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CONTEMPORARY TOPICS IN LIGHTING

This issue is devoted to the papers presented at the Third International Conference on lighting ILUMINAT 2005 & BALKANLIGHT 2005 with Energy Efficiency and New Trends in Lighting as the main themes. It is edited with the financial support of OSRAM Romania.

JT Kim, **G Kim** and **Moon** refer in their two papers to daylight topic. The first paper *Redesign of the differentiated window system composed of the daylight and view pane of glass* deals with performance data of various transmitted glazing materials for the design strategies of differentiated window systems in terms of day-lighting. An experimental design of window system consists of two different parts of glazing area, a *daylight glazing* and a *view window*: higher placed daylight windows takes natural light and bounces it into deep space of the interior and the lower view window with low transmittance plays a role in enhanced visual comfort within the perimeter area. A scale model measurement was carried out with the fundamental configuration of all-glass facades and compared with the proposed new. A detailed daylight analysis of this individual unit space was performed to determine how variable transmitted glazing materials modify the intensity and distribution of daylight from the differentiated windows. The final conclusion of the study is that the differentiated window has photometric advantages by the optical function of upper daylight window.

The second paper *LIGHTSCAPE as an evaluation tool of daylighting and visual performance* refers to the validity of Lightscape program as a tool of visualization when it is used to evaluate and predict physical quantities of indoor daylighting. The evaluation model is an indoor space that has side lighting with light shelf. It were compared the measured illuminance and luminance values of the scale model in a clear sky and the quantitative values from the results of the computer simulation. The relative errors in the ratios of measured values in the indoor space were in reasonable limits that the prediction method of the indoor scene could be a valuable tool as well.

Kostic, Djokic, Pojatar and **Strbac-Hadzibegovic** analyse the influence of the theory of mesopic vision on the road lighting design. A comprehensive techno-economic analysis compares financially road lighting solutions realized by Metal Halide and High Pressure Sodium lamps, by considering all relevant road lighting classes, lighting arrangements and reflection classes. They proved that MH lamps are economically comparative or even more favourable than HPS lamps for lighting classes characterized by lower luminance levels.

Manav and **Küçükdoğu** investigate the effects of color temperature and illumination level on the visual appeal of an office setting. A test office was arranged for the study and the lighting parameters were investigated independently. Perceived brightness was increased at under 4000 K while the change in the saturation level was perceived better under 2700 K. Also, an increase in the illumination level affected the visual appeal and the pleasantness positively. Illumination level of 2000 lx was preferred for comfort, spaciousness, brightness evaluation and for the change in the saturation level. An interesting final conclusion of this study was that participants liked to control the lighting system, suggesting the use of flexible controlled lighting systems in office settings.

Onaygil, Güler and **Erkin** present two papers targeted to the *Applicable light points in the* *residences for compact fluorescent lamps and potential energy saving* and, respectively, *The effect of observer position and movement on road lighting criteria.*

A DSM project concerning Compact Fluorescent Lamps (CFL) was implemented in 105 residences in Istanbul with the aim of determining the energy consumed for lighting in each area of the residences and the energy saving potential. An average four incandescent lamps were replaced with CFLs. The illumination levels obtained in the different rooms of the houses were checked both by calculations and measurements. Following the statistical data from the electrical distribution company, it is calculated a 9% of energy reduction comparatively with previous year by replacing an average of four lamps per residence. Measured consumption using small hour-meter devices brings out 12.3% of electrical energy saving in total electrical energy consumption and 52.5% of electrical energy saving in lighting. Residential lighting consumption can be reduced at about 13% with CFLs from 23% with incandescent lamps.

The aims of the study related to the effect of observer position and movement on road lighting criteria are to expose the differences on the measurement fields and the position of the observers defined in the American National Standards (ANSI) and European Standards (EN) based on CIE (International Commission on Lighting) recommendations, and to define the most suitable measurement conditions by considering the observer position both fixed and moving with the realized field measurements. The increase of visibility related to the contrast parameter is being confirmed for moving observer situation. In the fixed observer situation the opposite situation is valid. When the real conditions are considered, accepting moving observer conditions shall be more proper approach for STV calculations.

Slovenian experiences with overcoming different approaches to light pollution problem is presented by **Orgulan** and **Voršič**. They deal with some details that differ from recommended practice of CIE. Current proposal of Slovenian light pollution ordinance is also dividing environment in four zones of protection grades, but based on more precise and descriptive criteria. The lighting parameters in each defined zone of protection were adjusted to the latest CIE recommendation. Questions remain regarding the measurement equipments and costs for evaluation of the ordinance efficiency. For this purpose the authors carried out few evaluations of new and renewed lighting installations.

Suvagau and **Hughes** appraise the latest worldwide research on the mechanism of non-visual, photo-biological light process and the implication of lighting to the human health.

They comment the principles of healthy lighting and explore directions for lighting design practice transformation.

The Third International Conference on lighting **ILUMINAT 2005 & BALKANLIGHT 2005** hosted 9 Invited Papers, 39 papers and four posters, prepared by 90 authors - 34 from Romania. 46 authors – 20 from Romania - joined the Conference activities, together with other 45 participants, as students, Ph.D. students, designers, architects and lighting professionals. The conference run six plenary sessions where specialists of high performance and representativity expressed their positions, research programmes and novelties in energy efficiency in lighting. An exhibition was organized, with lighting devices created by a collective from the University of Arts and Design in Cluj-Napoca. Another exhibition of lighting equipments has been organised by the sponsors. The conference allowed the exchange of knowledge on the new policies and strategies of the European programmes (WP6, Green Light) aimed at increasing the energy efficiency, at sustaining the environment and at a durable development. The conference created a frame of international and Balkans regional cooperation of lighting specialists.

REDESIGN OF THE DIFFERENTIATED WINDOW SYSTEM COMPOSED OF THE DAYLIGHT AND VIEW PANE OF GLASS

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Clear glazing preserves the views, but low vertical glazing within normal viewing angles should be treated in optical way because it can be a strong source of glare. Besides aesthetics and visual contact to outdoors, the use of clear glass on the whole façade might cause a sort of visual problem due to the harness of direct sun and brighter sky surface than affordable. A window might be differentiated into its component parts, the higher daylight window and the lower view pane of glass applied with various transmittances. Visible light transmission may be higher in the upper glazing to increase daylight and lower in the view glazing to minimize glare. This paper deals with performance data of various transmittal-glazing materials for the design strategies of differentiated window systems in terms of daylighting. A scale model measurement was carried out with the fundamental configuration of all-glass facades and compared with the proposed new.

1. Introduction

Windows, the glass facade of buildings, let us view to outdoors and brighten the interiors with natural light. Growing use of transparent glass wall with metal frames is popularly detected in modern building practices to balance visual concerns with taking advantage of daylight. It is also reflecting a deep-rooted preference for the enhancement of available natural light, for one particular kind of comfort instead of other issues. Most windowed area in perimeters of glass buildings may get too much light, creating excessive glare, and thus, light entering the building should be carefully controlled. The longing for light in the deep interior of fat glass buildings, however, should be satisfied and it may conflict with the visual situation of the perimeter. Two approaches exist; physically, higher-located windows might let in light high, where it illuminates the ceiling (simulating our experience of the sky) and deliver light deep into a building's interior. Optically, low-transmittance glass prevents glare with lower brightness of window surfaces. The second approach geometrically does not harm to the expression of architectural philosophy. Much of design projects seek to justify the ongoing use of glazed structures, so it is not surprising that their attention often focused on glazing materials. More advanced windows with various coatings have already developed on the edge of wide use as a solution.

This project issues an experimental design of window system consisted of two different parts of glazing area; a daylight glazing and a view window. Higher placed daylight windows takes natural light and bounces it into deep space of the interior and the view window with low transmittance plays a role in enhanced visual comfort within the perimeter area. In addition, this paper situates synthetic context of photometric benefit of a differentiated daylight-redirecting system, addressing its methodological approaches with a sophisticated scale model construction.

2. Design of Differentiated Window System

In general, conventional windows are consisted with homogeneous glazing material for the whole glass pane and the conventional optically clear window introduces more daylight into the space than any other glazing materials due to higher visible light transmission. Huge clear windows, however, should be carefully preferred because excessive amount of daylight might cause lot of visual problem to human subjects unless the glazing's above normal vision angle treated properly from direct view. Compromising these contradictory might be the use of two different windows; an upper daylight glazing with high visible transmission and lower view window with lower transmission. Former researches proposed experimental configurations of a window system of which glass plane was differentiated into two functions [2. 7]. To get as much daylight as possible with direct sun penetration, as shown on Figure1, the higher part of a window might be deigned by clearest glass, while the lower part is finished by tinted glasses so that it allows vision to the outside and prevents glare from excessive brightness of window surface.

In brief, the upper "daylight glazing" is designed to supply a maximized natural light deep into interior space from the window wall. Glass for this daylight window should be high transmittal such as clear glass (75% or more) and low solar heat gain coefficient (30% or less). The lower "view window" is supposed to provide a comfortable vision to the exterior. This gives the occupants of the space the ability to relax their eye muscles by allowing for deep visual focus. The glazing for the view window is often tinted to about 50% visible light transmission. Using some optically treated glasses can reduce the contrast ratio between the interior surfaces and brighter exterior view, which will help to avoid glare condition of the space. For the view window, a variety of functional glasses developed recently might be applied and their optical characteristics are shown on Table 1. Visible transmission is high for clear glass (about 78% for a single pane) but pastel glass has relatively lower transmittance, 27%.

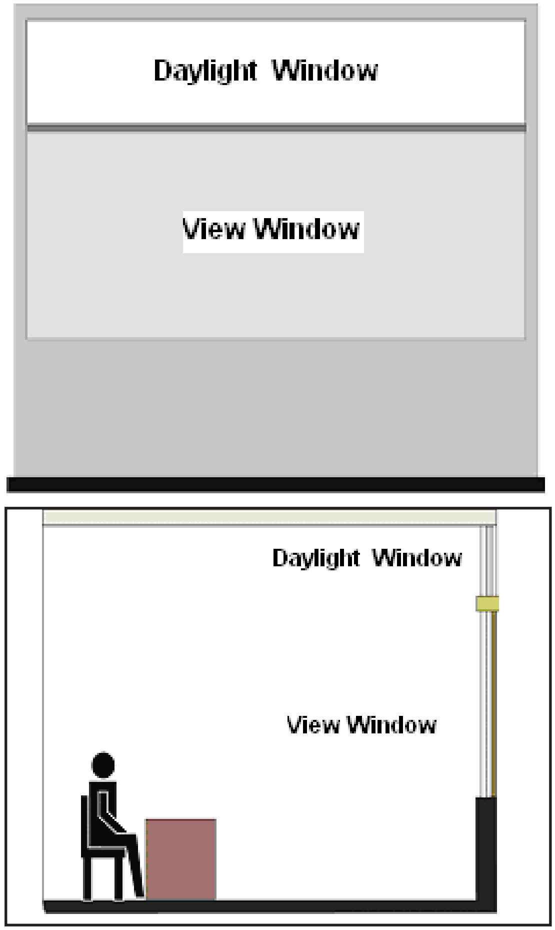

Figure 1 Configuration of the differentiated window

Table 1 Optical characteristics of view window glasses

Glass	Thick-ness (mm)	Optical values				Color
		Visible light (%)		Solar radiation (%)		
		trans-mittance	reflec-tance	trans-mittance	reflec-tance	
Clear (CL)	18	78	14	63	12	none
Color (GN)	18	66	11	41	8	green
Pastel (PTS)	18	27	16	19	15	light blue
Low-E (GN+LE)	18	58	10	29	11	green

3. Design of Evaluation Methodology

A variety of evaluation methods are available to the designer for simulating the daylight performance of buildings. The physical model simulation promises the simple and more versatile for studying a daylighting system. Full-scale mockup model simulation provides the most reliable technique but if the scale model is its duplicate in all aspect and details, the evaluation results in the scale model will be almost identical to those of the mockup model.

Figure 2 View of the scale model

For the comparative measurement, as shown on Figure 2, a scale model (1:10) of the typical office space is constructed so that the glazing material and the orientation of the space can be readily changed. This scale model represents actual dimensions of 4.9 m (W) x 7.2 m (D) x 2.6 m (H) in SI unit. The photocells are mounted on a block of wood so that the height of the photocell can be coincident with the desired plane height at the scale. The height from the perimeter floor level to the top of the photometric sensor, which measures 79cm including the thickness of the base mount for photocell, represents the general work-plane height. The inside surfaces of the model are finished as same materials in the real building as possible so that the surface gives same effect of real wall for the light behavior. The measured of reflectance are shown on Table 2.

Table 2 Reflectance of interior finishes

surface	material	reflectance (%)
wall	plywood with paint	68
floor	asphalt tile 300×300mm	51
ceiling	textile 300×300mm with paint	87

4. Data Acquisition

4.1 Performance Index: Light Factor

A serious difficulty in evaluating daylighting performance is the variability of light from the sky and sun. Unlike artificial light sources, natural sources cannot be effectively expressed by a single coefficient of utilization for a given space with the light admitting system. This led to the development of the daylight factor in 1895, and the definition is the ratio between unobstructed outdoor light level and indoor light level by daylight only. With a given sky luminance distribution, variation in daylighting inside will correspond exactly to variations outside for a given sky condition i.e., the DF ratio remains the same. The Daylight Factor is a convenient index to represent the performance characteristics and to predict the potential light level of a daylighting design. It can be also used to evaluate the performance of daylighting design alternatives, because the value of the daylight factor is altered by any change in architectural parameters, such as window dimensions or height above the working plane, ceiling height, surface reflectance, ground reflection, and obstructions.

Even though it is a convenient indicator of daylighting performance, limitations have been often noted for various reasons. One of the limitations in use is that the combined effects of daylight and direct sunlight under real skies are difficult to quantify. The need for performance indicators other than the daylight factor has been raised in this situation, and a new daylighting performance index, Light Factor (LF) has been established as follows:

$$LF = \frac{\text{indoor horizontal illuminance from natural light}}{\text{unobstructed exterior illuminance under real sky}} \times 100\ (\%)$$

As another indicator to express the daylighting performance by using both the horizontal exterior illuminance and vertical indoor illuminance is introduced [6] that is referred to as Surface Light Factor (SLF), hereafter defined as follows:

$$SLF = \frac{\text{indoor specific surface illuminance from natural light}}{\text{unobstructed exterior horizontal illuminance under real sky}} \times 100\ (\%)$$

4.2 Measurement

A whole series of measurement with the scale model was conducted based on IEA monitoring protocol process [9]. The model was tested in Suwon, Korea for days under real skies when the weather conditions were not exactly identical for whole time period but sufficiently close.

Figure 3 View of measurement in scale model

The varying nature of the skies detected was not particularly critical for the measurement because the performance index might translate the indoor daylight as a ratio as mentioned above. The model was facing south orientation on the proper horizontal level so that the measured values might be compared symmetrically. Figure 4 shows that the scale model is being tested under a real sky and the location of illumination measurement is displaced on Figure 3. As a main instrument to read the illumination levels on both indoor and outdoor, a set of Licor photocell equipment, (LI-210SA) and Topcone IM5 light meters are used. This system measures illuminance on number of sensor locations, displays this data in lux, and saves this data to HP 34970A data logger.

5. Comparative Daylight Performance

5.1 Daylight in differentiated window

A detailed daylight analysis of the individual unit space was performed to determine how variable transmitted glazing materials modify the intensity and distribution of daylight from the differentiated windows. As a base case, a conventional window was initialized with a variety of glazing materials. The measurement of the scale model indicates that the interior light levels have been changed proportionally dependent on the transmittance of the glass.

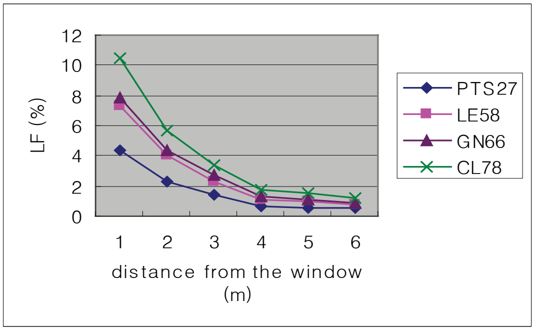

Figure 4 LF values in conventional window

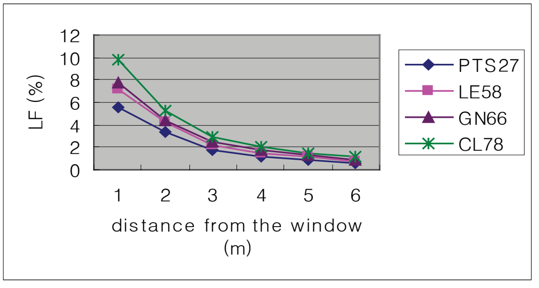

Figure 5 LF values in differentiated window

Using lower transmitted glass such as the pastel plays a role in decreasing the severe LF value at perimeter adjacent the window, as shown on Figure 4, still holding same amount of daylight in the rear space.

For the differentiated window, daylight glazing with high visible transmission delivered more natural light deep into the space. As figure 5 presents the work plane light factors' distribution under a real sky, the overall LF values at the center and rear space became higher than those of the conventional. In case of pastel glass with transmittance of 27%, for example, the average LF values was increased to 125 ~170%. In brief, the test shows the benefit of view glazing of the differentiated window must be stressed for daylight application.

5.2 Daylight on specific interior surface

As described earlier for SLF in 4.2, the daylight performance of a system can be expressed in another way and one might be the ratio between outdoor illuminance and indoor's on a specific surface at particular direction. When the transmittance is getting higher in the conventional window, the SLF values at ceiling (1.5m, 3.5m) and wall (1.5m, 3.5m) are proportionally going up (Figure 6).

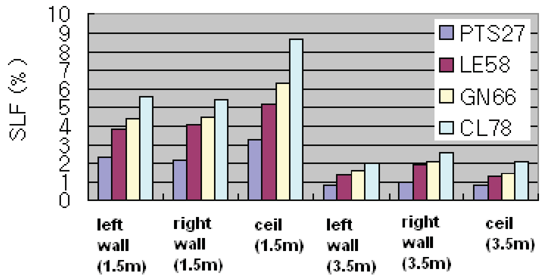

Figure 6 SLF values in conventional window

To give additional insight into the daylight performance of the differentiated window, we also measured the ratio of SLF in each case. The measured SLF values at same location of each surface with the view window are 100%~600% higher than those of the conventional. However, it should be noted that the increment might be stemmed from the geometrical relationship between the incidence of direct sunray through the view window and the location of measurement at a specific time period (Figure 7).

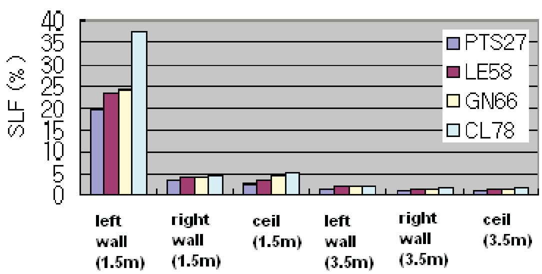

Figure 7 SLF values in differentiated window

6. Conclusion

This research aimed to generate two points of daylighting application as follows: 1) providing daylight performance data with a variety of glazing materials for a large window and 2) designing and evaluating an experimental type of window. For this purpose, we compared the daylight and distribution performance of new defined type of window configuration to the conventional window counterpart with a variety of glazing materials. The comparison was made for a deep, south-facing perimeter zone with large window, without any interior obstruction. The conventional window is the base single homogeneous glass pane, where as the differentiated window uses of two different glazings; an upper daylight glazing with high visible transmission and lower view window with lower transmittal glass.

