Appliances & Lighting
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Lighting & Human Life

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1 Introduction

The first article in this series of three was focused on vision, and the relation between lighting and human life.

In this second article, we are focusing **on lighting design and lighting systems. We will discuss the relationship between illumination criteria and appropriate techniques**, including **energy savings considerations**. Some actual technical solutions are reviewed.

2 Illumination level

2.1 Standard criteria for setting illumination levels

The standard approach in designing a lighting system is based on **light quantity**. Light quantity, measured in lux, is normalized according to the activities planned in the room. It has been demonstrated that one needs more lux to sew than to read, and more lux to read in a room than to take a shower in the bathroom. Classical design systems include the definition of categories, mostly in terms of buildings and rooms (classroom, kitchen, bedroom, corridor, shopping area, etc.) and categories of anticipated activities.

Nevertheless, as we have seen in the first article, human vision is more sensitive to lighting quality than to lighting quantity. As an example, the doubling of the illumination level generally leads only a small improvement in visual performance, though drastically increasing energy consumption. Decreasing illumination levels generally causes a reduction in visual performance. However dropping the light level by half, for example, does not usually make a substantial difference as long as the light quality remains good. Differences of less than 25% in light levels are more or less meaningless with respect to visual performance.

This fact has been progressively integrated into the most practical standards. Although the majority of normative texts are still based on lighting quantity, quality criteria which directly influence the illumination level (and therefore energy consumption) is the primary subject matter to be addressed in this paper. More details on the lighting quantity measurements can be found in *Advanced Lighting Guidelines* (see bibliography).

2.2 Advanced criteria for designing lighting systems

2.2.1 Viewer's and task criteria

A series of factors influence the way the viewer perceives light in a given context, and should therefore be the initial criteria in any lighting design process:

- The adaptation level of the viewer: when the eye is night adapted (the night vision effect), a person typically needs lower overall light levels than when day adapted. This is also generally the case for building used at night or requiring subdued light levels such as cinemas, theatres, or concert halls.
- Viewer's age: the natural aging of the human eye reduces visual acuity and increases sensitivity to glare. Hence, choosing light levels at the top level in a given range is generally necessary for facilities intended for the elderly.
- Visual size of the task: very large visual tasks tend to require lower light levels.
- Interaction of tasks: many jobs involve adjacent tasks with apparently contradictory specific needs. A classical example is the coexistence of computer and paper work. Task-ambient (more details below) lighting design or dimming controls can help achieve an acceptable compromise.
- Dynamic light level: vision is a dynamic process, which varies with user preference, time of day, weather conditions, and other factors. Variable electric light levels offer significant potential for energy savings and other beneficial effects (well being, mood, etc.).

2.2.2 Light source spectrum criteria

As we have seen in the first article, the eye and vision process do not react equally across the light spectrum and the vision field. This fact, in particular, plays an important role in interior lighting and in low light/large visual field situations.

It has been demonstrated (Berman 1992) that the pupil size, which influences both visual acuity and depth of focus, is controlled by the response of rods rather than by the cones.

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Visual acuity is improved with a smaller pupil. This explains why the pupil becomes smaller in responses to light sources that are enhanced in blue-green light, the portion of spectrum where rods are most responsive. This is called the scotopic effect. Light sources can be classified with a scotopic/photopic ratio (S/P), expressing the property of the source to favour scotopic effect. A high S/P ratio leads to enhanced visual acuity and depth of focus for a given light level.

The table below gives a short classification of light sources:

Light source	S/P ratio
Low pressure sodium	0.2
Warm white fluorescent	1.00
Incandescent (2,850 °K)	1.41
Incandescent (4,100 °K)	1.54
Daylight fluorescent	2.22
Sun	2.28

Lumen measurements are based on the spectrum of photopic vision (central, cones, day vision). But when the visual task is non-central, then both rod and cone responses contribute to vision. This is typically the case in outdoor lighting situations such as streets, roads, or walkways. As a consequence, it is now generally accepted that, when off-axis detection is the primary concern (highways, security lighting, etc.), a lumen correction factor between 1.2 and 1.4 is applied for modern mercury-arc white light sources as compared to high pressure sodium. It means that a 10,000 lumen metal halide lamp would give the same non-central visibility as a 12,000 to 14,000 lumen high pressure sodium lamp.

