 - relaxation).
- The circadian rhythm can be stabilized by varying the illuminance over 24 hours according to nightly sleep and daily activation as well as relaxation phases (B3 – circadian rhythm).
- In windowless spaces the luminous flux functions like a zeitgeber due to the variation of the luminous flux similar to changes of natural light outside: At dusk or dawn low lighting levels indicate the beginning or end of daylight hours while a higher lighting level signals noonday (P2 – chronological orientation).
- A light centre with a particularly high illuminance supports the self-portrayal or representation of spaces, people, merchandise or objects (P6 – self expression/presentation).
- Increasing the illuminance assures better mental activation / concentration and performance (P9 – mental activation).
- Low illuminance enhances mental relaxation and stimulates regeneration (P10 – mental relaxation).
- Illuminance levels should be adapted to the character of the architecture. Quiet areas, e.g. churches should rather be illuminated with low light levels (A4 supporting the character of the architecture).

The entire catalogue of measures for all means of design listed in the order of »very relevant« and »relevant« for the fashion company can be found in Appendix A1.2.2.

Summary

When designing the lighting scheme for the fashion company it is important to implement adjustable lighting (luminous flux of the light source, regulation and control of the lighting system) and also adjustability of the colour temperature (light colour, spectral distribution, dimmability of the lighting components). This is necessary in order to meet the biological requirements. Glare-free light (light emitting area) with excellent colour rendering (spectral distribution of the light source) meets the functional requirements regarding recognising details, shape and colours. The language of form of the lighting system and its integration into the architecture (number, arrangement and positioning of luminaires) should support or enhance the character of the architecture as well as of the company. Zone lighting (number, arrangement and positioning of luminaires) creates focal points as well as colour and brightness contrasts in the room resulting in a representative appearance.

Now the actual design of the lighting scheme can take place in order to best meet the requirements of the client and the users.

Figure 3: Visualization of lighting solution 1 with recessed luminaires.

This publication compares a lighting scheme based on the catalogue of measures for the particular lighting solution (lighting solution 2) with another design previously developed (lighting solution 1). This serves to make apparent different opinions regarding lighting quality.

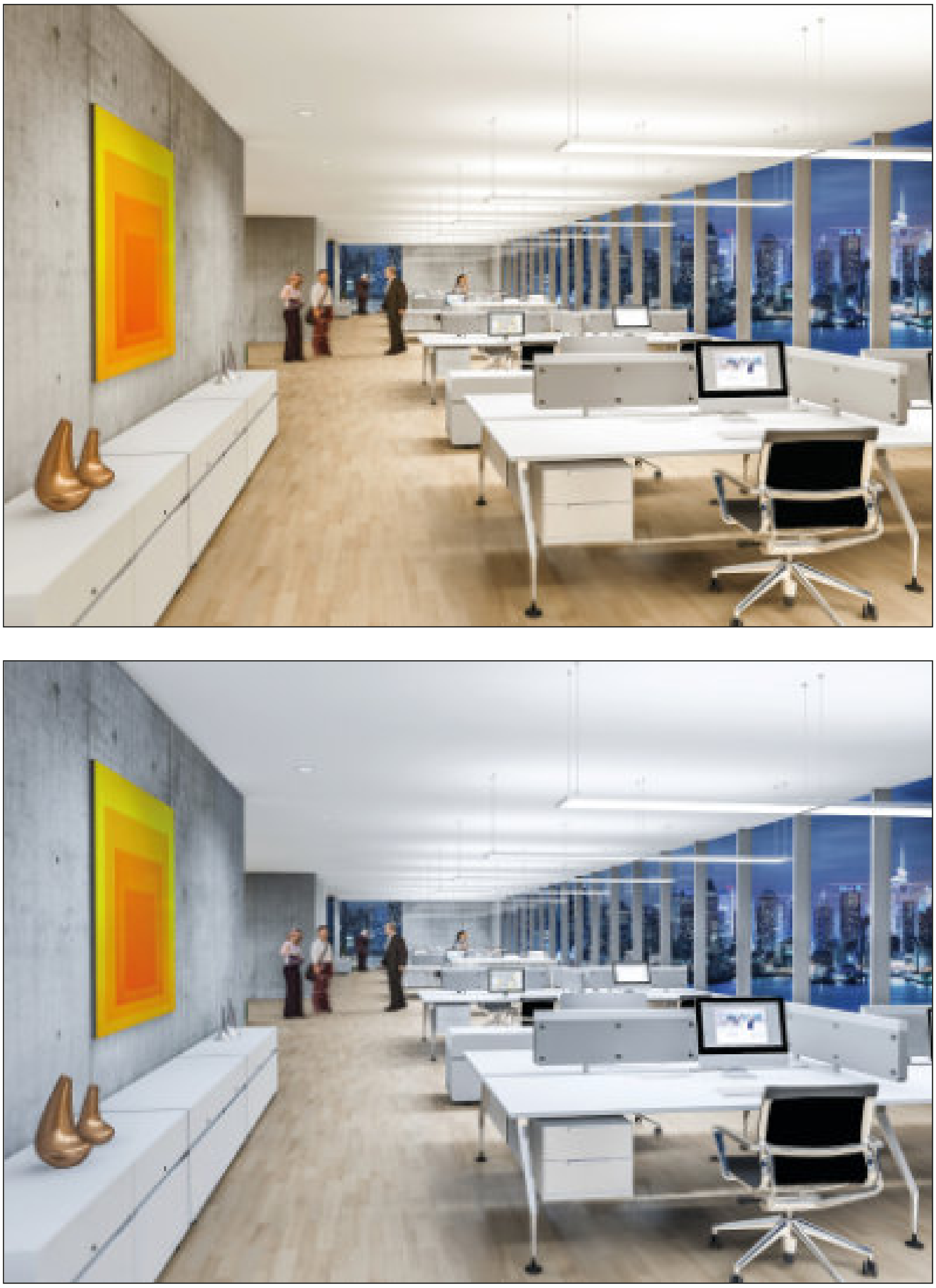
Lighting solution 1: Luminaires recessed in the ceiling (without consideration of the catalogue of measures)

Lighting solution 1 is based on general lighting realized with recessed LED luminaires with lens optics. Light control is accomplished by means of square lenses facilitating high efficiency and excellent glare control. The batwing type light distribution creates uniform illumination across the room. The colour rendering index of the LEDs is Ra > 80 with a correlated colour temperature of 4,000 K. The lighting system is dimmable.

Lighting solution 2: Direct/Indirect lighting (with adjustable colour temperature, time and daylight dependent controls with additional downlights (taking into account the catalogue of measures)

Lighting solution 2 consists of several components. Direct/Indirect pendant luminaires provide workplace illumination. Due to the micro-pyramid optic the luminaires can either be arranged parallel or perpendicular to the windows without causing any direct glare or veiling reflections on glossy surfaces and computer screens. Furthermore the lighting can be continuously adjusted between 3,000 K and 6,500 K. Additional downlights complement the illumination in the areas further away from the windows, the corridor areas as well as the walls. All luminaires are controlled via a central lighting management system subject to time of day and availability of natural light.

Figure 4:
Visualisation of lighting solution 2 with Direct/Indirect luminaires with adjustable colour temperature and additional downlights



Both lighting solutions represent technologically state-of-the-art lighting and cannot be described per se as poor lighting solutions. Nevertheless there are serious differences in the assessment of the lighting solutions, particularly when compared to the previously defined requirements.

Step 3: Assessment of the lighting solution and comparison with the user requirements

The following evaluation parameters may be applied when assessing lighting quality:
- Task illuminance (E)
- Uniformity of illuminance (U_o)
- Colour contrast (FK)
- Brightness contrast (artistic) (HK)
- Discomfort glare (B_{psy})
- Disability glare (B_{phy})
- Glare by reflection (B_{Re})
- Light colour (CCT)
- Colour rendering (R_a)
- Contrast rendering (CRF)
- Cast shadow (SS)
- (Balanced) luminance distribution (Bal)
- Modelling (Mod)
- Avoidance of flicker (Fl)
- Melanopic effect ($a_{mel,v}$)
- Potential damages (H_{dm})
- Qualitative factors (Q)

The evaluation parameters and their application are described in detail in Appendix B4. Please refer to pertinent literature, standards, or guidelines for establishing the measure of the evaluation. If not available, an expert will determine the measure of evaluation. Both proposed lighting solutions will now be reviewed with regards to meeting the requirements.

Reviewing lighting solution 1 with the aid of the evaluation parameters

Table 3 shows a summary of the evaluation parameters in a nominal/actual comparison. The size of the evaluating measure will be determined by an expert. Evaluation parameters that do not meet the requirements are marked in red. Those that meet the requirements are shown in green.

Since the lighting solution 1 is »only« designed with direct lighting and a single, non-adjustable light colour, the parameters colour contrast and brightness contrast are not fulfilled. There may also be disability and reflective glare since the light sources are only partially shielded. Furthermore the biologic requirements cannot be met because the colour temperature and the direction of incidence cannot be varied.

Table 3: Nominal/Actual comparison of the evaluation parameters for lighting solution 1: green = evaluation parameter met; red = evaluation parameter not met

	Nominal	Actual	Result
Task illuminance (E)	500 ... 1,000 lx	1,000 lx	🟩
Uniformity of illuminance (U_o)	0.6	0.6	🟩
Colour contrast (FK)	At least two CCTs	One CCT	🟥
Brightness contrast (artistic) (HK)	At least two different illuminance values	One illuminance value	🟥
Discomfort glare (B_{psy})	UGR < 19	UGR < 19	🟩
Disability glare (B_{phy})	Shielded light source	Partially shielded	🟥
Glare by reflection (B_{Re})	< 1,500 cd/m²	< 3,000 cd/m²	🟥
Light colour (CCT)	3,000 K ... 6.000 K	4,000 K	🟥
Colour rendering (Ra)	80	80	🟩
Contrast rendering (CRF)	Luminaires located laterally from workplace	Luminaires located laterally from workplace	🟩
Cast shadow (SS)	no SS on WP	no SS on WP	🟩
(Balanced) luminance distribution (Bal)	direct/indirect	Only direct	🟥
Modelling (Mod)	between 0.3 ... 0.6	no between 0.3 ... 0.6	🟥
Avoidance of flicker (Fl)	No flicker	No flicker	🟩
Melanopic effect ($a_{mel,v}$)	Variable between 0.3 and 1.0	0.5	🟥
Potential damages (H_{dm})	-	-	🟩
Qualitative factors (Q)	-	-	🟩

Appendix A1.3.1. shows a detailed review of the evaluation parameters for the fashion company in this example. It can be said that the lighting solution 1 only meets some of the defined requirements as previously agreed with the client and therefore the lighting quality cannot be rated as optimal.

Reviewing lighting solution 2 with the aid of the evaluation parameters

The review of the evaluation parameters in a nominal/actual comparison and its result are shown in Table 4.

	Nominal	Actual	Result
Task illuminance (E)	500 ... 1,000 lx	1,000 lx	■
Uniformity of illuminance (U_o)	0.6	0.6	■
Colour contrast (FK)	At least two CCTs	CCT variable	■
Brightness contrast (artistic) (HK)	At least two different illuminance values	Illuminance values variabel	■
Discomfort glare (B_{psy})	UGR < 19	UGR < 19	■
Disability glare (B_{phy})	Shielded light source	Shielded light source	■
Glare by reflection (B_{Re})	< 1,500 cd/m²	< 1,500 cd/m²	■
Light colour (CCT)	3,000 K ... 6,000 K	variable between 3,000 K ... 6,000 K	■
Colour rendering (R_a)	80	80	■
Contrast rendering (CRF)	Luminaires located laterally from workplace	Luminaires located laterally from workplace	■
Cast shadow (SS)	no SS on WP	no SS on WP	■
(Balanced) luminance distribution (Bal)	direct/indirect	direct/indirect variable	■
Modelling (Mod)	between 0.3 ... 0.6	0.5	■
Avoidance of flicker (Fl)	No flicker	No flicker	■
Melanopic effect ($a_{mel,v}$)	variable between 0.3 ... 1.0	variable between 0.3 ... 0.9	■
Potential damages (H_{dm})	-	-	■
Qualitative factors (Q)	-	-	■

Table 4: Nominal/Actual comparison of the evaluation parameters for lighting solution 2: green = evaluation parameters fulfilled

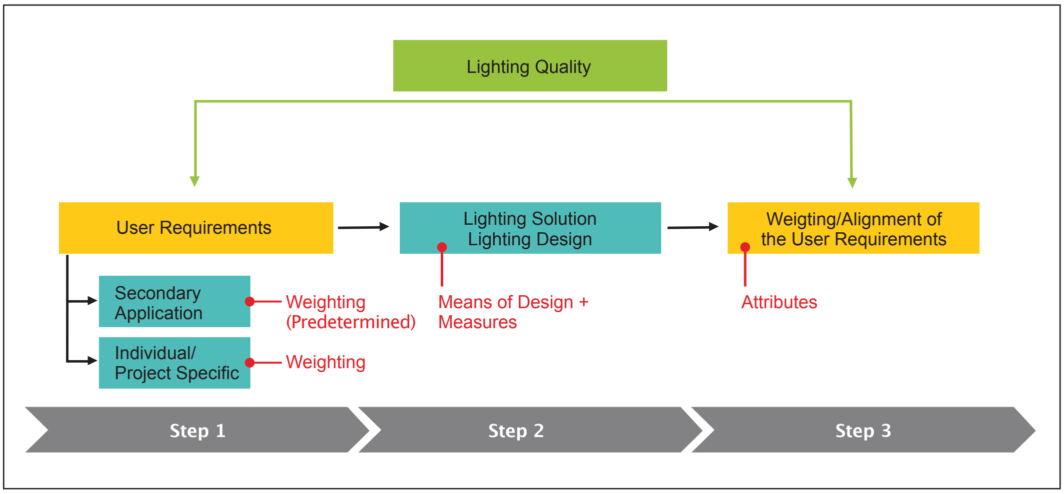
Contrary to lighting solution 1, the lighting systems proposed in lighting solution 2 offer variable colour temperature. The direct/indirect portions as well as the zone lighting differentiating between working area and corridors facilitate colour and brightness contrasts resulting in a representative appearance but also meet the biological requirements. The areal direct/indirect illumination of the pendant luminaires offers advantages compared to the LED lens optics with regard to disability glare as well as modelling and also regarding perceptibility of details and shapes. The lighting solution 2 meets all requirements of all evaluation parameters. A detailed consideration is contained in Appendix A1.3.2. As a result one can say that lighting solution 2 fulfils almost all requirements and therefore the lighting quality is to be rated as very high.

3 Lighting quality – Summary, differentiation and perspective

3.1 Summary

The example in chapter 2.2 and the general description in Appendix B outline the user requirements and their weighting, the means of design for the lighting solution, the measure for fulfilling the requirements as well as the attributes for their evaluation. The comparison of the evaluated lighting solution with the user requirements determines the degree of lighting quality (also refer to Figure 5).

Figure 5: Process steps and methods for describing lighting quality



In the previous chapter a concrete link between means of design and requirements has been established. As a consequence this resulted in a catalogue of measures adapted to the user requirements.

Finally good lighting quality represents congruence between user requirements on the one hand and the evaluation of the lighting solution on the other hand. Quantitative parameters of lighting engineering that allow for an evaluation of the lighting scenario are listed. The consolidation of requirements and evaluation as well as the degree of fulfilling the requirements represents a measure for the lighting quality.

3.2 Definition of lighting quality

In this publication we attempt to draw a standardized picture of lighting quality based on historical approaches and a user oriented concept. The following definitions are feasible:

Lighting quality describes the measure of experiencing light inside a room or in an environment. It is subject to dynamic changes. Lighting quality depends on functional, biological, psychological and architectural requirements formulated by the user. Processes and methods leading back to these requirements are necessary in order to capture lighting quality. The measure (degree) of lighting quality results from the comparison between user requirements regarding a lighting solution and the evaluation of the realized lighting solution.

The process described in this publication explains how user requirements are weighted, how means of design of the lighting solution are applied and how the attributes are employed for the evaluation. Thus the user plays a central role in this process. Who the user may be, is subject to a broader view in this publication:

- Works in the room (employee)
- Provides the room (client, employer, investor)
- Designs the room (architect)
- Maintains and takes care of the room (facility manager)

This type of approach does not mean that a lighting design has to be carried out requesting to know the user requirements. Generally the user is not directly involved in the lighting design. Nevertheless the user ultimately evaluates the lighting solution. Let us emphasize again how important it is to involve the user regarding the various decisions in the process. Ultimately the lighting quality results from the congruence between requirements and evaluation of a lighting scenario, which can be optimized in repeated steps of the process.

3.3 Taking into account natural light

The standard EN 12461-1 says: »The illumination of a space is facilitated with natural light, artificial light or a combination of both.«
Daylight has an important influence with regard to the evaluation of lighting quality in interiors. It keeps changing during the day as well as over the year. Daylight influences the following four individual requirements (also refer to Table 11):

Functional requirements: In interiors visual conditions keep changing due to changes in natural light, particularly due to the dynamic variations of illuminance levels, luminance values near the windows and the correlated colour temperature.

Biological requirements: Humans are well adapted to changes in daylight due to their circadian rhythm, particularly to the changes between day and night.

Psychological requirements: Daylight generally has a positive influence on humans emotionally. In particular the visual link (to the exterior) offers valuable information about the outside world.

Architectural requirements: Users of daylight as well as protection from sunlight determine the architectural design of facades and daylight openings.