To give detail insight into the daylight performance of the differentiated window, a sophisticated scale model was constructed and daylight has been measured based on IEA monitoring protocol process under real skies. The daylight performance data was translated into a ratio between outdoor illuminance and the interiors. The scale model test of the conventional window indicates that the interior light levels have been changed proportionally dependent on the transmittance of the applied glass. The comparison of daylight distribution analysis showed that the differentiated window has lots of photometric advantage by the optical function of upper daylight window. In particular, the contribution of higher daylight window into deep rear space must be stressed for daylighting application.

Acknowledgement

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INFLUENCE OF THE THEORY OF MESOPIC VISION ON ROAD LIGHTING DESIGN

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Although possessing considerably better colour rendering and more acceptable colour appearance than high pressure sodium (HPS) lamps, for economic reasons metal halide (MH) lamps are still rarely considered in road lighting. The latest results in the field of mesopic vision encouraged a comprehensive techno-economic analysis which compared financially road lighting solutions realized by MH and HPS lamps. Based on previous findings regarding both perceived brightness and visual performance, the analysis considered all relevant road lighting classes, lighting arrangements and reflection classes. It proved that for lighting classes characterized by lower luminance levels MH lamps are economically comparative or even more favourable than HPS lamps.

1. Introduction

A lot of parks, squares, walking and pedestrian areas (spaces where people gather) are lit by HPS lamps, independent of the fact that the result is a poor and unnatural night presentation (yellowish, with no colour diversity). Aware of an unacceptable night appearance of such areas, the leading lamp manufacturers constructed MH lamps with a ceramic discharge tube. On one hand, they were characterized by excellent colour rendering, stable colour temperature, increased efficacy and longer life (compared with ordinary MH lamps), and on the other they could replace HPS lamps in existing luminaires, using the existing ballasts. This offered a possibility for improved presentation of urban spaces previously illuminated by inadequate HPS lamps.

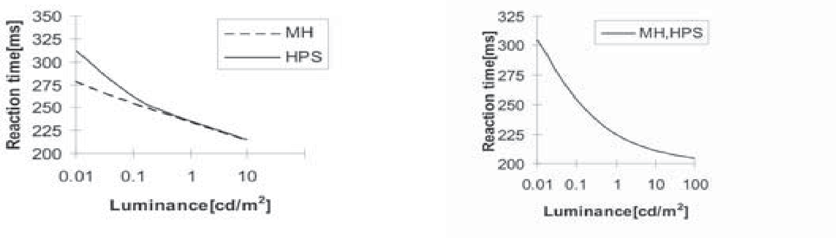
Nowadays withdrawal of HPS lamps from places where they do not belong is being realized. In addition, the theory of mesopic vision supported by some experiments raised the following question: are HPS lamps, from the financial point of view, undoubtedly a better solution for road lighting than MH lamps, as usually believed? In order to answer this question, a comprehensive techno-economic analysis was conducted. Its essence and results will be presented after taking a look into the previous research in the field of mesopic vision.

2. Briefly on previous research

The twilight zone that lies between the scotopic and photopic regions (0,001 cd/m^2 <L< 3 cd/m^2) is called mesopic. Through the mesopic range the eye response is dependent on the luminance level (which is not the case in the photopic and scotopic regions). Its gradual change from $V(\lambda)$ to $V'(\lambda)$ happens when the light level is reduced.

A considerable part of research in the theory of mesopic vision was devoted to the development of the concept of "equivalent lumens". Using this concept, Adrian [1] has computed equivalent lumens for different lamp types applied in road lighting. As expected, it was shown that under mesopic conditions the equivalent lumens could be considerably different from "normal" (photopic) ones. It should be emphasized that Adrian's results are based on brightness matching experiments, regarding tasks which occupy both the on-axis and off-axis regions of the eye.

Junjian He and his associates [2, 3] have also investigated in this area. Involving tasks situated both on-axis and off-axis, their research was related to visual performance, with reaction time as its indicator. Figure 1 contains on-axis and off-axis reaction times of an observer plotted against background luminance level for both HPS and MH lamps [2].



a) **b)**

Figure 1 Reaction times for MH and HPS lamps (according to He's experiment)
a) off-axis detection, b) on-axis detection

Lewis has also investigated spectral effects testing observer reaction times [4,5]. Observers were asked to react to a simulated road hazard (set slightly off-axis). Their task was to identify if the pedestrian (shown on the slide) was facing towards or away from the road. Lewis' results are shown in Figure 2 [6].

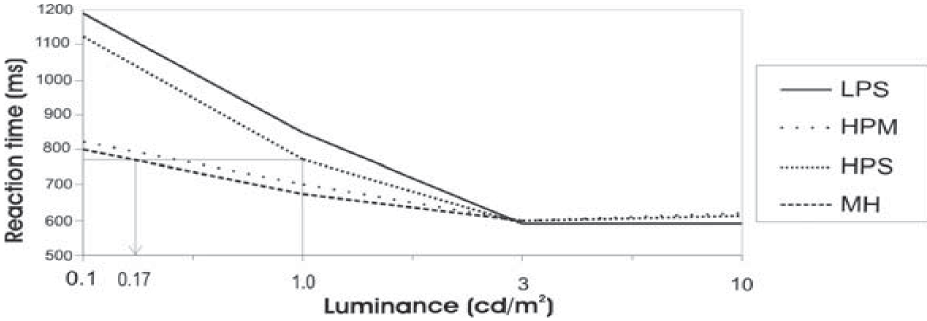


Figure 2 Reaction time data for a realistic task (according to Lewis' experiment)

Due to a great diversity in the findings, in order to handle various effects of lamp spectral distribution Lewin [6] proposed the use of a set of relative values which he called "Lumen Effectiveness Multipliers" (LEMs). Since the future application of LEMs will be primarily in street lighting, where the most common light source is high-pressure sodium, Lewin proposed to base LEM on an HPS lamp as a standard, that is:

$$LEM = \text{Visual effectiveness of the light source} \Big/ \text{Visual effectiveness of a high pressure sodium source}$$

The following equation, equivalent to the previous, is easily applicable:

$$LEM = L_{photopic\ HPS} / L_{photopic\ the\ light\ source}\ ,$$

where the above luminances represent photopic luminance levels which provide equal values of a parameter relevant for chosen conditions (perceived brightness, reaction time defined by He, reaction time defined by Lewis, etc.).

3. Choice of adequate lems for the techno-economic analysis

The objective of this research was to investigate in which cases of road lighting the application of MH lamps with a ceramic discharge tube is economically comparative with the use of HPS lamps. Therefore, two different lighting solutions, one with MH, and the other with HPS lamps, were compared for each of the considered road situations. Both lighting solutions had to provide similar visual conditions, expressed through relevant parameters represented not only by the perceived brightness, but by the reaction times defined by He and Lewis, as well. The analysis started using the concept of equal brightness (equal mesopic luminance levels), which assumed the application of "Adrian's LEMs" presented in [6]. However, it was necessary to check if the use of Adrian's LEMs was in favour of the solution with MH lamps regarding visual performance.

It was concluded first that the use of Adrian's LEMs, assuming equal brightness, does not practically influence reaction time defined by He (for luminance levels between 0.3 and 2 cd/m^2 (determined by [7]) for both on-axis and off-axis detection relative difference in reaction times when using MH and HPS lamps amounts up to 3,7% only).

Although the use of Adrian's LEMs reduces photopic luminance levels when MH lamps are applied, it was also shown that reaction time defined by Lewis' experiment is still in favour of MH lamps (for the relevant luminance levels, the reaction time is shorter (up to 26%) when using MH lamps than when applying HPS lamps).

The above proves that the use of Adrian's LEMs provides equal brightness, practically equal reaction time defined by He and better visual performance (shorter reaction time) defined by Lewis when applying MH lamps. This is why the use of Adrian's LEMs keeps the designer on the safe side when applying MH lamps.

Table 1 The luminance levels (L_{av}) determined by EN 13201, Adrian's LEMs valid for MH lamps and the corresponding luminance levels (L_{avMH})

Road lighting class	ME1	ME2	ME3	ME4	ME5	ME6
L_{av} (cd/m^2)	2.00	1.50	1.00	0.75	0.50	0.30
LEM	1.23	1.29	1.35	1.44	1.56	1.68
L_{avMH} (cd/m^2)	1.63	1.16	0.74	0.52	0.32	0.18

4. Technical data necessary for the economic comparison

The economic comparison was limited to those luminance levels belonging to the mesopic region, which are determined by EN 13201 [7]. Each of them corresponds to a specific ME road lighting class (see Table 1).

All relevant road lighting classes, lighting arrangements and road surface reflection classes were taken into account. Note that the lighting solutions had to fulfil all of the requirements from Table 1a from [7] (ME-series of lighting classes) regarding a particular road lighting class. The luminance level represented the only exception, since the whole analysis was based on equivalent mesopic luminance levels (and not the photopic ones). In order to achieve equal mesopic luminance levels, the photopic luminance level from Table 1a [7] was adopted for the lighting solution designed by HPS lamps, while Adrian's LEMs were used to calculate the photopic luminance level for the lighting solution realized by MH lamps. These LEMs are given in Table 1, computed using the data from [6] and applying the Lagrange method of interpolation. Table 1 also contains photopic luminance levels (L_{avMH}) which are recommended when applying MH lamps.

The following lighting arrangements were considered: single sided, staggered (zigzag), opposite, and central (twin-bracket). All standard reflection classes (R1-R4) were taken into consideration. The common input data for all of the lighting designs included:

- lane width of 3.75 m,
- central reservation width of 3 m,
- distance between the lighting post and the carriageway of 1 m (1,5 m for the central arrangement),
- type of HPS lamp: SON-T PLUS (Philips, Eindhoven),
- types of MH lamp: CDM-T and CDM-TT (Philips), and
- types of luminaire: IRIDIUM SGS252 and SGS253 (Philips), with a glass protector (degree of protection: IP 66). Note that the luminaire degree of protection IP6X is (or is becoming) most frequently requested.

The maintenance factor was determined to amount 0.77 for HPS lamps and 0.71 for MH lamps, both set in IRIDIUM luminaires (a medium atmospheric pollution was assumed) [8].

5. The cost-discount method applied

The generally accepted cost-discount method [9] was applied for the economic comparison of HPS and MH lamps in road lighting. The total costs within the same (amortization) period, T, including both the initial and maintenance costs, were considered.

The initial (investment) costs involve the cost of the overall design (which includes lighting design), the cost of material, equipment and devices (posts, cables, luminaires, lamps, etc.), the cost of all the necessary work, as well as the cost of testing the new lighting installation. Since a lot of various costs are practically equal in both cases (costs of design, transformer station, distribution boards, cables, testing procedure, etc.), only costs of poles, brackets, luminaires and lamps (including their installment) were compared. Therefore, the initial costs (C_{in}) can be calculated by using the following equation:

$$C_{in}=N_p[C_p+C_b+k(C_l+C_{l.s.}+C_{wl})+C_{wp}], \quad (1)$$

where:

- N_p is the number of poles along a considered road section (length of D=3 km was adopted),
- C_p is the price of the pole with the necessary equipment and accessories,
- C_b is the price of a single or twin bracket (if necessary),
- k is the number of luminaires per pole,
- C_l is the price of the luminaire (with control gear and ignitor),
- $C_{l.s.}$ is the price of the light source,
- C_{wl} is the cost for the luminaire installment, and
- C_{wp} is the cost for the pole installment.

The maintenance costs involve the electricity cost, as well as the actual maintenance costs, predominantly including the costs intended for luminaire cleaning and lamp replacement. Being considerably smaller than the previous, the costs for control gear and ignitor replacement (in case of failure) were not taken into account.

The annual electricity cost (C_e) can be computed using the following equation:

$$C_e=kN_pC_{1e}, \quad (2)$$

where C_{1e} is the annual electricity cost per luminaire.

Since an optimum maintenance procedure assumes an organized group lamp replacement, with the luminaire cleaning taking place only when the lamp is replaced [10], the cost for the group lamp replacement can be calculated using the following equation:

$$C_{gr}=kN_p(C_{l.s.}+C_{g.r.w.}), \quad (3)$$

where $C_{g.r.w.}$ involves the vehicle and work cost for a lamp replacement and luminaire cleaning. The group replacement periods amount to 3 years for HPS, and 1.5 years for MH lamps [8].

The total cost, C, discounted to the end of the exploitation period, T, can be computed using the following equation:

$$C=C_{ind}+C_{ed}+C_{grd}, \quad (4)$$

where C_{ind}, C_{ed} and C_{grd} represent discounted investment, electricity and group lamp replacement costs, respectively.

6. Results of the application of the cost-discount method

Total (discounted) costs of photometrically comparative lighting solutions for relevant roads and their lighting and reflection classes, realized by both HPS and MH lamps, were calculated. All of them were computed assuming the average value of the discount rate i=7.5%, as well as the following exploitation periods: T=21, 24, 27 and 30 years (usual exploitation periods belong to the range of 20-30 years). These costs are presented in 16 tables, each containing the values for a specific reflection class and a single exploitation period. Table 2, referring to R3 and T=24 years, is selected for presentation here.

A simple conclusion can be achieved analyzing the mentioned tables: independent of the road surface reflection class, lighting solutions realized by MH lamps are economically comparative or even more favourable than those realized by HPS lamps for roads belonging to road lighting class ME6, ME5 or ME4 (L_{av}=0.3–0.75 cd/m^2).

Since many roads in residential and other city areas satisfy the above conditions (road lighting class: ME6, ME5 or ME4), in order to achieve a better night appearance of such areas, the lighting solutions with MH instead of HPS lamps should be applied in cases where new lighting installations are planned or where general reconstruction of the lighting installation is done.

Note that the decrease of the price of MH lamps with a ceramic discharge tube, as well as the increase of the electricity cost rate, are expected in the future. Both expected changes are in favour of MH lamps (in most cases the total installed power is smaller when applying MH lamps).

Table 2 Total (discounted) costs of comparative lighting solutions for relevant roads and their lighting classes (standard reflection class=R3 and *T*=24 years

Arrangement	Lighting class	Total (discounted) costs (€)		$\frac{C_1 - C_2}{C_1} \cdot 100$
		C_1 (SON-T Pro)	C_2 (CDM-T(T))	
Single sided 2 lanes	ME6	609 802	549 473	9.9%
	ME5	634 736	598 893	5.6%
	ME4b	753 542	725 113	3.8%
	ME3c	1 004 680	1 034 288	-2.9%
Staggered 3 lanes	ME6	1 004 733	829 252	17.5%
	ME5	1 004 409	933 859	7.0%
	ME4b	1 080 016	1 059 946	1.9%
	ME3b	1 194 302	1 205 311	-0.9%
	ME2	1 506 983	1 561 526	-3.6%
Opposite 3 lanes	ME5	1 249 785	1 285 891	-2.9%
	ME4a	1 198 041	1 238 165	-3.3%
	ME3a	1 351 341	1 501 711	-11.1%
	ME2	1 664 896	1 966 687	-18.1%
	ME1	2 124 504	2 194 867	-3.3%
Opposite 4 lanes	ME5	1 566 696	1 549 751	1.1%
	ME4a	1 450 046	1 422 511	1.9%
	ME3a	1 532 482	1 623 470	-5.9%
	ME2	1 639 193	1 908 856	-16.5%
	ME1	2 234 247	2 475 704	-10.8%
Twin central 2 lanes	ME3a	1 275 068	1 464 653	-14.9%
	ME2	1 284 448	1 440 547	-12.2%
	ME1	1 762 459	1 959 223	-11.2%
Twin central 3 lanes	ME3a	1 262 265	1 356 586	-7.5%
	ME2	1 882 675	2 293 661	-21.8%
	ME1	2 388 751	3 070 527	-28.5%

7. Conclusions

Considerably better colour rendering and more acceptable colour appearance of MH lamps when compared with HPS lamps produce a more attractive night appearance of the road and its immediate surrounds, including pedestrians. In addition, the application of the mesopic vision theory shows that there are a lot of cases in which MH lamps are even economically more justified than HPS ones.

Our analysis of previous research in the mesopic field (carried out by other authors) showed that the use of Adrian's LEMs represents a conservative approach. It ensures equal brightness and practically equal or even better visual performance when MH lamps are applied.

Our techno–economic analysis proved that the application of MH lamps is economically comparative with the use of HPS lamps for road lighting classes ME6, ME5 and ME4, emphasizing that this is valid for all standard reflection classes. When MH lamps are applied it is recommended to use the photopic luminance levels given in the last row of Table 1, which are lower than those valid for the use of HPS lamps. The application of these luminance levels provides significant energy savings, as well as lower light pollution.

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THE EFFECTS OF COLOR TEMPERATURE AND ILLUMINANCE ON PLEASANTNESS: A CASE STUDY FOR OFFICE SETTINGS

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Effects of color temperature and illumination level on the visual appeal of an office setting were investigated where their effects were evaluated independently. 2700 K was selected for relaxation, while 4000 K was preferred for comfort and spaciousness. Perceived brightness has increased under 4000 K while the change in the saturation level was perceived better under 2700 K. Also, an increase in the illumination level affected the visual appeal and the pleasantness positively. 2000 lx was preferred for comfort, spaciousness, brightness evaluation and for the change in the saturation level.

1. Introduction

Pleasantness is a subjective impression that evaluates whether a space is appealing or not. The IES Lighting Handbook [1] indicates that, the feeling arises in types of spaces where the visual appeal of the environment is important. According to Steffy [2], pleasantness is the appropriate marriage of light and architecture, results in improved morale, communication and productivity.

Though user satisfaction depending on color temperature and illuminance has been studied and the change in space perception due to these parameters was tested, the most preferable lighting that satisfies this condition is inconclusive. According to Fleischer et al [3], there is a direct relationship between pleasantness and illuminance level. It was also observed that, under full spectrum lighting conditions, pleasantness and motivation have increased. The IES Lighting Handbook suggests that, non uniform brightness and peripheral lighting satisfy alertness and enhance the impression of pleasantness.

Depending on the applied test results, cooler light sources and higher illumination levels, warmer light sources and lower illumination levels lead to a pleasant environment [3-5]. However, there is neither a specific lamp type nor a color temperature that best enhances the impression. Also, the impact of color temperature and illumination level on pleasantness has not been evaluated independently.

This study aims to investigate the role of color temperature and illumination level as lighting parameters that improve user pleasantness and productivity in an office setting where their effects are evaluated independently.

2. Experimental Set-up

A test office was arranged for the study that has the following dimensions, 3.46x 7.00x 2.80 m. The suspended ceiling was white, walls were painted in light grey and the flooring was light brown laminated wood ($p_c = 0.86$, $p_w = 0.78$, $p_f = 0.54$).

The room was furnished as a cell office and daylight penetration was controlled through dark blue roller blinds. The lighting system was supplied by 6 luminaires (TBS 300/ 2 36 M5) recessed in the suspended ceiling . A total of 12 fluorescent lamps were used, each of which is connected to dimmable electronic ballasts and regulated by Lightmaster 100 Lighting Control System. Three different color temperatures were selected for the study; 2700 K, 4000 K and the mixture of the two. Maximum level of illumination was 2000 lx when 12 of the lamps were operated.

