DIRECT VERSUS DIFFUSE LIGHTING : WHAT ABOUT ?

SUR L'ECLAIRAGE DIRECT ET DIFFUS

DIE PROBLEMATIK DER DIREKTEN SOWIE DIFFUSEN BELEUCHTUNG

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SUMMARY

The major quality aspect in lighting is the way the light is distributed geometrically within the space of the illuminated environment. It has a remarkable influence on the appearance of surfaces and objects.
The purpose of the paper is to show how in practical examples direct and diffused lighting is applied with respect to the *seeing task* in interior lighting.

In this context, the visual implications of direct and diffused lighting on three-dimensional object's reflection and appearance is discussed theoretically and illustrated practically.

SOMMAIRE

La distribution géométrique de la lumière dans une espace éclairée représente la qualité principale d'une installation d'éclairage. Ceci a une influence remarquable sur l'apparence d'objets et de surfaces de forme tridimensionnelle.
Le but de cet article est de montrer comment l'éclairage direct ou diffusé est appliqué vis-à-vis la *tâche visuelle* dans un environnement intérieur.

L'impact visuel de l'éclairage direct ou diffusé sur la réflexion et l'apparence d'objets et de surfaces est discuté théoriquement et illustré pratiquement à l'aide de diapositives.

ZUSAMMENFASSUNG

Das wichtigste Qualitätskriterium bei Beleuchtungsanlagen ist die räumliche Distribution des Lichtes. Diese räumliche Lichtdistribution hat einen wichtigen Einfluß auf das Aussehen der Gegenstände.
Dieser Artikel erläutert wie die direktionellen Eigenschaften der Beleuchtung bezüglich der *Seh-Aufgabe* bei der Innenraumbeleuchtung in der Praxis angewendet werden kann.

Die visuelle Implikation der direktionellen sowie omnidirektionellen Beleuchtung auf die Reflexion und das Aussehen dreidimensioneller Gegenstände wird erörtert. Schließlich wird das Thema mit entsprechenden Beispielen illustriert.

1. INTRODUCTION

From the point of view of directional, three-dimensional distribution in a room or visual environment, lighting can be seen as varying from direct, semi-direct over mixed direct-indirect lighting to semi-indirect and indirect lighting (see also CIE 17.4; 845-09-14 to 18). In this, we are considering two typical distinct types of lighting, namely *directional lighting* with incidence predominantly from one or two particular directions and *diffused or omnidirectional lighting* lacking incidence from predominant directions (see also CIE 17.4; 845-09-19 and 20).
Herein we consider artificial as well as daylighting.

In terms of luminance contrasts, describing at some extent the *seeing task* such as reading written text or observing visual information on paper or display terminal, diffused lighting always creates an additional veil leading to a decrease in luminance contrast and consequently to a lower degree of visibility; this in spite of a potentially and considerable higher illuminance level.
Just, ceilings in light colours are contributing to overall illumination levels and from there they are increasing lumen efficiency of the installation. They also prevent a tunnel-like appearance of the environment with a flashing light flux and highly dynamical light sensation when walking under distinct light sources.

The way surfaces and objects are observed, as a outward appearance, is crucial as a quality indicator because it will be linked directly to the inner and outer quality of the product itself.

2. APPEARANCE OF SURFACES AND OBJECTS

2.1 Appearance, what’s alike ?

The appearance of three-dimensional objects is fundamental and can be seen in essence in the first place as the surface's and the object's observed colour and brightness patterns; in the second place as its silhouette and form too.
Elements to be considered here are the **luminance distribution (brightness pattern)** *on* the object, the **object colour**, the **surface roughness** and the **viewing direction.**

The *appearance* of objects in an illuminated environment is determined by different types of parameters :

a) The quality of incident light (i. e. lighttechnical parameters as the colour temperature, the level of illuminance and above all the directional properties of the light together with the luminance control of the luminaires);

b) Object parameters as the degree of gloss, roughness, texture, colour; time-dependency (moving or standing still). In practical applications, reflection properties are most important;

c) Environmental properties;

d) Observer qualities (physiological and psychological properties; viewing directions).