Thus the lighting effect in an interior space is determined by both natural light and artificial light. Ultimately the appraisal of the lighting scenario in the interior is determined by the total illumination at any given point in time and under intuitive inclusion of the light source(s). It is important to undertake the appraisal of a room always at a predetermined point in time. It is quite possible that the evaluation of a room with artificial lighting differs between day and night. However, this does not have any impact on the process. This publication provides – where necessary – a hint regarding the effect of daylight.

3.4 More evaluation parameters of a lighting solution: Differentiation to product quality, energy efficiency and cost

The product quality resulting from product design and workmanship in production is not equal to lighting quality.

The formal aesthetics of the room, however, influenced by the light distribution, is clearly part of the lighting quality of the illuminated room. The requirement of enhancing the formal aesthetics of the room with the lighting solution is fulfilled by illuminating surfaces and objects as well as by form, colour and arrangement of the luminaires.

Negative effects on the aesthetics of a room may be caused by luminaire designs that do not integrate well with the architecture due to their form, dimensions, proportions, rhythm, and structure or by the fact that their character does not go well with the interior. Small things such as the “imperfect” luminaire arrangement or non-horizontal suspension may take away from an otherwise appealing interior. The same goes for poor workmanship, which may negatively influence the appearance of the lighting system.

Currently project designs are strongly dominated by energy saving and cost efficiency. The reduction of the energy consumption as an overriding factor is introduced step by step across the whole world. The question arises to what degree these energy saving requirements limit die implementation of high quality lighting concepts.

Today there are many discussions regarding the question if lighting quality and energy efficiency are contradicting each other or if both parameters could be fulfilled at the same time. Simply meeting the standards does not automatically include considering the user needs.

Lighting quality results from comparing requirements and the degree of compliance. Energy efficiency and costs are not contained in the process described in this publication.

Energy efficiency and costs of a lighting solution are therefore no criteria for the evaluation the lighting quality.

Appendix A: Tables related to the application example for the evaluation of light

A 1 Relevant tables

This appendix provides all relevant tables for working through the process of evaluating the lighting quality for the example presented in chapter 2.

A 1.1 Step 1: Determining the project specific (individual) user requirements

Table 5: Overview showing the project specific user requirements for the example „Group Office“. Numerical values: 3 = strongly relevant; 2 = relevant; 1 = less relevant; 0 = not applicable

	Functional requirements (see chapter 2.1)	Typical requirements (see chapter 3.1)	Group office (see chapter 3.1)	Individual requirements in the example
F1	Seeing and identifying details	2	2	2
F2	Seeing and identifying shapes	2	2	3
F3	Seeing and identifying colours	2	2	3
F4	Speed of perception and identification	2	2	2
F5	Seeing and identifying over a period of time	3	3	2
F6	Directing attention	1	1	2
F7	Order/ability to differentiate	2	2	2
F8	Physical safety	1	1	1
F9	Physical protection	0	0	0
Biological requirements (see chapter 2.2)				
B1	Activation	3	3	3
B2	Relaxation	3	3	3
B3	Circadian rhythm	3	3	3
B4	Protection against radiation	1	1	1
B5	Physiological effects of radiation	1	1	1
Psychological requirements (see chapter 2.3)				
P1	Spatial orientation	2	3	2
P2	Chronological orientation	3	3	3
P3	Orientation regarding proceedings	2	2	2
P4	Privacy	2	3	1
P5	Personal territory	2	3	2
P6	Self-expression/presentation	1	2	3

P7	Feeling of savety	2	2	2
P8	Self monitoring	2	1	2
P9	Mental activation	3	3	3
P10	Mental relaxation	3	3	3
P11	Familiarity	2	2	2
Architectural requiremtnes (see chapter 2.4)				
A1	Structuring the room according to its form	1	1	1
A2	Structuring the room according to rhythmicity	1	2	1
A3	Structuring the room according to zones	2	2	2
A4	Supporting the character of the architecture	1	1	3
A5	Emphasizing architectural – creative – features	1	1	2

The individual user requirements for the respective project are determined either by the client alone or jointly by the client and the user

Table 6:
Tabular illustration of the strongly relevant as well as the relevant means of design for fulfilling the requirements:
green field with numerical value 3 = strongly relevant;
blue field with numerical value 2 = relevant;
grey field = relevant as per Table 1, does not apply here

A 1.2 Step 2: Lighting design with the aid of the means of design and measures for fulfilling the requirements

A 1.2.1 Selection of relevant means of design for fulfilling the requirements

		Means of design							
		Luminous flux of the light source	Relative size of the light emitting area	Number, arrangement and position of source(s)	Light colour	Light distribution	Spectral distribution of the light source	Dimmability of the lighting system	Operating the lighting system
Functional requirements									
F1	Seeing and identifying details	2		2		2			
F2	Seeing and identifying shapes			3		3			
F3	Seeing and identifying colours				3		3		
F4	Speed of perception and identification	2				2			
F5	Seeing and identifying over a period of time							2	
F6	Directing attention	2	2	2	2	2		2	
F7	Order/ability to differentiate	2		2	2				
F8	Physical safety	[grey]						[grey]	
F9	Physical protection	[grey]					[grey]		
Biological requirements									
B1	Activation	3	3	3	3	3	3	3	
B2	Relaxation	3			3	3	3	3	
B3	Circadian rhythm	3		3	3	3	3	3	
B4	Protection against radiation						[grey]		
B5	Physiological effects of radiation						[grey]		
Psychological requirements									
P1	Spatial orientation	2		2	2				
P2	Chronological orientation	3			3	3		3	
P3	Orientation regarding proceedings	2							
P4	Privacy	[grey]		[grey]		[grey]			[grey]

P5	Personal territory	2	2	2		2		2	2
P6	Self-expression/presentation	3		3		3		3	3
P7	Feeling of savety	2				2			
P8	Self monitoring							2	2
P9	Mental activation	3	3		3	3	3	3	
P10	Mental relaxation	3	3		3	3	3	3	
P11	Familiarity	2		2	2	2			2
Architectural requiremtnes									
A1	Structuring the room according to its form								
A2	Structuring the room according to rhythmicity								
A3	Structuring the room according to zones		2	2	2				
A4	Supporting the character of the architecture	3	3		3	3		3	
A5	Emphasizing architectural – creative – features		2	2	2	2			

The combinations illustrate, which means of design must receive special consideration

A 1.2.2 Catalogue of measures: List of measures from step 2

Strongly relevant (3) – ordered by means of design

Luminous flux of the light source

- Increasing the illuminance level enhances activation of the human body (B1).
- Low illuminance levels help to relax the human body (B2).
- The circadian rhythm can be stabilized by varying the illuminance over 24 hours according to nightly sleep and daily activation as well as relaxation phases (B3).
- In windowless spaces the luminous flux functions like a zeitgeber due to the variation of the luminous flux similar to changes of natural light outside: At dusk or dawn low lighting levels indicate the beginning or end of daylight hours while a higher lighting level signals noonday (P2).
- A light centre with a particularly high illuminance supports the self-portrayal or representation of spaces, people, merchandise or objects (P6).
- Increasing the illuminance assures better mental activation / concentration and performance (P9).
- Low illuminance enhances mental relaxation and stimulates regeneration (P10).
- Illuminance levels should be adapted to the character of the architecture. Quiet areas, e.g. churches should rather be illuminated with low light levels (A4).

Relative size of the light emitting area

- The larger the light emitting area, the more receptors on the retina will be stimulated. Thus physical activation can be enhanced (B1).
- Large light emitting areas are visually perceptible and support the ability to concentrate and to perform (P9).
- Smaller light emitting areas are less obtrusive and enhance well-being and relaxation (P10).
- The dimension of the area determines the character of architecture, e.g. generosity due to large light emitting areas (A4).

Number, layout and position of the light source(s)

- Spotlighting of objects enhances their three-dimensional form (F2).
- Light sources located in the upper visual field support the biological effectiveness because the melanopic ganglion cells in the nasal area and the lower part of the retina are most sensitive (B2).
- Adapted to the circadian rhythm light should be emitted predominantly by large area light sources in the upper visual field at times of activation (refer to activation) (B3).
- Locating light sources and spotlighting for enhancing one's personal area (P6).

Light colour

- The choice of the light colour and the spectral composition of the light source determine the conspicuity of colours. Objects in red or orange hues are better illuminated with warm white light (e.g.wood). Objects in blue or green hues are better illuminated with daylight white light (e.g.: steel) (F3).

- Employing daylight white enhances general activation (B1).
- Employing warm white light promotes general relaxation (B2).
- Higher colour temperatures during the day and lower ones in the evening and possibly at night stabilize the circadian rhythm (B3).
- The choice of the light colour is subject to the time of day and maysupport orientation in terms of time, particularly in windowless rooms, Thus the illumination signals morning and evening with warm white light colour while daylight white is associated with noontime. Warmer light colours are preferred in winter, cooler ones in summer (P2).
- Daylight white illumination supports the ability to concentrate on one's task as well as the performance (mental activation) (P9).
- Warm white illumination enhances well-being, rest and mental relaxation (P10).
- The light colour should support the character of the architecture. For instance, in comfortable environments (hotel, theatre, etc.) warm white illumination is employed (A4).

Light distribution
- The direct portion of the light distribution improves plasticity (F2).
- Indirect light and bright ceilings as well as large diffuse areas stand for activation (B1).
- Direct (reduced) light and dark ceilings stand for relaxation (B2).
- Indirect or diffuse large area light during the day and direct light and dark ceilings at night support the circadian rhythmicity (B3).
- A reference to early morning or late evening hours can be established with directional light while diffuse indirect light rather marks midday (P2).
- Large diffuse light sources or a large portion of indirect light have a representative character (P6).
- Indirect light and bright ceilings as well as large diffuse areas stand for activation (P9).
- Direct (reduced) light and dark ceilings stand for relaxation (P10).
- Open architecture is enhanced by indirect light, closed architecture by direct light (A4).

Spectral distribution of the light source
- A preferably continuous and complete colour spectrum facilitates adequate conspicuity of colours and permits colour surveys (F3).
- Especially shortwave spectral portions affect physical activation (B1).
- Longwave spectral components support well-being and physical relaxation (B2).
- The adjustment of the spectral components in line with the natural activity (during the day) and relaxation phases (at night) support the circadian rhythm (B3).
- Illumination with shortwave spectral components enhances mental activation (P9).
- Illumination with longwave spectral components enhances mental relaxation (P10).

Controllability of lighting systems

- Pre-set lighting scenes and dynamic sequences with higher illuminance levels and higher colour temperatures during the day (B1).
- Pre-set lighting scenes and dynamic sequences with lower illuminance levels and lower colour temperatures in the evening hours (b2).
- Adjusting the illumination in terms of colour temperature and luminous flux in line with the natural activity (during the day) and relaxation phases (at night) support the circadian rhythm (B3).
- Time dependent controls (time management) and changing lighting scenarios linked to a timer (P2).
- Personal options for adjusting one’s own lighting scenario (P6).
- Pre-set lighting scenes and dynamic sequences with higher illuminance levels and higher colour temperatures during the day (P9).
- Pre-set lighting scenes and dynamic sequences with lower illuminance levels and lower colour temperatures in the evening hours (P10).

Operating the lighting system

- Additional (visible) control devices for a personal area or operation adapting automatically to the user, enhances the self-presentation and representation (P6).

Relevant (2) – ordered by means of design

Luminous flux of the light source

- Choosing the appropriate illuminance level depends on the dimensions of the details (refer to DIN EN 12464-1 for values). A higher illuminance level improves the perceptibility of details (F1).
- Details can be recognized quicker at higher illuminance levels (F4).
- Illuminance levels must be graded subject to the importance of the visual task (F6).
- Different illuminance levels provide order or structure in a room (e.g.: different zones: working area = high illuminance; corridor = low illuminance) (F7).
- Entrances and exits or pathways can be accentuated by higher brightness levels (luminance) (P1).
- Variations in brightness enhance the recognition of processes and actions (P3).
- Local additional lighting or a clearly defined area with higher illuminance levels separates a personal territory from the general area (P5).
- A higher level of subjective safety is achieved by avoiding dark areas as well as assuring adequate lighting levels in all corners of the room (P7).
- The luminous flux should be available in a natural and commonly known amount in order to provide the feeling of familiarity (P11).

Relative size of the light emitting area

- Large light sources in interiors attract attention while small light sources are less obtrusive and create an effect due to their arrangement (refer to B 3.3) (F6).
- The dimensions of the light emitting areas are adapted to the room modules (A3).
- The form and size of the light emitting area may well be a design feature by itself or enhance the architectural features (A5).

Number, layout and position of the light source(s)

- Several point light sources should be avoided since they generate multiple shadows and impair the conspicuity (F1).
- The arrangement guides the view in the order of the importance of the visual tasks (F6).
- The position and direction of light emission accents the visual tasks (F7).
- Locating light sources with regard to the structures of the rooms, e.g. in order emphasize pathways, doors (P1)
- Locating light sources for marking one’s personal area (P5).
- Using common forms of the layout (e.g. illustration of symbols) or spotlighting common forms and objects (P11).
- Supporting room modules by the arrangement of light sources or by spotlighting (A3).
- Adapting the arrangement of light sources or by spotlighting architectural features (A5).

Light colour

- Colour contrasts, which are achieved with the separate illumination of two different colour temperatures, directs perception and creates focal points for attention (F6).
- By selecting the appropriate luminous colour, for instance, for a certain visual task or a function of the room, it is possible to support the order respectively structure of the room or the distinctness of functions (F7).
- Spatial orientation as well as the perception of dimensions and distances can be supported by the appropriate light colour. Daylight white illumination signals size, spatial depth and far distances while warm white light rather means short distances and closeness. By trend, cooler light colours are generally employed in southern, Mediterranean regions and warmer light colours in northerly, Scandinavian regions (P1).
- Warm and neutral light colours are generally perceived as familiar (P11).
- Different light colours for the different modules provide order and structure to the room (A3).
- The suitable light colour enhances material and shape of architectural features (A5).

Light distribution

- Directional light helps to improve conspicuity of details on surfaces (F1).
- Quick perception is improved by a sensible ratio between directional and diffuse portions of light (F4).
- Directional light creates focal points of attention (F6).
- Directional light focused on a specific area marks the personal territory (P5).
- The subjective feeling of safety is enhanced by a sensible ratio between direct and indirect light. Dark areas should be avoided (P7).
- A balanced ratio between direct and indirect light as well as directional and diffuse portions of light is perceived as familiar (P11).
- Direct/indirect luminaires are generally objects as well as design elements in the room (A5)

Controllability of lighting systems

- To facilitate and realize pre-planned lighting scenarios for various requirements over time (F5).
- Automatic (time, scenes) or via sensors (presence) reacting lighting (F6).
- Individual options of influencing the personal lighting scene (P5).
- Individual option for controlling one’s own lighting scenario (P8).

Operating the lighting system

- The personal territory can be controlled by a lighting control system or a simple switch (P5).
- The easy (understandable, intuitive) access or the assignment of control elements for parts of the room and functions supports the requirement according to one’s own control (P8).
- Control devices marked with known symbols or labelled or located at familiar locations facilitate a higher level of acceptance and familiarity in operating the controls (P11).

A 1.3 Step 3: Evaluation of the lighting solution and comparison with the user requirements

A 1.3.1 Investigating the lighting solution 1 with the aid of theevaluation parameters: Detailed consideration of the evaluation parameters

	Nominal	Actual	Result
Task illuminance (E)	500 ... 1,000 lx	1,000 lx	green
Uniformity of illuminance (U_o)	0.6	0.6	green
Colour contrast (FK)	At least two CCTs	One CCT	red
Brightness contrast (artistic) (HK)	At least two different illuminance values	One illuminance value	red
Discomfort glare (B_{psy})	UGR < 19	UGR < 19	green
Disability glare (B_{phy})	Shielded light source	Partially shielded	red
Glare by reflection (B_{Re})	< 1,500 cd/m²	< 3,000 cd/m²	red
Light colour (CCT)	3,000 K ... 6,000 K	4,000 K	red
Colour rendering (Ra)	80	80	green
Contrast rendering (CRF)	Luminaires located laterally from workplace	Luminaires located laterally from workplace	green
Cast shadow (SS)	no SS on WP	no SS on WP	green
(Balanced) luminance distribution (Bal)	direct/indirect	Only direct	red
Modelling (Mod)	between 0.3 ... 0.6	0.5	green
Avoidance of flicker (Fl)	No flicker	No flicker	green
Melanopic effect ($a_{mel,v}$)	Variable between 0.3 and 1.0	0.5	red
Potential damages (H_{dm})	-	-	green
Qualitative factors (Q)	-	-	green

Table 7: Nominal/Actual comparison of the evaluation parameters for lighting solution 1: green = evaluation parameter met; red = evaluation parameter not met

The evaluation of the nominal values has been determined by an expert

Table 8:
Evaluation parameters for lighting solution 1 in detail:
green field = strongly relevant requirement;
blue field = relevant requirement;
grey field = relevant as per Table 1, does not apply here;
red lettering = evaluation parameters not fulfilled

Result for lighting solution 1

		Means of design (see appendix B3)							
Requirements (see appendix B1)		Luminous flux of the light source	Relative size of the light emitting area	Number, arrangement and position of source(s)	Light colour	Light distribution	Spectral distribution of the light source	Dimmability of the lighting system	Operating the lighting system
Functional requirements									
F1	Seeing and identifying details	*E* *Fl*		U_o B_{Re} *CRF* *SS*		*Uo* *Bal* B_{psy} B_{phy} *SS*			
F2	Seeing and identifying shapes			*SS* *Mod*		*Bal* *Mod*			
F3	Seeing and identifying colours				R_a *CCT*		R_a		
F4	Speed of perception and identification	*E* *Fl*				*Bal* *Mod*			
F5	Seeing and identifying over a period of time							*Q*	
F6	Directing attention	*E*	*Q*	*HK* *Q*	*FK*	*Q*		*Q*	
F7	Order/ability to differentiate	*E*		*HK* *Q*	*Q*				
F8	Physical safety	*E*						*Q* *Fl*	
F9	Physical protection	*E* H_{dm}					H_{dm}		
Biological requirements									
B1	Activation	*E*	*Q*	*Q*	*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B2	Relaxation	*E*			*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B3	Circadian rhythm	*E*		*Q*	*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B4	Protection against radiation						H_{dm} *Q*		
B5	Physiological effects of radiation						*Q*		

Psychological requirements									
P1	Spatial orientation	E HK		HK Q	CCT Q				
P2	Chronological orientation	E			CCT Q	Bal		Q	
P3	Orientation regarding proceedings	E HK							
P4	Privacy	E HK		HK Q		Bal Q			Q
P5	Personal territory	E HK	Q	HK Q		Bal Q		Q	Q
P6	Self-expression/ presentation	E HK		HK Q		Bal Q		Q	Q
P7	Feeling of savety	E				U_o Bal Q			
P8	Self monitoring							Q	Q
P9	Mental activation	E	Q		CCT	Bal	$a_{mel,v}$	Q	
P10	Mental relaxation	E	Q		CCT	Bal	$a_{mel,v}$	Q	
P11	Familiarity	E		Q	CCT	Bal Q			Q
Architectural requirements									
A1	Structuring the room according to its form		Q	Q					
A2	Structuring the room according to rhythmicity		Q	HK Uo Q	FK Q				
A3	Structuring the room according to zones		Q	HK Uo Q	FK Q				
A4	Supporting the character of the architecture	E	Q		CCT Q	Bal Q		Q	
A5	Emphasizing architectural – creative – features		Q	Q	CCT Q	Q			

The evaluation has been determined by an expert

Overview over »strongly relevant«requirements:

F3	A4	F1	B1	B2	B3	P2	P6	P9	P10

Two of ten »strongly relevant« requirements have been fulfilled.
Eight of ten »strongly relevant« requirements have only been partly fulfilled.