The lighting system was designed to provide 8 different lighting scenarios that were numbered on a remote control. The system could be adjusted to maintain a constant illumination level of 500 lx, 750 lx, 1000 lx and 2000 lx on the working surface while 2700 K, 4000 K and the mixed color temperature mood could be operated separately. A total of 56 office workers participated in the study who evaluated the room from the same view point.

Physical comfort conditions were evaluated for every lighting scenario, measurements were taken by LMT Luminance Meter L1009, LMT P01704 Luxmeter and using Calculux Indoor 5.0 Computer Program.

3. Experimental Method

Part 1

For this part of the study, the color temperature was adjusted to the 'mixed color temperature' mood and the only variable was the 'illumination level'. 500 lx and 2000 lx illumination levels were compared by a questionnaire that had 8 questions regarding the visual satisfaction from the space. Subjects were free to change the lighting scenarios from the remote control on their own until they decided the lighting scenario that best satisfied the tested parameter. In case none of the lighting choices satisfied the tested parameter, they were asked to mention 'there is no difference'. Tested parameters were related to the perceived brightness, the change in the saturation level of the colors, being comfortable, spacious and relaxed.

In the study, the term 'pleasantness' was defined as follows; an impression related to the visual appeal of the environment, a feeling towards to the atmosphere of the space that gives visual satisfaction from the environment. All of the above parameters were evaluated accordingly.

Results indicate that, an increase in illumination level improved 'comfort and spaciousness' as seen in Figure 1. This result is parallel to the findings of Sawada; as the user group got used to the color temperature and the physical qualities of the test room, a sudden change in the illumination level affected visual appeal and comfort conditions positively. Perceived brightness of the objects has increased, the room was perceived as wide and spacious.

Previous studies indicate that low illumination levels with non uniform lighting conditions increased visual comfort . In the present study, on the contrary, a decrease in the illumination level affected visual comfort negatively, but relaxation has increased.

Brightness evaluation was compared for two different illumination levels. Taken measurements by LMT Luminance Meter L1009 was compared to the 'perceived brightness' of the participants (please refer to Table 1) When the lighting level was increased from 500 lx-mixed CT to 2000 lx-mixed CT, brightness evaluation for the objects on the table and on the wall opposite to the view point has increased suddenly and this change was evaluated positively.

A comparison was made for the 'saturation level' of the objects on the table and on the wall opposite to the view point. Results show that an increase in the illumination level affected visual appeal of the surrounding positively and saturation has increased, as seen in Figure 1.

Participants liked the 'mixed color temperature mood' and nearly 80% offered to use it at office settings (62% offered to use 2000 lx-mixed color temperature choice, 14% offered to use mixed color temperature and an illumination level between 500 lx-2000 lx).

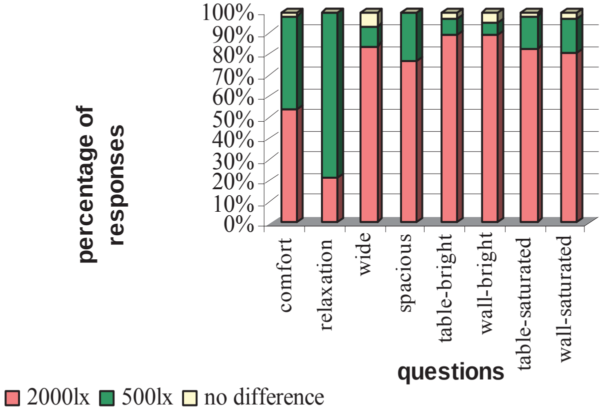


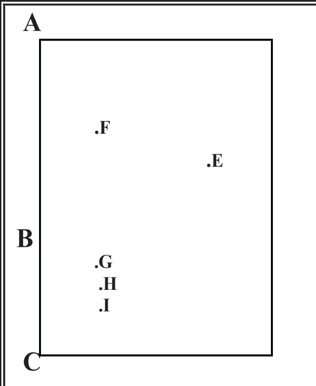
Figure1 Evaluation of the test room under 2000 lx and 500 lx illumination levels

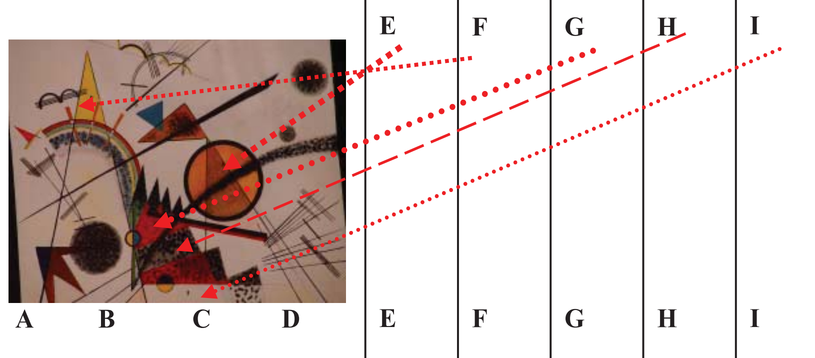
Part 2

In this part of the study, illumination levels were fixed at 500 lx, 750 lx and 1000 lx respectively, 2700 K and 4000 K color temperatures were compared and visual satisfaction from the space was evaluated accordingly. Subjects were asked to fill in the questionnaire that was defined in *Part 1*, the procedure and the tested parameters were the same. Results show that, 4000 K color temperature was preferred for the parameters of 'comfort and spaciousness' under three of the illumination levels as seen in Figure 2a-2c. Previous studies indicate that, lower color temperatures lead to a 'relaxing' atmosphere. In the present study, results are parallel to this; under three of the illumination levels, 2700 K was preferred for the impression of relaxation.

'Brightness' evaluation of the objects on the table and on the wall were compared for 2700 K and 4000 K under 500 lx, 750 lx and 1000 lx for which, preferences of results have changed as seen in Figure 2a-2c.

Table 1 Luminance values of different points on the wall surface opposite to the view point (cd/m^2)





	A	B	C	D	E	F	G	H	I
1000 lx-4000 K	108	128	114	118	64	104	30	73	126
750 lx-4000 K	86.3	102	92.1	94.2	53.5	82.5	25.3	59.5	102.5
500 lx-4000 K	57.9	68.4	60.9	63.4	35.5	55.4	17.1	40	68.2
1000 lx-2700 K	99	129	112	121	76.5	114	39	76.4	132.3
750 lx-2700 K	79.3	104	90.7	97.5	61.4	90.3	31	58.1	105.2
500 lx-2700 K	58.5	75.7	60.4	66.3	37.5	62.8	22.4	43.6	77.1
2000 lx-mixed CT	160	198	191	195	120	194	66.8	139	248
500 lx-mixed CT	57.6	71.6	62.1	66.7	39.4	60.1	19.9	41.5	72.3

Table 2 Luminance values of different points on the poster that cover the table surface (cd/m^2)

.A′ .B′ .C′ .D′	Point A′ (BLACK)	Point B′ (WHİTE)	Point C′ (RED)	Point D′ (GREY)
1000 lx-4000 K	22.1	241	71.1	37.9
750 lx-4000 K	17.5	191.1	56.7	31.5
500 lx-4000 K	11.8	127.9	37.5	21.6
1000 lx-2700 K	24	260	128	54
750 lx-2700 K	22	206	101.4	46
500 lx-2700 K	17.4	147.3	60.5	24.3
2000 lx-mixed CT	56.7	495	158	85.7
500 lx-mixed CT	12.4	135.8	44.3	21.6

The number of preferences are too close to each other that makes it difficult to state a color temperature under which 'brightness' values are perceived beter and the visual appeal increases positively. Also, measured luminance values on the wall and on the table were compared for each illumination level from Table 1 and Table 2. Though, brightness evaluation of the participants (test results) and measured luminance values differ for each illumination level, the number of responses and measured values are too close to each other that makes it difficult to state a color temperature that increases the visual appeal in the space. The result is in accordance with Tiller and Veitch and Miyasawa [6,7] who concluded that brightness evaluation is subjective and differs from the measured values in a space.

'Color perception' and the evaluation of the change in saturation was examined under 500, 750 and 1000 lx for two color temperatures. Results indicate that, especially warm colors were perceived as more saturated under 2700 K color temperature.

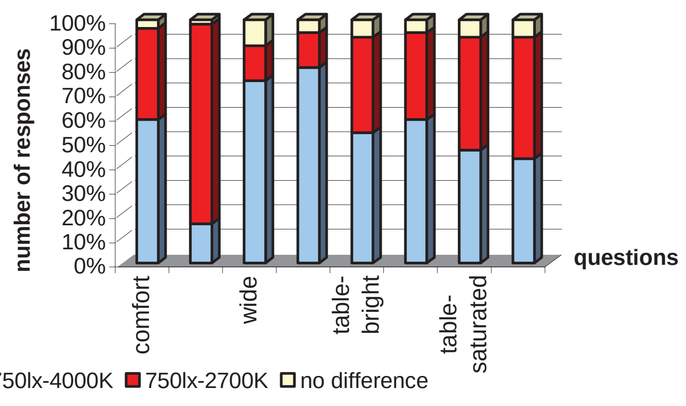


Figure 2a Evaluation of the test room under 750 lx-4000 K and 750 lx-2700 K color temperatures

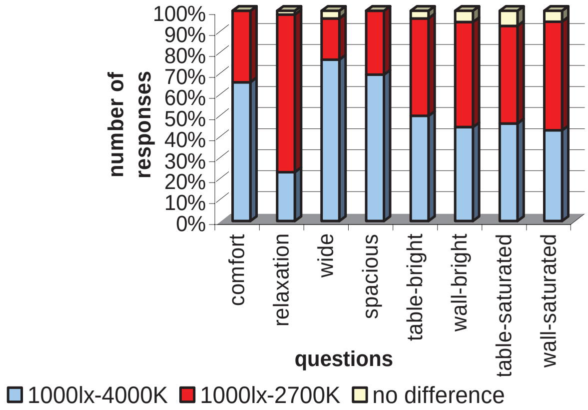


Figure 2b Evaluation of the test room under 1000 lx-4000 K and 1000 lx-2700 K color temperatures

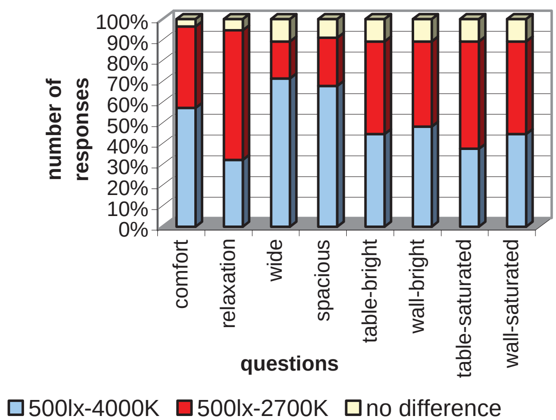


Figure 2c Evaluation of the test room under 500 lx-4000 K and 500 lx-2700 K color temperatures

4. Conclusion

The change in color temperature and illumination level has affected the visual appeal of a space. 2000 lx was preferred to 500 lx for the impressions of comfort, spaciousness, brightness and saturation evaluation. 4000 K color temperature was preferred to 2700 K for the impressions of 'comfort and spaciousness', while 2700 K was suggested for 'relaxation' and the 'saturation evaluation'. However, it is difficult to suggest a color temperature that enhances the brightness in a space, as 'perceived brightness' is a subjective evaluation. Further research can be conducted to find a coefficient for the evaluation of 'perceived and measured brightness values' and for the best color temperature. Participants liked the 'mixed color temperature mood' and the majority offered to use it at offices. Combination of warmer and cooler color temperatures (mixed CT) can be suggested. Finally, in the study, it was observed that participants liked to control the lighting system. It can be suggested to use a flexible lighting system that can be controlled by the user group at an office setting.

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Topics of interest are daylight, energy consumption and energy efficient lighting design.

LIGHTSCAPE AS AN EVALUATION TOOL OF DAYLIGHTING AND VISUAL PERFORMANCE

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A computer simulation on artificial lighting and daylighting using computer programs is an analyzing method that can offer various weather conditions while simultaneously eliminating difficulties in producing a model experiment and reducing errors in measurement. The objectives of this study lie in suggesting an application method of evaluation tools and demonstration of limits and characteristics so as to more easily determine the daylighting performance in the very initial stages of planning for an arbitrary office space in which windows with daylight access are built. We produced scale model of the general light inducing type side lighting with lightshelf and ceiling, and the luminance and illuminance were measured in a clear sky. And a comparison of the measured values and the calculated values from a computer simulation using the Lightscape program was performed.

1. Introduction

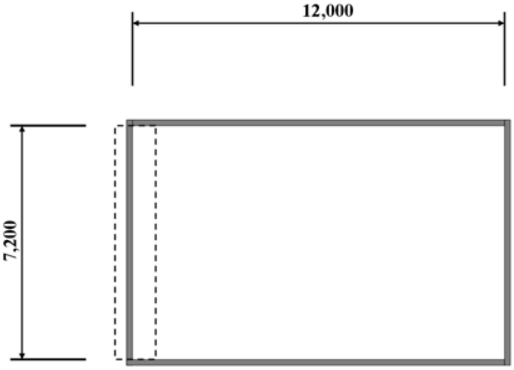
Various techniques that enable measurement and visualization of daylighting performance have been developed recently. The experiment method using a scale model and the computer simulation method have become typically recognized as the available tools for predicting daylighting performance. However, the computer simulation method has been utilized more widely than the experiment method since the experiment method has various limitations in itself. Various programs including Lightscape, Lumen Micro, Adeline, etc. have been used for conducting computer simulation on daylighting, among which Lightscape has been recognized to have more excellent adoptability, convenience, and visualization compared to the others.

Thus, the objectives of the study lie in evaluating the validity of Lightscape as a tool of visualization when it is used to evaluate and predict physical quantities of indoor daylighting. Provided that the validity of Lightscape has been evaluated, a designer will utilize it effectively as a tool for evaluating daylighting performance in primary design stages.

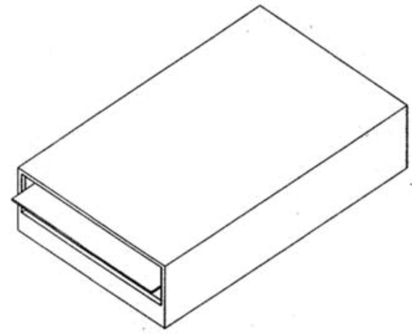
2. Research design and methodology

In this study, daylight illuminance induced into the scale model through the side lighting with light shelf was measured and was compared with the calculated values from a computer simulation using the Lightscape program. By comparing with photos of the scale model and images generated from Lightscape, a correct reflection to generate realistic images by visualizing the numeric values produced from the computer simulation was analyzed. Detailed contents and methodology of the study are as follows.

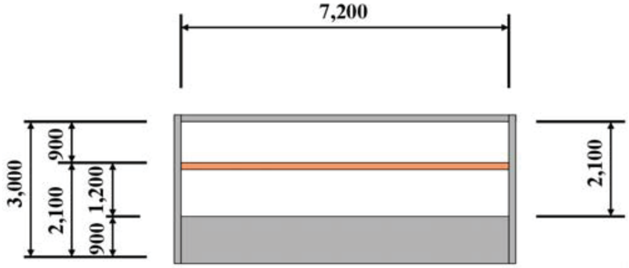
- An indoor space comprising of the side windows with light shelf was selected as the model for evaluation in this study. Because the indoor daylight illuminance distribution for ordinary side lighting is simple, side lighting with light shelf of varying light environments were selected for evaluation.
- The space to be evaluated was matched close to the actual Lightscape variables and physical characteristics through which the scale model was made and computer simulation was conducted.
- The validity of Lightscape was evaluated by comparing the measured values from experiments of the scale model which were conducted in a clear sky and the quantitative values from the results of the computer simulation. .



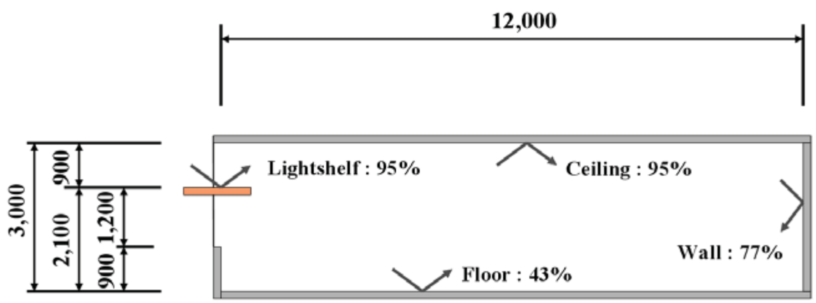
(a) Floor Plan



(b) Isometric



(c) Front Elevation



(d) Main Section and Reflectance

Figure 1 Shape, dimensions, and illuminance of the evaluation model. The validity of Lightscape was evaluated by comparing photos taken from the scale model and the images visualized from the computer simulation

2.1 Evaluation model and measurement outline

A scale model was made to analyze the distribution of illuminance and luminance in the indoor space through side lighting with light shelf, then illuminance and luminance of the inner space in a clear sky was measured. The indoor space of the subject building in which light shelf was built on the side windows to the right eastern direction with dimensions of 12 m (depth) x 7.2 m (width) x 3 m (height) and was reduced by 1/6 to produce the model. The model was made from plywood and iron angles were used in the exterior parts so as to make it easy to assemble, disassemble and adjust the height. A series of the experiments were conducted on the roof of the Engineering building of K University to minimize exterior influences.

2.2 Experiment outline using the scale model

The reason for selecting the indoor space that has side lighting with light shelf installed is to measure the daylight illuminance and luminance through a series of experiments using scale model and to compare these measured values with the Lightscape simulation values. Total 84 points, 7 rows on the width and 12 columns on the depth were set by making a symmetry on the center of the room width in order to measure the illuminance and a total of 78 points, 1 m and 2 m points in the height and 2 m points on the ceiling central row, on the left wall and the right wall were set to measure luminance as shown in Fig. 4.

All the measurements of indoor daylight illuminance were carried out simultaneously for each row to maintain a consistent clear sky and to minimize error due to variations in the clear sky. One photometric sensor was set on the exterior to measure the outer illuminance and 7 photometric sensors were set in the interior to measure the daylight illuminance in each row. The evaluation model and summary of the measurements are shown in Table 1 and the positions of the sensors in Fig. 3. The evaluation space was reduced by 1/6 to make the model for measuring luminance. shown in Table 1 and the positions of the sensors in Fig. 3. The evaluation space was reduced by 1/6 to make the model for measuring luminance. The inner walls were applied with blue/green wall paper, the floor with blue/green carpet tiles, and the ceiling with white form boards.

TOPCON IM-3 Illuminance Meter was used to measure outer illuminance and TOPCON BM-8 Luminance Meter was used to measure inner luminance in the scale model. The luminance was measured at a total of 78 points, 48 points of 1 m and 2 m in the heights on the inner left wall and the inner right wall, 30 points on the ceiling, and.

The inner walls were applied with blue/green wall paper, the floor with blue/green carpet tiles, and the ceiling with white form boards.

