GLARE MANAGEMENT GUIDELINES FOR ARTIFICIAL LIGHTING

The Energy and Resources Institute

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Foreword

Mahindra Lifespace Developers Limited (MLDL) and The Energy and Resources Institute (TERI) joined hands to establish the Mahindra-TERI Centre of Excellence (CoE) to promote innovative low-cost-high-impact construction technologies tailored to suit the Indian buildings sector. The objective of the CoE is to create a coherent database comprising of innovative technologies and provide an effective dissemination strategy for sustainable and energy efficient building design and water use.

Human beings today spend 90% of their time indoors, and are increasingly dependent on mechanical heating, cooling and artificial lighting systems. Today, buildings consume more than 40% of the total global primary energy and are also responsible for 19% of the energy related greenhouse gas (GHG) emissions. The building stock in India is predicted to grow five-fold by 2030 compared to levels in 2005. With the given challenges and demand come opportunities for the large-scale adoption of innovative technologies as well, which need to be tapped effectively.

Sustainable building design philosophy focuses on increasing the efficiency of resource use in buildings while minimizing the impact of building on environment and health & well-being of its occupant throughout its life cycle. Optimizing energy and water use, waste generation, waste management, indoor air quality, thermal and visual comfort, etc., are critical to design a sustainable building. Informed decisions in selection of active and passive design strategies, material, construction technology, and efficient end use systems help building practitioners in delivering green buildings.

This collaborative partnership between TERI & MLDL will help to build a greener urban future by developing innovative energy efficient solutions tailored to Indian climates.

I congratulate the teams from MLDL and TERI for their effort in putting together these "Glare Management Guidelines for Artificial Lighting". I urge building design professionals to use these guidelines in optimizing artificial lighting systems, while at the same time minimizing glare from such designs.

Dr Ajay Mathur

Director General, TERI

Preface

The Mahindra-TERI Center of Excellence (CoE) was established to carry out integrated research on resource efficiency, enhanced occupant comfort, and sustainable construction materials for the building industry. The objective is to provide validated information on materials, technologies and occupant comfort pertaining to the built environment with the underlying principles of "Greener yet Cheaper" built spaces.

Issues related to glare management have been persistent for the last many years and have posed a challenge to building professionals and architects, as these concepts have limited know-how in the Indian geo-climatic context. Lighting can enhance form and function, improve safety and security that create good work spaces. Good lighting at the workplace with well-lit task areas is essential for optimizing visual performance, visual comfort and overall ambience. The impact of good lighting extend beyond visual effects – they enhance productivity, make the environment more amiable and increase occupant comfort.

We, at the Mahindra-TERI CoE are pleased to introduce "Glare Management Guidelines for Artificial Lighting" as a first step towards achieving visual comfort and glare free spaces in the built environment relevant to the Indian context. These guidelines have been prepared to help building professionals, owners and end users to generate awareness on the impacts of glare. These encompass definitions for various types of glare indices, including their impact on human health. The methodology for calculating the glare indices are also included as a part of the guidelines which will help design professionals to quantify glare in numeric terms. Best practices to reduce glare in the urban built environment have also been incorporated, to provide ready solutions for the end users.

The abridged version of the "Glare Management Guidelines for Artificial Lighting" have been developed through a consultative process involving academia, lighting experts and building professionals. These guidelines will keep evolving in keeping with the advancements in technologies and practices in the urban built environment.

I gratefully acknowledge the support of all those associated with the development of these guidelines and look forward to their continued guidance for its enhancement.

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Introduction

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1.1 The Context

The perception of space is directly connected to the way light integrates with it. What we see, what we experience and how we interpret the elements is affected by how light interacts with us and with the environment. Regarding architecture, in whatever dimension it can be analyzed, either as space, as material or as color, it is essentially dependant on the lighting situation that involves both the object and the observer.

Daylight and the artificial lighting are able to affect not only distinct physical measurable conditions in a space, but also to instigate and provoke different visual experiences and moods. Due to the light, it is possible to perceive different atmospheres in the same physical environment. Light constitutes an element of fundamental relevance for the design of spaces and therefore it plays a significant role in the discussion of quality in architecture.

When dealing with lighting analysis, many specialists consider light quality to be only physical aspects and run their principles by making measurements. They often rely their ideas based on a numeric and scaled light level, discussed in number of lux, which can be compared and detected by instruments. However, if we study deeper our relation to light, we will understand that light comprises a more complex field.

