SLOVENSKO DRUŠTVO ZA RAZSVETLJAVO / SDR
LIGHTING ENGINEERING SOCIETY OF SLOVENIA
2000 Maribor, Vetrinjska ul. 16/I, Slovenija

PETNAJSTO MEDNARODNO POSVETOVANJE
FIFTEENTH INTERNATIONAL SYMPOSIUM

RAZSVETLJAVA 2006
LIGHTING ENGINEERING 2006

Z B O R N I K
P R O C E E D I N G S

Razsvetljava delovnih mest
Lighting of Work places

12. - 13. oktober, 2006
BLED, SLOVENIJA

Posvetovanje:	**RAZSVETLJAVA 2006**, Bled, 12.-13. oktober 2006
Organizacija:	Slovensko društvo za razsvetljavo / SDR
Urednik zbornika:	mag. Andrej ORGULAN
Organizacijski odbor	
predsednik:	mag. Matej B. KOBAV
člani:	doc. dr. Grega BIZJAK, mag. Matej B. KOBAV, mag. Andrej ORGULAN
Programski odbor in recenzenti	
predsednik:	doc. dr. Grega BIZJAK
člani:	dr. Grega BIZJAK, Marko BIZJAK, Stanko ERŠTE, dr. Marc FONTOYNONT, mag. Gorazd GOLOB, dr. Marta KLANJŠEK GUNDE, Matej B. KOBAV, mag. Andrej ORGULAN, Peter RAYNHAM, dr. Raša URBAS
Tehnična ureditev:	Andrej ORGULAN
Tisk:	Založniško tiskarska dejavnost Univerze v Mariboru
Naklada:	150 izvodov

CIP – Katoložni zapis o publikaciji
Univerzitetna knjižnica Maribor

628.976(082)

Mednarodno posvetovanje Razsvetljava (15 ; 2006 ; Bled)
Razsvetljava delovnih mest : zbornik = Lighting of work places : proceedings / Petnajsto mednarodno posvetovanje Razsvetljava 2006 = Fifteenth International Symposium Lighting Engineering 2006, 12. - 13. oktober, 2006, Bled, Slovenija ; [organizacija] Slovensko društvo za razsvetljavo = Lighting Engineering Society of Slovenia ; [urednik zbornika Andrej Orgulan]. - Maribor : Slovensko društvo za razsvetljavo, 2006

ISBN 86 - 435 - 0799 - 7
1. Vzp. stv. nasl. 2. Orgulan, Andrej 3. Slovensko društvo za razsvetljavo (Maribor)
COBISS.SI – ID 57549313

RAZSVETLJAVA 2006 / LIGHTING ENGINEERING 2006

CILJI IN VSEBINA POSVETOVANJA

Letos skušamo že trinajsto leto zapored s strokovno obravnavo svetlobne tehnike približati to problematiko javnosti. Osnovne teme na dosedanjih posvetovanjih so bile:

leta 1992 – RAZSVETLJAVA '92	–	Več svetlobe ob manjši porabi energije;
leta 1993 – RAZSVETLJAVA '93	–	Energijsko optimiranje razsvetljave;
leta 1994 – RAZSVETLJAVA '94	–	Vzdrževanje razsvetljave in ekološki problemi;
leta 1995 – RAZSVETLJAVA '95	–	Energijska učinkovitost v sistemih za notranjo in zunanjo razsvetljavo
leta 1996 – RAZSVETLJAVA '96	–	Meritve v svetlobni tehniki kot funkcija učinkovite rabe energije
leta 1997 – RAZSVETLJAVA '97	–	Razsvetljava in energija
leta 1998 – RAZSVETLJAVA '98	–	Svetila in svetlobna tehnika
leta 1999 – RAZSVETLJAVA '99	–	Razsvetljava prodajnih prostorov
leta 2000 – RAZSVETLJAVA 2000	–	Novosti v zunanji razsvetljavi
leta 2001 – RAZSVETLJAVA 2001	–	Razsvetljava ambientov
leta 2002 – RAZSVETLJAVA 2002	–	Svetloba in okolje
leta 2003 – RAZSVETLJAVA 2003	–	Učinkovita kombinacija umetne in dnevne svetlobe
leta 2004 – RAZSVETLJAVA 2004	–	Učinkovita kombinacija umetne in dnevne svetlobe
leta 2005 – RAZSVETLJAVA 2005	–	Svetloba in okolje

S posvetovanjem je seznanjen Centralni urad Mednarodne komisije za razsvetljavo – CIE.