Overview over »relevant«requirements:

P3	P7	P8	P11	F1	F4	P1	P5	F5	F6	F7	A3	A5

Four of 13 »relevant« requirements have been fulfilled.
Four of 13 »relevant« requirements have only been partly fulfilled.
Five of 13 »relevant« requirements have not been fulfilled.

A 1.3.2 Investigating lighting solution 2 with the aid of the evaluation parameters:

	Nominal	Actual	Result
Task illuminance (E)	500 … 1,000 lx	1,000 lx	■
Uniformity of illuminance (U_o)	0.6	0.6	■
Colour contrast (FK)	At least two CCTs	CCT variable	■
Brightness contrast (artistic) (HK)	At least two different illuminance values	Illuminance values variabel	■
Discomfort glare (B_{psy})	UGR < 19	UGR < 19	■
Disability glare (B_{phy})	Shielded light source	Shielded light source	■
Glare by reflection (B_{Re})	< 1,500 cd/m²	< 1,500 cd/m²	■
Light colour (CCT)	3,000 K … 6,000 K	variable between 3,000 K … 6,000 K	■
Colour rendering (R_a)	80	80	■
Contrast rendering (CRF)	Luminaires located laterally from workplace	Luminaires located laterally from workplace	■
Cast shadow (SS)	no SS on WP	no SS on WP	■
(Balanced) luminance distribution (Bal)	direct/indirect	direct/indirect variable	■
Modelling (Mod)	between 0.3 … 0.6	0.5	■
Avoidance of flicker (Fl)	No flicker	No flicker	■
Melanopic effect ($a_{mel,v}$)	variable between 0.3 … 1.0	variable between 0.3 … 0.9	■
Potential damages (H_{dm})	-	-	■
Qualitative factors (Q)	-	-	■

Table 9: Nominal/Actual comparison of the evaluation parameters for lighting solution 2: green = evaluation parameters fulfilled

The evaluation has been determined by an expert

Table 10:
Evaluation parameters for lighting solution 2 in detail:
green field = strongly relevant requirement;
blue field = relevant requirement;
grey field = relevant as per Table 1, does not apply here;
red lettering = evaluation parameters not fulfilled

Detailed consideration of the evaluation parameters:

Requirements (see appendix B1)		Means of design (see appendix B3): Luminous flux of the light source	Relative size of the light emitting area	Number, arrangement and position of source(s)	Light colour	Light distribution	Spectral distribution of the light source	Dimmability of the lighting system	Operating the lighting system
Functional requirements									
F1	Seeing and identifying details	*E* *Fl*		U_o B_{Re} *CRF* *SS*		*Uo* *Bal* B_{psy} B_{phy} *SS*			
F2	Seeing and identifying shapes			*SS* *Mod*		*Bal* *Mod*			
F3	Seeing and identifying colours				R_a *CCT*		R_a		
F4	Speed of perception and identification	*E* *Fl*				*Bal* *Mod*			
F5	Seeing and identifying over a period of time							*Q*	
F6	Directing attention	*E*	*Q*	*HK* *Q*	*FK*	*Q*		*Q*	
F7	Order/ability to differentiate	*E*		*HK* *Q*	*Q*				
F8	Physical safety	*E*						*Q* *Fl*	
F9	Physical protection	*E* H_{dm}					H_{dm}		
Biological requirements									
B1	Activation	*E*	*Q*	*Q*	*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B2	Relaxation	*E*			*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B3	Circadian rhythm	*E*		*Q*	*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B4	Protection against radiation						H_{dm} *Q*		
B5	Physiological effects of radiation						*Q*		

Psychological requirements									
P1	Spatial orientation	*E* *HK*		*HK* *Q*	*CCT* *Q*				
P2	Chronological orientation	*E*			*CCT* *Q*	*Bal*		*Q*	
P3	Orientation regar-ding proceedings	*E* *HK*							
P4	Privacy	*E* *HK*		*HK* *Q*		*Bal* *Q*			*Q*
P5	Personal territory	*E* *HK*	*Q*	*HK* *Q*		*Bal* *Q*		*Q*	*Q*
P6	Self-expression/ presentation	*E* *HK*		*HK* *Q*		*Bal* *Q*		*Q*	*Q*
P7	Feeling of savety	*E*				U_o *Bal* *Q*			
P8	Self monitoring							*Q*	*Q*
P9	Mental activation	*E*	*Q*		*CCT*	*Bal*	$a_{mel,v}$	*Q*	
P10	Mental relaxation	*E*	*Q*		*CCT*	*Bal*	$a_{mel,v}$	*Q*	
P11	Familiarity	*E*		*Q*	*CCT*	*Bal* *Q*			*Q*
Architectural requirements									
A1	Structuring the room according to its form		*Q*	*Q*					
A2	Structuring the room according to rhythmicity		*Q*	*HK* *Uo* *Q*	*FK* *Q*				
A3	Structuring the room according to zones		*Q*	*HK* *Uo* *Q*	*FK* *Q*				
A4	Supporting the character of the architecture	*E*	*Q*		*CCT* *Q*	*Bal* *Q*		*Q*	
A5	Emphasizing architectural – creative – features		*Q*	*Q*	*CCT* *Q*	*Q*			

Result for lighting solution 2

Overview over »strongly relevant«requirements:

F3	A4	F1	B1	B2	B3	P2	P6	P9	P10

Nine of ten »strongly relevant« requirements have been fulfilled.
One of ten »strongly relevant« requirements has only partially been fulfilled.

Overview over »relevant« requirements:

P3	P7	P8	P11	F1	F4	P1	P5	F5	F6	F7	A3	A5

Twelve of 13 »relevant« requirements have been fulfilled.
One of 13 »relevant« requirements has only partially been fulfilled.

Appendix B: Detailed explanations of the individual process steps

B 1 Individual user requirements

The user requirements extend far beyond the pure perceptibility and readability of the task. Additional requirements, for instance, resulting from individual needs or regarding the aesthetic perception may be essential for the qualitative perception of the lighting scenario in a room.

This chapter describes the user requirements. If possible or recommended, the definitions of the respective minimum requirements are listed. Prior to defining any requirements it is important to capture basic conditions such as, for instance, structural conditions, the utilization context or the environment.

The requirements may be subdivided into four main groups.
Table 11 shows an overview of the generalized requirements for interior applications.

Table 11:
Overview over requirements

Chapter B 1.1		Chapter B 1.2		Chapter B 1.3		Chapter B 1.4	
Functional requirements		Biological requirements		Psychological requirements		Architectural requirements	
F1	Seeing and identifying details	B1	Activation	P1	Spatial orientation	A1	Structuring the room according to its form
F2	Seeing and identifying shapes	B2	Relaxation	P2	Chronological orientation	A2	Structuring the room according to rhythmicity
F3	Seeing and identifying colours	B3	Circadian rhythm	P3	Orientation regarding proceedings	A3	Structuring the room according to zones
F4	Speed of perception and identification	B4	Protection against radiation	P4	Privacy	A4	Supporting the character of the architecture
F5	Seeing and identifying over a period of time	B5	Physiological effects of radiation	P5	Personal territory	A5	Emphasizing architectural – creative – features
F6	Directing attention			P6	Self-expression/ presentation		
F7	Order/ability to differentiate			P7	Feeling of savety		
F8	Physical safety			P8	Self monitoring		
F9	Physical protection			P9	Mental activation		
				P10	Mental relaxation		
				P11	Familiarity		

The following chapters list the requirements as examples but without claiming to be complete.

B 1.1 Functional requirements

Functional requirements refer to facilitating visual tasks or activities with visual tasks. The peculiarities of the requirements differ subject to the type of activity, the environmental conditions or the individual needs. In some applications the requirements with a room or over a period of time may differ. In this case the lighting system should be flexible in order to be adapted to the different needs.

Definition of the visual task:
The visual task describes the strongly relevant elements of an activity to be carried out. It is the object or structure that must be seen/recognized in order to gain information and to be able to react. The elements and details of the visual tasks may vary in terms of size, contrast, movement, duration, colour, form and importance.

F1 – Seeing and identifying details

Description:
The conspicuity of visual details varies subject to contrast, brightness, dimension and duration of presentation. The size of a detail of the visual task serves as a simple example: The larger the details, the better the conspicuity. The conspicuity depends on the distance and the angle of observation. For instance, the writing on a blackboard may be easy to read from the first row of seats while it is virtually invisible when viewed from the last row. The conspicuity depends greatly on the individual visual performance. In this publication details are defined as two-dimensional objects.

Examples:
- Reading written text
- Checking for errors
- Quality control

Definition of minimum requirements:
One should carry out typical visual tasks without difficulty, at least with regard to size and contrast.

F2 – Seeing and identifying shapes (spatial perception of form)

Description:
Just like details, forms (shapes) must be perceptible. A form is a three-dimensional object in a room.

Examples:
- Seeing a ball
- Sorting objects
- Recognising faces in communicative tasks

Definition of the minimum requirements:
One should perceive typical forms without difficulty, at least with regard to size and contrast.

F3 – Seeing and identifying colours and colour variations (colour sensitivity)

Description:
Colours unlock themselves as elements of information and means of design. One should be able to recognise colours and differentiate between different ones. The conspicuity depends on the individual ability to perceive colours.

Examples:
- Recognizing colours, e.g. red, green and blue
- Differentiating similar hues
- Colour and quality control
- Colour matching

Definition of the minimum requirements:
One should recognise typical colours and differentiate between them without difficulty.

F4 – Speed of perception and identification = Rapidity of adequate conspicuity

Description:
Details, forms and colours are recognised with a certain speed.

Examples:
- Recognition of a disruption in the production that only appears for a few moments
- Rapid recognition of safety relevant objects

F5 – Seeing and identifying over a period of time/visual capacity

Description:
The conspicuity must be assured over a certain period of time. Whenever the mental concentration recedes, it often coincides with a lesser degree of conspicuity.

Examples:
- Reading over a longer period of time
- Focused work over the whole day

F6 – Directing attention

Description:
Attention is directed in such a way that objects and details are prioritised according to their importance. This is particularly important in multi-functional rooms. Focusing on the main visual task enhances the ability to work and to concentrate.

Examples:
- Productive gradation/structuring according to importance of the visual tasks or the perception relevant details

- Since the first visual impression is particularly important when entering a room, purposeful guidance of the observer's view by means of light lines and light centres
- Arranging the working environment with regard to importance and type of activity

F7 – Order/ability to differentiate

Description:
Objects and visual details can be differentiated due to the conspicuity.

Examples:
- Structuring according to the ability to differentiate (not according to importance) the type of visual task

F8 – Physical safety

Description:
This requirement means that potential danger is minimized or not existent, avoiding danger is possible and there is subjective clarity regarding safety. Danger spots can easily and quickly be identified.

Examples:
- Recognizing safety relevant details, e.g. escape routes, steps, etc.
- Recognition of objects, which could endanger the actual safety, e.g. automatic transport trolleys in production halls

Definition of minimum requirements:
- Adequate illumination of danger spots (stairs, thoroughfares, etc.)
- Avoidance of dark zones
- Avoidance of sources of glare, where danger spots may develop
- Installation of safety lighting according to EN 1838

F9 – Physical protection

Description:
This requirement relates to the protection of objects against potential damage caused by light, UV or IR radiation.

Examples:
- Bleaching of dyed fabrics due to sunlight
- Change of materials and colours of sensitive art objects due to photo-chemical processes caused by short wave blue light and UV radiation or thermal damage due to IR radiation

Definition of minimum requirements:
- Avoiding damage of objects due to UV/IR radiation
- Reduction of short wave visible spectral components (consider influence on colour rendering)

B 1.2 Biological requirements

Biologic requirements relate to vegetative functions that are triggered by light received with our eyes. Very often the users do not recognize the link between light and non-visual effects. Please note the statement as published in DIN SPEC 5031-100:

»Since the verification that melanopsin is contained in human ganglion cells and their spectral sensitivity in the blue range, it is not any longer sufficient to evaluate optical radiation exclusively by their photometric affects as described in DIN 5031-3. Subject to the point in time of exposure to narrow band short wave light, the latter causes the suppression of the discharge of Melatonin, an increased heart rate, influences the thermoregulation of the human body, enhances alertness, changes the frequency in the electroencephalogram and delays the phase of the circadian system. Furthermore there are very fast reactions (within seconds) to short wave light such as, for instance, the reflex of the pupil or changes of the brain activity.«

B1 – Activation

Description:
Activation describes the state of alertness, receptiveness and performance. Concentration is high. The person feels "ready to go". The environment feels fresh and stimulant.

Examples:
- Examination of the patient by a medical doctor
- Practising sport
- Monitoring screens and displays in control rooms

B2 – Relaxation

Description:
Relaxation is a state of rest and regeneration. Restlessness is avoided. The environment has a calming and relaxing effect.

Examples:
- Regeneration after treatment in a hospital
- Relaxation after a long period of mental concentration at the end of a workday or sports training

B3 – Circadian rhythm

Description:
The change between day and night leads to a rhythm of activity followed by sleep. This rhythm is »circa one day long«. A stable circadian rhythmicity has great influence on the general state of health. Different chronotypes, such as early or late risers, have different needs.

Examples:
- Stabilising the circadian rhythm by providing natural light
- Simulating the natural bright and dark phases occurring outside in the interior

Definition of minimum requirement:
- Sufficiently long stay in daylight resp. higher lighting levels in the morning
- Avoiding high lighting levels and high colour temperatures prior to going to sleep

Remark:
- The natural rhythmicity is disturbed if there is not enough exposure to daylight, for instance, in an elderly/nursing home due to insufficient mobility or at the workplace in a windowless room.
- The circadian rhythm of shift workers is often influenced – mostly negatively – since the synchronisation with the natural night/day rhythm as well as societal activities is disturbed.

B4 – Protection against radiation

Description:
Damaging radiation impairs or damages one's health and must be avoided or at least reduced to an acceptable level in terms of health risks (photo biological safety).

Examples:
- Direct, long lasting viewing of a light source with damaging spectral components

Definition of minimum requirement:
- Adherence to limits regarding photo biological safety

B5 – Physiological effects of radiation

Description:
Radiation is conducive to health in certain ranges of wavelength. For instance, UV radiation helps to produce vitamin D3. UV radiation may be permitted in a dose that is conducive to one's health.

Examples:
- Supporting osteogenesis with vitamin D3
- Utilization of heat radiation for therapeutic purposes

B 1.3 Psychological requirements

Meeting psychological requirements is one of the fundamental individual needs of humans. This includes information about the environment such as location, time, weather, proceedings as well as safety and orientation. The expectations of the user are an important aspect in terms of the psychological requirements. People generally assess a room or information always while taking into account their subjective, socio-cultural context, their experiences and expectations. In this context the term »mental concept« describes the expectations of the people and refers to the subsequently presented criteria. The need for a pleasant atmosphere and mood is also part of the psychological requirements. General preference, contentedness, relaxation or well-being are all influenced by light.

P1 – Spatial orientation

Description:
People need to have some knowledge of the location in order to gain some spatial orientation. A totally unknown location will be investigated in search of some elements that may provide orientation.

Examples:
- Visual link to the exterior/outlook
- Capturing and understanding the functions of a room at a glance, e.g., recognizing the altar in a church or the placing of merchandise in a shop
- Geographic reference
- Recognizing and understanding parts of the room, such as passages, traffic and waiting areas

Definition of minimum requirements:
- Recognising and intuitive understanding of the functions of a room at first glance as well as recognizing pathways and openings (refer to examples).