A good lighting is dependent on the function. If the contrast is clear, our interpretation will be easier and less activity for the brain will be required. In order to interpret a space, it is not necessary to increase the lighting or uniform illumination. The difference of brightness, between lit and shadowed surfaces, contributes to our understanding of spatiality. Moreover, the spatial distribution of light is also extremely important for the spatiality, but also to orientation and the atmosphere.

Good lighting in a building provides sufficient light in the right place. This enables the occupants to see easily and in comfort allowing them to perform their work efficiently without strain or fatigue. In addition, good lighting enhances the appearance of a space to provide a pleasant internal environment and can contribute to the creation of different atmospheres appropriate for different activities.

1.1.1 The Context of Good Lighting

Lighting is vital to the modern world – it enables a 24-hour society to exist. When first introduced, electric lighting was expensive and available to few. Today, it is ubiquitous and cheap. Lighting is used for many different purposes – to ensure visual work can be done accurately,quickly, safely and in comfort, to make places attractive and interesting,

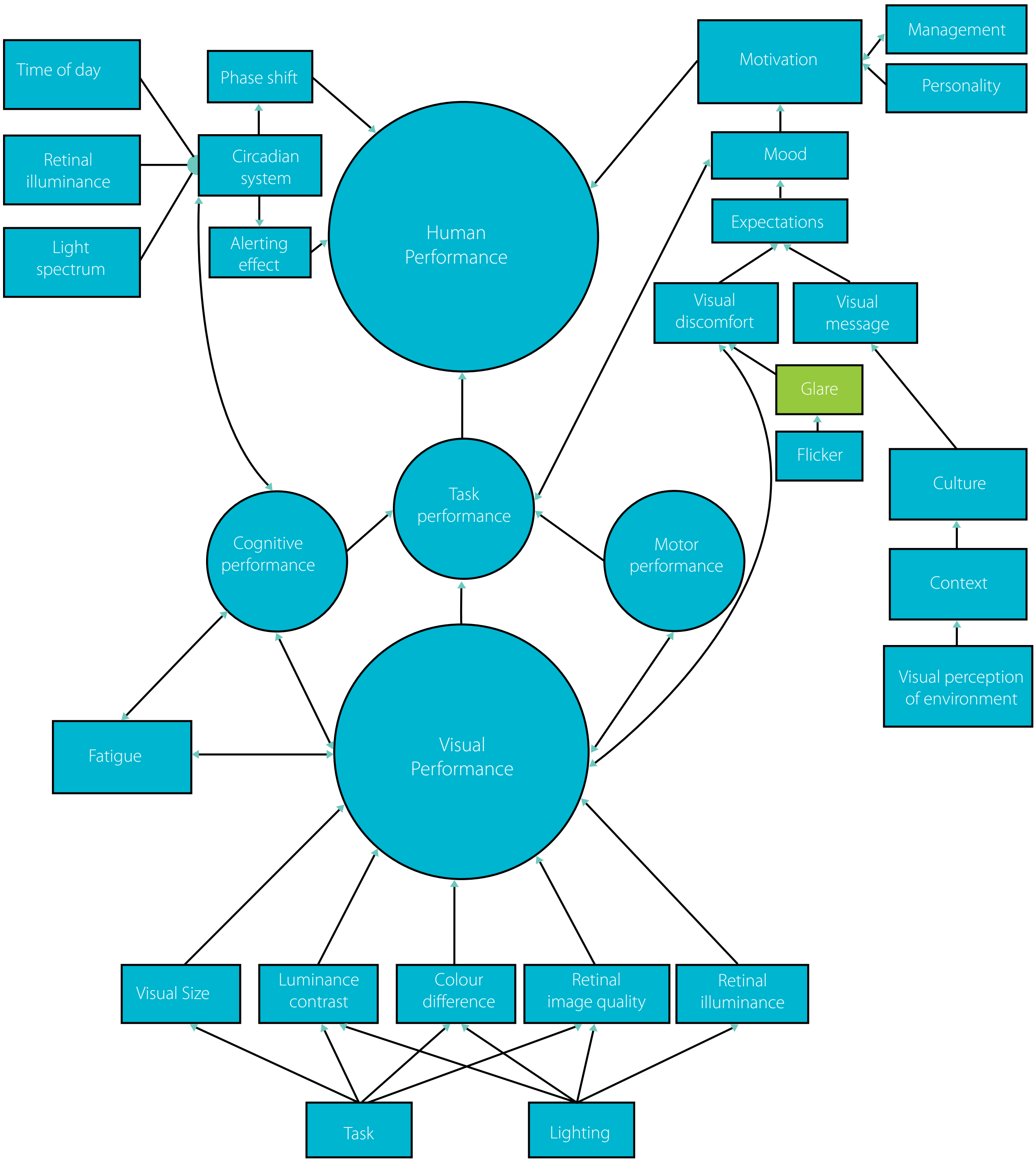

Figure 1 Relation between Human Health and Visual Comfort

Source: Human Factors and Lighting (Boyce, 2003) to generate business activity, to enhance security and to promote human health. Together, these functions make a real contribution to the quality of life of millions.

However, lighting comes at a cost, both financial and environmental. The financial cost involves first costs, the cost of the electricity consumed and disposal costs. The environmental cost takes three forms: the consequences of generating the electricity required to power lighting, the chemical pollution upon disposal and the presence of light pollution at night. This means that lighting recommendations are a balance between the benefits and costs. Lighting recommendations reflect this balance and are inevitably a consensus view of what is reasonable for the conditions prevailing when they are written (Boyce, 1996). That consensus will be different in different countries and different at different times in the same country, depending on the state of knowledge about lighting, the technical and economic situation, and the interests of the people contributing to the consensus.

1.1.1 Lighting and its Importance

Light can affect what people can do and what they choose to do via three different routes; through the visual system, through non-visual effects on human physiology and throughperception. The outcome in any particular case is human performance in its widest sense.

Lighting conditions in which achieving a high level of visual performance is difficult will be considered uncomfortable as will conditions in which the lighting leads to distraction from the task, as can occur when glare and flicker are present. Lighting conditions can influence our lives in many different ways, sometimes being the primary factor and at other times being only one factor amongst many. Lighting recommendations for different applications are produced with this diversity in mind, some applications giving priority to the ability to see detail and others focusing on the 'message' delivered through the perception of the space and the people in it.