OBJECTIVES THROUGH THE YEARS

The basic topics of the symposia in particular have been the following:

in 1992 – LIGHTING ENGINEERING '92	–	More Light with Less Energy Consumption;
in 1993 – LIGHTING ENGINEERING '93	–	Energy optimised Lighting;
in 1994 – LIGHTING ENGINEERING '94	–	Maintenance and Environmental Problems;
in 1995 – LIGHTING ENGINEERING '95	–	Energy Efficiency in Building and Public Lighting Systems.
in 1996 – LIGHTING ENGINEERING '96	–	Lighting Engineering and Energy Efficiency
in 1997 – LIGHTING ENGINEERING '97	–	Lighting and Energy
in 1998 – LIGHTING ENGINEERING '98	–	Lights and Lighting
in 1999 – LIGHTING ENGINEERING '99	–	Retail Lighting
in 2000 – LIGHTING ENGINEERING 2000	–	Outdoor Lighting
in 2001 – LIGHTING ENGINEERING 2001	–	Ambience Lighting
in 2002 – LIGHTING ENGINEERING 2002	–	Light and Environment
in 2003 – LIGHTING ENGINEERING 2003	–	Effective Combination of Artificial Lighting with Daylight
in 2004 – LIGHTING ENGINEERING 2004	–	Effective Combination of Artificial Lighting with Daylight
in 2005 – LIGHTING ENGINEERING 2005	–	Light and Environment

The symposium has been noted by the International Commission on Illumination – CIE.

POKROVITELJI POSVETOVANJA / SPONSORS OF THE SYMPOSIUM

INTRA LIGHTING d.o.o., SITECO d.o.o.,
JAVNA RAZSVETLJAVA d.d., MTS International

SPONZORJI / CONTRIBUTORS TO THE SYMPOSIUM

ISKRA ISD, d.d., Adria-Lighting, GE, Salonit Anhovo d.d. in drugi
Univerza v Ljubljani, FE, Univerza v Mariboru, FERI

VSEBINA / CONTENTS

* prispevki so v angleškem jeziku (op. ur.)

Marc Fontoynont

NEW CHALLENGES IN LIGHTING

Keywords: *Lamps, Indoor lighting, lighting quality, luminous environment.*

2 Novi izzivi v razsvetljavi

Ključne besede: *svetilke, notranja razsvetljava, kakovost razsvetljave, svetlobno okolje*

Interest in lighting techniques is growing wordwide, due to the combination of three major factors. 1) the higher understanding of the consequences of good/bad lighting in buildings and cities, 2) the growing concern for energy conservation 3) the revolution of lamp technologies.

On the side of supply of lamps and luminaires, the major challenge today is to prepare the progressive replacement in the next 20 years of most tungsten-halogen sources in buidings by three lamp technologies : very compact fluorescent lamps, very compact metal-halide, LED and OLED technologies. In street lighting, the plan is to get rid of mercury lamps and replace them by lamps such as metal-halide.

In indoor lighting, good lighting design, and good control strategy (in response to daylight and occupancy) can lead to very substantial energy savings, higher than 50% of current practice with improved lighting quality. This means 1 to 3 Euros of electricity saved per square meter of floor area per year.