2.2.3 Light distribution — task and ambient lighting

Task ambient lighting strategies produce energy savings in three ways:

- Locating the light source close to the task efficiently produces the illumination levels needed for the task
- Task illumination levels, usually higher, do not need to be maintained uniformly through the space, enabling ambient levels to be lower
- When not occupied, empty spaces do not need to be illuminated

2.2.4 Colour appearance

There is a general preference for a narrow range of source colour temperature, usually known as the Kruitof's curve. Light sources in the A zone (high lighting and low colour temperature) are perceived as ‘too warm’, sources in the C (low lighting and high colour temperature) as ‘too cold’. This needs to be adapted to situations, both in terms of applications (office work, home, etc.) and climate, as colour temperature can affect perceptions of thermal comfort.

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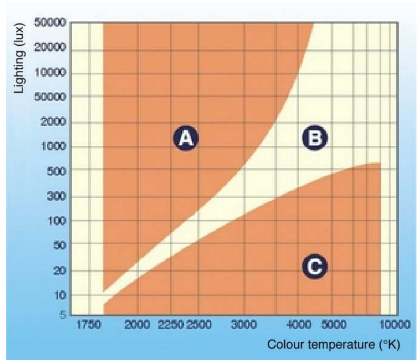

Figure 1: Kruithof's curve

The quality of colour rendering, usually measured through the Colour Rendering Index (CRI) also plays a role. Nevertheless, most light sources used today have a CRI higher than 70. Products above 90 exist. General rules, based on the IESNA (*Illuminating Engineering Society of North America*) guidelines, are given below:

Lamp Colour Temperature (Kelvin)	Applications
< 2,500	Bulk industrial and security lighting
2,500 - 3,000 (warm)	Low light levels in most spaces. General residential lighting. hotels, restaurants. Sources include fluorescent and compact fluorescent, and halogen IR lamps.
2,950 - 3,500 (neutral)	Display lighting in retail and galleries. Sources include halogen IR, white sodium and ceramic metal halide.
3,500 - 4,100 (cool)	General lighting in offices, schools, stores, industry, medical facilities, display lighting. Sources include induction, fluorescent, compact fluorescent and metal halide.
4,100 - 4,500 (very cool)	General lighting in offices, schools, stores, industry, medical facilities and sports lighting. Sources include induction, fluorescent, compact fluorescent and metal halide.
5,000 – 7,500 (cold)	Special application lighting where colour discrimination is critical; uncommon for general lighting. Sources include fluorescent, compact fluorescent and metal halide.

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3 Daylight

Daylight enjoys a significant advantage over electric light. The spectral content of natural light produces about 2.5 times as many lumens per kWh of cooling load. And if introduced through modern high-performance glazing with low emissivity coating, natural light can produce almost three times more illumination for the same cooling load of electric light.

The challenge of employing daylight is that, in addition to providing light, windows and skylights have many additional functions or impacts: they can provide views, ventilation, and a communication conduit with the outside world. They can also allow noise and distraction (or animation, depending on the particular circumstances and opinion) into the space. It is therefore very difficult to isolate the lighting function from all other aspects. The decision process inevitably involves a compromise.

The biggest difficulty today occurs because lighting design usually comes at the end of the building design process. Openings and volumes are often based on other criteria and spatial requirements without due consideration to visual needs. The primary energy issue is introducing a controlled amount of daylight such that the additional cooling load of the daylight is less than the cooling load of electric lighting that is turned off or dimmed during daylight periods.

3.1 Daylight as a light source

For lighting design purposes, at least four sky conditions should be considered:

- Direct sun
- Clear blue sky
- Partly cloudy sky
- Overcast sky

The position of the sun and related intensity is quite easily predictable with such easy-to-use tools as *Carnaval* or the *Satel-light data base*[1]. However cloudy conditions create more difficult situations due to rapidly varying illuminance levels. This is why a static approach to the use of daylight, even if helpful to establish the extremes, might not lead to appropriate decisions about the most energy efficient daylight design choices.