TOPCON IM-3 Illuminance Meter was used to measure outer illuminance and TOPCON BM-8 Luminance Meter was used to measure inner luminance in the scale model. The luminance was measured at a total of 78 points, 48 points of 1 m and 2 m in the heights on the inner left wall and the inner right wall, 30 points on the ceiling, and both the luminance and the illuminance were measured at a point on the exterior.

Table 1 Simulation design for the lightshelf

Model		Illuminance Model	Luminance Model
Size		7.2 m (W) x12 m (D) x 3 m (H)	
Opening Size		7.2 m (W) x 2.1m (H)	
Scale		1/6 (1.2 m × 2 m × 0.5 m)	
Reflec-tance	Ceiling	95%	93%
	Wall	77%	54%
	Floor	43%	39%
	Lightshelf	95%	93%
Lightshelf Size		1200 mm (inter : 900 mm, outer 300 mm)	
Place		Seoul, Latitude 37, Longitude -127	
Time		GMT +9 Japan, Korea 12:00, Noon	
Month/Day		3/21	

Figure 2 1/6 Model

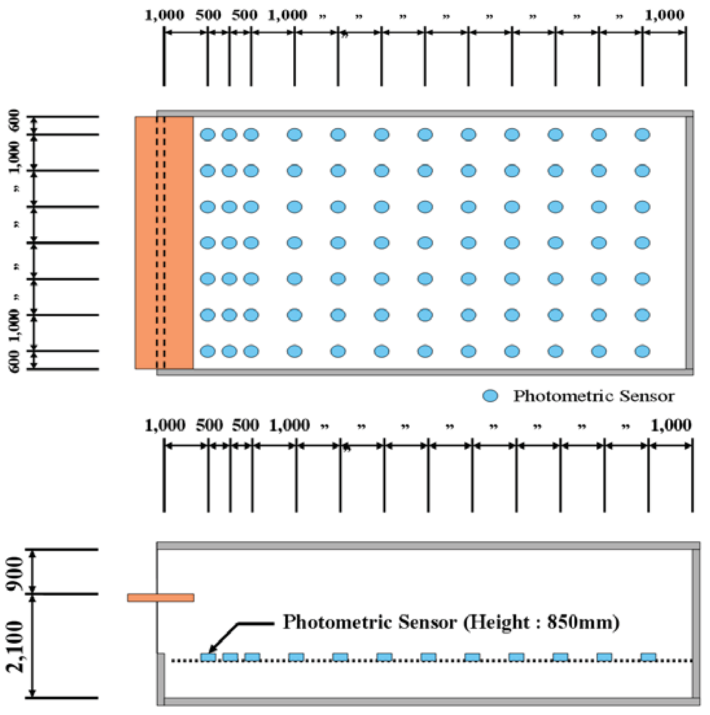


Figure 3 Arrangement of Photometric Sensors for the measurement of illuminance.

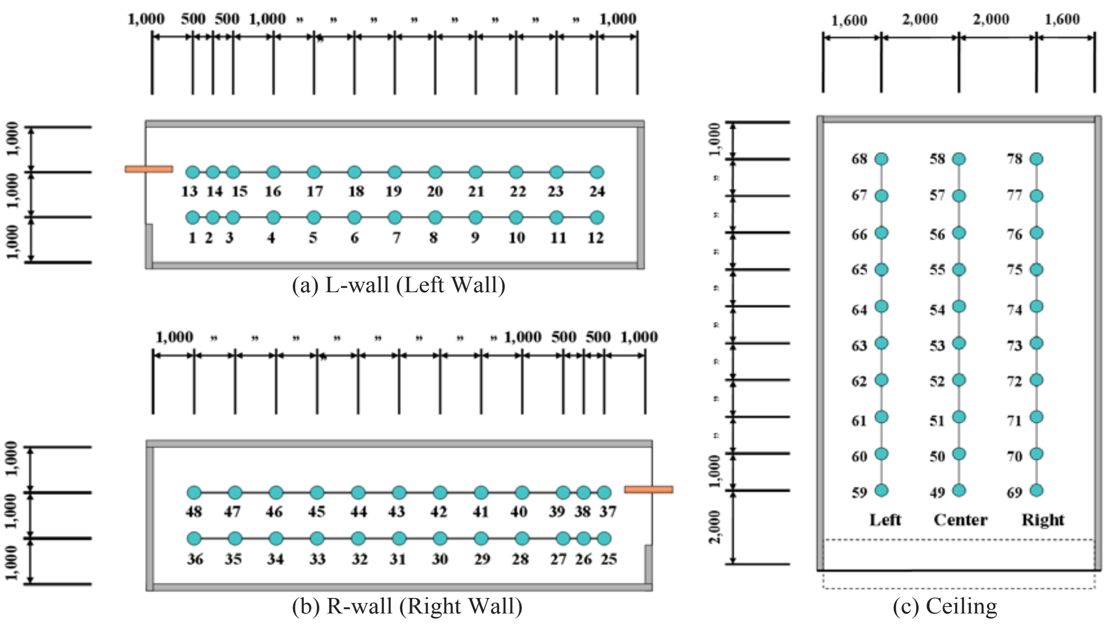


Figure 4 Points for measuring luminance.

2.3 Lightscape simulation outline

Lightscape requires an additional modeling program for accuracy except when it is used for simple surfaces as it doesn't have self modeling functions. And Lightscape has good compatibility with the programs of AutoCAD or Autodesk Viz because all are made by Autodesk Co..

The simulation was modeled using AutoCAD 2002. To carry out solid modeling, a 3D model was made by using a floor plan constructed with line command. Each of the surfaces were divided using Explode commands, and all the layers and colors were set for each material. When layers and colors are set with AutoCAD, it becomes easy to apply the variations of materials by utilizing layers and colors in Lightscape. The exterior walls and the interior walls were made separately because of the occurrence of a "light leaks" when it is modeled with a single exterior wall using AutoCAD.

Measured reflectance scale of 95% for white water paint was used on the ceiling in the model for measuring the illuminance and although the evenness of the surface was improved using an electrical sanding machine, it could not be as smooth as glass, so such roughness and shadows were expressed by adjusting the contrast and complexity values of Procedural Texture's Bump Mapping and Intensity Mapping so as to reflect those on Lightscape. A wooden patterned wall paper on the walls was scanned to set up the texture and the measured reflectance scale was set at 77%. Carpet tiles of the LG red type for offices was used by scanning it and the practical reflectance scale was set at 43%. The white water paint with a reflectance scale of 95% was selected for the light shelf.

Table 2 Lightscape Simulation Parameters

Simulation Model			Parameter	
			Illuminance	Luminance
Time	Time		GMT+9 Japan, Korea 12:00, 24 Hour	
	Month/Day		3/21	
Place	North		0 (South)	
	Location/North		Seoul, Latitude 37, Longitude -127	
Sky Condition			Clear	
Properties	Display	Brightness	90	
		Contrast	90	
Lightshelf	Physics	Reflectance	0.95	0.93
	Color	H.S.V	0.00, 0.00, 0.95	
	Size		1200mm (inter: 900, outer: 300)	
	Setting Height		2100mm	
	Material		White Paint	White Board
Ceiling	Physics	Reflectance	0.95	0.93
	Color	H.S.V	0.00, 0.00, 0.95	
	Intensity Mapping	Width	100	
		Contrast	0.12	
		Complexity	1	
	Material		White Paint	White Board
Wall	Physics	Reflectance	0.77	0.54
	Material		Wall Paper	
Floor	Physics	Reflectance	0.43	0.39
	Material		Carpet Tile	

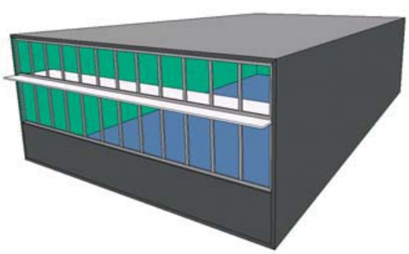


Figure 5 AutoCAD Model

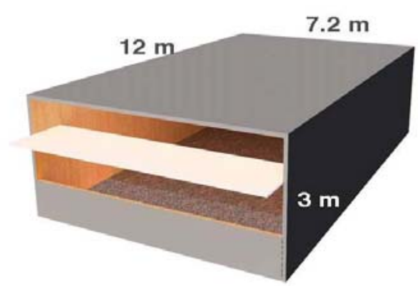


Figure 6 Rendering Image

Since the work plane must not influence the distribution of daylighting that are different from walls or ceiling, an additional surface processing was done. Lightscape is equipped to select the receiving function for 3D surfaces that save meshes of radiosity and records illuminance. Occlusion and reflection had not been selected at that time so that it would not influence the other 3D surfaces.The mesh resolution value, that regulates the resolution of the work plane surface, was given the maximum value of 10. Both daylighting and sky lighting were utilized in the processing of daylight setup. Southern direction and an altitude of the sun was set in the direct control and the altitude of the sun on March 21 (the spring equinox) was utilized. Illuminance of the direct sunlight were simulated by using 98,230 lx.

Measured reflection ratio of 93% was utilized on the white ceiling in the computer simulation model to measure luminance. Wall paper of blue-green type on the walls was scanned to set up the texture and the measured reflection ratio was set at 54%. Carpet tiles of blue-green type for offices were used by scanning it and the practical reflection ratio was set at 39%. The configuration equal to the simulation model for the illuminance was utilized in processing of the daylight setup and the simulation was carried out using the illuminance value of 76688 lx. Radiosity processes were conducted until it reached 99.999% and rendering option was selected to get a final image after having finished it.

3. PERFORMANCE AND ANALYSIS

3.1 Illuminance Analysis

Measured values from the experiment using the scale model and the calculated values from a computer simulation are listed in Table 3 and Figure 7. The measured values were compared with the ratios of daylight illuminance (Indoor illuminance divided by exterior illuminance × 100%). The range of relative errors except for the Rows No.1, No. 4, No. 5, and No. 6 are within 2% and the whole range of relative errors is within 3.36% when the averaged values were compared in each row.

Table 3 Daylight - Illuminance ratio and Relative errors

Column / Row	average relative errors (%)	A		B		C		D	
		measured values	calculation values	measured values	calculation values	measured values	calculation values	measured values	calculation values
Average	3.36								
1	5.17	7.32	7.05	8.37	8.25	8.30	8.88	8.30	7.59
2	1.10	6.73	6.65	7.98	7.93	8.13	8.16	8.13	8.31
3	1.68	6.22	6.28	7.48	7.34	7.70	7.51	7.70	9.05
4	8.04	4.37	4.70	5.24	5.63	5.42	5.83	5.42	5.94
5	11.23	2.79	3.08	3.28	3.60	3.35	3.71	3.35	3.82
6	4.74	1.97	2.06	2.27	2.33	2.30	2.41	2.30	2.46
7	1.88	1.43	1.41	1.63	1.57	1.63	1.60	1.63	1.64
8	1.50	1.06	1.07	1.19	1.15	1.18	1.18	1.18	1.20
9	1.39	0.82	0.82	0.91	0.89	0.89	0.90	0.89	0.91
10	1.05	0.65	0.65	0.72	0.70	0.71	0.70	0.71	0.71
11	1.27	0.56	0.57	0.61	0.60	0.61	0.61	0.61	0.62
12	1.29	0.53	0.53	0.58	0.57	0.58	0.57	0.58	0.57

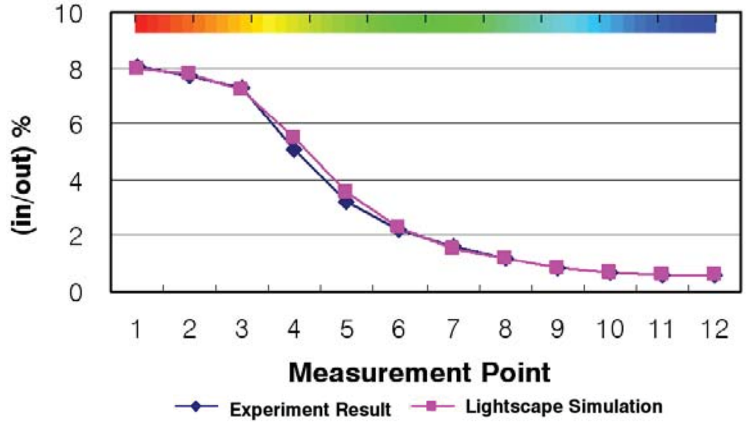


Figure 7 Illuminance Level

3.2 Luminance Analysis

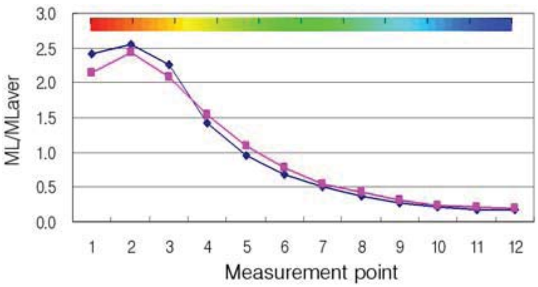
The relative errors between the luminance measured from the experiment using the scale model in a clear sky condition and the brightness calculated from the Lightscape program are listed in Table 4.

The average relative error at 1 m and 2 m points in the height on the left wall and the right wall is 14.47% and the averaged relative error of the measuring points on the ceiling is 6.55% which shows that the relative error of the measuring points on the ceiling was relatively low. The average relative error of the measuring points in Rows No. 1 to No. 6 which are near the window is 10.04% and that of the measuring points in Rows No. 7 to No. 12 is 10.51%.

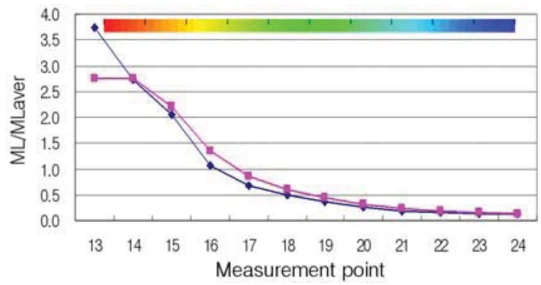
Table 4 March 21, 12:00 - Relative errors

Relative errors	**Average**	**Measurement Point**											
average (%)	**10.51**	**18.59**	**2.72**	**4.99**	**11.79**	**12.40**	**9.74**	**7.78**	**9.90**	**11.22**	**10.09**	**15.16**	**15.85**
L┌ R-wall 1m		1	2	3	4	5	6	7	8	9	10	11	12
relative errors(%)	11.26	11.16	4.71	7.52	8.45	14.74	13.24	10.00	13.51	14.29	9.09	16.67	11.76
ML/MLaver		2.42	2.55	2.26	1.42	0.95	0.68	0.50	0.37	0.28	0.22	0.18	0.17
CL/CLaver		2.15	2.43	2.09	1.54	1.09	0.77	0.55	0.42	0.32	0.24	0.21	0.19
L┌ R-wall 2m		13	14	15	16	17	18	19	20	21	22	23	24
relative errors(%)	17.67	26.01	0.73	8.29	28.30	28.36	18.00	16.22	15.38	21.05	18.75	14.29	16.67
ML/MLaver		3.73	2.74	2.05	1.06	0.67	0.50	0.37	0.26	0.19	0.16	0.14	0.12
CL/CLaver		2.76	2.76	2.22	1.36	0.86	0.59	0.43	0.30	0.23	0.19	0.16	0.14
C-ceiling				49	50	51	52	53	54	55	56	57	58
relative errors(%)	9.07			0.40	4.95	1.89	3.23	4.88	10.71	9.52	12.50	15.38	27.27
ML/MLaver				5.00	2.02	1.06	0.62	0.41	0.28	0.21	0.16	0.13	0.11
CL/CLaver				4.98	1.92	1.04	0.64	0.43	0.31	0.23	0.18	0.15	0.14
L┌ R-ceiling				59	60	61	62	63	64	65	66	67	68
relative errors(%)	4.03			3.76	5.45	4.59	4.48	0.00	0.00	0.00	0.00	14.29	7.69
ML/MLaver				4.79	2.02	1.09	0.67	0.43	0.31	0.23	0.18	0.14	0.13
CL/CLaver				4.97	1.91	1.04	0.64	0.43	0.31	0.23	0.18	0.16	0.14

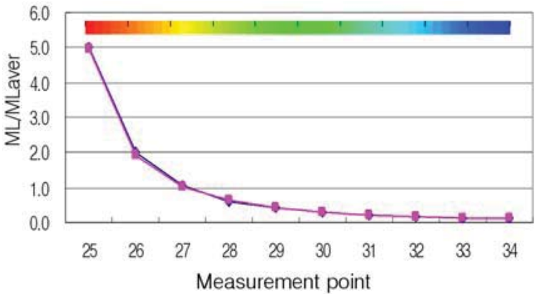
ML: Measured luminance, MLaver: Average luminance on the measuring row.
CL: Calculated luminance, CLaver: Averaged luminance on the calculating row.



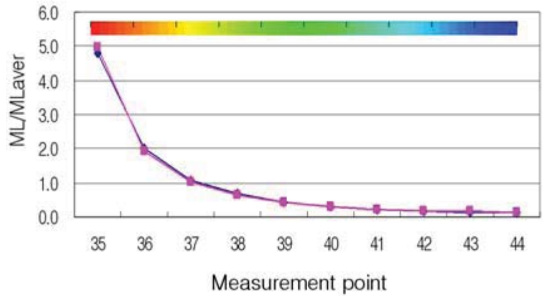
(a) L ·R-wall, 1m



(b) L ·R-wall, 2m



(c) C-ceiling



(d) L ·R-ceiling

Experiment Result   Lightscape Simulation

Figure 8 March 21 12:00, Luminance Levels

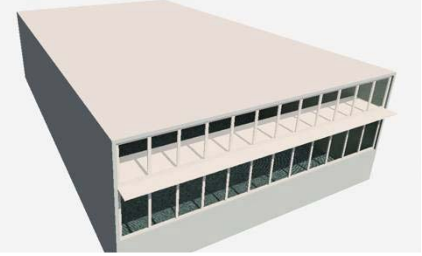
Photo Image	Lightscape Image
	
	

Figure 9 Realistic Visualization

3.3 Comparison of the indoor scene by photograph and computer Simulation

In order to compare an indoor shape when it shines directly on the window in a clear sky, the interior part of the scale model was photographed and compared with the image that was generated from the Lightscape simulation Figure 8. The results tell us that the two images are so similar to each other that it is impossible to distinguish the two by the naked eye, and the prediction method of the indoor scene will be a valuable tool.

4. Conclusion

In this study, Lightscape, which has been utilized widely to evaluate daylighting performance and visualizations, was evaluated to determine whether it would be appropriate for the weather conditions in Korea as well as its validity. For the evaluation model, side lighting with light shelf was selected, and experiment using the scale model and Lightscape simulation were carried out. And validity, ratios of daylight illuminance, and comparison with the generated images and the visualized images are described as follows.

Relative error in the ratios of illuminance in the indoor space with a 1.2 m length light shelf was 3.36%. The usability of Lightscape for predicting daylighting performance was very high because the whole range of the relative errors was within 10%. These are indicated by the visualized data as shown in Figure 8. The results tell us that the two images are consistent with each other making it impossible to distinguish with the naked eye, and that the prediction method of the indoor scene will be a valuable tool as well.