The particular problem is the determination of the visual implications of the lighting system.
It is remarkable that not at least geometrical properties do influence substantially the "object depending parameters" as luminance, colour appearance and surface details as lustre, haze, dullness; scratches and markings.

2.2 Visual implications on object's appearance

Two main groups of object materials can be distinguished here : metallic (or electrically conductive) and non-metallic (or electrically non-conductive) specimen.
The leading parameter to consider is the type of directionality of the lighting.

a) Glossy electrically non-conductive materials

Two types of reflection can be distinguished here : *boundary or bouncing reflection* and *deep reflection or re-emission*.

The **boundary reflection** takes place at the surface of the material without penetrating. It complies with the laws of Snellius and Fresnel, with a refractive index equal to 1.5 for air/glass media. The colour of the bouncing reflection corresponds perfectly to the colour content of the lighting source; in this way one can eventually speak of *white reflection* as the source is mostly "white". For incident angles not corresponding to grazing incidence, the coefficient of boundary reflection is approximately 4% for unpolarised light. This coefficient attains the value of 100% for an incident angle of 90° with the normal to the surface.

Re-emission or **deep reflection** leaves the material into the same halfroom after having penetrated into it and having taken its colour property. Re-emission is pseudo Lambertian : light is reflected in **all** directions with the same luminance. The luminance can easily be calculated as $\rho_{r.e.}$. E/π where $\rho_{r.e.}$ is the coefficient of re-emission equal to $(1 - \rho_{b.r.} - \alpha)$; E represents the illuminance, $\rho_{b.r.}$ the coefficient of boundary reflection and α the absorption coefficient.
Metals are not presenting this type of reflection even when made matt with a piece of emery cloth.

Concerning the **visual implications** of these materials under a direct "white" lighting system, the object colour is observed in all directions with the same luminance except for the specular direction where the ("white") boundary reflection is overstriking the (coloured) deep reflection. The colour of a layer of red lacquer will then be observed as a dirty, aged red; eventually as pink.
As the coefficient of boundary reflection is angle-dependent, the colour of the material as observed in the specular direction is changing with this angle. The observed colour will adopt more and more the colour of the source with increasing angles. With perfect grazing incidence (and viewing), the boundary reflection reaches 100%. From there, black surfaces are able to reflect all the incident light; red surfaces are able to show green light spots on the (white) ceiling with luminances almost as high as the source itself.
To perceive surface scratches or pits in a French polished piece of furniture, adequate lighting should be direct in nature and viewing more or less according to the specular direction.

When light incidence is hemispherical (diffused), the source component of the reflection is striking over the deep reflection for all directions.
As a consequence the real object colour is not observed in any direction; the colour appearance is dull and polluted by the "source" which can be the highly luminant ceiling or the painted wall - all of them strongly deteriorating room elements and thus influencing considerably appearance of objects.
On the contrary, direct lighting is less dependent on degrading room elements.

b) Semi-glossy and matt electrically non-conductive materials

With “white” direct lighting incident on semi-glossy surfaces, the specular direction is no longer unique but spread over a certain solid angle depending on the degree of surface roughness.
The observed colour is again the object colour “polluted” with the (viewing direction dependent) source component of the reflection, this for a wider range of directions around the theoretical specular direction.