Europe is a territory where consideration for lighting quality are quite high, although large differences exist between countries. It is a place where major multinational lighting and electrical equipment companies are based (Philips, OSRAM, Schneider-Electric, Siemens, etc.) and where a large amount of very innovative SME propose lightings solutions. These companies are strong actors in the field of evolution or lighting techniques. Their challenge is to propose solutions of higher performance: more durable, higher light quality, lower glare, higher compacity, possible dimming and management.

Fig 1. Example of computer generated images of various lighting schemes for cubicles tested to identify preferences among observers (source: Charton, ENTPE)

At work places, this progress needs to be clearly compared with the consequences, both for the users and the building managers. The annual cost of energy for lighting required per worker is of the order of 1 or 2 hours of salary cost for the employer. The amortizing cost of the lighting equipment is of the same order. This is very low. It means two things.

First, that the investment cost and running cost of a lightings installation is cheap in comparison with the general costs involved in the activity of a company.

Second, that the consequences of a bad or good lighting are probably much higher that the cost of the installation. Which is to say that an investment in a high quality lighting scheme may be a very good and profitable investment.

We can design lighting keeping in mind two major objectives:

A) the highest satisfaction of the users

B) the lowest energy consumption and running costs.

We have conducted a campaign of testing efficient lighting installations during 6 months in the area of Lyon, France. 26 work places were tested, each of them with a specific lighting scheme. The goal was to identify directions in preferred lighting schemes requiring less electrical power. Users could adjust their lighting conditions thanks to different control systems : dimmer, daylight and occupancy sensors, separate ambient/task luminaires. The preferred lighting schemes were carefully recorded through measurements of illuminance distribution, luminance values in the field of view, electric power required by the lighting installation for the selected lighting scheme.

Selected electric power densities and lighting quality parameters were compared. No correlation was found between perceived lighting quality parameters and electric power densities, but some solutions were found, with the best assessment in quality with less than 10W/m^2 of installed electric power.