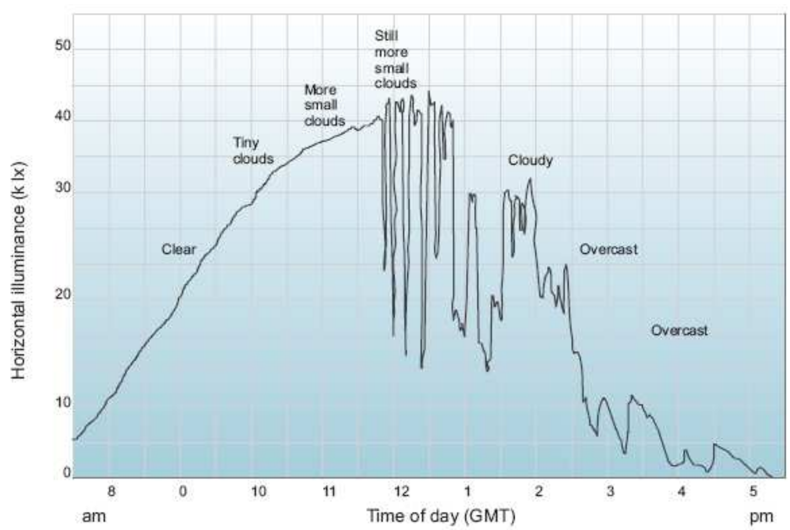

Figure 2: Evolution of illuminance during a standard cloudy day

1 The *Carnaval* open-source software is available for free on www.incub.net. The *Satel-Light database* is accessible through www.satel-light.com

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The efficacy of daylight is defined as the ratio of visible radiation to the total amount of the spectrum present. It can be expressed in lumen per watts. This efficacy is highly variable as a function of solar position, atmospheric conditions, and cloud cover. Sunlight has much more heat content per lumen than daylight. As light is filtered through a glazing material, this ratio also changes considerably, as a function of the optical properties of the glazing material.

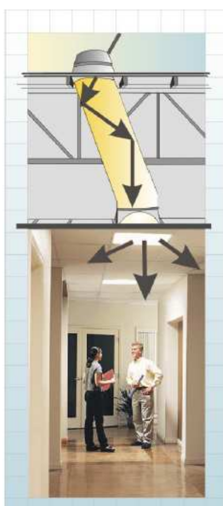
The table below describes the range of performance of daylight as a light source. It clearly illustrates that daylight is very often as efficacious as the most efficient of our current electric sources.

	Point of reference	Value
Efficacy	Sunlight, outside of glazing	80-110 lm/W
	Overcast or clear sky, outside of glazing	105-140 lm/W
	Sunlight, insight of glazing	75-225 lm/W
	Overcast or clear sky, inside of glazing	100-290 lm/W

3.2 Daylight systems and controls

In a daylighting scheme, the building itself serves the function of a luminaire. The windows and skylights deliver daylight to the interior spaces and the building surfaces act as shading devices and reflectors to shape the resulting distribution of daylight. Because the sun is always moving and daylight conditions are constantly changing, it is more difficult to develop photometric descriptions for daylighting strategies than for electric luminaries.

Therefore, advanced daylighting design combines multiple daylighting and electric lighting strategies to optimize the distribution of light.



Some advanced daylight systems, including reflectors and refractors to direct the daylight, are mentioned below.

Light pipes: mirrored or prismatic surfaces that reflect or refract direct sun through a hollow to deliver it deeper into the space

Reflective light shelves, which reflect daylight onto the ceiling, allowing daylight to penetrate deeper into the space

Louvers, preferably adjustable, which can include photovoltaic cells

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4 Electrical Lighting

The most common lighting design for commercial spaces has long been general lighting, in which a single type of luminary is laid out in a more-or-less regular grid or pattern, producing relatively uniform illumination throughout a given area. Significant problems began appearing in the 70s when the wide-spread use of cubicles, partitions, and furniture were introduced to create individual workspaces. This practice resulted in creating large areas of lighting irregularities. Such problems were amplified with the development of computer work stations. Task lighting appeared to balance the low adaptability of ambient lighting.

The intent of ambient lighting is to illuminate the majority of the space to about one-third of the appropriate task illumination level. In reality, this means providing an ambient light level of around 200 lux. This level is sufficient illumination to permit casual task work in most environments. The main concern in creating appropriate ambient lighting is uniformity, undisturbed by such things as directional luminaries placed too close to walls, up-lights within 50 cm of the ceiling, poor balance of light, improperly located accent or wall-washing lighting, etc.

Accurate computer simulation can help design appropriate ambient lighting. The Dialux software[2], used as a standard platform by many luminary manufacturers is a helpful basic tool for preliminary design.

Figure 3: Example of Dialux simulation

Task lighting requires concern for the direction and intensity of the light, as well as the amount of illumination. The main difficulty here is that many tasks exhibit specular reflections that can affect contrast.

The general rule says that light to the sides of tasks produce maximum visibility, while light to the front of the task produces maximum reflected glare.

A review of several cases and actual lighting technologies will be presented in a subsequent article in this series.

2 Available for free from www.dial.de

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