P2 – Chronological orientation

Description:
The most important orientation in terms of time is the time of day. In addition daylight provides information regarding time, since everybody is capable of establishing a relationship between daylighting scenario and time of day provided he knows which day of the month it is. The expectation of a certain amount of daylight represents a reference that is then compared with the lighting levels of the surroundings. People expect it to be brighter outside than in an interior space during the day. The opposite is true at night.

Examples:
- Commencing work in the morning after dawn
- Finishing work and starting leisure time after sunset

Definition of minimum requirements:
- Ensuring of direct and indirect information during day and night

P3 – Orientation regarding proceedings

Description:
People need to have some knowledge about proceedings in order to feel save and as an aid to their orientation.

Examples:
- Reference to proceedings (political, representative, devotional, etc.)
- Need for information, for instance, about the weather
- Information about persons as well as their tasks and actions in their direct vicinity

P4 – Privacy

Description:
Man relies on his social contacts, affiliation to groups and communication with fellow human beings. Some »free space« for the purpose of retreat and relaxation should be available at times when there is no desire for exchanges and communication.

Examples:
- Shared dinner in a restaurant
- Resting in a hotel room

Remarks for a better understanding:
Privacy is distinguished by the following attributes:
- Freedom of choice: one can choose between independence and collaboration.
- Territorial identity: It is easier for an employee to accept the loss of control in a group if there is a territory the person may individually control.
- Controlling the surroundings: a personal territory is an important precondition for self-expression and individual presentation corresponding with one's own physiological needs. Amongst others, these are control over light, air and noise.
- Access control: Contributes to the need of intimacy and information privacy.

P5 – Personal territory

Description:
A personal territory is an area with defined boundaries as basis for the actions and the purpose of the „owner". Humans generally show a tendency to personalize their work places and their living environment.

Examples:
- Marked-off area with personal objects
- Earmarked or discernible environment of the person's actions
- Independent choice of activity and arrangement of the environment

P6 – Self-expression/presentation

Description:
The kind of presentation of one's person and his position is known as self-expression. Emphasizing one's significance and function is a signal to the social environment at the same time.

Examples:
- Representative clothing, e.g.: to wear or not to wear a tie
- Clarification of the social/organisational standing, for instance when stating title and line function (management function) on business cards or in email signatures
- Representation of brand marks, e.g.: by Logos and advertising

P7 – Feeling of safety

Description:
The absence or avoidance of dangers and insecurities in interior spaces is known as the feeling of safety.

Examples:
- Comprehensive capturing of a room scenario even when viewed against glare
- Bright, well-lit areas for easy recognition

P8 – Self monitoring

Description:
This aspect determines the influence on and the understanding of the direct environment.

Examples:
- Option for individual intervention, e.g.: by turning on or off the lighting
- Compensation of reduced visual performance due to age, e.g.: by higher task illuminance

P9 – Mental activation

Description:
Mental activation is the cognitive stimulation by an external influence.

Examples:
- Concentration on demanding tasks
- Increasing the level of interest
- Mental fitness, e.g.: creative labs

P10 – Mental relaxation

Description:
Mental relaxation means cognitive relaxation as a consequence of external influences or the lack of stimulation.

Examples:
- No stress
- No distracting attractions

P11 – Familiarity

Description:
Familiarity or intimacy is characterised by understanding or accepting a situation. New or unknown situations may lead to uncertainty, fear and panic.

Examples:
- The known domestic environment
- Well-rehearsed procedures in every day life

B 1.4 Architectural requirements

The built environment is the space in which people move. People make demands in terms of conscious and subconscious requirements.

»Architectural requirements on a lighting concept result from the structure of the architecture to be illuminated. In this context the purpose of the lighting solution is to emphasize the structure of the room, to clarify its form, rhythm and modules, enhance architectural features and to support the intended mood of the building. The architecture shall be supported both by the arrangement of luminaires and their lighting effects, but should possibly also be affected in its appearance.« (Ganslandt, Hofmann: Handbuch der Lichtplanung/*Handbook of lighting design)*

A1 – Structuring the room according to its form

Description:
Geometric forms and structures bring order to and define a room.

Examples:
- Luminaire geometry adapted to the room geometry
- Marking pathways with the luminaire layout
- Luminaire layout according to areas of use

A2 – Structuring the room according to rhythmicity (spatial and/or in terms of time)

Description:
Forms and elements of the room appearing in a – uniform – spatial or timely sequence are enhanced.

Examples:
- Repeating certain elements/features in the room
- Luminaire arrangement according to distinct structures, e.g.: lines, grids, checkerboards, etc.
- Adapting the luminaire layout to a modular ceiling
- Timed adaptation of the illumination

A3 – Structuring the room according to zones

Description:
Zones belonging together and structural elements in the room are emphasized.

Examples:
- Illumination of a suite, e.g.: in the living room or an open plan office
- Accentuating walls and – vertical – elements in the room
- Illuminating different elements in a shop, e.g.: changing cubicles, shelves, displays, cash registers, pathways, etc.

A4 – Supporting the character of the architecture

Description:
The character, the emotional effect and the mood to be triggered that emanate from the architecture, are adopted and illustrated.

That means:
- Adopting historical, cultural or sociologic statements determined by the architecture
- Selection of luminaires that correspond to the basic »mental concept« due to their form, type and arrangement

Examples:
- Selection of matching stile elements, e.g.: chandeliers in a ballroom

A5 – Emphasizing architectural – creative – features

Description:
Elements or objects, modules and structures of the room may be complemented, interrupted or superimposed by special features.

Examples:
- Illumination of small architectural details
- Spotlighting paintings or sculptures
- Uniform illumination of a vaulted ceiling

B 2 Weighting requirements subject to the applications

The weighting of the requirements subject to the application is valid for a broadly defined user (see chapter 1.1).

The individual requirements differ subject to the main application and its specific secondary application. They are weighted as predetermined examples.

There are some »typical« requirements for each application. Specific types of rooms and activities represent secondary applications.
This publication covers the following applications:
- Office
- Education
- Hospital
- Care
- Industry
- Art and culture
- Hotel
- Shop

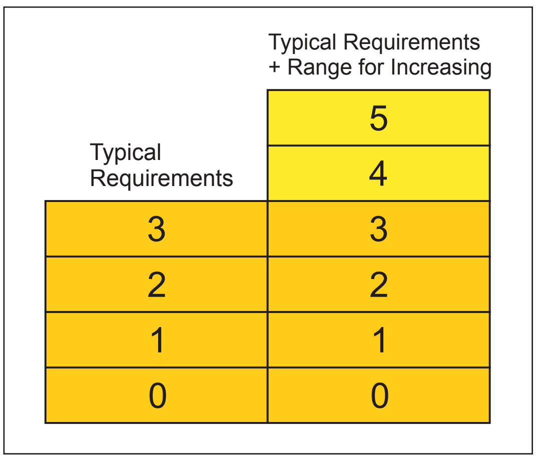
The weighting is done according to the »importance« respectively »relevance« for fulfilling the »typical« requirement. The weighting is divided into three categories:

1 = less relevant
2 = relevant
3 = strongly relevant

A requirement not relevant for an application is weighted »0«.

Deviations from the typical requirement:

Specific applications such as type of room or activity may be connected to aspects, which lead to a strengthening or weakening of typical requirements. In such instances the value for the typical application may be increased by +1 or decreased by -1 regardless of the original value. Value 5 represents the maximum increase while the value 0 stands for the minimum (refer to Figure 6).



Scaling:
5 = Maximum
4-5 Range for increasing the requirements
+1 Increase due to criteria
- 1 Decrease due to criteria
1-3 Bandwidth of the typical requirement
3 = strongly relevant
2 = relevant
1 = less relevant
0 = not applicable

Figure 6:
Scaling of the weighting for fulfilling the requirements

The following chapter exemplarily describes the specific secondary applications as room types and activities for each application. The tables 3 through 10 show the predetermined weightings for fulfilling the »typical« requirement and its specific secondary applications. In addition the user has the option to directly weight the requirements subject to the relevance in a project.

Applications and room types as well as their introductory descriptions have been selected as examples and do not claim to be complete.

B 2.1 Office

Offices may be exemplarily subdivided into the following criteria:

B 2.1.1 Executive's office
Executive's offices usually have only one workplace for normal office work and therefore are subject to the same requirements as any other office workplace. In addition, the executive's office should have a representative character. It is important to set focal points attracting attention and to earmark the personal territory. Should the office have some unique architectural features, then the lighting should emphasize such features. Light should also provide orientation in terms of time.

B 2.1.2 Single cell office
The workplace in a single cell office is subject to the same lighting requirements as the executive's office. Some emphasis should be put on privacy as well as the personal territory. In order to assure focused work there should also be phases for – general and mental – activation and relaxation.

B 2.1.3 Group office
A group office consists of several workplaces with the same lighting requirements as in the single office. Each individual will normally create his own personal territory. Communication should be supported. General and mental activation and relaxation are important in the daily routine. Furthermore the orientation in terms of time and space is important in the group office.

B 2.1.4 Open plan office
An open plan office also consists of individual workplaces. In addition there are often meeting and traffic zones. Noise, disquiet and distraction play a major role. The desire for a personal territory may well vary from person to person. Orientation in terms of time and space is very important. This is particularly true for workplaces further away from the windows. The arrangement of the furniture or the room as such may be accentuated by the lighting system and provide orientation.

B 2.1.5 Conference room
A conference room is usually utilised for shorter periods of time. Rarely one spends a whole day in a conference room. Supporting communication as well as the use of presentation media has high priority. However, occasional focused reading and writing over longer periods of time should also be supported. Orientation in terms of time – particularly regarding the time spent in the room – is important. Architectural requirements play a major role subject to the respective use, for instance for internal meetings, meetings with clients or with special emphasis on representation. Operating the lighting system is particularly important: Any input devices must be easily recognized and must be simple to operate; the lighting scenario should be understood spontaneously.

Table 12:
Office: Weighting of the typical requirements as well as weighting of requirements in individual room types.
3 = strongly relevant;
2 = relevant;
1 = less relevant;
0 = not applicable

		Typical requirements office	Executive's office	Single cell office	Group office	Open plan office	Conference room	Individual requirements
Functional requirements								
F1	Seeing and identifying details	2	2	2	2	2	1	
F2	Seeing and identifying shapes	2	2	2	2	2	2	
F3	Seeing and identifying colours	2	2	2	2	2	2	
F4	Speed of perception and identification	2	2	2	2	2	2	
F5	Seeing and identifying over a period of time	3	2	3	3	3	2	
F6	Directing attention	1	2	2	1	1	1	
F7	Order/ability to differentiate	2	2	2	2	2	1	
F8	Physical safety	1	1	1	1	1	1	
F9	Physical protection	0	0	0	0	0	0	
Biological requirements								
B1	Activation	3	3	3	3	3	3	
B2	Relaxation	3	3	3	3	3	3	
B3	Circadian rhythm	3	3	3	3	3	2	
B4	Protection against radiation	1	1	1	1	1	1	
B5	Physiological effects of radiation	1	1	1	1	1	1	
Psychological requirements								
P1	Spatial orientation	2	2	2	3	3	2	
P2	Chronological orientation	3	3	3	3	3	2	
P3	Orientation regarding proceedings	2	2	2	2	2	2	
P4	Privacy	2	2	2	3	3	1	
P5	Personal territory	2	2	2	3	3	1	
P6	Self-expression/presentation	1	3	3	2	2	2	
P7	Feeling of savety	2	2	2	2	2	2	
P8	Self monitoring	2	2	2	1	1	3	
P9	Mental activation	3	3	3	3	3	3	
P10	Mental relaxation	3	3	3	3	3	3	
P11	Familiarity	2	2	2	2	2	1	
Architectural requirements								
A1	Structuring the room according to its form	1	2	1	1	1	2	
A2	Structuring the room according to rhythmicity	1	1	1	2	2	1	
A3	Structuring the room according to zones	2	1	1	2	2	1	
A4	Supporting the character of the architecture	1	2	1	1	1	2	
A5	Emphasizing architectural – creative – features	1	2	1	1	1	2	

B 2.2 Education

Rooms in educational facilities may be subdivided into the following categories:

B 2.2.1 Classroom (children)

Children often have to get up early and study very focused over a longer period of time. Therefore adequate conspicuity of very different visual tasks should be assured during class. The room should provide orientation and generate a feeling of familiarity. Light should generally and mentally activate and also offer repose. A good reference to daylight is necessary for the circadian rhythmicity, which also provides orientation.

B 2.2.2 Classrooms (adults)

Adults, regardless if they are students at a university or participants undertaking continuing education, utilize classrooms during the day as well as in the late hours of the evening. Visual tasks comprise writing and reading, observing presentations (data projectors) as well as recognizing conversational partners. Mental concentration should be promoted. Additional objectives are general and mental activation over longer periods of time and also in the evening.

B 2.2.3 Workshop

A workshop is intended for skilled manual work. Recognizing details, forms and colours is a top priority. Dark areas in the room should be avoided in order to also assure physical safety and enhance the subjective feeling of safety.

B 2.2.4 Computer room

A computer room should facilitate undisturbed working with screens in all parts of the room. It is particularly important to avoid or at least reduce any veiling reflections on computer screens. The lighting level should be adapted to the respective type of work.

B 2.2.5 Lecture room

A lecture room should facilitate the common basic activities such as reading and writing in all areas of the room. This includes writing on the board as well as reading info on the board respectively the information displayed by a data projector. The lighting system should be adaptable to suit the respective visual tasks and also the spatial orientation for guiding the student’s attention.

B 2.2.6 Sports hall

One key requirement in a sports hall is to assure uniform lighting conditions over the entire area. Subject to the type of sport the lighting levels should be sufficiently bright. In addition, rapid conspicuity is important for successful sports activities as well as for the avoidance of injuries. Subject to the respective type of sport potentially different directions of view have to be taken into account.

B 2.2.7 Teacher’s lounge

Many different activities take place in the staff room. They range from meetings to focused preparation of the upcoming lectures and on to relaxation. Therefore the lighting must be flexible and must cater for a wide range of different requirements.

B 2.2.8 Library

The key visual task in the library is reading while seated at a table but also reading the spine of the books on the shelves. Since people often work very focused over longer periods of time, mental activation has high priority. Another important requirement is the possibility for retreat and privacy. Besides orientation in terms of time the spatial orientation should also be supported.

Table 13:
Education: Weighting of the typical requirements as well as weighting of requirements in individual room types.
3 = strongly relevant;
2 = relevant;
1 = less relevant;
0 = not applicable

		Typical requirements education	Classroom (children)	Class room (adults)	Workshop	Computer room	Lecture room	Sports hall	Teacher's lounge	Library	Individual requirements
Functional requirements											
F1	Seeing and identifying details	2	2	2	3	2	2	2	2	3	
F2	Seeing and identifying shapes	2	2	2	3	2	2	3	2	2	
F3	Seeing and identifying colours	2	2	2	3	2	2	2	2	2	
F4	Speed of perception and identification	2	2	2	3	2	2	4	2	2	
F5	Seeing and identifying over a period of time	3	3	3	2	2	2	2	2	3	
F6	Directing attention	2	2	2	2	2	2	2	2	2	
F7	Order/ability to differentiate	2	2	2	2	2	2	2	2	2	
F8	Physical safety	2	2	2	4	2	2	3	2	2	
F9	Physical protection	0	0	0	0	0	0	0	0	0	
Biological requirements											
B1	Activation	3	3	3	3	2	2	4	2	2	
B2	Relaxation	3	3	3	2	2	2	2	3	2	
B3	Circadian rhythm	3	4	4	1	2	2	1	3	3	
B4	Protection against radiation	1	1	1	1	1	1	1	1	1	
B5	Physiological effects of radiation	1	1	1	1	1	1	1	1	1	
Psychological requirements											
P1	Spatial orientation	2	2	2	2	2	2	2	2	3	
P2	Chronological orientation	3	3	3	2	2	3	2	2	3	
P3	Orientation regarding proceedings	2	2	2	2	2	2	2	2	2	
P4	Privacy	1	1	1	1	2	1	0	2	3	
P5	Personal territory	1	1	1	1	1	1	0	1	3	
P6	Self-expression/presentation	1	1	1	1	1	1	1	1	1	
P7	Feeling of savety	2	2	2	2	2	2	2	2	2	
P8	Self monitoring	1	1	2	1	2	2	1	2	1	

P9	Mental activation	3	3	3	2	2	3	2	2	4	
P10	Mental relaxation	3	3	3	2	2	3	2	3	3	
P11	Familiarity	2	3	2	2	2	2	2	2	2	
Architectural requirements											
A1	Structuring the room according to its form	1	1	1	1	1	2	1	1	2	
A2	Structuring the room according to rhythmicity	1	1	1	1	1	1	1	1	1	
A3	Structuring the room according to zones	1	2	2	1	1	1	1	1	2	
A4	Supporting the character of the architecture	1	1	1	1	1	2	1	1	2	
A5	Emphasizing architectural – creative – features	1	1	1	1	1	2	1	1	2	

B 2.3 Hospital

The rooms in hospitals may be subdivided into the following categories:

B 2.3.1 Patient's room

Lighting requirements in patient's rooms may differ greatly and need to be very flexible. Well-being and relaxation are top priorities for the patients. The artificial lighting should be adapted to the circadian rhythm for patients spending the whole day or days in this room. Privacy should be assured in rooms with several patients and also when visitors are present. When doctors do their ward rounds, examinations and treatments the lighting must meet all functional requirements: Medical doctors and nursing staff must be able to recognize the respective visual tasks. Orientation and safety must also be assured at night.

B 2.3.2 Intermediate Care

The lighting requirements for Intermediate Care are pretty similar to those in the patient's rooms. Medical staff should be able to select functional lighting for more intense observation. Privacy is not quite as relevant as in other areas.