The average relative error of the ratios of brightness was 10.51% at 12:00 hours on March 21. The average relative error at 1 m and 2 m points in height on the left wall and the right wall was 14.47% and the average relative error of the measuring points on the ceiling was 6.55% which show that the relative error of the measuring points on the ceiling is relatively low. The average relative error of the measuring points in Rows No. 1 to No. 6 which are near the window was 10.04% and that of the measuring points on the Row No. 7 to No. 12 was 10.76%.

The validity as a tool of visualization will be evaluated more accurately through a comparison of indoor colors in future studies.

Acknowledgement

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APPLICABLE LIGHT POINTS IN THE RESIDENCES FOR COMPACT FLUORESCENT LAMPS AND POTENTIAL ENERGY SAVING

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There has been a demand-side energy management project implemented in 105 residences in Istanbul with the aim of determining the energy saving potential in the residences and energy consumed for lighting in each area of the residences by using Compact Fluorescent Lamps (CFLs) which were installed by the residents' desire. This project lasted for one year; statistical data obtained from the surveys and consumption data obtained from Bosphorus Electrical Distribution Company (BEDAS) analyzed intensively. Also devices called hour-meters installed on the lighting points in some residences to calculate the usage time of the lamps individually for determination of light (lamp) usage characteristics of the residents. Thus, the results show the applicable light points for lamp replacements and electrical energy saving potential in the residences.

1. Introduction

Energy efficiency is one of the most important topics in sustainable energy strategies. Efficiency in demand side, especially in the residences, can be done without high investments; particularly it can be most effective by using high efficiency devices like compact fluorescent lamps (CFLs) and it brings considerable effect on the total electrical energy consumption.

There are many kinds of demand-side management projects being implemented on efficient lighting by CFLs in all around the world, especially for determining the potential energy saving in the residences. Those projects had been started in early 1990's with the aim of decreasing the electrical energy consumption in the residences by using CFLs. Some of those projects were pilot and some others were county-wide projects. Some of the most important projects realized were in Mexico in 1992-1993 which was a pilot project and after that a country-wide project in South Africa by Lawrence Berkeley National Laboratories [1]. There was also a country-wide project in Sri Lanka in the middle of the 90's by Sri Lanka Ceylon Electricity Board and then in Bangladesh, project called ALGAS has been started in 2000 with the aim of replacing half of the incandescent lamps with CFLs in the whole country [2, 3]. In Europe, there had been a demand side management project called EURECO implemented in 2002 by Commission of European Countries [4]. That was one of the most detailed projects exposing all potential electrical energy saving in the residences including the savings by CFLs. EURECO was implemented in four countries which were Italy, Portugal, Greece and Denmark with 100 residences in each and it was so detailed that lighting was just one of the chapters of the project.

In most of the similar pilot projects being implemented around the world, the results are calculated on the assumption that accepts the replacement of all incandescent lamps with CFLs with suitable luminous flux without taking into account of the residents' desire and the appropriateness of the lighting installations. It can not be suitable to replace an incandescent lamp with a CFL in most installations due to the lighting fixtures.

With this purpose, there has been a demand side management project started in a settlement with 280 residences in Istanbul by Istanbul Technical University, Institute of Energy with the supports of Turk Philips Company and BEDAS (The Bosphorus Electricity Distribution Company) in order to determine the energy saving ratios over one year by using CFLs at the residences [5]. It is aimed to replace the incandescent lamps with suitable CFLs by the desire of the demand-side users and appropriateness of their installation so the results so applicable results could be obtained.

2. THE PILOT PROJECT In ISTANBUL

This project was decided to be studied in a settlement of middle-income level people. So 280 residences in a housing state called Terasevler in Kagithane – Istanbul was included in this project. At the beginning of the project, all the residences in this pilot area were visited and informed about the CFLs. A questionnaire was done during the visits to take the information about the types, power consumption and estimated usage of the electrical and lighting equipments in the residences. At the end of these visits, 105 over 280 residences accepted to participate in this study. Some of the other residences could not be included in this project because they were empty or recently moved, already CFL users, or their installations were not suitable and some of them did not want to participate in this project. 54 of the residences participated in the project are 125 m^2, 51 of them are118 m^2 in size.

After the questionnaire, the incandescent lamps that can be replaced with CFLs were replaced with the suitable CFLs. It was strived to replace the incandescent lamps with CFLs of equivalent light luminous flux with about 3000 hours of life and the light color of the CFLs used in the project is cool daylight. In this study, the residents did not pay for the CFLs; lamps were replaced in free of charge

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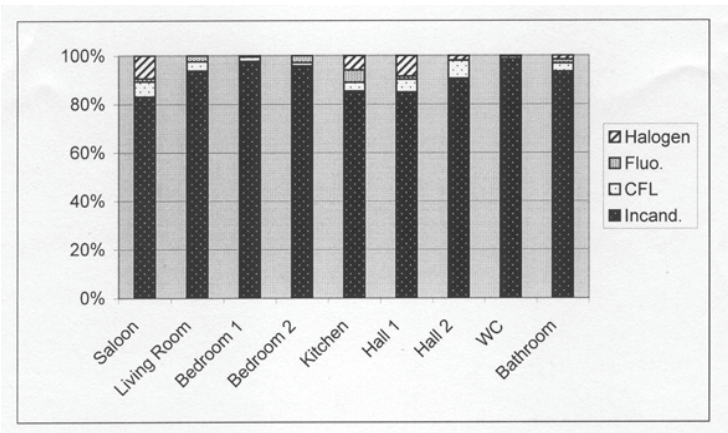

Figure 1 Distribution of the lamps before the replacement

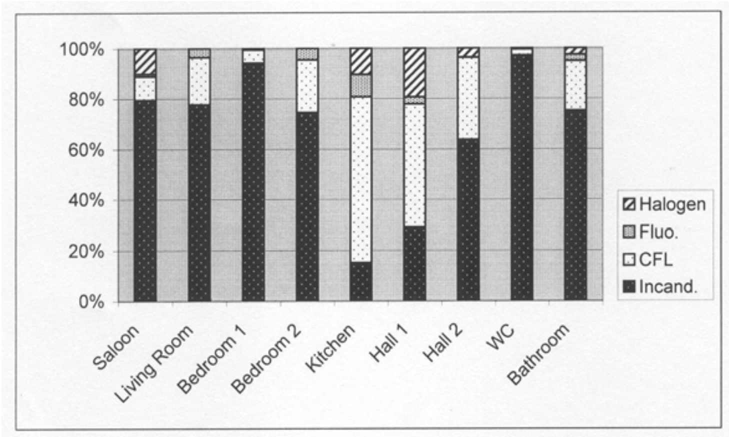

Figure 2 Distribution of the lamps after the replacement

After the replacements, the illumination levels obtained in the different parts of the houses were checked both by calculations and measurements. With examining the calculated and measured data, it is seen that lighting levels with CFLs are 20% - 30% higher than with incandescent lamps. In the project, 128 of 11W, 95 of 14W and 199 of 20W, totally 422 CFLs with cool daylight color temperature were replaced with incandescent lamps. The average number of CFLs per house replaced in free of charge is 4. Figures 1 and 2 show the percentages of the distribution of the lamps according to the areas before and after the replacement in 105 residences. The percentage of the incandescent lamps before the replacement has been decreased from 77% to 51% after the replacement, and the percentage of CFLs have been increased to 42%, which was 16%. Total power of incandescent lamps before the replacement was 27.8 kWh and the replacement brought out the decrease to 6.7 kWh with CFLs.

As it is seen from the figures, incandescent lamps especially in the kitchen, bathroom and the halls, were replaced with CFLs with the desire of the residents and the appropriateness of their lighting installations. In order to determine the electrical energy saving potential in the residences, the electrical energy bills of the residences over one year before and after the lamp replacement were obtained from BEDAS and the consumption values were analyzed comparatively.

Average electrical energy consumption over one year before the lamp replacement is calculated as 178 kWh / month based on the data taken from electrical distribution company. After the lamp replacement, it is calculated as 162 kWh / month which give about 9% of energy reduction comparatively with previous year by replacing an average of four lamps per residence.

After monitoring the residences for one year, some of the residences were chosen to monitor their usage of lighting appliances in order to determine accurate energy saving ratio. For monitoring all lighting appliances in those residences, a small device called hour-meter, which can count the usage time of the electrical devices, was installed in all lighting appliances in those residences (Figure 3). Since the usage time of the lamps is known, the consumption of lighting can be calculated directly. Therefore, all lighting appliances were monitored for one month and their usage time, in other words, their energy consumption values were determined.

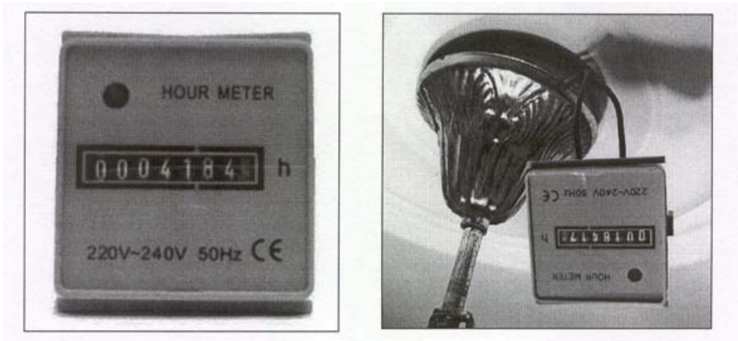

Figure 3 Hour-meter installed in lighting appliances

3. Energy saving potential in applicable lighting points

By installing the hour-meter devices to the lighting appliances in the residences, the monthly and daily average usage of the lamps were determined and given in Table 1. Also from the figures 1 and 2, it is seen that, the lighting points that the residents' choice for replacing incandescent lamps with CFLs were mostly in the kitchen, halls and bathroom. Actually, lighting appliances in those areas are also available for lamps replacement than the other areas because of the usage of basic luminaries so that, it is easier to replace an incandescent lamp with a CFL in the kitchen, halls and bathroom. For example, in general the luminaries in the saloon and living room were not technically suitable to be installed with a CFL.

Table 1 Average usage time of the lamp points in the residences.

		Monthly Average [h]	Daily Average [h]	Average Installed Power [W]
Saloon	1	82	2.7	80
	2	41	1.4	98
Living Room		11	0.4	125
Bedroom 1		42	1.4	65
Bedroom 2		41	1.4	63
WC		6	0.2	60
Kitchen		**135**	**4.5**	**100**
Hall 1		**53**	**1.8**	**71**
Hall 2		**203**	**6.8**	**68**
Bathroom		**44**	**1.5**	**74**
			TOTAL Installed Power	804

This situation shows that, both the residents' choice and the appropriateness of the lighting installation and also the usage time of the lamps in the kitchen, halls and the bathroom make those light points suitable for lamp replacement to get applicable results in the residences. As it can be seen from Table 1, installed power of the lamps in the kitchen, halls and bathroom is calculated as about 39% of the total residence. Thus, replacing the lamps in those points would make an important effect in total electrical energy consumption.

From the usage time of the lamps given in Table 1, energy consumption of lighting and its ratio in total consumption can be calculated easily. To achieve an accurate energy saving ratio by replacing incandescent lamps with CFLs in the kitchen, halls and bathroom; firstly electrical energy consumption of lighting, with assuming all lamps were incandescent lamps, is calculated and then electrical consumption of lighting is calculated with assuming the lamps in the kitchen, halls and bathroom were replaced with equivalent CFLs and given in Table 2.

Table 2 Monthly average consumption of electrical energy and energy saving ratios

		Average
Without CFLs	Total Electrical Energy Consumption [kWh]	310.7
	Consumption of Lighting [kWh]	72.7
	Ratio of Lighting (%)	23.4
With CFLs	Total Electrical Energy Consumption [kWh]	272.6
	Consumption of Lighting [kWh]	34.5
	Ratio of Lighting (%)	12.7
	Overall Electrical Energy Saving (%)	12.3
	Energy Saving in Lighting (%)	52.5

According to these assumptions and calculations, average total electrical energy consumption is calculated as 310.7 kWh/ month when all lamps are assumed to be incandescent. On the other hand, total electrical energy consumption is calculated as 272.6 kWh / month when the lamps in the kitchen, halls and bathroom are assumed to be equivalent CFLs. This brings out 12.3% of electrical energy saving in total electrical energy consumption and 52.5% of electrical energy saving in lighting. Also it is seen that, lighting with incandescent lamps is more than 23% in total electrical energy consumption in the residences which can be reduced about 13% with CFLs.

4. Conclusions

In this study, it is aimed to replace the incandescent lamps with CFLs by the desire of the residents and determine the energy saving ratio comparatively with previous year and applicable light points for CFLs. The results of the pilot project show that almost 10% of electrical energy can be saved by replacing four CFLs per residence by the desire of the resident.

After determining energy saving ratio over one year, applicable light points for lamp replacement were determined as kitchen, halls and bathroom both by the surveys done and data taken by installing hour-meter devices to the lighting points in the residences. Since those light points are considered, it is calculated that replacing incandescent lamps in the kitchen, halls and bathroom with equivalent CFLs will bring more than 10% of electrical energy saving in total electrical energy consumption and more than 50% of electrical energy saving in lighting. It is also seen that the luminaries in the kitchen, halls and bathroom are more suitable for installing CFLs than the luminaries in other areas.

According to the report of Turkish Electrical Distribution Company published in 2003, electrical energy consumption of the residences in Turkey is about 25 TWh which is about 22.5% of total electrical energy consumed in Turkey [6]. By replacing incandescent lamps with CFLs in applicable light points in Turkey, more than 10% of electrical energy can be saved which is more than 2.5 TWh of electrical energy. 2.5 TWh of electrical energy is almost the gross production of Catalagzı Thermal Plant in Turkey [7]. This saving in energy will also help for mitigation of the gas emissions resulted from electrical energy production.

It is clearly seen that, there is considerable electrical energy saving potential in the residences by using CFLs in applicable points. Since this kind of projects are supported by governments with the aim of increasing the usage and the purchase of the CFLs, important energy saving opportunities can be achieved at the demand-side.

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THE EFFECT OF OBSERVER POSITION AND MOVEMENT ON ROAD LIGHTING CRITERIA

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There have been luminance and visibility measurements on a real test road for determining the differences on observer position and observer movement in the standards and recommendations. In the study, it is also aimed to examine the calculation methods, which can be applied in using the visibility factor in road lighting designs. As a result, it can be said that calculations done with different observer positions for each lane is more realistic either for luminance or small target visibility (STV) measurements. Fixed observer is more suitable for road lighting calculations by luminance method where moving observer is more suitable for STV calculations.

1. Introduction

The luminance concept, which is about the reflection of the light from the road surface, represents the real conditions better than illuminance concept. Because of this, the luminance concept is generally used for road lighting installations for providing the accurate visual conditions. However, to deal with the detailed visual conditions and also for efficient use of energy for road lighting installations, visibility factor arises as a new criterion for road lighting installations.

Visibility is evaluated by Visibility Level (VL), which is calculated by the visibility model defined by Adrian [1], for an observer and critical target. The STV (small target visibility) method of design determines the visibility level of an array of targets on the road. The weighted average of the visibility level of the targets results the STV.

There is no explanatory information on taking visibility level as an independent method or as a complementary criterion for luminance concept. However, due to the latest studies on this subject expose the necessity of supplying the minimum luminance level and uniformity requirements in the applications of small target visibility for the safety conditions [2, 3].

There is need of some measurement conditions to calculate whether the luminance or visibility values and to compare the different road lighting designs in each other. Because the position of the observer and the measurement points on the road surface are important parameters both for luminance concept and visibility criteria, those positions should be defined exactly. For this situation, calculation points, calculation field and observer position are clearly defined in the recommendations and standards.

But, with the information achieved from the applications and with the new criterion that come out lately, some differences can be seen between the conditions defined in the recommendations and standards.

One of the aims of this study is to expose the differences on the measurement fields and the position of the observers defined in the American National Standards (ANSI) and European Standards (EN) based on CIE (International Commission on Lighting) recommendations.

Other aim of this study is to define the most suitable measurement conditions by considering the observer position both fixed and moving with the realized field measurements.

2. Positions of observer and calculation points

The definitions in the CIE Publication No: 30-2 named "Calculation and Measurement of Luminance and Illuminance in Road Lighting" published in 1982 [4], and the definitions in the CIE publication No: 140 named "Road Lighting Calculations" published in 2000 [5] for updating CIE 30-2 are given under this title in order to understand the change of the definitions in time. On the other hand, because STV criterion and moving observer conditions are considered in this study, the definitions in the publication ANSI/IESNA RP-8-00 published in 2000 [6] with having some differences from the CIE recommendations are also summarized.

2.1 According to CIE 30-2 -1982

If the spacing between the luminaires is equal or smaller than 50 m, there should be 10 grid points in the longitudinal direction. Otherwise, the spacing between the grid points should be equal or smaller than 5 m. The first calculation points in the longitudinal direction should be aligned with the luminaire. For the transverse direction of the road, there should be 5 grid lines for each lane with one point positioned in the center line of the lane.

The observer should be located at 60 m back from the first luminaire in the calculation field and 1.5 m above the road. The observer should be located in one quarter of the road width from the right side for the calculation of average luminance and overall uniformity, and in the center line of each lane for the calculation of longitudinal uniformity [4].

2.2. According to RP-8-2000

In the longitudinal direction, the distance between grid points should be one tenth of the spacing between luminaires or 5 meters, whichever is smaller. The first calculation points should be spaced at half of the grid points beyond the first luminaire. For the transverse direction of the road, there should be 2 grid lines for each lane and they should be placed in one quarter of the lane.

The observer should be located at 83 m straight back from the calculation points for each grid line and 1.45 m above the road. The observer should move to keep the distance constantly at 83 m [6].

2.3 According to CIE 140-2000

If the spacing between the luminaires is equal or smaller than 30 meters, there should be 10 grid points in the longitudinal direction. Otherwise, the spacing between the grid points should be equal or smaller than 3 m. The first calculation points should be spaced at half of the grid points beyond the first luminaire. For the transverse direction of the road, there should be 3 grid lines for each lane with one point positioned in the center line of the lane.

The observer should be located at 60 m back from the first luminaire in the calculation field and 1.5 m above the road. The observer should be located in the middle of each lane for the calculation of average luminance, overall uniformity, and longitudinal uniformity. The calculations for each observer position should be done and the lowest values should be selected as operative values [5].

The same definitions have been also accepted in the European Standard EN 13201 that was published in 2003 [7].

3. Experimental study

Measurements are done on the real road in Ayazaga Campus of Istanbul Technical University, which is closed to the traffic and restricted from the outside light. The lighting arrangement of the test road is single sided "right". Semi cut-off luminaires marked Philips Malaga, has a high-pressure sodium clear tubular lamp (SON-T Plus, 150W) are used in the installation. The luminous flux of each lamp is 17500 lm. The luminous intensity distribution diagram of the luminaires is shown in Figure 1.