Although il-luminance on the working plane is the most widely used lighting recommendation, simply providing that illuminance is not enough to ensure good quality lighting. Depending on how the illuminance is delivered, the result can either be comfortable or uncomfortable. Visual discomfort occurs when the lighting makes it difficult to see what needs to be seen, causes distraction or pushes one to the limits of the visual system, all of which are likely to affect visual performance negatively. Aspects of lighting that can commonly cause visual discomfort are insufficient light, excessive light, shadows, veiling reflections, glare and flicker.

Glare

2

2.1 Introduction to Glare

Glare is a condition of vision in which there is a feeling of discomfort and/or a reduction in visual performance. It occurs when the luminance or luminance ratios are too high. Two well known types of glare have been distinguished in the literature: disability glare and discomfort glare. Disability glare reduces visibility due to scattered light in the eye, whereas discomfort glare causes "a sensation of annoyance or pain caused by high luminances in the field of view". The latter type of glare causes a feeling of discomfort without necessarily impairing vision. Both types of glare have been extensively studied in the literature. However, while disability glare is well understood, much less is known about discomfort glare.

The subject of glare has concerned researchers since the early years of the twentieth century (Poulton 1991), but even today, the causal mechanism of discomfort glare is not well understood (Boyce 2014). However, the four factors that contribute to the perception of discomfort glare produced by an individual light source are well known and described as(DiLaura et al. 2011):

- luminance of the light source;
- position of the light source in relation to the point of fixation;
- visual size of the light source; and
- luminance of the background.

Glare can be described in one of three main ways: according to the process that created the glare, according to an individual's perceived degree of glare intensity, and according to the results of the glare. Many existing glare indices include:

- DGP (Daylight Glare Probability),
- DGI (Daylight Glare Index),
- UGR (Unified Glare Rating),
- VCP (Visual Comfort Probability), and

DGP and DGI were specifically developed for daylight glare, which needs to be treated differently from visual discomfort issue of electrical light sources. The equations of the glare indices look complex, but they use same variables, with different weighting factors. Crucial values such as background mean luminance, glare source luminance, glare source position, solid angle of glare sources, vertical il-luminance, and direct vertical il-luminance should be obtained to calculate those equations:

2.2 Types of Glare Indices

Glare is a complex phenomenon and several approaches characterized by different complexity in the calculation have been used for assessing it or for predicting potential discomfort events. The direct approach consists in measuring or calculating the luminance of a given light source seen by a given observation point. A more elaborated approach relates the glare risk to the luminance contrast of objects present in the visual field of an observer. Other glare indices are based on equations that relate some key factors to subjective judgments of the degree of discomfort experienced in indoor environments The definition of various glare indices are as follows:

2.2.1 Visual Comfort Probability (VCP)

This index aims at evaluating the percentage of the population of observers who would consider comfortable a given luminous environment produced by a lighting system for performing a task.