B 2.3.3 Intensive care

Besides the functional lighting necessary for observation and examination the support of the circadian rhythm and orientation in terms of time are particularly important criteria in intensive care. This results from the often missing link to natural light.

B 2.3.4 Treatment room

The lighting in a treatment room must meet various requirements. It is important to enhance the »well-being« of the patients and to minimize possible anxiety, for instance, when there is not yet a clear diagnosis. However, the functional lighting should not be compromised due to the above considerations, since recognizing colours, forms and structures as part of the visual task are not just important but essential.

B 2.3.5 Waiting room

Patients spend a lot of time in waiting rooms, be it at the hospital or the doctor's practice. People tend to get restless in such situations. The appropriate illumination in waiting areas may help to minimize possible anxiety and generate familiarity and well-being.

B 2.3.6 Operating theatre

In the operating theatre functional lighting requirements are particularly important: colours, forms and structures must be easily detected and differentiated. This is particularly important for minimal contrasts that must be recognized easily and quickly. Since surgery may take many hours, the lighting should help to prevent fatigue and keep the mental activity at a high level.

Table 14: Hospital: Weighting of the typical requirements as well as weighting of requirements in individual room types.
3 = strongly relevant;
2 = relevant;
1 = less relevant;
0 = not applicable

		Typical requirements hospital	Patient's room	Intermediate care	Intensive care	Treatment room	Waiting room	Operating theatre	Individual requirements
Functional requirements									
F1	Seeing and identifying details	3	3	3	4	3	1	5	
F2	Seeing and identifying shapes	3	3	3	3	3	2	4	
F3	Seeing and identifying colours	3	3	3	3	3	1	5	
F4	Speed of perception and identification	3	3	3	3	3	1	5	
F5	Seeing and identifying over a period of time	2	1	1	1	3	1	4	
F6	Directing attention	2	2	2	1	2	2	3	
F7	Order/ability to differentiate	2	2	2	1	2	2	2	
F8	Physical safety	2	2	2	2	2	2	4	
F9	Physical protection	0	0	0	0	0	0	0	
Biological requirements									
B1	Activation	3	2	3	3	2	2	4	
B2	Relaxation	3	3	4	4	2	2	3	
B3	Circadian rhythm	3	4	4	5	2	2	4	
B4	Protection against radiation	1	1	1	1	1	1	1	
B5	Physiological effects of radiation	1	1	1	1	1	1	1	
Psychological requirements									
P1	Spatial orientation	2	2	1	1	2	2	2	
P2	Chronological orientation	3	3	3	4	2	3	4	
P3	Orientation regarding proceedings	3	3	2	2	2	3	2	
P4	Privacy	3	3	3	3	1	1	1	
P5	Personal territory	1	1	1	1	1	1	1	

P6	Self-expression/presentation	1	1	1	1	1	1	1	
P7	Feeling of savety	3	3	3	3	3	3	3	
P8	Self monitoring	2	3	2	1	2	1	3	
P9	Mental activation	2	2	2	3	3	1	5	
P10	Mental relaxation	3	3	3	3	1	3	3	
P11	Familiarity	3	3	3	2	2	3	1	
Architectural requirements									
A1	Structuring the room according to its form	2	2	1	1	1	2	1	
A2	Structuring the room according to rhythmicity	1	1	1	1	1	1	1	
A3	Structuring the room according to zones	1	1	1	1	1	1	1	
A4	Supporting the character of the architecture	2	2	1	1	2	3	1	
A5	Emphasizing architectural – creative – features	2	2	1	1	1	2	1	

B 2.4 Care

Rooms in areas for general care may be subdivided into the following categories:

B 2.4.1 Common or recreation room

The common room is the heart respectively the communication centre in the care for mostly elderly persons. It is desirable that the residents spend most of the day in this room. Daytime activity helps to improve sleep at night. Thus the circadian rhythm is stabilized. The rhythm facilitates general and mental relaxation on the one hand and activation on the other. The appropriate illumination also provides information regarding the time of day and the season.

B 2.4.2 Corridor

The corridor is not only the link between the individual rooms of the residents and the common room for all residents but is also the channel of supply for nurses as well as meeting point for residents, nurses and visitors. Accordingly wide spread are the lighting requirements. Lighting should facilitate visual tasks such as reading and recognizing other persons, guiding, creating safety and orientation. Poor lighting may quickly lead to misperception due to disturbing veiling reflections that may result in inhibition thresholds.

B 2.4.3 Resident's room

The resident's room represents the personal territory of the person living here and should mainly focus on supporting privacy and familiarity. As a retreat, the room should emanate an atmosphere of relaxation. It should be easy to find any objects.

B 2.4.4 Nurse's room

The activities in the nurse's room are manifold just as the lighting requirements: reading and writing, working with computer screens, but also relaxation and communication should be supported. The fact that the room is used virtually around the clock makes it a special workplace. On the one hand the nursing staff should be able to relax but should also be able to carry out focused work, particularly at night.

B 2.4.5 Entrance/foyer

The entrance area respectively the foyer in health care facilities should have an inviting and representative ambience. Architectural elements should be enhanced and orientation, particularly for visitors, should be supported.

Table 15:
Care: Weighting of the typical requirements as well as weighting of requirements in individual room types.
3 = strongly relevant;
2 = relevant;
1 = less relevant;
0 = not applicable

		Typical requirements care	Common or recreation room	Corridor	Resident's room	Nurse's room	Entrance/foyer	Individual requirements
Functional requirements								
F1	Seeing and identifying details	2	2	1	2	2	1	
F2	Seeing and identifying shapes	2	3	3	2	2	2	
F3	Seeing and identifying colours	2	2	2	2	2	1	
F4	Speed of perception and identification	1	1	1	1	1	1	
F5	Seeing and identifying over a period of time	2	2	1	2	3	1	
F6	Directing attention	2	2	3	2	1	2	
F7	Order/ability to differentiate	2	3	2	3	1	1	
F8	Physical safety	3	3	3	3	1	2	
F9	Physical protection	0	0	0	0	0	0	
Biological requirements								
B1	Activation	3	4	2	2	3	1	
B2	Relaxation	3	4	2	4	3	1	
B3	Circadian rhythm	3	5	3	4	3	1	
B4	Protection against radiation	1	1	1	1	1	1	
B5	Physiological effects of radiation	1	1	1	1	1	1	
Psychological requirements								
P1	Spatial orientation	3	3	4	3	2	2	
P2	Chronological orientation	3	3	3	3	3	1	
P3	Orientation regarding proceedings	3	3	2	2	3	1	
P4	Privacy	2	2	1	3	2	1	
P5	Personal territory	2	1	1	3	2	1	
P6	Self-expression/presentation	1	1	1	1	1	3	
P7	Feeling of savety	3	3	4	3	1	1	

P8	Self monitoring	2	1	1	3	3	2	
P9	Mental activation	3	4	2	2	4	1	
P10	Mental relaxation	3	3	2	4	4	1	
P11	Familiarity	3	3	2	4	2	1	
Architectural requirements								
A1	Structuring the room according to its form	2	2	3	1	1	2	
A2	Structuring the room according to rhythmicity	1	1	2	1	1	1	
A3	Structuring the room according to zones	2	2	1	3	1	2	
A4	Supporting the character of the architecture	2	2	1	1	1	3	
A5	Emphasizing architectural – creative – features	2	2	1	1	1	3	

B 2.5 Industry

Spaces utilized for industrial applications may be subdivided into the following categories:

B 2.5.1 Assembly hall

In the assembly hall functional requirements have top priority. The visual tasks must be clearly defined. Subject to the visual tasks the requirements may vary regarding the conspicuity of details, shapes and colours. Generally speaking, the visual tasks in an assembly hall are carried out for longer periods of time. The workers should be generally and mentally activated.

B 2.5.2 Fancywork

If the visual task consists of the recognition of particularly small, fine details, the required visual performance of the workers is increased considerably. Even minor contrasts must be quickly detected with certainty. Illumination that guides attention assures the appropriate light at the location of the most delicate visual task and the highest level of concentration.

B 2.5.3 Workplace in the food or chemical industry

The lighting requirements must also be adapted to the various visual tasks in the food respectively chemical industry as described in chapters B 2.5.1 and B 2.5.2. In addition, requirements are more stringent due to safety and hygienic aspects.

B 2.5.4 Machine work

Automated processes dominate in machine work areas.Workers are mainly occupied with process and quality control. When using machines, physical safety of the workers in terms of quick recognition of dangers is of great importance. Stroboscopic effects with rotating parts should be avoided.

B 2.5.5 Quality control workplaces

Such workplaces focus almost exclusively on functional requirements: Quick and certain recognition of details, forms and colours, material faults and quality deficits represent the visual task. The workers must be able to carry out their tasks at a high level of concentration over longer periods of time. Other requirements have lower priorities.

B 2.5.6 Storage

Storage areas are generally only occupied for short periods of time. The need for uniform vertical illumination for best possible recognition of merchandise and its labels on the shelves must be taken into account. Objects and movements within the traffic zones must be quickly and reliably recognized in order to prevent accidents. When nobody is present the lighting should be turned off.

B 2.5.7 Logistics

Besides the functional requirements as described in chapter B 2.5.6, orientation should be focused on.

Table 16:
Industry: Weighting of the typical requirements as well as weighting of requirements in individual room types.
3 = strongly relevant;
2 = relevant;
1 = less relevant;
0 = not applicable

		Typical requirements industry	Assembly hall	Fancywork	Workplace in the food or chemical industry	Machine work	Quality control workplaces	Storage	Logistics	Individual requirements
Functional requirements										
F1	Seeing and identifying details	3	3	5	3	3	5	2	2	
F2	Seeing and identifying shapes	3	3	3	3	3	5	2	2	
F3	Seeing and identifying colours	2	2	3	4	2	5	1	1	
F4	Speed of perception and identification					4	4	3	3	
F5	Seeing and identifying over a period of time	3	3	4	4	2	5	1	1	
F6	Directing attention	2	2	2	2	2	4	2	2	
F7	Order/ability to differentiate	2	2	3	3	2	3	2	2	
F8	Physical safety	3	3	2	3	4	1	2	2	
F9	Physical protection	0	0	0	0	0	0	0	0	
Biological requirements										
B1	Activation	3	3	4	3	2	4	1	1	
B2	Relaxation	2	2	2	2	2	2	1	1	
B3	Circadian rhythm	3	3	3	3	3	3	1	1	
B4	Protection against radiation	1	1	1	1	1	1	1	1	
B5	Physiological effects of radiation	1	1	1	1	1	1	1	1	
Psychological requirements										
P1	Spatial orientation	2	2	2	2	2	2	3	3	
P2	Chronological orientation	3	3	3	3	3	3	1	2	
P3	Orientation regarding proceedings	1	2	1	2	2	1	2	3	

P4	Privacy	1	1	1	1	1	1	1	1	
P5	Personal territory	1	1	1	1	1	1	1	1	
P6	Self-expression/presentation	1	1	1	1	1	1	1	1	
P7	Feeling of savety	2	2	2	3	3	2	2	2	
P8	Self monitoring	2	2	3	2	2	4	1	1	
P9	Mental activation	3	3	4	4	3	4	1	2	
P10	Mental relaxation	2	2	2	2	2	2	1	2	
P11	Familiarity	1	1	1	1	1	1	1	1	
Architectural requirements										
A1	Structuring the room according to its form	1	1	1	1	1	1	1	1	
A2	Structuring the room according to rhythmicity	1	1	1	1	1	1	1	1	
A3	Structuring the room according to zones	2	3	2	2	2	1	2	2	
A4	Supporting the character of the architecture	1	1	1	1	1	1	1	1	
A5	Emphasizing architectural – creative – features	1	1	1	1	1	1	1	1	

B 2.6 Art and culture

Spaces utilized for art and culture may be subdivided into the following categories:

B 2.6.1 Museum

Perfect conspicuity and presentation of the exhibited objects such as paintings and sculptures are the central aim in exhibition halls or galleries. Pieces of art are often very sensitive and get affected by shortwave (UV) and longwave (IR) radiation and should be illuminated subject to their material. In addition, curators often have concrete ideas about the presentation of the exhibits in terms of lighting and colours. Architecture itself also plays a major role in influencing museums and exhibitions. Therefore clear structures according to space and rhythmicity as well as enhancing architectural features are chief requirements.

B 2.6.2 Theatre

This publication does not refer to stage lighting but rather to the theatre as the location of events. The building as such is subject of consideration, particularly the foyer and the auditorium. Many theatres are located in historical buildings where enhancing the architecture and the spatial orientation are the focal points. The illumination should provide a pleasant shadiness for perceiving faces and three-dimensional objects as well as considering how to guide attentiveness.

B 2.6.3 Fair and exhibition halls

In larger open halls such as exhibition halls the order of differentiation between various zones of utilisation requires attention. Facilitating spatial orientation as well as direction are the top priorities.

B 2.6.4 Sacred buildings

Sacred buildings are places of peace and reflection, but also of festive rituals and ceremonies. The lighting should adequately support the character of a sacred space and the various different moods of sacred activities.

Table 17:
Art and culture: Weighting of the typical requirements as well as weighting of requirements in individual room types.
3 = strongly relevant;
2 = relevant;
1 = less relevant;
0 = not applicable

		Typical requirements art and culture	Museum	Theatre	Fair and exhibition halls	Sacred buildings	Individual requirements
Functional requirements							
F1	Seeing and identifying details	2	4	2	2	1	
F2	Seeing and identifying shapes	3	4	3	3	2	
F3	Seeing and identifying colours	2	4	2	2	1	
F4	Speed of perception and identification	1	1	1	1	1	
F5	Seeing and identifying over a period of time	1	1	1	1	1	
F6	Directing attention	3	5	3	3	3	
F7	Order/ability to differentiate	2	3	2	2	2	
F8	Physical safety	2	2	2	2	2	
F9	Physical protection	3	4	2	1	3	
Biological requirements							
B1	Activation	1	1	1	2	1	
B2	Relaxation	3	3	3	1	2	
B3	Circadian rhythm	1	1	1	1	1	
B4	Protection against radiation	1	1	1	1	1	
B5	Physiological effects of radiation	1	1	1	1	1	
Psychological requirements							
P1	Spatial orientation	3	3	4	4	2	
P2	Chronological orientation	2	2	2	2	1	
P3	Orientation regarding proceedings	2	2	3	3	2	
P4	Privacy	1	1	1	1	3	
P5	Personal territory	1	1	1	1	1	
P6	Self-expression/presentation	1	1	1	2	1	
P7	Feeling of savety	2	2	2	2	1	
P8	Self monitoring	1	1	1	1	1	
P9	Mental activation	2	2	2	2	1	
P10	Mental relaxation	2	2	3	1	3	
P11	Familiarity	2	2	2	1	4	

Architectural requirements								
A1	Structuring the room according to its form	3	3	3	3	2	
A2	Structuring the room according to rhythmicity	3	3	3	3	2	
A3	Structuring the room according to zones	3	3	4	2	3	
A4	Supporting the character of the architecture	3	5	4	2	5	
A5	Emphasizing architectural – creative – features	3	4	5	3	5	

B 2.7 Hotel and restaurant

Spaces utilized as parts of hotels and restaurants may be subdivided into the following categories:

B 2.7.1 Restaurant, dining room

Atmosphere and character play a decisive role for the well-being of the guests in restaurants. Generally speaking, a restaurant should invite to relax and provide a private if not intimate atmosphere. Besides these requirements it is also necessary to be able to recognize the colours of food and beverages, but also the partners at the table in a natural and unadulterated way.

B 2.7.2 Cash points

The lighting of cash registers must adhere to the same requirements as for the illumination of workplaces as described in chapter B 2.1. Natural chromaticity of food is also important at the cash register.

B 2.7.3 Kitchen

Safety and hygiene determine the lighting requirements in the kitchen. Of course, the visual requirements like recognizing details, forms and colours must be met. Visual performance of the personnel should be high during the entire shift.

B 2.7.4 Hotel room

A hotel room is guest a private room for the – at least for the duration of stay. Well-being, relaxation and privacy take priority. Personal control over the room and lighting scenario increase the guest's acceptance.

B 2.7.5 Reception/lobby

The entrance area and the reception must cater for different tasks. Initially the recognition of the visual task, i.e. writing, reading and computer work at the reception desk as well as the mutual recognition of faces must be assured. Like the façade of the building, the lobby and entrance area serve as the business card of the hotel and present demands towards the architecture.

B 2.7.6 Corridor

Spatial orientation has top priority in hotel corridors. Guest rooms and escape routes must be easily and reliably found.