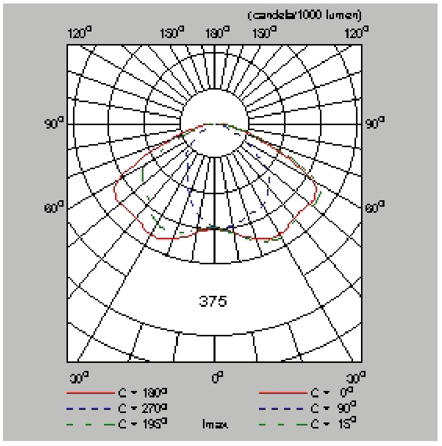

Figure 1 The luminous intensity distribution diagram of the luminaire used in the experiment

3.1 Experiment Set-up

The installation arrangement parameters and geometry of test road and target used in the experiment are,

Spacing (s) : 30 m
Road width (w) : 7 m
Number of lane (l) : 2
Lane width (w_l) : 3.5 m
Road type : R3
Montage height (h) : 11 m
Overhang (k) : 0 m
Tilt angle (t_k) : 10°
Target size (α) : 20 cm x 20 cm flat square
Target reflectance factor (ρ) : 20%

The measurement field and the positions of luminaires are shown in Figure 2. Contributions of seven luminaires are taken into consideration in the measurements. The measurement field lies between two luminaires (luminaire 3 and luminaire 4). The positions of the measurement points in this field are shown in Figure 3. The grid points in the measurement fields are arranged according to the latest recommen-dations, which are CIE 140 – 2000 and EN 13201. The luminance measurements for every test situation are carried out totally in 60 points on the test road with two lanes. Each lane contains three lines and each line has 10 measurement points. Visibility level measurements were done for each lane for 30 points.

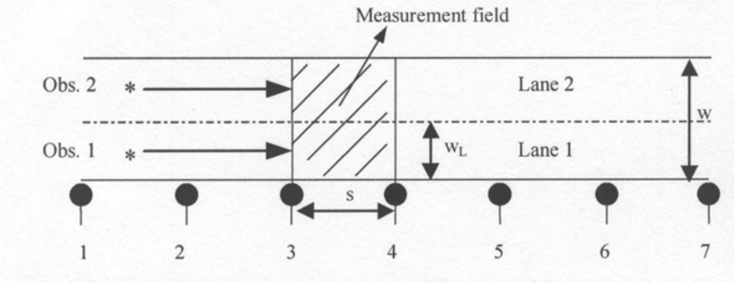

Figure 2 Measurement field and position of the luminaires

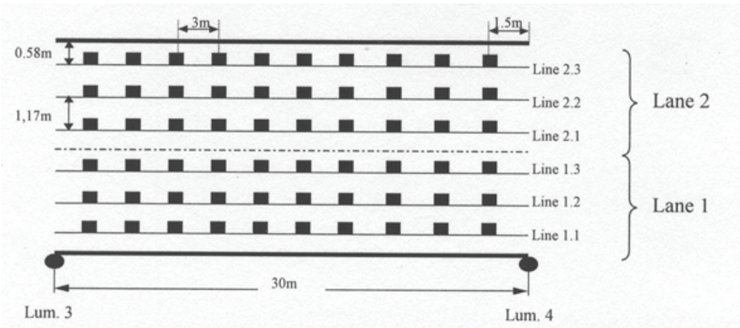

Figure 3 Position of calculation points in the measurement field

3.2 Experiment Method and Measurement Results

A LMT 1009 model luminance meter with 6′ photometer aperture was used in the experiments. The luminance meter was placed on a tripod 1.5 m height from the road surface.

The experiments were done in two groups with the aim of determining the criteria of road lighting depending on luminance method and visibility factor.

3.2.1 According to the Luminance Method

In first group of experiments, observer was simulated as fixed in 60 m back from the measurement field (3rd luminaire) and 1.5 m above the road surface. The measurements were repeated for the observer position according to publication CIE 140. Then, the observer is placed in the centre of each lane in turn in transverse direction. Observer 1 is located in the middle of the first lane which is 1.75 m inside and observer 2 is located in the middle of the second lane which is 5.25 m inside of the road. Observer positions in transverse direction are also shown in Figure 2.

Luminance values in 60 points in measurement field were measured for two observer positions. The average luminance (L_{avg}), overall uniformity (U_o) and longitudinal uniformity (U_l) values were calculated according to the measurement results and given in Table 1.

Table 1 Road lighting criteria for fixed observer

	L_{av}	U_o	U_{l1}	U_{l2}
Observer 1	1.48	0.74	0.82	0.83
Observer 2	1.61	0.56	0.70	0.77

In the second group of the experiments, luminance values on the calculation points were measured for moving observer. At the beginning of the measurement the observer is located at a distance of 83 m from the first calculation row of points and on a line parallel to the centerline of the road that passes through the calculation points. The height of the eye of the observer is 1.5 m which results in a downward direction of view of one degree. The observer was moving forward by keeping the distance between the calculation points fixed as 83 m. The measurements and calculations were repeated also for observer 1 and 2 positions and the results are given in Table 2.

Table 2 Road lighting criteria for moving observer

	L_{av}	U_o	U_{l1}	U_{l2}
Observer 1	1.35	0.81	0.77	0.80
Observer 2	1.50	0.77	0.79	0.81

3.2.2 According to Visibility Factor

The calculation method of STV criteria based on visibility concept is defined in ANSI / IESNA RP-8-00/2000 and the minimum values for different road classes are given also. There is any information about calculation on visibility concept in the CIE and EN publications. Only in the publication CIE 115/1995, STV criteria is defined orally and minimum visibility level values for different lighting classes are given as a Table [8]. Although it is stated that STV concept is used, there is no any clear information about the visibility concept if the recommended value is given for only one target or it is for the average value in a calculation field. According to these explanations, it can be seen that there is lack of information about the calculation and usage of visibility criteria in road lighting.

In the publication RP-8-00 / 2000, it is stated that “STV is a weighted average of the values of target Visibility Level over a grid of points on an area of road for one direction of traffic flow” and “To calculate STV for a grid of points and one direction of traffic flow, VL and relative weighted VL must be calculated for each calculation points using steps one through ten”.

First of all, the target to be seen should be defined to define the visibility criteria. The age, position and the visual conditions of the observer are important parameters that affect the results. In this study, a group of experimental study has been done with the aim of comparing the observer position and movement conditions according to the European conditions in visibility calculations. Thus, the visibility of flat square targets with 20% reflectance factor in dimensions of 20 cm x 20 cm are located on the calculation points are determined.

In the first group of the measurements, observer is fixed from a distance of 60 meters. The angular dimension of the target is varying between 11.18 and 7.47 minutes of arc for this position. The height of the eye is taken as 1.5 m then target and adaptation luminance values were measured for two different observer positions located in the middle of the lanes. Adaptation luminance was determined as the average value of the road surface luminance obtained from right and left of the target. Measurements were repeated for 30 points where the observer located in the middle of each lane.

By accepting the observer age as 30 and observation time as 0.2 s, the visibility level values (VL) of each target were calculated according to Adrian’s formula by using the measured values [1]. STV values and the weighted average of values on 10 calculation points located on the middle line of each lane (line 1.2 or line 2.2) as defined in RP-8-00/2000 are calculated and given in Table 3. The minimum and maximum values of visibility level for 10 points are also given in this table.

Table 3 Visibility criteria for fixed observer – on the center line only

	$\|VL_{min}\|$	$\|VL_{max}\|$	STV
Observer 1	5.31	18.45	8.81
Observer 2	4.17	13.34	6.50

By considering better simulation of the visual conditions on the road, the calculations were repeated for 30 calculation points on the each lane and the weighted average of visibility levels (STV) and the maximum and minimum visibility values obtained are given in Table 4.

Table 4 Visibility criteria for fixed observer – on the lane

	$\|VL_{min}\|$	$\|VL_{max}\|$	STV
Observer 1	4.13	18.90	8.22
Observer 2	4.17	16.72	8.13

In the second group of measurements, observer is located at a distance of 83 m from the calculation points. The angular dimension of the target from this distance is 8.28 minutes of arc. The measurements and calculations for this "moving observer" situation were repeated for 30 points of each lane and for 2 observer positions. In Table 5, only the values are given that are obtained from the calculation points (10 points) on the middle line of the lane. And also all the points on the lane (30 points) were considered, the calculations were done and the results are given in Table 6.

Table 5 Visibility criteria for moving observer – on the center line only

	$\|VL_{min}\|$	$\|VL_{max}\|$	STV
Observer 1	5.07	11.79	6.65
Observer 2	3.88	8.45	5.34

Table 6 Visibility criteria for moving observer – on the lane

	$\|VL_{min}\|$	$\|VL_{max}\|$	STV
Observer 1	4.33	11.79	6.42
Observer 2	3.88	10.79	6.09

4. Conclusion

According to the recommendations, the lowest values that are obtained are determined as the criteria for this road lighting. For this situation, as the luminance levels and uniformity factors obtained by fixed and moving observer positions (Table 1 and 2) are considered, the following values are obtained for this test road:

For the fixed observer condition;

$L_{av} = 1.48$ cd/m^2

$U_o = 0.56$

$U_l = 0.70$

For moving observer condition;

$L_{av} = 1.35$ cd/m^2

$U_o = 0.77$

$U_l = 0.77$

It can be understood from the values given in the tables that, calculations done for the observers positioned on the each lane like in CIE 140 and EN13201, express the real conditions better than the calculations done based on for only one observer position like in the previous recommendations (CIE 30-2). The position of observer 1 in the experiments is also the same as the position defined in CIE 30-2. It is also clear that moving observer affects the results. Otherwise, fixed observer situation seems to be more safety because of the importance of uniformity in road lighting calculations with luminance method for visibility and comfort conditions

Positioning observers in each lane also seem to be a proper approach for STV calculations. Since the critical conditions are considered, moving observer condition is more suitable for these STV calculations.

There seemed to be no important difference between calculating STV by considering all the points on the lane and by considering the calculation points along on the middle line of the lane like in calculating longitudinal uniformity (U_l). However, this kind of experiments should be repeated in different lighting arrangements in order to generalize these results.

In order to expose the relation between longitudinal uniformity (U_l) and small target visibility (STV) for fixed and moving observer conditions, Table 7 is formed by the values given in the previous tables.

Table 7 Relation between Ul and STV

	Fixed Observer		Moving Observer	
	U_l	STV	U_l	STV
Observer 1	0.82	8.81	0.77	6.65
Observer 2	0.77	6.50	0.81	5.34

As the uniformity decreases, allegation on increase of visibility related to the contrast parameter is being confirmed for moving observer situation. Thus, in the fixed observer situation the opposite situation is valid. When the real conditions are considered, accepting moving observer conditions shall be more proper approach for STV calculations.

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SLOVENIAN EXPERIENCE WITH THE ENFORCEMENT OF LIGHT POLLUTION LEGISLATION

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When we speak about light, we usually don't think of it as an environmental factor, which is burdening our surrounding. The light and lighting is mostly considered as feature, which enables us to expand our activities beyond the time schedule of daylight. But, consideration about influences of light on the environment will soon become part of everyday task of light planning organizations. Avoiding of light pollution is spreading in the last years from especially protected areas around the world into our local environment. Slovenian government will probably soon accept the light pollution ordinance, which will legalize the obligatory judgment of burdening the environment with light. This paper presents experiences with overcoming different approaches to light pollution problem. Typically, astronomers and other "victims" of light pollution are standing on the opposite side from experts in lighting engineering area and their claims are often far from objective, so a series of compromises must be made before such bill or similar legislation acts can be adopted.

1. Introduction

With increasing environmental awareness in the early nineties, more and more people became aware of possibility that light can cause pollution too. The problem is not captured exactly in this timeframe, but was not so popular before. Astronomers were fighting against over lighting of observatory vicinities for decades and after density of population has increased, they moved most of professional observatories in less populated and less polluted countries. But not everybody that wishes to observe the night sky can just move to somewhere else.

Technical committees at CIE were dealing with problems of sky glow and light intrusion long before this problem became so escalating, but most conclusions and premises never became obligatory – at least not the part of light pollution that causes sky glow. Both problems: night sky glow and light intrusion were usually managed separately and an ordinary lighting designer has very rarely confronted the problems such as exceeding the upward luminous flux or how to aim the floodlights to not spill too much light in the sky.

On the other side, problems of controlling glare in road lighting installations or minimizing light intrusion in residential areas are well known and solutions for these problems are documented in international recommendations, national standards and ordinances. One can say that this aspect of light intrusion is part of good lighting practice in many countries for many years. So why are there so many problems if we make this good practice obligatory?

Most of proposals for ordinances are based on the sample provided by Dark Sky Association, which is based on practice from district in the vicinity of astronomy observatory in USA and is accessible from internet. First versions of this sample were written without help from lighting designer experts, advocating just the claims of astronomers and not taking into account the progress in lighting technology. Typical consequences caused by such approach are some common misunderstandings of lighting principles such as choosing of right light sources for lighting application or controlling the luminous intensity distribution, which are typical for the early samples of ordinance. There are also many other problems when adopting some foreign solution. State of the road lighting solutions was quite different in Europe and in the USA. In Europe ware used mostly semi-shielded luminaries for street lighting, while in some parts of the USA were widely used non-shielded ones.

Instead of joining forces for reaching the best possible solution this approach divided community in two poles what isn't the easiest way for making consensus on such complex problem. There are some other experts too, that ought to be consulted when making decisions about outdoor lighting: architects and lighting designers involved with city beautification, psychologists and forces dealing with crime, biologists and of course municipality, because they are providing necessary funds that makes lighting solutions feasible.

2. Approaches for preventing light pollution

Members of Lighting Engineering Society of Slovenia has strictly advocate that the accepted measures must be in accordance to CIE recommendations and that they have to be in the standard form that can be measured and predicted with common programming, modeling and measuring techniques. Compromise of the national proposal of light pollution ordinance has reached the acceptable level in 4 or 5 iterations of negotiation with all interesting parties. One of the misleading parameters that we didn't success to be removed from proposal is energy conserving parameter. It is very popular for everybody to address some problems with energy efficiency and energy conservation especially as the term light pollution is so much environmentally oriented. But preventing light pollution doesn't mean automatically lowering energy consumption as well. There are some specific situations in street lighting where introducing fully cut-off luminaries can increase energy consumption.

There are a lot of solutions and different approaches for minimizing effects of light spill but they are mostly interpreted and explained in literature [3, 4], so this paper will deal just with some details that differ from recommended practice of CIE. Particular measures for controlling light pollution can be divided in following groups:

- Division of environment in particular areas by the sensitivity to the light pollution (zones);
- Limiting of the lighting parameters for each of this zones:
  - Illuminance levels at the building surface planes (vertical – for intrusion light);
  - Luminous intensity at the angle causing glare (not for traffic lighting);
  - Luminous intensity distribution relative to specific planes (including street lighting);
  - Luminance levels of surfaces of buildings (for beautification lighting);
  - Luminance levels of advertising boards;
  - ULR – the upward light output ratio of luminaries:
- Declaration of curfew time for decreased levels ;
- Prescribing the color of light (optional);
- Maximum installed luminous flux per area unit.

Each of these measures can of course vary from one zone to another and can be optional. Some measures provide effect of single aspect of light pollution while others reduce multiple. These aspects of light pollution can be divided in following groups:

- direct light intrusion – residents
- light intrusion for animals, plant life – environment
- traffic participants
- urban sky glow
- atmospheric scatter

Each group has its own requirements and interests. Some of interests are common to all groups and some are in contradiction to each other.

2.1 Defining zones

There is some kind of defining different susceptibility levels in different areas of environment in every approach to limiting the light pollution. CIE recommendations [4, 5] are dividing environment into different zones, which have different limitations about applied lighting regarding the brightness level of local environment and expected activities in that zone [1, 3]. Example of simple dividing is shown in table 1. Newer documents indicates, that more precise dividing is required by specific lighting design aspects and activities in astronomic observatories. To meet this criterion sub-zones have been introduced with far more precise description of expected activities.

Table 1 CIE basic zoning system [1]

E1	natural	intrinsically dark	national parks or protected sites
E2	rural	low district brightness	agricultural or residential rural areas
E3	suburban	medium district brightness	industrial or residential suburbs
E4	urban	high district brightness	town centers and commercial areas

Current proposal of Slovenian light pollution ordinance is also dividing environment in 4 zones, but based on more precise and descriptive criteria. There are still some areas that are defined as highly protected but could be treated as normal areas in 3. or even 4. zone. More difficult than defining zones is actually applying this division to the real communities. Some of areas that are in the first grade of protection (E1) could be in the near of urban areas and there isn't enough space to gradually decrease level of protection. Proposed radius for zone E1 in Slovenian ordinance is 20 km. This is not big radius, but if such protected area lies in vicinity of bigger city it is hard to comply to this criteria. On the other hand distances from reference point to borderlines of neighboring zones in Slovenian proposal are lesser than those recommended by CIE (Table 2).

Table 2 Minimum distance between the zone borderline and the reference point by CIE

Zone rating	surrounding zones		
	E1-E2	E2-E3	E3-E4
E1	1	10	100
E2		1	10
E3			1
E4	no limits		

In Picture 1 are shown locations of astronomical observatories, national parks and national preserves, that belongs in zones E1 or E2. It becomes obvious that some compromises must be made regarding distances from protected sites to urban area borders.

2.2 Limiting of the lighting parameters

Most of the lighting parameters in each defined zone of protection were adjusted to the latest CIE recommendation. Examples are shown in Tables 3 and 4, where the limiting values for illuminance levels at windows surface for lighting of public areas an luminous intensity levels of street lighting are shown.

Table 3 Limits for vertical illuminance levels at windows surface for light sources for public areas [7]

Protection level	illuminance (lx) until curfew (23 h)	illuminace (lx) after curfew (23 h)
I zone	2	1
II zone	5	1
III zone	10	2
IV zone	25	4

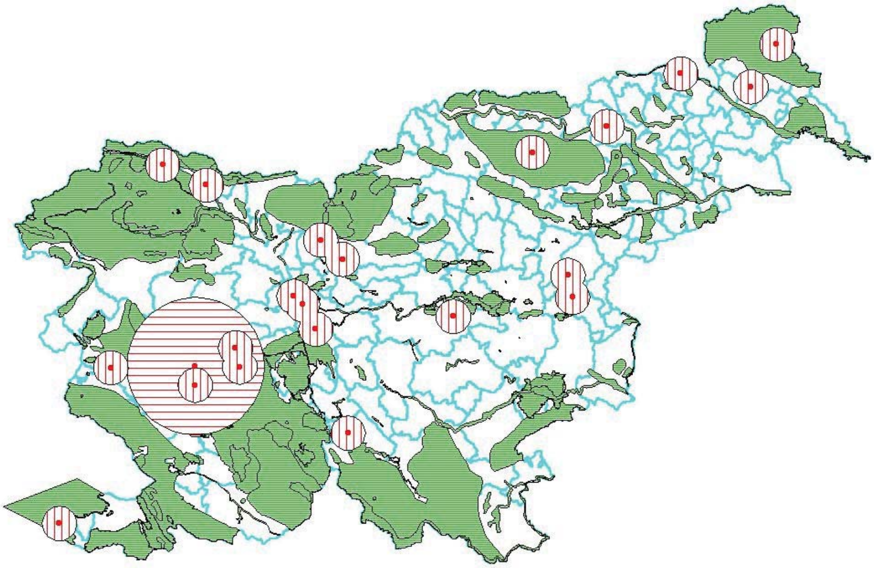
Ordinance proposal define both limiting values for public area lighting and street lighting for following lighting parameters:

- Illuminance levels at the building surface planes (for intrusion light);
- Luminous intensity limits at the angle causing glare (not for traffic lighting);
- Luminous intensity distribution relative to specific planes (including street lighting);
- Luminance levels at surfaces of buildings (for beautification);
- Luminance levels of advertising boards;

Some of the restrictions are not valid, if small light sources are used (up to 1000 lm total luminous flux), or automatic control system is used to turn off lighting installation after curfew.