The acceptability criterion is the perception of glare caused by direct light from light sources and the comfort threshold ,so-called Borderline between Comfort and Discomfort.

The equation to calculate VCP is:

$$VCP = \left[224.4 - 46.8\, x \log\left(\sum_i \left(\frac{0.5\, x\, L_{s,i} x \left(20.4\, x\, \omega_{s,i} + 1.52\, x\, \omega_{s,i}^{0.2} - 0.075\right)}{P_i\, x\, L_a^{0.44}}\right)^{-0.0914}\right)\right] + 50$$

Where,

L_s =luminance of the source [cd/m2]; ω_s =solid angle of the source [sr], and P_i = Guth position index [-].

Basically, Il-luminance Engineering Services suggests that an artificial lighting source does not cause discomfort glare if three conditions are contemporary satisfied:

- The VCP value is strictly higher that 70,
- The luminance ratio between the luminance of the brightest 6.5 cm2 area and the average luminaire luminance value does not exceed 5:1 at 45°, 55°, 65°, 75° and 85° calculated from the nadir for both transversal and longitudinal visions,
- Maximum luminance values of the lighting sources viewed both transversally and longitudinally do not have to exceed the thresholds reported in Table 1.

Angle from nadir	Maximum luminance
85	1695
75	2570
65	3860
55	5500
45	7710

VCP was developed just for assessing typically-sized, ceiling-mounted luminaires with a uniform luminance. Therefore, it is not recommended for use with non-uniform or very large or very small light sources, such as compact luminaires as halogens, or for evaluating glare due to daylight

2.2.2 Discomfort Glare Indice (DGI)

DGI is a short-term, local, one-tailed index which, according to several authors, has some noticeable limitations:

- It refers only to uniform light sources: this excludes direct sunlight and does not consider that non-uniform sources can cause more glare when positioned perpendicularly to the line of view and less glare when located between 10° and 20° from the line of view.
- DGI is not reliable when the source fills almost the whole field of view and when the background luminance equals the source luminance .

The formula to calculate the DGI is:

$$DGI = 10\ x\ log\left(0.476 \sum_i \frac{\omega_{s,i}^{0.8}\ x\ L_{s,i}^{1.6}}{L_b + 0.07\ \ x\ \omega_{s,i}^{0.5}\ x\ L_{s,i}}\right)$$

Where,

Ls =luminance of the source [cd/m2],

Lb = background mean luminance [cd/m2],

ωs =solid angle of the source [sr]

2.2.3 Unified Glare Rating

UGR ranges between 10 (imperceptible) to 34 (intolerable) with a three-unit step. A value of 19 is typically considered the frontier between comfort and discomfort glare. UGR only deals well with very small glare sources with a solid angle included in the range [3·10-4, 10-1] sr. Thus, UGR is suitable to assess glare due to artificial light sources rather than to large-area sources like windows or curtain walls. Moreover, since the position index applies for directions that are above the observer's line of sight, this index is not suitable for predicting glare in those layouts where the glare sources are positioned below the observer's line of sight.

The formula for calculating UGR is:

$$UGR = 8\ x \log\left(\frac{0.25}{L_b} \sum_i \frac{L_{s,i}^2\ x\ \omega_{s,i}}{P_i^2}\right)$$

Where,

Ls =luminance of the source [cd/m2],

L_b = background mean luminance [cd/m2],

ω_s =solid angle of the source [sr], and

P_i = Guth position index [-].

2.3 Daylight Glare Probability

Discomfort Glare Probability (DGP) is a short-term, local, one-tailed index assessing glare. The formula for calculating DGP is

Where,

$$DGP = 5.87 \times 10^{-5} \times E_v + 0.092 \times \log\left(1 + \sum_i \frac{\omega_{s,i} \times L_{s,i}^2}{E_v^2 \times P_i^2}\right) + 0.16$$

E_v =vertical illuminance at eye level [lux],

E_d =direct vertical illuminance [lux],

L_s =luminance of the source [cd/m2],

ω_s =solid angle of the source [sr], and

P_i = Guth position index [-].