Table 18:
Hotel and restaurant: Weighting of the typical requirements as well as weighting of requirements in individual room types.
3 = strongly relevant;
2 = relevant;
1 = less relevant;
0 = not applicable

		Typical requirements hotel	Restaurant, dining room	Cash points	Kitchen	Hotel room	Reception, lobby	Corridor	Individual requirements
Functional requirements									
F1	Seeing and identifying details	2	2	3	3	1	1	1	
F2	Seeing and identifying shapes	2	3	2	3	2	2	2	
F3	Seeing and identifying colours	2	3	2	3	2	1	1	
F4	Speed of perception and identification	1	1	1	3	1	1	1	
F5	Seeing and identifying over a period of time	1	1	1	2	1	1	1	
F6	Directing attention	2	3	2	1	3	3	2	
F7	Order/ability to differentiate	2	2	2	3	2	2	1	
F8	Physical safety	1	1	1	3	1	1	3	
F9	Physical protection	0	0	0	0	0	0	0	
Biological requirements									
B1	Activation	1	1	2	4	1	1	1	
B2	Relaxation	3	4	1	1	5	2	1	
B3	Circadian rhythm	1	1	1	2	2	1	1	
B4	Protection against radiation	1	1	1	1	1	1	1	
B5	Physiological effects of radiation	1	1	1	1	1	1	1	
Psychological requirements									
P1	Spatial orientation	3	3	2	2	3	3	3	
P2	Chronological orientation	1	1	1	2	2	1	1	
P3	Orientation regarding proceedings	3	2	2	2	1	3	2	
P4	Privacy	3	4	1	1	5	2	2	
P5	Personal territory	3	3	1	1	3	1	1	
P6	Self-expression/presentation	1	1	1	1	1	3	1	
P7	Feeling of savety	1	1	1	1	2	1	2	
P8	Self monitoring	3	1	1	1	5	3	1	
P9	Mental activation	1	1	2	4	1	1	1	
P10	Mental relaxation	3	3	1	1	5	2	1	
P11	Familiarity	2	3	1	1	4	3	2	
Architectural requirements									
A1	Structuring the room according to its form	2	2	1	1	2	3	2	
A2	Structuring the room according to rhythmicity	2	2	1	1	2	2	2	
A3	Structuring the room according to zones	2	3	1	1	3	2	2	

A4	Supporting the character of the architecture	3	5	1	1	5	4	3	
A5	Emphasizing architectural – creative – features	3	4	1	1	3	5	3	

B 2.8 Shop

Spaces utilized in shops may be subdivided into the following categories:

B 2.8.1 Sales area
Presenting the merchandise is the main objective in the sales area. The products, their colours, details and shapes, must be recognizable easily and quickly. The lighting system can assist in directing attention, can set focal points for attentiveness and support the spatial orientation. Of course, the merchandise must be protected against damaging radiation.

B 2.8.2 Cash registers
Lighting in the area of the cash registers shall meet the functional requirements as outlined in chapter B 2.7.2.

B 2.8.3 Storage area
The lighting requirements for storage areas are listed in chapter B 2.5.6.

B 2.8.4 Shop windows
Shop windows should be designed and illuminated in such a way that they attract the attention of the passers-by within seconds. The objective is to lure the potential customer into the shop. Important requirements are the quick recognition of shapes, colours and objects.

B 2.8.5 Changing cubicle
The decision to buy or not to buy a piece of clothing is often made in the changing cubicle. Extremely good perceptibility of colours and forms is very important. Both the person as well as the garment should appear advantageous and natural. The cubicle should appear inviting.

B 2.8.6 Supermarket
For many people shopping in a supermarket is a daily routine.Quick orientation and guidance, good and reliable identification of merchandise, directing attention to special offers and the familiar appearance are the most important factors. One should be able to clearly recognize colours and forms.

Table 19: Shop: Weighting of the typical requirements as well as weighting of requirements in individual room types.
3 = strongly relevant;
2 = relevant;
1 = less relevant;
0 = not applicable

		Typical requirements shop	Sales area	Cash register	Storage area	Shop windows	Changing cubicle	Supermarket	Individual requirements
Functional requirements									
F1	Seeing and identifying details	2	3	2	2	2	3	3	
F2	Seeing and identifying shapes	3	3	2	2	3	3	3	
F3	Seeing and identifying colours	3	5	3	1	4	5	5	
F4	Speed of perception and identification	2	2	1	2	3	2	2	
F5	Seeing and identifying over a period of time	1	1	2	1	1	1	1	

F6	Directing attention	3	5	1	2	5	3	4	
F7	Order/ability to differentiate	3	3	1	2	3	2	4	
F8	Physical safety	1	1	1	2	1	1	1	
F9	Physical protection	3	3	1	2	2	2	3	
Biological requirements									
B1	Activation	1	2	2	1	1	2	1	
B2	Relaxation	1	2	1	1	1	2	1	
B3	Circadian rhythm	1	1	1	1	1	1	1	
B4	Protection against radiation	1	1	1	1	1	1	1	
B5	Physiological effects of radiation	1	1	1	1	1	1	1	
Psychological requirements									
P1	Spatial orientation	3	4	2	3	2	2	4	
P2	Chronological orientation	2	2	1	1	2	2	1	
P3	Orientation regarding proceedings	3	3	2	2	1	3	3	
P4	Privacy	1	1	1	1	1	3	1	
P5	Personal territory	1	1	1	1	1	3	1	
P6	Self-expression/presentation	2	3	1	1	3	2	2	
P7	Feeling of savety	2	2	1	2	1	2	2	
P8	Self monitoring	1	2	1	1	3	2	2	
P9	Mental activation	2	2	2	1	2	2	2	
P10	Mental relaxation	1	1	1	1	1	1	1	
P11	Familiarity	1	2	1	1	1	3	2	
Architectural requirements									
A1	Structuring the room according to its form	2	2	1	1	1	2	2	
A2	Structuring the room according to rhythmicity	2	2	1	1	1	2	3	
A3	Structuring the room according to zones	2	3	1	1	2	2	3	
A4	Supporting the character of the architecture	3	3	1	1	2	2	3	
A5	Emphasizing architectural – creative – features	3	3	1	1	2	2	2	

B 3 Means of design for the lighting solution and measures for fulfilling the requirements

There are several means of design available to the lighting designer for planning and realizing lighting solutions. We will have a closer look at eight means of design for fulfilling the user requirements.

B 3.1 Luminous flux of the light source
B 3.2 Relative size of the light emitting area
B 3.3 Number, arrangement and position of the light source(s)
B 3.4 Luminous colour
B 3.5 Light distribution
B 3.6 Spectral distribution of the light source
B 3.7 Controllability and dimmability of the lighting system
B 3.8 Operating of the lighting system

Table 20: Individual requirements and the means of design to be applied in an overview

		Means of design (see appendix B 3)							
Requirements (see appendix B 1)		Luminous flux of the light source	Relative size of the light emitting area	Number, arrangement and position of source(s)	Light colour	Light distribution	Spectral distribution of the light source	Dimmability of the lighting system	Operating the lighting system
Functional requirements									
F1	Seeing and identifying details	■		■		■			
F2	Seeing and identifying shapes			■		■			
F3	Seeing and identifying colours				■		■		
F4	Speed of perception and identification	■				■			
F5	Seeing and identifying over a period of time							■	
F6	Directing attention	■	■	■	■	■		■	
F7	Order/ability to differentiate	■		■	■				
F8	Physical safety	■						■	
F9	Physical protection	■					■		
Biological requirements									
B1	Activation	■	■	■	■	■	■	■	
B2	Relaxation	■			■	■	■	■	

	Measures for fulfilling the requirements	Tab. 21	Tab. 22	Tab. 23	Tab. 24	Tab. 25	Tab. 26	Tab. 27	Tab. 28
B3	Circadian rhythm	■		■	■	■	■	■	
B4	Protection against radiation						■		
B5	Physiological effects of radiation						■		
Psychological requirements									
P1	Spatial orientation	■		■	■				
P2	Chronological orientation	■			■	■		■	
P3	Orientation regarding proceedings	■							
P4	Privacy	■		■		■			■
P5	Personal territory	■	■	■		■		■	■
P6	Self-expression/presentation	■		■		■		■	■
P7	Feeling of savety	■				■			
P8	Self monitoring							■	■
P9	Mental activation	■	■		■	■	■	■	
P10	Mental relaxation	■	■		■	■	■	■	
P11	Familiarity	■		■	■	■			■
Architectural requirements									
A1	Structuring the room according to its form		■	■					
A2	Structuring the room according to rhythmicity		■	■	■				
A3	Structuring the room according to zones		■	■	■				
A4	Supporting the character of the architecture	■	■		■	■		■	
A5	Emphasizing architectural – creative – features		■	■	■	■			

The means of design (Appendix B3, top line) are available in order to meet the requirements (Appendix B 1, left column). Relevant combinations are marked in grey. A grey field stands for a weighted requirement per application (Appendix B2) as well as measures (Appendix B3, Tables 21 through 28) and attributes for the evaluation (Appendix B 4).

The means of design and their general influence on the evaluation of the lighting quality are described in a generally understandable way. Additional means of design, such as the selection of the reflectance of surfaces may be applied in the same manner.
In an in depth consideration the means of design can also be assigned to photometric parameters, which allow evaluating and measuring them. This classification and the explanation of the photometric parameters are outlined in Appendix A1.
In the tables the means of design are mapped to the relevant user requirements they can predominantly fulfil. With 30 requirements and eight means of design there are potentially 240 combinations. 101 relevant combinations have been selected, where the requirements can be fulfilled in a sensible manner with the means of design (also refer to Table 20).

Based on this, concrete measures for fulfilling the selected relevant requirements are compiled (Appendix B3, Tables 21 through 28). The descriptions are exemplary and in-depth for providing a better understanding of the general influence on lighting quality. They do not claim to be complete.

In view of the following step some attributes for the evaluation of lighting quality are specified.

B 3.1 Luminous flux of the light source

Description
The luminous flux is an important means of design in lighting planning.

Table 21: Measures for fulfilling the requirements for the means of design »Luminous flux of the light source«

		Measures for meeting the requirements	Attributes for the evaluation of the lighting quality (see app. B 4)
Functional requirements			
F1	Seeing and identifying details	Choosing the appropriate illuminance level depends on the dimensions of the details (refer to DIN EN 12464-1 for values). A higher illuminance level improves the perceptibility of details.	E Fl
F4	Speed of perception and identification	Details can be recognized quicker at higher illuminance levels.	E Fl
F6	Directing attention	Illuminance levels must be graded subject to the importance of the visual task.	E
F7	Order/ability to differentiate	Different illuminance levels provide order or structure in a room (e.g.: different zones: working area = high illuminance; corridor = low illuminance).	E
F8	Physical safety	A minimum illuminance level is required at locations where there may be danger or obstacles (e.g.: steps, staircase) in order to avoid accidents.	E
F9	Physical protection	Low illuminance levels slow down the potential damage of objects.	E H_{dm}
Biological requirements			
B1	Activation	Increasing the illuminance level enhances activation of the human body.	E
B2	Relaxation	Low illuminance levels help to relax the human body.	E
B3	Circadian rhythm	The circadian rhythm can be stabilized by varying the illuminance over 24 hours according to nightly sleep and daily activation as well as relaxation phases.	E

Psychological requirements			
P1	Spatial orientation	Entrances and exits or pathways can be accentuated by higher brightness levels (luminance).	*E* *HK*
P2	Chronological orientation	In windowless spaces the luminous flux functions like a zeitgeber due to the variation of the luminous flux similar to changes of natural light outside: At dusk or dawn low lighting levels indicate the beginning or end of daylight hours while a higher lighting level signals noonday.	*E*
P3	Orientation regarding proceedings	Variations in brightness enhance the recognition of processes and actions.	*E* *HK*
P4	Privacy	A lower lighting level with a clear boundary to other zones creates a visual area of retreat.	*E* *HK*
P5	Personal territory	Local additional lighting or a clearly defined area with higher illuminance levels separates a personal territory from the general area.	*E* *HK*
P6	Self-expression/ presentation	A light centre with a particularly high illuminance supports the self-portrayal or representation of spaces, people, merchandise or objects.	*E* *HK*
P7	Feeling of savety	A higher level of subjective safety is achieved by avoiding dark areas as well as assuring adequate lighting levels in all corners of the room.	*E*
P9	Mental activation	Increasing the illuminance assures better mental activation/concentration and performance.	*E*
P10	Mental relaxation	Low illuminance enhances mental relaxation and stimulates regeneration.	*E*
P11	Familiarity	The luminous flux should be available in a natural and commonly known amount in order to provide the feeling of familiarity.	*E*
Architectural requirements			
A4	Supporting the character of the architecture	Illuminance levels should be adapted to the character of the architecture. Quiet areas, e.g. churches should rather be illuminated with low light levels.	*E*

Influence on the evaluation of the lighting quality

The luminous flux of the light source

- On the visual task influences its conspicuity (illuminance levels);
- Generates the impression of brightness (luminance levels) via their visible areas and the reflections on surfaces;
- May generate a biological effect;
- May cause disturbing or detracting effects such as discomfort or disability glare (luminance levels);
- Can visually structure a room with its distribution across the room (illuminance levels, reflectance factors).

B 3.2 Relative size of the light emitting area

Description

The photometrically relevant dimension of the light source is the geometric extent of the effective light emitting area. The relative size of the light emitting area refers to the ratio between the dimension of the light source and its distance and angle of observation to the illuminated area. A light source is called point light source, if it is to be regarded as small in relation to the dimensions of the room. This is valid, for instance, for high pressure discharge lamps, LEDs and tungsten halogen lamps with housings not substantially larger.

Influence on the evaluation of the lighting quality

The size of the light source

- Affects the subjective impression of glare: The smaller the light source with equal luminous flux the higher the probability of glare;
- Affects the type of shadows: The smaller the light emitting area, the stronger the shadows of objects. Thus every individual point light source generates a sharp shadow. The larger the light source, the less likelihood of creating sharp shadows;
- Affects the uniformity: Several larger light sources provide better uniformity (also refer to B 4.2);
- May generate biological effects.

		Measures for meeting the requirements	Attributes for the evaluation of the lighting quality (see app. B 4)
Functional requirements			
F6	Directing attention	Large light sources in interiors attract attention while small light sources are less obtrusive and create an effect due to their arrangement (refer to B 3.3).	*Q*
Biological requirements			
B1	Activation	The larger the light emitting area, the more receptors on the retina will be stimulated. Thus physical activation can be enhanced.	*Q*
Psychological requirements			
P5	Personal territory	Luminaires with light emitting surfaces of different size earmark the personal area.	*Q*
P9	Mental activation	Large light emitting areas are visually perceptible and support the ability to concentrate and to perform.	*Q*
P10	Mental relaxation	Smaller light emitting areas are less obtrusive and enhance well-being and relaxation.	*Q*
Architectural requirements			
A1	Structuring the room according to its form	The size of the light emitting area is rated according to the proportion of the room.	*Q*
A2	Structuring the room according to rhythmicity	The rhythm of the room can be replicated by the rhythm of the dimensions of the light emission areas.	*Q*
A3	Structuring the room according to zones	The dimensions of the light emitting areas are adapted to the room modules.	*Q*
A4	Supporting the character of the architecture	The dimension of the area determines the character of architecture, e.g. generosity due to large light emitting areas.	*Q*
A5	Emphasizing architectural – creative – features	The form and size of the light emitting area may well be a design feature by itself or enhance the architectural features.	*Q*

Table 22: Measures for fulfilling the requirements for the means of design » Relative size of the light emitting area «

B 3.3 Number, layout and position of the light source(s)

Description
The number of light sources is directly related to the selected luminous flux. The light source arrangement relative to each other generally follows a geometrical specification and may follow a certain pattern (e.g. line, row, square, chequerboard, irregular, etc.) or predetermined room geometries. Due to the position of the light sources and their appointed direction, it is possible to predetermine the incidence direction on the visual task or the object.

Influence on the evaluation of the lighting quality
The number of light sources
- Determines the number of shadows. Every point light source generates sharp shadows on every object. Large surface light sources generate soft or no shadows;
- Influences the uniformity of the illuminance.

Arrangement and position of the light source(s)
- Determine the direction of the shadow or shadows;
- Determine the length of the shadows: The lower the incident angle, the longer the shadow
- Influence the uniformity of the illuminance;
- Serve to enhance the ambience of the room.

Shadows may be disturbing subject to number, sharpness and length. Total freedom of shadows prevents the perception of plasticity and may lead to monotony and a flat appearance of the room.

Table 23: Measures for fulfilling the requirements for the means of design »Number, layout and position of the light source(s)«

		Measures for meeting the requirements	Attributes for the evaluation of the lighting quality (see app. B 4)
Functional requirements			
F1	Seeing and identifying details	Several point light sources should be avoided since they generate multiple shadows and impair the conspicuity.	U_o B_{Re} *CRF* *SS*
F2	Seeing and identifying shapes	Spotlighting of objects enhances their three-dimensional form.	*SS* *Mod*
F6	Directing attention	The arrangement guides the view in the order of the importance of the visual tasks.	*HK* *Q*
F7	Order/ability to differentiate	The position and direction of light emission accents the visual tasks.	*HK* *Q*

Biological requirements			
B1	Activation	Light sources located in the upper visual field support the biological effectiveness because the melanopic ganglion cells in the nasal area and the lower part of the retina are most sensitive.	*Q*
B3	Circadian rhythm	Adapted to the circadian rhythm light should be emitted predominantly by large area light sources in the upper visual field at times of activation (refer to activation).	*Q*
Psychological requirements			
P1	Spatial orientation	Locating light sources with regard to the structures of the rooms, e.g. in order emphasize pathways, doors.	*HK* *Q*
P4	Privacy	Locating light sources for defining a private area.	*HK* *Q*
P5	Personal territory	Locating light sources for marking one's personal area.	*HK* *Q*
P6	Self-expression/ presentation	Locating light sources and spotlighting for enhancing one's personal area.	*HK* *Q*
P11	Familiarity	Using common forms of the layout (e.g. illustration of symbols) or spotlighting common forms and objects.	*Q*
Architectural requirements			
A1	Structuring the room according to its form	Supporting the shape of the room by the arrangement of light sources or by spotlighting.	*Q*
A2	Structuring the room according to rhythmicity	Supporting the rhythmicity of the room with the arrangement of the light sources or by spotlighting.	*HK* *U* *Q*
A3	Structuring the room according to zones	Supporting room modules by the arrangement of light sources or by spotlighting.	*HK* *U* *Q*
A5	Emphasizing architectural – creative – features	Adapting the arrangement of light sources or by spotlighting architectural features.	*Q*

B 3.4 Light colour

Description

The light colour denominates the hue of white light. There are three typical light colours, namely warm white (correlated colour temperature below 3,300 K), neutral white (between 3,300 K and 5,000 K) and daylight white (above 5,000 K). Equal light colours may be composed of different spectral components

Influence on the evaluation of the lighting quality

The light colour depends on the application and the intended effect:

- Warm white colours convey a homelike character.
- Daylight white colours stand for cool and matter-of-fact environments.
- The light colour should be coordinated with the objects illuminated. For instance, warm light colour for bakery or meat products, daylight white colours for seafood.
- Warm white colours convey ease and relaxation.
- Neutral white colours stand for focused and creative work.
- Daylight white colours are activating and clean.
- The biological rhythm can be stabilized by employing »cooler« colours during the day and »warmer« colours in the evening. A high colour temperature in the evening hours can lower the melatonin level and subsequently the quality of sleep.