Table 4 Limits for luminous intensity of street lighting luminaries in the direction from light source in question to the observing point, where the possible glare is evaluated.

Protection level	Luminous intensity (cd) evening and night
I zone	200
II zone	400
III zone	400
IV zone	1000



Picture 1 Locations of astronomical observatories and national parks in Slovenia

2.3 Lighting parameters that are missing in ordinance proposal

In ordinance proposal are not included:

- limiting values for ULR;
- Prescription of the light color;
- Maximum installed luminous flux per area unit.

ULR limitation values and maximum installed luminous flux per area unit would be recommended approach for further limitation of some special lighting design. While the control over luminous intensity distribution can provide protection from light aimed to the upper hemisphere, for example in city lighting applications is much easier to control complete upwards directed light – ULR.

While the statement of energy conservation remains in ordinance proposal, there is very little direct contribution to actually preserving energy with the proposed limitation system. Very stimulative proposal in this direction is limitation of total installed luminous flux per area unit [4], which could also be better indication for total contribution to urban sky glow. Reason for this statement is that, if we apply lighting on a very large area, that area will reflect large amount of light indirectly and even if only cut-off luminaries are used (not likely in city areas) more light can be reflected toward sky than with more effective lighting approach.

3. Practical example of light pollution evaluation

Even when suitable ordinance or bill is adopted there remain some open questions like how will it perform in practice, how much will it cost or what equipment will be needed for evaluating its efficiency. For this purpose we carried out few evaluations of new and renewed lighting installations. The example shown is not typical but it will show some limitations and possibilities for future improvements of similar ordinances. Although the procedures for light pollution evaluation are prescribed in accompanied document to ordinance, a lot of measurement and calculation procedures are left to the evaluator himself. The short list of actions and methods required is:

- collecting information about object in question
  - classification of location and vicinity in protection zones
  - lighting project in question and in vicinity
- analysis of lighting before construction of new installation
  - measurement of illuminance and luminance in area
  - modeling of project and surrounding
  - calculation of existent light pollution
- analysis of influence of the new lighting installation
  - measurements of illuminance and luminance
  - modeling of the new lighting installation
  - evaluation of the new lighting system
- evaluation of contribution of new lighting system to light pollution in area

Lighting of some smaller objects can be evaluated simply with some measurement or lighting calculation but it is not so easy to exclude influence of other lighting applications nearby.

Opportunity to check suitability of proposed ordinance has shown up, when lighting installation on international custom railway station had to be renewed because of entering the European community. Experiences in some minor evaluations have shown that new lighting installations in urban area are not questionable and almost every aspect of light intrusion limitation was fulfilled, with some simple measures. Limitations for urban zone (E4) are obviously not very rigorous. The evaluated area lies in relatively small town and protection zones in vicinity varied from E3 to E2 in nearby.

We performed initial measurements of illuminance levels at near objects and try to eliminate background light from other lighting installations.

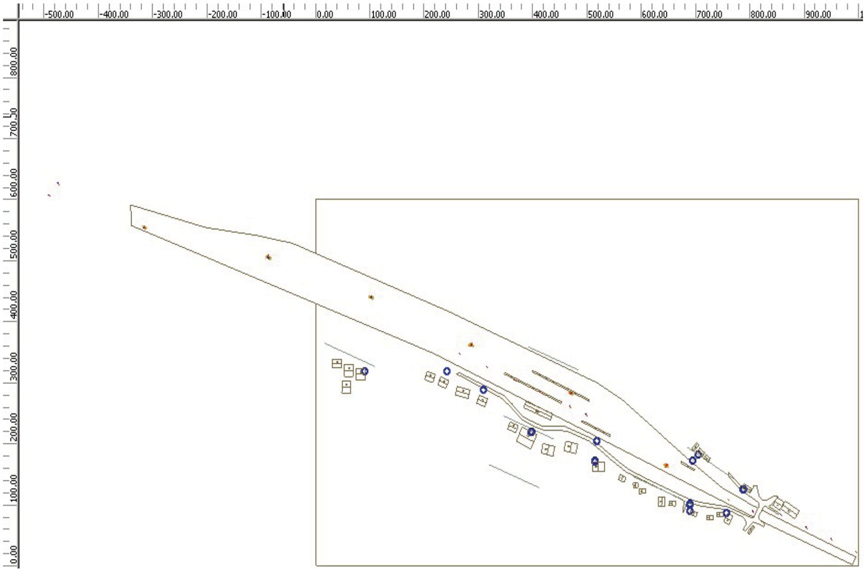
Modeling of problem in suitable lighting calculation application was quite a challenge, because area in question was about 1,5 km long. Computer model takes into account only buildings that are near enough for assumption that light intrusion will excess the limitation values. The area under evaluation is shown in picture 2, and the computer simulation in picture 3. There are around 100 floodlights and additional street lighting luminaries used for lighting the area. Lighting installation runs all night long but curfew couldn't be regarded because of special purpose of whole area and evaluated object.

Main problems with evaluation were following:

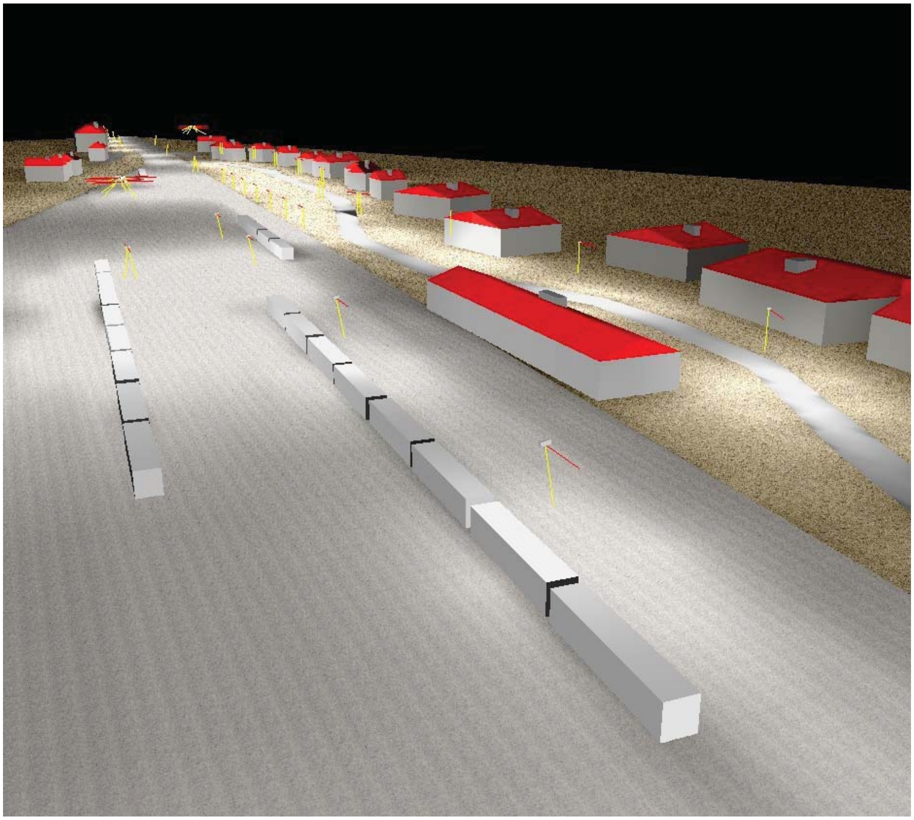
- acquiring correct luminaries data for lighting calculation – existing lighting installation is old enough that data format changed in the meantime
- gaining control for lighting installation to perform all necessary measurements
- determining correct protection zone for specific areas
- very time consuming computer simulation
- lighting applications are not suitable for evaluation of glare in large areas
- lighting applications are not suitable for determining luminous intensities in specific directions.

After we checked that results of simulation correspond with measured values we performed evaluation of light trespass to the near buildings regarding the illuminance levels and possible glare. Luminance levels were taken into consideration but values were far below limits. We noticed exceed values of illuminance levels at objects windows in several locations and also exceed values of luminous intensity in given directions for large number of floodlights, but only for some specific locations.

Further inconsistency of such evaluation showed after all simulations and measurements were complete – before and after taking into account renewed lighting installation. We have to determine our own indication system for weighting the contribution of lighting system to the total light pollution in area. Just to determine if lighting installation fulfils the limitations provided in ordinance is not enough. Limitations are cumulative, at least for illuminance levels, so the next installed luminaire can exceed limitation value although only small fully cut-of luminaire is used.



Picture 2 Ground plan of area in question



Picture 3 Lighting simulation of railway station and vicinity

Based on some evaluations we proposed following model for determining intensity of influence of lighting installation on nearby environment:

Table 5 Determination of lighting installation influence level on the environment

Influence level	description
Nonexistent	influence is at the level of background light
Small	Influence of lighting installation on the environment is less then ¼ of limitation value
Moderate	Influence of lighting installation on the environment is less then ½ of limitation value
High	Influence of lighting installation on the environment is less then limitation value
Very high	Influence of lighting installation on the environment is higher then limitation value

Proposed system is based on similar weighting factors that are use for other environmental parameters that must be evaluated, such as noise or chemical ingredient.

4. Conclusion

Purpose of this paper was not only to present the current proposal of lighting pollution ordinance which can soon come to force but to show how to overcome some problems that we have dealt with during the reconciliation the form and values with different that are usually involved in developing such documents. Document was initially proposed by initiative of astronomers but was later heavily discussed and changed by the help of Slovenian lighting society. It is still far from perfect, but could be enforced in similar form.

By enforcing such bill or ordinance at the national level everybody who deals with lighting design or planning have to be aware that a lot of additional work has to be done for complete evaluation. Some of analyses require specific skills that are not common to most of lighting designers, additional measuring equipment and perhaps developing or adapting lighting calculation programs to be capable of some additional calculations. Main problems are to be expected for older lighting installation where planning documentation is not available, or is not complete, or is obsolete.

Most harmless introduction of such ordinance would be, if light pollution evaluation would be mandatory only for new installations and in case of renewing installations only new part of it would be subject to evaluation. Other measure that is easy to perform is to introduce limits for total luminous flux installed per area unit. Such measure could be very effective and easy to control. Praxis will show, if similar evaluations will be fully performed in future, what could mean a significant addition to the expenses for building documentation or will be scaled down to simple approximations. Either way it will represent additional work for lighting experts, because it could be technically quite demanding.

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LIGHTING FOR GOOD HEALTH

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In the recent years, fundamental lighting research has moved beyond the study of visibility alone to a more comprehensive model of lighting quality, which integrates human needs with the architecture, the environment and the economic conditions. And lighting for good health is part of this equation. Scientists have long known that light plays also an important role in regulating the human body's daily biological rhythms, including the sleep-wake cycle, alertness, and hormone production. Also, UV radiation from light sources can harm objects and humans. Colour temperature and spectral colour of sources can influence human's endocrine system. The functioning of the visual system is not constant, but ever changing as we age. As the average age of the population increases there is growing need to understand how our vision changes and how to design lighting for the aging eye

The present paper will present an overview of the latest worldwide research on the mechanism of non-visual, photobiological light process and the implication of lighting to the human health. Along these, the paper is proposing to comment the principles of healthy lighting and explore directions for lighting design practice transformation.

1. Introduction

In the recent years, fundamental lighting research has moved beyond the study of visibility alone to a more comprehensive model of lighting quality, which integrates human needs, health and well-being with the architecture, the environment and the economic conditions.

In today's world, economical engines of modern societies are functioning continuously, without any stop. Globalisation is twisting time zones, internet and satellite communications have virtually eliminated distances, pushing economies around the world to a stage of "perpetum mobile". And many workers have to adopt the same functional patterns. However, these employees can not perform like machines, constant over the 24-hour day; rather their productivity, alertness, and mental performance diminishes on the night shift.

For thousands of years, humans have awakened with the sun and slept at night. It has only been

The old emphasis on lighting for visibility alone has given way to a more comprehensive

during the past century that we have broken with what nature dictates. And artificial light is the key factor. Indubitably, one of the most important inventions for humanity, electrical lighting is showing its limits when human activity patterns are becoming too "artificial":

- In western societies, people spend up to 90% of time indoors
- We are destined to be a 24-hour society even though human physiology intends us to be awake during the day and asleep during the night. In North America, up to 25 million people work irregular shifts, with the majority forced to work through the night shift.
- Lighting design in buildings addresses mostly the horizontal illumination levels and not the qualitative factors that define the well being of the occupants: visual comfort, aesthetics, productivity and communication, energy efficiency, architecture integration, etc.

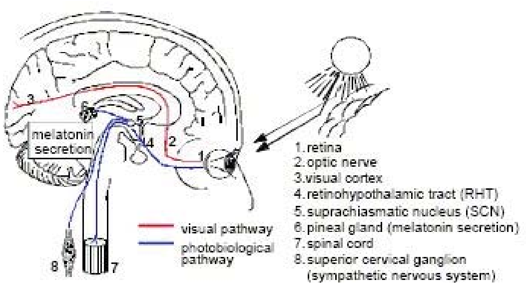
model of lighting quality, in which lighting must meet many human needs while being integrated with the architecture, the environment and the economic conditions. Lighting for good health is part of this definition.

2. The photobiological light process

2.1 The Circadian Cycle

And we thought we knew (almost) everything about how light interacts with the eyes and the brain. That is still true for the visual process: light reaches the retina, and rods and cones transmit the information via the neural connections to the visual cortex.

However, recent research showed new findings about the second light related process: non-visual, or photobiological. Like the visual system, the photobiological process starts at the eye, but unlike the visual one, it does not transmit information direct to the visual cortex. Light signals received at photosensors in the retina are transmitted via the retino-hypothalmic tract (RHT) to other areas in the brain [11], like the suprachiasmatic nuclei (SCN) in the hypothalamus (Figure 1). SCN connects to the spinal cord, and the pituitary, pineal, adrenal and thyroid glands. Signal proceeded by SCN lead to a cascade of hormonal changes in these glands, determining thus human body's health and its metabolism response status.



c/o Philips Lighting ALG

Figure 1 A simplified illustration of "the eye-to-brain" pathways for the visual and photobiological process.

The resulting series of neuroendocrine changes are responsible for regulating the human body's daily biological rhythms—also known as circadian rhythms—including the sleep-wake cycle, alertness, and hormone production [12].

The circadian rhythm is probably the area of most of the ongoing research on non-visual lighting impact. The oscillation of hormones the circadian rhythm induces has a profound effect on most physiological functions in the body including the immune system.

The main hormone responsible for the circadian rhythm is the melatonin. Melatonin is secreted by the pineal gland, then absorbed into the bloodstream and hence serving as a chemical messenger throughout the body. The message is that of time as determined by the SCN, the master clock of the body. During the 24-hour, day-night natural process, melatonin synchronises the activation of other physiological functions to the times they should occur [15]. Normally, the pineal gland secrets high levels of melatonin at night and low levels during some parts of the day (see next).

When this process is disrupted through environmental light changes, it may lead to some of the more damaging emotional and physiological effects associated with seasonal depression (SAD), jet lag, and shift work.

Researchers [12] have identified some of the light factors that determine the adjustment of the circadian cycle in humans (Figure 2):

- ***light intensity and duration***; research found that higher intensity levels in work environments during dark hours could be beneficial. However, more study is required to establish adequate levels of light intensity and duration.
- ***timing***; because of circadian fluctuation of immune responses, it is possible to adjust the time of day a particular disease is treated to optimise the immune response. This is known as chronotherapy. For instance, researchers have found that treating cancer in the evening, when the cancer-fighting immune cells are activated, is much more effective than administering the treatment at random times of day.
  Chrono-therapy is now being considered as an adjunct to treatment of disorders other than cancer, for instance autoimmune disorders, heart disease and diabetes, which have circadian components.
- ***wavelength***; recent research (see next) finds that the blue light is more effective in suppressing melatonin.
- ***light pattern and contrast;***

- ***light history;*** previous light exposure may influence light sensitivity of the human circadian system. A lower light sensitivity may facilitate a phase delay, which has been associated with increased daytime sleepiness and sleep difficulties.

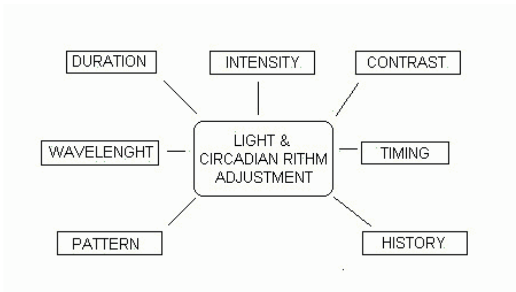


Figure 2 Light factors that determine the adjustment of the circadian cycle in humans.

2.2 New Retinal Photoreceptors

Let's start analysing the connectivity between circadian rhythms and light, starting with the retina. Recent research has introduced another set of retinal photoreceptors beside the well-known rods and cones: the intrinsically photosensitive retinal ganglion cells (abbreviated ipRGC). These ganglion cells [3, 14], are not located at the same level of the retina as the rod and cone photoreceptors used in vision, but rather at the collector and ganglion cell level. The ipRGC ganglions carry the light stimulus to the photobiological neural pathway, to control the circadian rhythm (as well as other metabolism responses). More evidence about this role of ipRGC has been supplemented by findings that special strains of rodents genetically bred to have no rods and cones are still active following a light-dark cycle. Moreover new research proposes that there may also be secondary photoreceptors in the skin that control alternative circadian mechanisms.

The ipRGC contain a chemical called melanopsin, similar to the photopigments in the rods and cones. Melanopsin is then instrumental in determining the pineal gland to produce or suppress melatonin, a hormone closely related to the body's master clock. Under normal circadian conditions, there is a small peak of melatonin production every afternoon at about 4PM and a much larger peak released later in the evening between approximately 10PM and 3AM. Darkness conditions also stimulate the melatonin production [6].

To conclude, melatonin levels remain high for most of the night while we sleep, then drop in the morning as we awaken.

Analysing the characteristics of ipRGC, one can conclude that these are ideal for simple "day or night" detectors:

- Peak sensibility in the blue colour (near 480 nm), matching the spectral distribution of the diurnal sky.
- Slow reaction speed (about 10 seconds compared with milliseconds for cones and rods) makes them insensitive to rapid changes in ambient lighting.
- Spaced sparsely throughout the retina (estimated at about few thousands compared with millions of cones and hundred millions for rods) ipRGC can not identify details as cones do.

So, ipRGCs seem to help regulate circadian rhythms in response to light (daytime or nighttime). Also they may be responsible for the eye's "blue" sensitivity (for example towards cars with MH headlamps [10] and high colour temperature - above 5000 K - fluorescent lamps).

It could also explain why daylighting (with a blue dominated light spectrum) seems to increase visual and well-being comfort levels for office workers, increase retail sales and boost education results in schools, as recent research from the Heshong-Mahone group has found [16]. After analysing hundreds of daylighting examples in retail, office and educational buildings, these researchers have concluded that:

- efficient daylighting (skylights) can increase sales by 25% while saving between 25% to 60% energy;
- larger windows in classrooms may account for a 25% increase of marks and saving up to 70% energy;
- combined toplit and sidelit daylighting in offices may increase workers' performance/ productivity by up to 15% while saving up to 70% in energy.