The equation is valid within the range of DGP between 0.2 and 0.8, and for vertical eye illuminance (Ev) above 380 lx. The glare indices previously analyzed just focus on the contrast ratio between the background average luminance and the glare source luminance , DGP instead includes also an evaluation of the level of illuminance perceived by the observer by means of the term Ev. For this reason, DGP shows a stronger correlation with the user's response regarding glare perception. However, a limitation of procedure is that it usually involves a lot more computation time and user effort compared to the simple analytic calculations required by most of the other glare indices . First, designer must choose one or more viewpoints of interest, basically corresponding to key occupant positions in the space, then, renderings in the RADIANCE picture format have to be produced, and finally a glare evaluation has to be carried out using evalglare, a specifically developed software able to detect glare sources on a 180° fish-eye scene.

Design Guidelines to Limit Glare

3.1 Effects of Glare and Human Health

People often use internal shading and artificial lighting to adjust or improve their indoor luminous environment and achieve visual comfort. However, different activities need different kinds of illumination, and different lamps

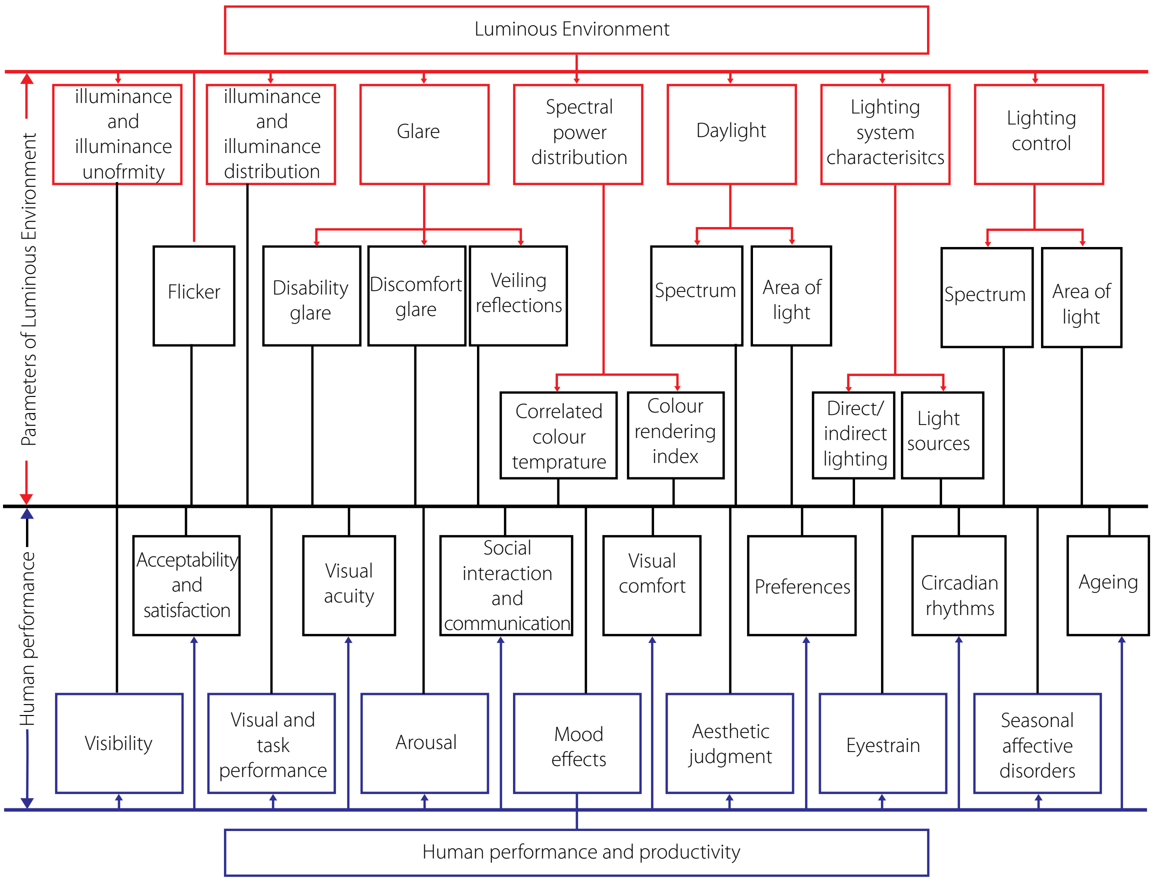

Figure 2 Luminous environment and human performance

Source: lighting quality and its effects on productivity and human healts((Králiková, Piňosová, & Hricová, 2016) provide different color temperatures which lead to different stages of human behaviour and effects the human performance.