Matting a glossy surface with sandpaper is therefore equivalent to illuminate the glossy surface with a diffused lighting system like a luminant ceiling (an indirect lighting source). Printed colour pictures or paintings should be in glossy enamel, illuminated under a direct lighting system.
Museum lighting systems are often artificially perfectly (indirectly) diffusing. This entails poor colour appearance and important loss of room impression.

c) Electrically non-conductive materials, without definite surface

With materials like carpets, the incident light enters the more or less upright structure of the surface. Only for grazing incidence (i. e. from angles with the normal to the “surface” over 70°), there exists boundary reflection “bouncing” on the surface. In this way, very rough surfaces (as road pavement) are presenting mirror-like reflection under these circumstances.
As a matter of course, the object colour is observed in all directions, even under diffused lighting.

d) Glossy electrically conductive materials

Because of a strong damping effect with metallic surfaces, deep reflection is not present. This is demonstrated by polishing for instance a copperplate with French talc : as under direct lighting the plate is blackening more and more for viewing directions outside the specular region, there is absence of re-emission. For these directions, glossy metallic surfaces reflect the image of the surrounding; if the surrounding is black then the surface appears black.

Boundary reflection occurs in the same way as with glossy non-metallic surfaces (with the colour content of the source and in intensity dependent on the angle of incidence/viewing). The existence of boundary reflection can be demonstrated by directing a beam of blue light onto a glossy copperplate : the reflected spot has the same blue colour.
Polishing a copperplate for instance increases the mirror-like reflection; from there the appearance of coloured metallic surfaces adopts more and more the colour of the source (for directions in the specular region). Moreover, with “white” incident lighting, metallic surfaces are appearing more and more “white” with increasing angles with the normal to the surface.

Apart from the source component of reflection, there is an important **metal component** with the colour of the metal and present in the specular direction. For glossy surfaces this direction is unique. Copper has a proper colour whereas aluminium is a neutral reflector.
In the specular direction, the (proper coloured) metal component with high luminance is flowing over the boundary reflection (with the colour content of the source and in contribution approximately 4% for normal incidence and viewing). For polished copper, the result of this overstriking is yellowish.

From there, light treatment and luminance control of luminaires is done preferably by shaping metallic reflectors. On the other hand, glossy white paint is presenting a great amount of deep reflection (at maximum 96% for normal incidences) : almost all reflection is Lambertian and screening off for definite angles is unfeasable; only 4% is controlable by shaping the reflector.

e) Matt electrically conductive materials

The specular direction is no longer unique but spread over a certain solid angle. The colour saturation of the source component and the metal component of reflection within this solid angle remains more or less constant and so is the observed colour (i. e. yellowish for copper).
By making matt the glossy metallic surface, no Lambertian reflection appears (with the colour of the material); within a more or less extended solid angle around the initial specular direction the overstriking of boundary reflection with the metallic component persists. For other viewing directions, no light is reflected under direct lighting.

f) Example

In practice, seeing tasks are often a combination of different material types. As an example, the presence of the "pill" on an aluminium base in a blister pack can easily be checked under direct lighting.
Somewhat outside the specular direction the metal appears black; the non-metal (the pill) appears Lambertian white (with high luminance).

In contrast with classical thoughts, disturbing glare can be eliminated, controlled or directed into non-disturbing directions, precisely by means of glossy instead of matt surfaces. Well-monitored grazing reflection can be applied too.

2.3 Impact of direct and diffused lighting

Unidirectional, multidirectional and omnidirectional-diffused lighting can be characterised by means of lighttechnical parameters as the light vector, the vector to scalar ratio, two- and three-dimensional illuminances.

At first, the principal direction of light incidence and from there the flow of light, is specified by the light vector $\vec{E}$.
The original vector to scalar ratio $\vec{E}/E_S$ pointing out the observed strength of the flow of incident light, has been refined by Kit Cuttle in [2].
Herein, sinβ . $\vec{E}/E_S$ is representing the directional strength of the *lighting pattern on an object*, observed at an angle β with the light vector $\vec{E}$.
In this context, the so-called visible hemisphere indicates at first sight the way a three-dimensional object will appear as observed from a certain direction.

Likewise, *modelling power or light relief* of diffused versus direct lighting is to be considered. Modelling is seen as the expression of the influence of the purely geometrical nature of light incidence on three-dimensional object's restauration.