If all these hypotheses could be proved scientifically, it would lead to major transformations in lighting equipment and design. To obtain the same visual comfort and performance, designers could use lower wattage, high colour temperature fluorescent systems and save energy. Moreover, using integrated controls for daylighting and artificial lighting could augment these savings

2.3 Blue Light Suppresses Melatonin

In recent years, researchers have learned that bright white light suppresses melatonin [7]. Previous studies have also suggested that melatonin suppression reacts differently to light of varying wavelengths, specifically showing a maximum sensitivity to short-wavelength ("blue") light [9].

A study published in NeuroReport by Lighting Research Center in Troy, New York, (LRC) shows that 18 lux of blue light from light-emitting diodes (LED) is more effective at suppressing melatonin levels than 450 lux of clear mercury white light because a "spectral opponent mechanism" likely contributes to the circadian system's response to light (Figure 3).

Figure 3 The LRC designed the luminaires for the study using LEDs

LRC researchers found that a form of opponency photo-process is involved in the suppression of melatonin by light in humans, making white light found in buildings much less effective at suppressing melatonin than thought [13].

Let's explain this "opponency". For colour vision, three types of cones (short, middle and long wavelength) process colour information in the retina corresponding to blue, green and red spectrums. The visual system separates cone responses into colour information processed by two opponent channels, the red vs. green and the blue vs. yellow. This is how we "see" colour.

In these opponent channels, light in one wavelength region (e.g., blue) increases a neural response, while light in the opposing region (e.g., yellow) decreases it. For example, colour of the ocean has a strong energy in the blue wavelength and an almost null one in the yellow spectrum. The neural response is then very high, so we end up seeing the ocean as "blue".

When the energy in the opposing wavelength regions is balanced, the resulting response in that channel will be null, signalling that there is no colour, and hence no light at all.

Similarly, in the case of the circadian system, a sufficient balance of light in each wavelength region results in a null response by the circadian system, just as if there is no light at all.

Until now the human circadian system was considered additive (if a certain amount of blue light and a certain amount of yellow light each produced the same level of melatonin suppression, then half of these amounts of blue and yellow added together would produce the same level of melatonin suppression). However, this theory is contradicted by recent study results showing a small amount of blue light producing a stronger suppression than a much greater amount of white light (blue plus yellow), suggesting the existence of spectral opponency in the human circadian system.

That explains why the circadian system in diurnal (active during the day) humans is preferentially sensitive to blue light, presumably the blue sky [16].

The use of light for purely medical purposes is outside the scope of this paper. However, it is safe to say that these findings show promise for a number of practical medical applications, including improving sleep quality in patients with Alzheimer's disease, advancing treatments for seasonal affective disorder, and studying effects of light on night-shift workers and premature infants [5, 6, 19].

One particular light treatment is used for the treatment of the Seasonally Affective Disorder (SAD). A form of mental depression, SAD is characterised by a seasonal cycle. The most encountered form is the winter SAD. Persons suffering from winter SAD experience increased lethargy, hyperinsomnia and lack of libido. Winter SAD has been found to be prevalent at higher latitudes (million cases in northern areas of USA, Canada and Europe) and to be correlated with the amount of exposure to daylight. Exposure to bright light (above 2000 lux) is a current form of treatment. This can be done by spending time outdoors, or siting more hours by a window or close to special high lumen, fluorescent desk lights [19].

2.4 The Circadian Dosimeter

The effect of light on the circadian system is of growing interest in the health field. However we can only use the circadian rhythm approach to investigate the positive and negative effects of light on human's health, well being and productivity if we can measure light exposure to the circadian system. To help further research in this area, the Light Research Centre (LRC) has developed a new tool designed to measure the level and spectral quality of light reaching a person's circadian system [13].

Light exposure means the light that is potentially received; but the dose depends on the viewer, too. Instead of reporting illuminance on a surface, we should think about how much light actually reaches the back of the eye, taking into account: the age and visual state of each subject, the background luminance, pupil diameter during the stimulus, and, measurement at the eye, in the direction of gaze.

Field researchers currently measure light reaching the circadian system with conventional handheld light meters. However, it is often difficult to position these instruments near the eye to measure light exposure over a period of time.

The circadian dosimeter or "Daysimeter" is a lightweight headset consisting of a photopic light sensor and a blue light sensor. The Daysimeter's wearable design allows researchers to continuously measure light exposure (Figure 4).

c/o Lighting Research Center

Figure 4 Prototype of the LRC's circadian dosimeter, the "Daysimeter".

The photopic light sensor can take illuminance measurements at the eye with accuracy compatible with standard, laboratory-grade photometry equipment. The spatial response of the circadian dosimeter's light sensors match closely a cosine response, allowing thus measurements taken with the Daysimeter to be compared to measurements taken with standard light meters.

The blue light sensor's sensitivity has a peak wavelength and spectral bandwidth that are a very close match with a proposed spectral sensitivity curve for the human circadian system. This reduces the need to filter the response, allowing the use of a smaller and less expensive detector assembly.

By employing two light sensors, the Daysimeter is measuring the circadian response from light sources according to the spectral opponency process. The impact of the opponent process on circadian light sensitivity can be evaluated by subtracting a portion of the photopic signal from the blue signal.

The circadian dosimeter records and stores time data, allowing the researchers to analyse the time of day and the duration of light exposure, both essential parameters in understanding the impact of light to the circadian cycle.

Currently LRC plans to use the device to characterise the luminous environments of teens with delayed sleep phase syndrome, seniors with Alzheimer's disease, premature infants in neonatal intensive care units, persons with seasonal affective disorder, and nurses working day and night shifts. It is expected that the data collected, together with medical measurements of melatonin levels and performance, will provide further insight into the role light plays in the entrainment and disruption of circadian patterns in humans.

By being able to measure the circadian light for day and night shift workers, lighting professionals could better understand, control and improve the luminous environment.

3. UV radiation

Ambient radiation from the sun or from artificial light sources contains varying amounts of UV-C (220-290 nm), UV-B (290-320 nm), UV-A (320-400 nm), and visible (400-700 nm) light. The shorter the wavelength, the greater the energy and therefore the greater the potential for biological damage: UV-C and UV-B cause sunburn and basal cell carcinoma; UV-A causes skin ageing and is thought to induce dermal melanoma, while visible light is largely benign.

Although UV-C is the most energetic wavelength and has the potential to do the most damage to the eye, most of what reaches the proximity of the earth is blocked by the ozone layer and does not reach the earth's surface. Also, the ozone layer blocks most of the UV-B radiation [18].

In order for a photochemical reaction to occur in the eye, the light must be absorbed in a particular ocular tissue. The human eye has unique filtering characteristics that determine in which area of the eye each wavelength of light will be absorbed. The cornea cuts off all light below 295 nm (all un-filtered UV-C and some UV-B), protecting thus the lens from the shortest, most energetic light wavelengths. The lens absorbs most of the remaining UV light, but proportionally with age:

- in adults, the lens absorbs the remaining UV-B and all of UV-A (295-400 nm) and therefore only visible light reaches the retina.
- the very young human lens transmits a small window of UV-B light (320 nm) to the retina;
- the elderly lens filters out much of the short blue visible light (400-500 nm).

Sunlight can potentially damage any organ that is exposed to any part of its spectrum. Aside from the skin, the organ most susceptible to sunlight induced damage is the eye. While light transmission through the eye is fundamental to its unique biological functions of directing vision and circadian rhythm, at the same time exposure to the intense light of the sun can pose a particular hazard: it can lead to impaired vision and, eventually, blindness.

Although the ozone layer blocks most of the harmful UV radiation, where this layer is depleted an increase is expected in damage to the cornea (photokeratitis), lens (cataractogenesis), and the retina (retinopathy) of the young, leading to blindness. Exposure to intense ultraviolet radiation in youth may also increase the induction of ocular tumours later in life [17].

Ultraviolet light avoidance with appropriate sunglasses and vitamin E supplementation may help retard or eliminate this blinding disorder in the elderly.

While most of the above-mentioned UV damage is related to sunlight exposure, lamp manufacturers have to consider the photobiological hazard their products will have on humans [1].

Issued in 2002, the CIE Standard 009/E provides guidance for evaluating the photobiological safety of lamps and lamp systems:

- stipulates that general lighting sources are to be evaluated for their photobiological hazards at 500 lux,
- photobiological hazards considered are: actinic UV (200-400 nm), near-UV (315-400 nm), retinal blue light (300-700 nm), retinal thermal (380-1400 nm), retinal thermal - weak visual stimulus (780-1400 nm), eye IR (780-3000 nm), thermal skin (380-3000 nm)
- specifies the exposure limits, reference measurement technique and classification scheme for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of radiation, including LEDs but excluding lasers, in the wavelength range from 200 nm through 3000 nm.

Most of the fluorescent lamps do not offer a retinal thermal or UV hazard, but for incandescent and halogen lamps at 500 lux the UV is the only hazard that creates a concern for lamp manufacturers. For sources not used for General Lighting each has to be evaluated individually.

4. Effect of aging on visibility

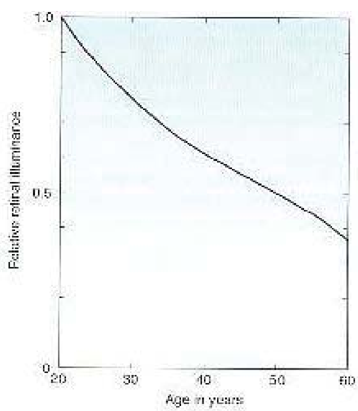
4.1 Seeing Quality Change with Age

While it has been generally known that we require more illumination to see as we get older, most visibility research has been based on the younger eye. This research tends to be conducted at Universities world wide, using students as the research subjects. Even today, current IESNA design guidelines, which include task illumination recommendations, are not made with respect to the age of the occupants. The designer is left to his own devices to “increase” illuminance levels above the recommended level for older occupants.

Visual requirements for older eyes are significantly different from those of the younger person in two ways:

1. Changes to the crystalline lens – with age, there is a thickening and hardening of the crystalline lens, which decrease the amount of light actually reaching the retina of the eye. A less flexible lens, has more difficulty focusing, especially on closer objects.
2. Pupil Size – in the older eye we find a general reduction in pupil size, again decreasing the amount of light reaching the retina.

Older persons require higher task illuminance for the same retinal illuminance, and because of reduced lens clarity, have reduced image quality (Figure 5).



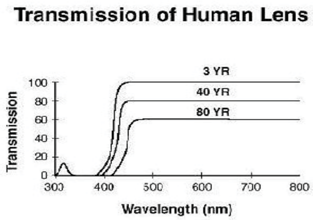
c/o IESNA Handbook [23].

Figure 5 Relative decline in retinal illuminance with age; Older eyes require greater illumination to offset reduced light reaching the retina

4.2 Effect of Changes Due to Aging

As we age, the lens in the eye thickens and the pupil shrinks, reducing the amount of light passing through to the retina. This also effects the circadian system, which may require a stronger light/dark stimulus due to deteriorating neural processes in the brain. Older people tend to be more "housebound" which can create an environment with little variation in light/dark intensity, resulting in a weak light/dark stimulus to the circadian system. As a result, the occurrence of sleep disturbances increases as we age. The combination of age-related changes influences the amount and magnitude of light/dark stimulus needed to affect the circadian system [22].

Light transmission through the human eye is deteriorating with age. It was noticed [20] that older eye shows decrease sensitivity to blue light as well as overall loss in light of other wavelengths arriving at the retina (Figure 6).



c/o Dr. Joan Roberts

Figure 6 This graph shows the loss in transmission factor in the human eye as we age.

IESNA, in its Recommended Practice for Lighting and the Visual Environment for Senior Living [22], discusses the need to fastidiously apply the principles of good lighting design to all lighted environments were seniors are the main occupants.

As the population of 60+ increases, the lighting designer must consider increasing recommended illuminance levels and take increasing measures to avoid glare and excessive luminance ratios.

In addition, the aging eye is slower to adapt to changes in illuminance levels. Lighting designers must limit abrupt changes in luminance between adjacent spaces. Hazardous areas, such as stairways and doorways require special attention to assist in safe movement.

Above age 65, neurological factors also become increasingly problematic. Eye defects such as macular degeneration, diabetic retinopathy increase with age.

These changes demand even more sophisticated lighting design [22].

5. How can lighting designers help

Some scientists think that urban environments offer biological darkness by day (in interiors with relatively low illuminance) and unnatural brightness by night (electric lighting extending apparent day length), producing apparently constant day length over the seasons, and having unknown health consequences.

If true, many people have disrupted daily and seasonal rhythms that could influence their health. To correct these issues, medical scientists and lighting designers will need to cross their discipline borders and work together to establish best practice guidelines.

Since 2000 there has been an increase in experimental research but more is needed to eliminate variations in results and set common principles of healthy lighting design. Some are highlighted in the CIE committee report on "Ocular Lighting Effects on Human Physiology, Mood, and Behaviour" (TC 6-11) chaired by Jennifer Veitch of the National Research Council Canada [21]:

- Light for biological action should be rich in the regions of the spectrum to which the nonvisual system is most sensitive (blue). The results of this study. It is not surprising that light level affects acuity, but there is a general absence of appreciation for the effects of light spectrum. A study at Lawrence Berkeley National Laboratory, California, shows that both light level and lighting spectrum affect visual acuity under typical conditions of reading. Comparing to different CCT (colour corrected temperature) fluorescent systems in a school, the study founded that at the same light intensity at the eye, visual acuity was significantly better under the high CCT lamps. Visual acuity measured under the traditional low CCT lamps was at least equal to that measured under the high CCT lighting when light levels were reduced by 50% [5]. These results suggest a highly cost effective strategy for improving elementary school classroom lighting based on replacing the conventional low CCT (3500K) lamps with high CCT lamps (5000K or higher). Users can adopt one of two strategies -maintain the status quo in visual acuity and achieve maximum savings in lighting energy costs, maintain current lighting energy costs but provide a higher degree of visual acuity [2].
- The important consideration in determining light dose is the light received at the eye, light both directly from the light source and reflected off surrounding surfaces. This principle is one that will directly influence how we use lighting design to support health. Bathing everyone in very high-intensity blue-green light is not the answer. The circadian dosimeter developed by LRC is a first right step towards measuring circadian light exposure. Once the necessary daily light dose is determined, we need to find out the best ways to deliver it to the eye, not to the desk. If it becomes desirable to change the light dose people receive indoors, then we will need to think differently about how we design: where to put the light, and for how long. If we need higher dosages, we probably don't need them all the time - and we can't afford the energy for it either - so we need to be more creative about where and when (and how long) to use the higher output, so we get the effects we seek. Our design criteria need to address this additional set of requirements.
- The timing of light exposure influences the effects of the dose. The effect of a light stimulus depends on the state of the system. Thus, bright light at night, before the low point in core body temperature, has the effect of delaying the circadian rhythm (the low point will come later than it would have). Bright light in the morning, after the low point of core body temperature, will advance the rhythm (the low point will come earlier on the following night than it would have). The same light exposure in the middle of the day might have very littler effect at all.

One can divide light exposure at night [6] based on the effects it has on:

- ***Physiology***; there is enough evidence to conclude that bright light can shift the phase of circadian rhythms and suppress melatonin rapidly. This can be used to correct the occasional/ temporary de-synchronisation between the circadian clock and the outdoors diurnal cycle caused by night-shift work or flying across time-zones. It can also increase alertness at night simply by suppressing melatonin.
- ***Performance***; the positive effects of light on the performance of worker during the circadian night are seen in the acceleration of workers' re-entrainment. In principle, this can be done by correctly timing exposure to light over the whole 24 hours. Of course, modifying behaviour in order to match a

schedule of light exposure requires a degree of compliance that not many people are likely to give. And also, it still takes a period of time before re-entrainment approaches completion, during which the performance of sensitivity tasks could be reduced.

However, exposure to bright light at night could improve performance depending on the structure of the task at hand and the work context. For example, tasks that are interesting or rewarding to the worker are self-paced, or complex but solvable are likely to benefit from the light exposure. On the other hand, for tasks that are repetitive, boring, externally paced, or of little interest to the worker, exposure to bright light might not be sufficient to overcome the negative effects of prolonged work at night.

Following these principles of healthy lighting, design practice transformation should also balance all other principles of lighting quality:

- For daytime applications, controlled use of daylighting (having a view is in itself beneficial), limiting glare and solar heat gain to avoid compromising comfort, is an energy-efficient strategy for providing more light where it is wanted. When sizing lighting systems for rooms, designers should also consider task/ ambient cumulative effects and make use wisely of the colour scheme for the reflective surfaces.
- For nighttime applications, high illuminance delivered architecturally can influence melatonin secretion and aid in circadian phase shifting, while shift work applications need to be tailored to the specific schedule. The bright light might not be needed constantly throughout the shift, but with additional luminaires and appropriate switching or automated controls, biologically effective lighting could be provided to those who must work overnight. This will beneficently reset the circadian clock. Luminous ceilings that deliver high illuminance, or simulated skylight apparatus that mimics the evening are both devices that have been tested for this purpose.
- Where designing spaces populated by older people, consider the special needs of the ageing eye, especially illuminance levels (by increasing quantity and distribution of light, using lighter coloured surfaces), contrast ratios and colour perception, and the control of glare.

We can be assured that lighting in the 3rd millennium will be an adventurous and fascinating endeavour, above and beyond past knowledge.

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LIGHT MEETS ARCHITECTURE

Student contest powered by Zumtobel

Based on an idea by Dorin BEU and Şerban ŢIGĂNAŞ and with the support of Zumtobel Lighting, an architecture student contest was launched in order to promote the importance of lighting for the final-year project. Students are encouraged to collaborate with their colleagues from technical universities where lighting engineering is teached.

Zumtobel's integral lighting solutions create both the practical use and added aesthetic value of light based on the interaction with space and architecture. To provide the best possible lighting quality for human needs, Zumtobel Lighting is currently researching the health-promoting effects of light and develops intelligent lighting management systems to reduce energy consumption and saving costs.

The 2006 competition requires new concepts for lighting solutions from architecture students and focuses on lighting solutions in any kind of buildings. Luminaries are only tools; the lighting solutions should be presented within the context of a relevant project.

Typical applications may include:

- Industry and engineering;
- Offices and education;
- Presentation and retail;
- Transit areas and car parks;
- Hospitality and wellness;
- Sports and leisure.

The winner will be invited for a week to visit the Zumtobel Lighting GmbH head office in Dornbirn, in order to get to know the company's products and services first hand, to study local projects of architectural interest and to participate in a renowned Austrian architectural practice. The best 10 projects will be exhibited in Cluj, Timisoara and Bucharest. The best three projects will be invited to a workshop at the Lighting Engineering Center – Technical University of Cluj-Napoca.

The contest results will be published in the **Ingineria Iluminatului** journal.

The competition is open to students enrolled in architecture courses at any university in Romania. The local jury will ensure the high quality of the contest.

The members of the jury are:

Şerban STURDZA (president of the jury)
Marius MARCU
Şerban ŢIGĂNAŞ
Vlad GAIVORONSCHI
Thomas HAEUSLE
Dorin BEU

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