The use of artificial lighting, should also be included in assessments of luminous comfort and provisions and design interventions should be made to limit glare in the indoor luminious environment. Glare not only creates a visual barrier but also affects the productivity and health of the human. While usage of light at night not only disturbs the day night cycle of the person but also can result in disrupting the sleep cycle resulting in depression, insomnia and cardiovascular diseases and other behaviour related issues in the human beings. Glare along with creating difficulty in the vision also commonly results in eyestrain, headache and fatigue. Glare is also responsible for decreasing the productivity of the person. Hence, it is necessary to incorporate best practices at the design stage of the building to improvise and reduce the glare probability in the occupant space.

3.2 Best design practices to reduce Glare in Built Environment

The issue of how to limit glare presents an ongoing challenge to lighting designers. Disability and discomfort glare can be difficult problems to resolve, particularly if not considered early enough in a project. LEDs are a point source of illumination and are therefore much more apparent if within someone's direct or peripheral view than a fluorescent lamp would be, thus creates more glare probability than the other lighting sources in the built environment. As mentioned in the chapters earlier about the point source lighting systems are the main cause for glare and introduction of LED technology into the mainstream lighting solutions have brought the issue of glare in the built environment.

- **Balanced luminous surroundings**

The most critical luminance relationships are those in between the daylight opening and its immediately adjacent surfaces and the surfaces surrounding the work tasks. Understanding the geometry between sun, sky, daylight opening and interior space at different times of the day and throughout the seasons is the key to setting the stage for visual comfort. But placing the opening just right to achieve a good balance between views of the outdoors, visual comfort, thermal control and architectural integrity can be tricky. Hence, it is necessary to design the built environment in accordance with the future sitting plan keeping in mind the probability of glare. It is required to install proper shading devices in order to achieve, visual comfort and the direct daylight does not hamper the vision of the occupant.

For artificial lighting, the positioning and selection of the fixtures plays the key role in

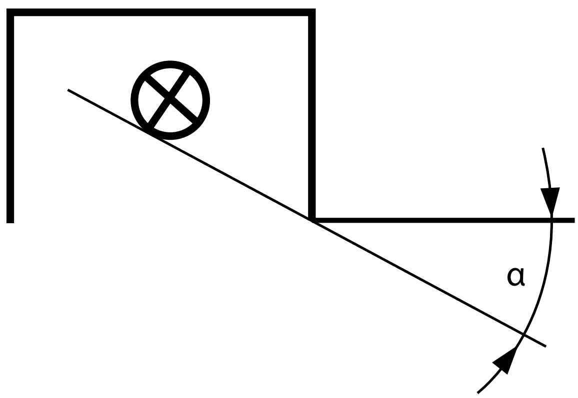

Figure 3 Shielding angle α

Table 1: Minimum shielding angles at specifi ed lamp luminances

Lamp luminance / kcd·m–2	Minimum shielding angle α
20 to < 50	15°
50 to < 500	20°
≥500	30°

the built environment. The fixtures selection shall be made in accordance with the requierement of the end user matching the color profile of the visual comfort along with incorporating integrated design approach to take into account the daylighting. The fixture positioning shall be fixed in accordance with the minimum shielding angle, so as to avoid glare. The minimum shielding angles for luminaires, in the visual field given in Table below shall be applied for the specified lamp luminances:

- **Surfaces, their size, location and luminance**

Bright surfaces attract attention and observers tend to be drawn to look at them even if there is no important visual information provided by such surface. If recommended luminance ratios between the task and surrounding surfaces are exceeded, discomfort or even disability glare might result. It is therefore important to understand the possible ranges of luminance which particularly critical surfaces might exhibit. The human eye has particular difficulty in dealing with high levels of luminance directly in the view region of the fovea. As a potential glare source moves towards the peripheral regions, the permissible luminance limit increases. Since most visual tasks require the worker to look straight ahead or slightly downwards, the high luminance of a vertical surface in or near the centre of the visual field is likely to be more uncomfortable than the luminance of the same magnitude from a horizontal surface at the same location due to the resulting apparent area.