Table 24: Measures for fulfilling the requirements for the means of design »Light colour«

		Measures for meeting the requirements	Attributes for the evaluation of the lighting quality (see app. B 4)
Functional requirements			
F3	Seeing and identifying colours	The choice of the light colour and the spectral composition of the light source determine the conspicuity of colours. Objects in red or orange hues are better illuminated with warm white light (e.g.wood). Objects in blue or green hues are better illuminated with daylight white light (e.g.: steel).	R_a *CCT*
F6	Directing attention	Colour contrasts, which are achieved with the separate illumination of two different colour temperatures, directs perception and creates focal points for attention.	*FK*
F7	Order/ability to differentiate	By selecting the appropriate luminous colour, for instance, for a certain visual task or a function of the room, it is possible to support the order respectively structure of the room or the distinctness of functions.	*Q*
Biological requirements			
B1	Activation	Employing daylight white enhances general activation.	*CCT*
B2	Relaxation	Employing warm white light promotes general relaxation.	*CCT*

B3	Circadian rhythm	Higher colour temperatures during the day and lower ones in the evening and possibly at night stabilize the circadian rhythm.	*CCT*
Psychological requirements			
P1	Spatial orientation	Spatial orientation as well as the perception of dimensions and distances can be supported by the appropriate light colour. Daylight white illumination signals size, spatial depth and far distances while warm white light rather means short distances and closeness. By trend, cooler light colours are generally employed in southern, Mediterranean regions and warmer light colours in northerly, Scandinavian regions.	*CCT* *Q*
P2	Chronological orientation	The choice of the light colour is subject to the time of day and maysupport orientation in terms of time, particularly in windowless rooms, Thus the illumination signals morning and evening with warm white light colour while daylight white is associated with noontime. Warmer light colours are preferred in winter, cooler ones in summer.	*CCT* *Q*
P9	Mental activation	Daylight white illumination supports the ability to concentrate on one's task as well as the performance.	*CCT*
P10	Mental relaxation	Warm white illumination enhances well-being, rest and mental relaxation.	*CCT*
P11	Familiarity	Warm and neutral light colours are generally perceived as familiar.	*CCT*
Architectural requirements			
A2	Structuring the room according to rhythmicity	The rhythmicity (also in terms of time) of a room can be achieved by employing different light colours.	*FK* *Q*
A3	Structuring the room according to zones	Different light colours for the different modules provide order and structure to the room.	*FK* *Q*
A4	Supporting the character of the architecture	The light colour should support the character of the architecture. For instance, in comfortable environments (hotel, theatre, etc.) warm white illumination is employed.	*CCT* *Q*
A5	Emphasizing architectural – creative – features	The suitable light colour enhances material and shape of architectural features.	*CCT* *Q*

B 3.5 Light distribution

Description
The light distribution describes how a light source, respectively a luminaire emits light.

Influence on the evaluation of the lighting quality
The light distribution determines how light emitted by the luminaires is distributed across the room and determines brightness levels on surfaces and also uniformities across the room:

- Direct light directs brightness onto horizontal surfaces. Ceilings and walls often remain dark – this may lead to the so called »cave effect«.
- Indirect light directs brightness to the ceiling and generates diffuse light with hardly any shadows while consuming more energy.
- Direct/indirect light enjoys the highest acceptance for workplaces.
- Luminaires emitting diffuse light prevent sharply defined shadows.
- Directional light generates shadows. The edge of the shadows depends on the size of the light source.
- Good modelling is achieved by a sensible ratio between diffuse and directional light. It improves the three-dimensional perception of persons and objects in the room.
- Shielding and limiting the light intensity of the direct portion of light limits glare that may be caused by the luminaire.

Table 25: Measures for fulfilling the requirements for the means of design »Light distribution«

		Measures for meeting the requirements	Attributes for the evaluation of the lighting quality (see app. B 4)
Functional requirements			
F1	Seeing and identifying details	Directional light helps to improve conspicuity of details on surfaces.	U_o *Bal* B_{psy} B_{phy} *SS*
F2	Seeing and identifying shapes	The direct portion of the light distribution improves plasticity.	*Bal* *Mod*
F4	Speed of perception and identification	Quick perception is improved by a sensible ratio between directional and diffuse portions of light.	*Bal* *Mod*
F6	Directing attention	Directional light creates focal points of attention.	*Q*
Biological requirements			
B1	Activation	Indirect light and bright ceilings as well as large diffuse areas stand for activation.	*Bal*
B2	Relaxation	Direct (reduced) light and dark ceilings stand for relaxation.	*Bal*

B3	Circadian rhythm	Indirect or diffuse large area light during the day and direct light and dark ceilings at night support the circadian rhythmicity.	*Bal*
Psychological requirements			
P2	Chronological orientation	A reference to early morning or late evening hours can be established with directional light while diffuse indirect light rather marks midday.	*Bal*
P4	Privacy	Direct light stands for privacy.	*Bal* *Q*
P5	Personal territory	Directional light focused on a specific area marks the personal territory.	*Bal* *Q*
P6	Self-expression/ presentation	Large diffuse light sources or a large portion of indirect light have a representative character.	*Bal* *Q*
P7	Feeling of savety	The subjective feeling of safety is enhanced by a sensible ratio between direct and indirect light. Dark areas should be avoided.	*Uo* *Bal* *Q*
P9	Mental activation	Indirect light and bright ceilings as well as large diffuse areas stand for activation.	*Bal*
P10	Mental relaxation	Direct (reduced) light and dark ceilings stand for relaxation.	*Bal*
P11	Familiarity	A balanced ratio between direct and indirect light as well as directional and diffuse portions of light is perceived as familiar.	*Bal* *Q*
Architectural requirements			
A4	Supporting the character of the architecture	Open architecture is enhanced by indirect light, closed architecture by direct light.	*Bal* *Q*
A5	Emphasizing architectural – creative – features	Direct/indirect luminaires are generally objects as well as design elements in the room.	*Q*

B 3.6 Spectral distribution of the light source

Description

The spectrum of a light source describes die spectral composition of the radiated power of the light source. Frequently the adjacent ranges of IR and UV radiation are shown besides the visible range.

Influence on the evaluation of lighting quality

The spectrum of a light source

- Determines the quality of the colour rendering;
- Influences the reflectance of coloured surfaces;
- Marks the UV and IR portions of radiation;
- Can support the biological effectiveness.

		Measures for meeting the requirements	Attributes for the evaluation of the lighting quality (see app. B 4)
Functional requirements			
F3	Seeing and identifying colours	A preferably continuous and complete colour spectrum facilitates adequate conspicuity of colours and permits colour surveys.	R_a
F9	Physical protection	In order to assure safety for objects (less risk of damage) the spectrum of the light source(s) should only emit a minimum of shortwave radiation. UV and IR are to be avoided.	H_{dm}
Biological requirements			
B1	Activation	Especially shortwave spectral portions affect physical activation.	$a_{mel,v}$
B2	Relaxation	Longwave spectral components support well-being and physical relaxation.	$a_{mel,v}$
B3	Circadian rhythm	The adjustment of the spectral components in line with the natural activity (during the day) and relaxation phases (at night) support the circadian rhythm.	$a_{mel,v}$
B4	Protection against radiation	When choosing the spectral distribution of a light source one should consider avoiding IR and UV as far as possible.	H_{dm} Q
B5	Physiological effects of radiation	The right spectrum also has a physiological effect. For instance, the UVB component facilitates the production of vitamin D or causing a sun tan.	Q
Psychological requirements			
P9	Mental activation	Illumination with shortwave spectral components enhances mental activation.	$a_{mel,v}$
P10	Mental relaxation	Illumination with longwave spectral components enhances mental relaxation.	$a_{mel,v}$
Architectural requirements			

Table 26: Measures for fulfilling the requirements for the means of design »Spectral distribution of the light source«

B 3.7 Controllability of lighting systems

Description

Controlling lighting systems assists in adapting the lighting installation to external influences by adjusting the illumination. The light emitted by a light source is measured with a sensor, compared to a specified value and subsequently adjusted to the latter. When controlling the lighting system a sensor receives a signal and the light source responds according to a predetermined function, e.g. via a characteristic control curve. Lighting controls facilitate dynamic illumination and allow adjusting the lighting to specified values. Generally such systems control luminous flux, light distribution andlight colour.

The most frequently used methods are:

- Switching and dimming luminaires
- Daylight dependent control
- Presence respectively absence dependent control
- Constant light control
- Time dependent control
- Load limitation
- Activity related control
- Dynamic illumination according to pre-programmed control characteristic curves
- Scene control based on pre-programmed light scenes

Influence on the evaluation of lighting quality

Lighting controls

- Influence the acceptance of the lighting system by intelligible adjustments;
- Adapt the lighting to individual requirements;
- React to variable time-dependent requirements;
- Support the biological effectiveness (and also productivity) of the illumination.

Table 27: Measures for fulfilling the requirements for the means of design »Controllability of lighting systems«

		Measures for meeting the requirements	Attributes for the evaluation of the lighting quality (see app. B 4)
Functional requirements			
F5	Seeing and identifying over a period of time	To facilitate and realize pre-planned lighting scenarios for various requirements over time.	*Q*
F6	Directing attention	Automatic (time, scenes) or via sensors (presence) reacting lighting.	*Q*
F8	Physical safety	Presence controlled illumination in otherwise dark rooms.	*Q* *Fl*
Biological requirements			
B1	Activation	Pre-set lighting scenes and dynamic sequences with higher illuminance levels and higher colour temperatures during the day.	*Q*
B2	Relaxation	Pre-set lighting scenes and dynamic sequences with lower illuminance levels and lower colour temperatures in the evening hours.	*Q*
B3	Circadian rhythm	Adjusting the illumination in terms of colour temperature and luminous flux in line with the natural activity (during the day) and relaxation phases (at night) support the circadian rhythm.	*Q*
Psychological requirements			
P2	Chronological orientation	Time dependent controls (time management) and changing lighting scenarios linked to a timer.	*Q*
P5	Personal territory	Individual options of influencing the personal lighting scene.	*Q*
P6	Self-expression/ presentation	Personal options for adjusting one's own lighting scenario.	*Q*
P8	Self monitoring	Individual option for controlling one's own lighting scenario.	*Q*
P9	Mental activation	Pre-set lighting scenes and dynamic sequences with higher illuminance levels and higher colour temperatures during the day.	*Q*
P10	Mental relaxation	Pre-set lighting scenes and dynamic sequences with lower illuminance levels and lower colour temperatures in the evening hours.	*Q*
Architectural requirements			
A4	Supporting the character of the architecture	Pre-set lighting scenes enhance various architectural features.	*Q*

B 3.8 Operating the lighting system

Description
The lighting system can be adjusted by directly accessible control devices or via automatic systems without direct user influence.

Influence on the evaluation of the lighting quality
Manual control of the lighting system influences predominantly user acceptance elicited by the following aspects:

- Individual influence
- Accessibility of control devices
- Understandability of control devices
- Logical changes of light, whenever the lighting is controlled automatically
- Adjustability for control sequences, if necessary, by a specialist, which are triggered by manual commands

Table 28: Measures for fulfilling the requirements for the means of design »Operating the lighting system«

		Measures for meeting the requirements	Attributes for the evaluation of the lighting quality (see app. B 4)
Functional requirements			
Biological requirements			
Psychological requirements			
P4	Privacy	A manual command at a workplace or in a private environment supports privacy.	*Q*
P5	Personal territory	The personal territory can be controlled by a lighting control system or a simple switch.	*Q*
P6	Self-expression/ presentation	Additional (visible) control devices for a personal area or operation adapting automatically to the user, enhances the self-presentation and representation.	*Q*
P8	Self monitoring	The easy (understandable, intuitive) access or the assignment of control elements for parts of the room and functions supports the requirement according to one's own control.	*Q*
P11	Familiarity	Control devices marked with known symbols or labelled or located at familiar locations facilitate a higher level of acceptance and familiarity in operating the controls.	*Q*
Architectural requirements			

B 4 Attributes for the evaluation of the lighting quality

The attributes for the evaluation of the lighting quality have already been dedicated to the requirements (according to chapter B 1) and their weighting (chapter B 2) in the tables in chapter B 2. Many of the attributes are known and defined in lighting engineering. They offer a system of units.

B 4.1 Task illuminance (E)
B 4.2 Uniformity of illuminance (U_o)
B 4.3 Colour contrast (FK)
B 4.4 Brightness contrast (artistic) (HK)
B 4.5 Discomfort glare (B_{psy})
B 4.6 Disability glare (B_{phy})
B 4.7 Glare by reflection (B_{Re})
B 4.8 Light colour (CCT)
B 4.9 Colour rendering (R_a)
B 4.10 Contrast rendering (CRF)
B 4.11 Cast shadow (SS)
B 4.12 (Balanced) luminance distribution (Bal)
B 4.13 Modelling (Mod)
B 4.14 Avoidance of flicker (Fl)
B 4.15 Melanopic effect ($a_{mel,v}$)
B 4.16 Potential damages (H_{dm})
B 4.17 Qualitative factors (Q)

For each attribute drawn for meeting the requirements that have been considered for the evaluation there are predetermined limits, which must be adhered to, although they do not necessarily represent an optimum.

With the aid of the attributes one can determine to what degree the initially defined user requirements are fulfilled. The feedback may be utilized for improving the overall solution.

The size of the attributes is determined by an expert who forms his opinion based on relevant guide lines, standards, manuals and experience.

An expert first and foremost refers to the documentation as listed below.
This list does not claim to be complete.

Guidelines
- Guidelines for energy efficiency of products and in buildings
- ASR A 3.4: Code for workplaces

Standards
- DIN EN 12464: Lighting of workplaces in the interior and exterior containing the basic criteria and limit values
- DIN EN 12193: Lighting of sports complexes
- DIN 5035-7: Lighting of rooms with computer based workplaces (display screens), stating type of lighting and lighting concepts

Manuals

- BGI 856: Beleuchtung im Büro, Anleitung der Unfallversicherungsträger mit Beispielen zur Gestaltung von Büroarbeitsplätzen
- DGUV-1 215-211: Tageslicht am Arbeitsplatz
- DGUV-I: Schriftenreihe, in der die richtige Anwendung von Licht in verschiedenen Anwendungen aufgeführt ist

Publications

- DIN SPEC 67600: Planungsempfehlungen für biologisch wirksame Beleuchtung
- LiTG-Publikationen: Anwendungsschriften zu verschieden Themen wie z. B. Blendung, Kontrastwiedergabe, Messung, Farbqualität; www.litg.de/publikationen
- CIE-Publikationen: Anwendungsschriften in englischer Sprache; www.cie.co.at/publications
- Licht.wissen 1–20: Anwendungsinformationen in allgemein verständlicher Art mit vielen praxisnahen Beispielen, Grafiken und Bildern; www.licht.de;
- Leitfaden zur DIN EN 12464-1: Schrift, die die Aspekte der DIN und der ASR gemeinsam berücksichtigt; www.licht.de
- VDE ZVEI: Photobiologische Sicherheit in der Beleuchtung; www.licht.de
- ZVEI: Planungssicherheit in der LED-Beleuchtung; www.licht.de

Table 29: Mapping of attributes to the means of design that are taken into account for the evaluation of the requirements: grey field = relevant combinations

Requirements (see appendix B1)		Means of design (see appendix B3)							
		Luminous flux of the light source	Relative size of the light emitting area	Number, arrangement and position of source(s)	Light colour	Light distribution	Spectral distribution of the light source	Dimmability of the lighting system	Operating the lighting system
Functional requirements									
F1	Seeing and identifying details	*E* *Fl*		U_o B_{Re} *CRF* *SS*		*Uo* *Bal* B_{psy} B_{phy} *SS*			
F2	Seeing and identifying shapes			*SS* *Mod*		*Bal* *Mod*			
F3	Seeing and identifying colours				R_a *CCT*		R_a		
F4	Speed of perception and identification	*E* *Fl*				*Bal* *Mod*			
F5	Seeing and identifying over a period of time							*Q*	
F6	Directing attention	*E*	*Q*	*HK* *Q*	*FK*	*Q*		*Q*	
F7	Order/ability to differentiate	*E*		*HK* *Q*	*Q*				
F8	Physical safety	*E*						*Q* *Fl*	
F9	Physical protection	*E* H_{dm}					H_{dm}		
Biological requirements									
B1	Activation	*E*	*Q*	*Q*	*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B2	Relaxation	*E*			*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B3	Circadian rhythm	*E*		*Q*	*CCT*	*Bal*	$a_{mel,v}$	*Q*	
B4	Protection against radiation						H_{dm} *Q*		
B5	Physiological effects of radiation						*Q*		

Psychological requirements									
P1	**Spatial orientation**	*E* *HK*		*HK* *Q*	*CCT* *Q*				
P2	**Chronological orientation**	*E*			*CCT* *Q*	*Bal*		*Q*	
P3	**Orientation regarding proceedings**	*E* *HK*							
P4	**Privacy**	*E* *HK*		*HK* *Q*		*Bal* *Q*			*Q*
P5	**Personal territory**	*E* *HK*	*Q*	*HK* *Q*		*Bal* *Q*		*Q*	*Q*
P6	**Self-expression/ presentation**	*E* *HK*		*HK* *Q*		*Bal* *Q*		*Q*	*Q*
P7	**Feeling of savety**	*E*				U_o *Bal* *Q*			
P8	**Self monitoring**							*Q*	*Q*
P9	**Mental activation**	*E*	*Q*		*CCT*	*Bal*	$a_{mel,v}$	*Q*	
P10	**Mental relaxation**	*E*	*Q*		*CCT*	*Bal*	$a_{mel,v}$	*Q*	
P11	**Familiarity**	*E*		*Q*	*CCT*	*Bal* *Q*			*Q*
Architectural requirements									
A1	**Structuring the room according to its form**		*Q*	*Q*					
A2	**Structuring the room according to rhythmicity**		*Q*	*HK* *Uo* *Q*	*FK* *Q*				
A3	**Structuring the room according to zones**		*Q*	*HK* *Uo* *Q*	*FK* *Q*				
A4	**Supporting the character of the architecture**	*E*	*Q*		*CCT* *Q*	*Bal* *Q*		*Q*	
A5	**Emphasizing architectural – creative – features**		*Q*	*Q*	*CCT* *Q*	*Q*			

B 4.1 Task illuminance (E)

Description

The illuminance with its unit Lux (lx) describes the luminous flux incident on a certain area. The illuminance is a fundamental premise for fulfilling the visual task. It serves as a measure in the task area. Different visual tasks influence the lighting level in the task area. This has an important influence on the work performance, productivity and work safety. The more difficult the visual task and the more critical the consequences and cost of a faulty solution, the higher should be the illuminance level.
The illuminance is a very important design parameter. When planning the lighting solution, the soiling of the installation is already taken into account via the maintenance factor. The DIN EN 12464 standard series specifies maintenance values for many different work places. These maintenance factors may not fall below the specified values at any time.