Diffused lighting (associated with positive or negative luminance contrasts) will always create poor modelling and colour distortion with all metallic and most non-metallic surfaces as with perfectly white reflecting walls and ceilings.
Poor modelling of omnidirectional diffused lighting is expressed as a flat, depthless and two-dimensional presentation of the three-dimensional object.

In interior lighting applications based on artificial light and daylight, the flow of light can be thought as a combination of a predominant horizontal and a predominant vertical contribution to the light flux.

In a way, modelling has to be seen as a further step from the concept of appearance of surfaces and surface details which are composing objects.

"Natural modelling" is happening with a balanced incident flow of light on the object, thought in a simplified way as a combination of a horizontal contribution counterbalanced with a vertical one. This balance does not necessary imply equal contributions.

From there, in interior lighting, modelling can be specified by the ratio of cylindrical to horizontal illuminance. Restauration is naturally with values of this ratio between 0.3 and 0.5. The choice of the horizontal illuminance (as a horizontal component) in the modelling parameter originates from the fact that in interior spaces lighting is mostly top lighting (artificial or daylight), particularly in the deeper zones of the building. Extrema values for the ratio correspond to 0 for dramatic modelling and 1 for perfectly diffused lighting with flat depthless modelling.

As the ratio of cylindrical to horizontal illuminance is a ratio of integrated quantities, the directional character of the lighting is not so very well expressed; although there is obviously more dependence of the illuminances on the directions of light incidence and viewing when thinking in terms of semi-cylindrical illuminance as in residential area lighting. The orientation of the half cylinder is most important then and backward lighting is less contributing to modelling than in interior lighting. The more diffused nature of the interior lit environment (caused by walls, ceilings and obstacles) is precisely expressed by the use of the concept of the cylindrical instead of the semi-cylindrical illuminance (with perfectly diffused lighting these two parameters present the same value).
Anyway, the ratio of cylindrical to horizontal illuminance is an indicator of putting forward the form of lit objects and from there it is a modelling describing parameter. Although averageing and spatial integration has no direct visual significance in terms of brightness.

Modelling in itself is not equivalent to the distribution of brightness patches or patterns on objects and curved surfaces; actually, it goes well beyond the simple luminance distribution.
Contrast with the background is of significance in simply *detecting* an object, while self-contrast on the object itself is the leading actor for spatial restauration or modelling.

In fact, modelling has to be seen as a **weighted combination** of the **directional nature** of the lighting and the **luminance distribution on the object** (in amplitude and vastness); and naturally ... it is **object dependent**.
So, lighting design is a harmonic composition in which emphasis is not to be put on isolated quantities only but further on *combined criteria* and the *interplay* of some (important) lighttechnical design parameters.
These are for instance illuminances (horizontal, vertical, cylindrical, hemispherical), luminance and colour contrasts, glare, modelling, etc.

When it comes to the criterion of *recognition* and *identification* of human faces and objects, and thus the reading of facial expression and intentions, good modelling is lending a helping hand to the semi-cylindrical illuminance as describing parameter [1]. This holds especially for directional lighting.
In residential area lighting, the distance for recognition is rising from approximately 6m to 7m when going from dramatic modelling (ratio of vertical to semi-cylindrical illuminance = 0.5) to a less dynamical shadowing (ratio of vertical to semi-cylindrical illuminance = 1.5); all this at a level of semi-cylindrical illuminance of 1 Lux.

3. CONCLUSION

To present a dynamical and vivid scene i. e. a revealing shadow play on objects, lighting should be mainly directional in nature.

Basically, it is explained and it will be illustrated in which way the directional qualities of the lighting can be balanced with emphasis on modelling, colour appearance, brightness and visibility. When looking around, one must conclude this theoretically known issue is often not very well understood in practical lighting applications.

Even recently published documents as the CIBSE Lighting Guide LG3 *"The visual environment for display screen use"* do not meet at some stage the objective of adequate lighting.

4. REFERENCES

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