Table 2: Suggested luminance limits for glare sources at various angles of vertical displacement from a horizontal line of sight (according to Robbins, Ref. 21, converted from foot-Lamberts).

Angle of Vertical Displacement from Horizontal Line of Sight	Suggested Luminance Limit
45°	2570 cd/m2
35°	1833 cd/m2
25°	1284 cd/m2
15°	856 cd/m2
5°	582 cd/m2

- **Solar shading and control**

There is a large selection of solar shading and control devices available. It ranges from fixed to moveable, from exterior to interior, from manually to automatically controlled, and from tinted or coated glazing and simple roller blinds to laser-cut panels and anidolic (non-imaging) light-redirecting systems. Careful consideration needs to be given to the selection of shading devices to achieve the desired outcomes. Some shading devices might be useful in reducing direct sunlight on a desk and the glare which might arise from this, but might also create significant view obstructions. Anidolic systems require a separate view aperture and attention to the luminance levels at the indoor light exit point of the systems which typically are fairly high. Blinds, louvers and fins can be mounted internally or externally to reduce glare. If they are not adjustable or removable they will, however, reduce daylight penetration into the space even when discomfort glare is not a noticeable concern. Reducing the visible transmittance of glazing in conjunction with solar radiation control is typically not advisable as it also reduces daylight penetration and might lead to a gloomy space appearance. Control strategies for shading and glare avoidance need to be carefully considered. A good understanding of solar geometry, climate data and available solar control options is essential for the designer, especially when a view occurs in the direction of incoming direct solar beam radiation.

- **Lighting of work stations with Display Screen Equipment (DSE)**

The lighting for the DSE work stations shall be appropriate for all tasks performed at the work stati on, e.g. reading from the screen, reading printed text, writing on paper, keyboard work. For these areas the lighting criteria and system shall be chosen in accordance with type of area.Reflections in the DSE and, in some circumstances, reflections from the keyboard can cause disability and discomfort glare. It is therefore necessary to select, locate and arrange the luminaires to avoid high brightness reflections. The designer shall determine the offending mounting zone and shall choose equipment and plan mounting positions which will cause no disturbing refl ections. In general, it is a much better strategy to arrange the luminaires around a work station in such a way that it is unlikely that they cause reflections in the screen. This is because by restricting the light at higher angles, there is less light able to reach the walls of a room, and the space may start to appear dark.

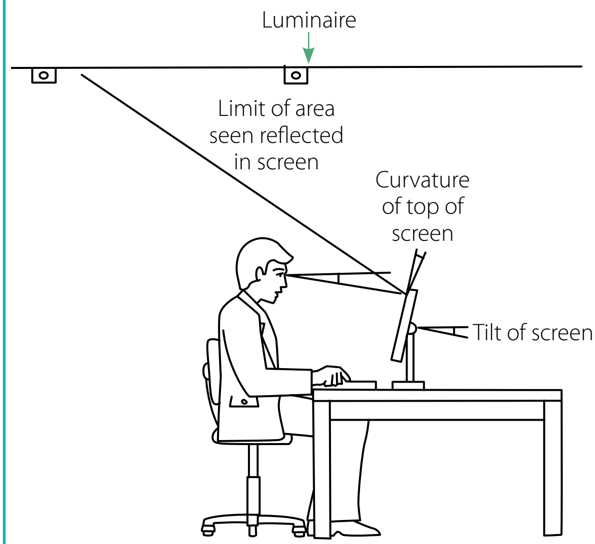

Figure 4 Method of determining which luminaires may cause problems with reflections on screen

Conclusion

In order to support building designers to devise buildings that explicitly optimize (also) visual comfort of future occupants, the several factors of visual comfort need to be encapsulated in a multi-objective optimization problem. To this aim, reliable metrics have to be firstly identified, improved or developed. These metrics shall be able to summarize in a long-term and global value both an integral of short-term assessments calculated over a given calculation period (e.g., for accounting the dynamic performance of solar shading) and a spatial weighted average of local assessments (e.g., for accounting the dimension and position of windows and skylights). Finally, their calculation has to be integrated into building performance simulation tools.