Value limits

- The maintenance value of the task illuminance, the illuminance in the general working area or in the room is laid down in the tables of the DIN EN 12464 series for workplaces. The illuminance values for the immediate environment and the background are directly linked to them.
- In areas that are not workplaces the minimum illuminance should be similar to the values, which are valid for workplaces with similar visual tasks.
- Regarding the biological effect DIN SPEC 67600 has to be consulted.

B 4.2 Uniformity of illuminance (U_o)

Description

The illuminance uniformity is the ratio between minimum and average illuminance within the evaluated area. The uniformity is to be adhered to a certain area. It should be particularly high in the zone in and around the visual task in order to ease the visual task. In larger areas, for instance, in classrooms, the illuminance level at the learning place with the lowest level is also recorded together with the uniformity across the room. For example: The lowest illuminance level is 180 lx while the maintained illuminance is 300 lx and the uniformity is 0.6. Zones of different lighting levels and the associated diversity are important means of design for the room. If the uniformity across the room is too even and without any contrast, then orientation is impeded.

Value limits

- The uniformity of the illumination in workplaces is determined in the tables of the DIN EN 12464 series.
- In case of accentuation (spotlighting) as a means of design there are no rules regarding the uniformity.

B 4.3 Colour contrast (*FK*)

Description

Colour contrast is the subjective evaluation of the colour difference between two or more surfaces that are within the field of vision or can be seen in sequence. The colour contrast plays a role for the conspicuity of a visual task, provided the latter consists of recognizing and differentiating colours. The colour contrast and different colours are scenic elements for stage-managing. Example: Blue lettering on red background causes the eye to focus on different distances (accommodation), which has a negative influence on the conspicuity.

Value limits

- There is no regulation for colour contrast.

B 4.4 Brightness contrast (artistic) (*HK*)

Description

Brightness contrast is the subjective evaluation of the difference in brightness between two or more surfaces that are within the field of vision or can be seen in sequence. The brightness contrast plays a role for the conspicuity of a visual task, provided the latter consists of recognizing and differentiating brightness levels. Brightness levels and the difference between brightness levels are scenic elements for stage-managing. The brightness of larger surfaces in the field of vision determine the adaptation level and therefore have great influence on the perceptibility of smaller contrast differences.

Value limits

- There is no regulation for brightness contrast.

B 4.5 Discomfort glare (B_{psy})

Description

Discomfort glare caused by windows and luminaires is a disturbance due to high luminance levels, an unfavourable luminance distribution or too high contrasts in the field of vision that are considered uncomfortable. The discomfort glare may lead to fatigue or bodily false positions over longer periods of time. This may also lead to pain.

The UGR method was introduced for the evaluation of glare caused by luminaires: UGR stands for »Unified Glare Rating«. In DIN EN 12464-1 the UGR method is defined as the obligatory method for evaluating and limiting discomfort direct glare. The UGR value corresponds to a glare opinion by an observer. Typical values are, in steps of three, between <13 and <28, where the glare impression increases approximately linear with the UGR value. Glare evaluation for the lighting of workplaces is an important parameter.

In representative environments high contrast levels may be desirable as means of design. In such cases they are generally not considered to be disturbing (e.g. chandelier in the opera foyer).

Value limits

- The UGR limit in the task area, in the area of activity or in the room is laid down in the tables of DIN EN 12464-1 for workplaces and may not be exceeded.

B 4.6 Disability glare (B_{phy})

Description

Disability glare is a reduction of visual performance caused by too high luminance values in the field of vision. It occurs in case of very high luminance values by light sources as well as windows in the field of vision, which cause stray light inside the eye resulting in a reduction of perceptible contrasts. Discomfort glare must be avoided under all circumstances by employing glare limitation devices such as blinds or shields in luminaires.

Value limits

- Shielding of the light sources is required.

B 4.7 Glare by reflection (B_{Re})

Description

Reflections are high luminance values in the task area, which disturb or prevent recognizing the actual task details. Reflections generate luminance contrasts and contrast reduction. If the luminance contrasts are either without bearing any information or superimposing important information, then even low luminance contrasts may cause discomfort glare. This effect may occur in case of direct glare by bright luminaires in the field of vision or as indirect glare caused by veiling reflections. The latter is caused by mirror images of the luminaires on specular (high gloss) materials.Such reflections are particularly disturbing on computer screens or glossy working materials.

The limitation of reflected glare on computer screens is an important evaluation parameter. Reflected glare can be avoided by reduction of the luminance values of luminaires and windows whose mirror images would appear on specular surfaces, or by simply using matt surface materials. Reflections may well be a means of design and therefore desirable, for instance, in order to enhance the gloss of glazing.

Value limits

- According to DIN EN 12464-1 the reflected luminance from luminaires in case of near vertical computer screens (15° from vertical) should be less than 1,500 cd/m² at a maximum shielding angle of 65°, respectively 3,000 cd/m² with an intrinsic screen brightness of > 200 cd/m².

B 4.8 Light colour / correlated colour temperature (CCT)

Description

The light colour of a lamp refers to the colour appearance (chromaticity) of white light emitted by the source. Light colour is a characteristic of the light source. It is decisive for the subjective acceptance of the ambience. Reddish colours stand for a comfortable atmosphere, bluish colours for clarity and activity. The visual performance is independent of the light colour appearance.

Value limits

- Colour temperatures between 3,000 K and 4,000 K are commonly used.
- Colour temperatures above 5,000 K should only be employed during the day.

B 4.9 Colour rendering (R_a)

Description

Colour rendering describes the effect of a light source on the colour appearance of objects that are illuminated in a conscious or subconscious comparison to the perceived colour of the same objects under a reference light colour of the same colour temperature. Colour rendering is a characteristic of the light source. It is decisive for a comprehensive perceptibility and distinctness of colours.

Value limits

- The minimum required general colour rendering index in the task area, in the working area or in the part of the room is laid down in the tables of DIN EN 12464-1 for workplaces and may not go below that limit.

B 4.10 Contrast rendering (*CRF*)

Description

Contrast rendering describes the capability to perceive brightness contrasts. The contrast rendering factor CRF assesses reflective glare caused by the lamps, luminaires or bright windows occuring on specular surfaces. It is a measure for the level ofdisturbance caused by reflections on specular surfaces. It is determined by the brightness of a glossy black surface in comparison to a white diffuse surface. High luminance values that are mirrored in glossy black in the direction of the observer's eye generate disturbances – related to white diffuse.

Value limits

- Currently there is no standard regulating contrast rendering.

B 4.11 Cast shadows (*SS*)

Description

Cast or hard shadows are generated by strong point light sources illuminating an object from one direction only. They are disturbing whenever they impair the conspicuity of the visual task or the ambience in the room. With artificial lighting it must be considered that every point light source can potentially create hard shadows.

Value limits

- Currently there is no standard regulating cast shadows.

B 4.12 (Balanced) luminance distribution (*Bal*)

Description

The luminance distribution in the field of vision controls the adaptation status of the eyes, which has an effect on the perceptibility of the task. In order to create a balanced luminance distribution the luminance values of all surfaces must be taken into account. They are determined by the reflectance of the surfaces and the illuminance on the surfaces. In order to avoid the impression of darkness, particularly at workplaces, and to enhance both the adaptation level as well as the visual comfort, one should strive for bright room surfaces – particularly on walls and ceilings – (also refer to the paragraph brightness contrast in chapter B 4.4). The luminance distribution is also a means of design.

Value limits

- The luminance ratio between visual task and the near field should not exceed 3:1, and 10:1 when relating to the far field.

B 4.13 Modelling (*Mod*)

Description

Modelling describes the balance between diffuse and directed light. The general appearance of an interior is improved, if its structural features, the persons as well as objects inside the room are illuminated in such a way that form and structure are clearly and pleasantly conveyed. The lighting should not be directed too strongly, because this may cause hard shadows. On the other hand the lighting should not be too diffuse, because then the modelling effect may be lost leading to an extremely expressionless illuminated environment. Strong multiple shadows generated by directional light from more than one position are to be avoided, since they may lead to confusing visual effects. The ratio between cylindrical and horizontal illuminance at a given point is an indicator for modelling. The grid points for cylindrical and horizontal illuminances must coincide when conducting lighting planning.

Value limits

- For regular luminaire or roof light arrangements a value between 0.3 and 0.6 is an indicator for good modelling.
- Daylight entering through windows is distributed mainly horizontally. The additional advantages of daylight can compensate the influence on the modelling value. Modelling values for daylight scenarios may therefore deviate from the range of values as described above.

B 4.14 Avoidance of flicker (*Fl*)

Description

Flashes are possible when switching on some lamps or during the operation of faulty luminaires. Flickering describes continuous periodic variations in brightness. It causes disturbances and can lead to physiological effects such as headaches. Stroboscopic effects may lead to dangerous situations, whenever they change the appearance of perceived motion of rotating or seesaw machine parts. Lighting systems should be designed in such a manner that both flicker and stroboscopic effects are avoided.

Value limits

- Flicker must be avoided.
- The switch-on / switch-off frequencies of light sources should be higher than 400 Hz.

B 4.15 Melanopic effect ($a_{mel,v}$)

Description

The melanopic effect specifies the circadian effect of a light source. The relevant formula is described in DIN SPEC 5031-100:2014. Larger blue portions contribute to the suppression of the hormone Melatonin in the evening and night hours, which may lead to a disturbance of sleep and therefore should be avoided. During the day larger blue portions support the activation.

Value limits

- The appropriate values are listed in DIN SPEC 67600.

B 4.16 Potential damages (H_{dm})

Description

The potential damages, as defined in the Technical Report CIE157:2004, describe the fixed ratio of the effective radiation (E_{dm}) and the illuminance (E). This is valid for a certain lighting scenario and certain objects or materials.

Value limits

- The appropriate values are listed in the Technical Report CIE 157:2004.

B 4.17 Qualitative factors (Q)

Description

Some aspects of lighting quality respectively of user requirements cannot be evaluated by lighting engineering or numerical parameters. They are summarized as qualitative factors in this publication. The evaluation is subjective and must be carried out by an expert.

Value limits

- Currently there are no standards in this regard.

Appendix C: Means of design and their dedicated photometric parameters

Photometric parameters can be attributed to the means of design of a lighting solution (Appendix B3), which make them assessable and measurable.

Precise definitions of the photometric parameters can be found in the International Lighting Dictionary by the CIE respectively in the EN 12665 standard. These definitions are described in simplified form and intelligible to all in this publication.

C 1 Luminous flux of the light source (also refer to B 3.1)

Here it must be differentiated between the emitted luminous flux of the light source and the incident luminous flux related to the area.

Luminous flux related to the light source

Attributed parameters:
- The luminous flux with its unit Lumen (lm) is the light output emitted by a light source (lamp).
- The luminous efficacy with its unit Lumen per Watt (lm/W) is the luminous flux of the lamp related to the required electrical power.
- The light output ratio of a luminaire (ηLB) is the ratio between the luminous flux emitted by a luminaire to the flux of the lamp(s) used and describes the efficiency of the luminaire.
- The luminous efficacy of a luminaire with its unit (lm/W) is the luminous flux of the luminaire related to the required electrical power.

Luminous flux related to an area

Attributed parameters:
- The illuminance with its unit Lux (lx) is the luminous flux incident on a given area (lm/m^2).
- The luminance of a light source with its unit Candela per Square Meter (cd/m^2) is the luminous flux of the light source emitted in a certain direction and related to the apparent size of the light emitting area when viewed from that direction. The luminance of a diffuse reflecting surface is proportional to the product of illuminance and reflectance of the surface.
- The brightness of a light source is the subjectively perceived luminance by the observer, which is also influenced by the adaptation level of the observer's eye.
- The brightness of a surface is the impression of brightness, which results from the evaluation of different luminance values related to each other. Here the material properties, in particular the reflection factors, are taken into account.
- The reflection factor is the ratio between the amount of luminous flux incident on a surface and the reflected luminous flux. It is subject to the spectral composition of light incident on the surface.

The luminance of an area, which does not result in fully diffuse reflection, is determined directionally by mixing the portions of directional and diffuse reflection related to the angle of incidence of the light source.

The term light source is consistently used, it describes mostly the lamp but occasionally also the luminaire.

C 2 Apparent size of the light emitting area (also refer to B3.2)

Attributed parameters:

- The unit of the light emitting area is (m^2).
- The projected light emitting area (m^2) is diagrammed as follows: Area $x \cos \gamma$ [m^2]. This describes the relative size of the light emitting area viewed under a certain viewing angle.

C 3 Number, arrangement and position of the light source(s) (also refer to B 3.3)

Attributed parameters:

- The number of luminaires, their geometric positions (layout) and the relative spacing between the light sources are taken into account.
- The direction of emission of directional lighting is determined by the position of the light source in the room relative to the illuminated object.

C 4 Luminous colour (also refer to B 3.4)

Attributed parameters:

- The correlated colour temperature with its unit Kelvin (K) is the temperature of the black body radiator with the closest possible luminous colour.

C 5 Light distribution (also refer to B 3.5)

Attributed parameters:

- The light intensity with its unit Candela (cd) describes the luminous flux per solid angle element in a certain direction.
- The light intensity distribution curve (LVK) also known as polar curve and illustrated as a polar diagram, shows in which direction the light source emits light.
- The type of lighting describes the predominant distribution of light from the luminaire into the lower respectively upper hemisphere. With direct lighting the luminous flux is solely emitted into the lower hemisphere, that is, downwards towards the working plane. Indirect lighting emits light only into the upper hemisphere, that is, upwards towards the ceiling. Direct/Indirect lighting emits light both upwards and downwards.
- The directional characteristics of a light source describe the type of direct respectively indirect radiation.

The light distribution ranges from fully diffuse to strongly directional. It depends on the dimensions of the light source (point source or linear with diffuse or clear surface), the reflector materials (diffuse dispersing to highly specular) and the cover (diffuse or directional to clear). Of course, the size of the light emitting area also plays a role.

- Modelling describes the balance between directional and diffuse portions of light.

C 6 Visible spectrum of the light source (also refer to B 3.6)

Attributed parameters:

- The unit of the wavelength of the optical radiation is Nanometer (nm).
- The spectral distribution of a light source results from the wavelengths. The spectrum is commonly illustrated as a relative distribution.
- The colour rendering index Ra is the value of a light source and indicates the colour impression of non-luminous colours (eight test colours compared to a reference light source).
- The spectral portions determine the chromaticity coordinates. The chromaticity coordinates are generally displayed as colour coordinates on a standardized colour table.

C 7 Controllability of the lighting system (also refer to B 3.7)

Attributed parameters:

- The response time describes the period of time in which a change between two lighting scenarios can be perceived whenever the lighting system is controlled either by a switch or by dimming. This time should be between 300 ms and 500 ms.
- The rate of change describes the speed with which the change between two scenarios varies steadily. The change should preferably not be noticeable and may definitely not be disturbing. The adjustment should take place over several minutes.
- With the availability it is assured that even when employing lighting control systems the necessary amount of light is available at the „right place at the right time“. The lighting system should, for instance, be switched on by the presence detector before the person enters the room and not only once the person stands in the (still dark) room.

C 8 Operating of lighting systems (also refer to B 3.8)

Attributed parameters:

- The clear understanding of how to operate the of how to operate the lighting controls can be assured by providing self-explaining visible symbols or inscriptions.
- The size of input devices influences the readability and usability.
- The number of choices should be in a good ratio between adjustment options by the user and ascertainability. Experience has shown that five to eight adjustment options are suitable.
- The easy accessibility in the space describes the positioning and flexibility of the control elements.

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