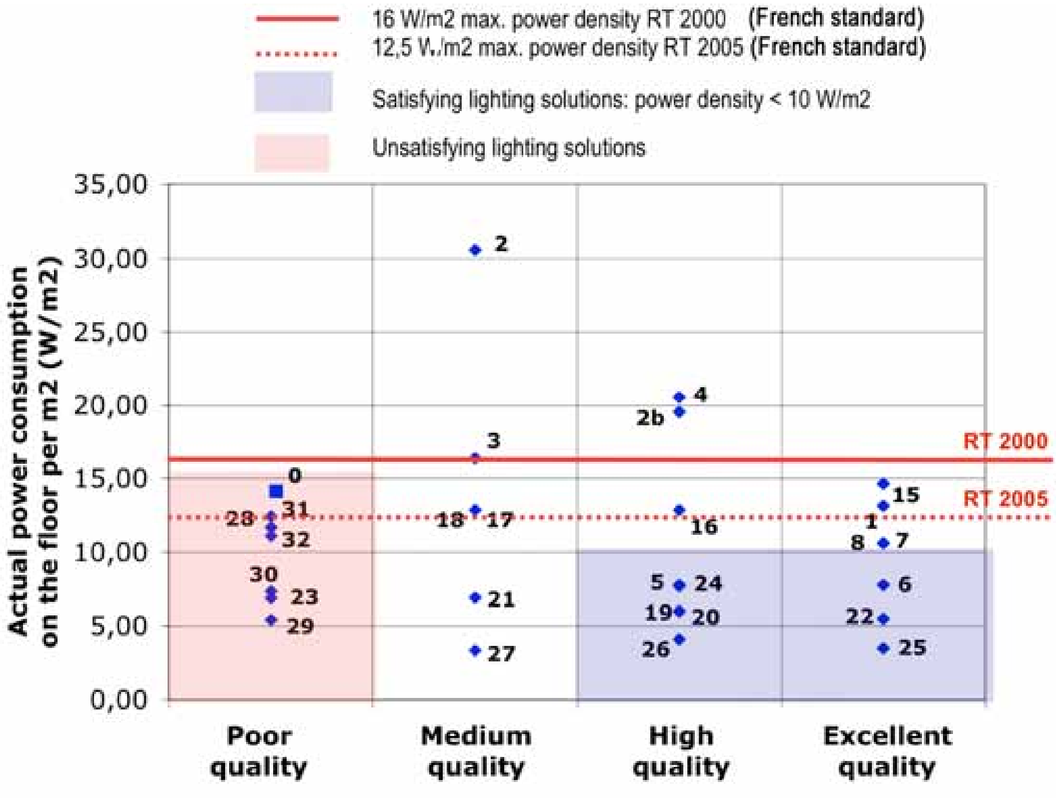


Fig 2. Perceived visual quality as a function of the electric power density for lighting for 26 lighting schemes. This graphs shows that there are various solutions, well accfpted by the users, of lighting schemes using less than 10W/m^2 of electric power density.

3 MOST EFFICIENT SCHEMES

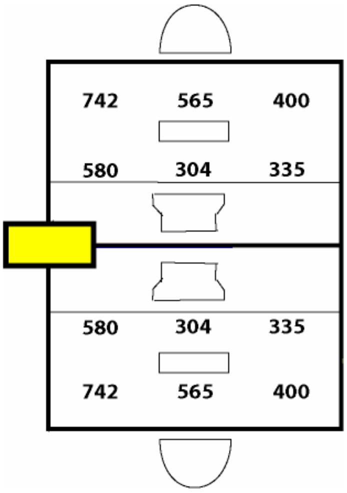


Fig 3. Direct-indirect stand alone luminaire. Its independence with the ceiling allow to locate the luminaire very precisely near the work space. The users appreciated the dimming option associated to the daylighting-occupancy sensor. Can be shared with another occupant. Considered as high standing. Typically 100W per work space required, less than 8W/m^2 in open plan office. Typical light sources about 2 CFL 55W per occupant, partly dimmed.

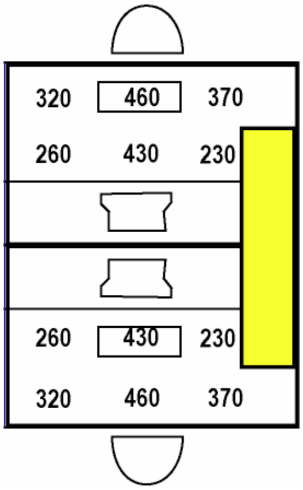


Fig 4. Direct-indirect suspended luminaire. Allow usage of 1.20 or 1.50m fluorescent tube. But work place cannot move if luminaire position is fixed. Leads to the lowest electrical consumption: 6W/m^2. In open plan office. Could use 2x54 W fluorescent tubes for two people.

4 CONCLUSION

Here are in summary the possible specifications of lighting installations in offices where the concern is of high perceived light quality and very low energy consumption.

Hide sources so that the maximum luminance of the luminaire, in all direction is below 7000 cd/m^2. Reduce uniformity on work plane to a value between 0.6 and 0.8 to provide a feeling of contrast while avoiding shadows. Allow individual control (dimming) so that the user get the exact illuminance he/she wishes. Select equipment with good optical performance. Prefer single fluorescent tube to compact fluorescent lamps to lower electric power requirement. Share luminaries between work places: best performance are obtained with one luminaire providing light for two workplaces.

Our study is being compared with other such experiences among participants of IEA Annex 45. We expect to develop more robust guidelines for highly efficient, high quality, lighting options for work places.

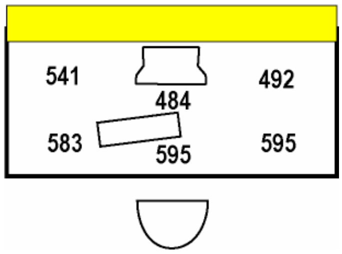


Fig 5. Indirect luminaire integrated to the furniture. Judged as very comfortable, the ceiling luminances are moderate, but the general feeling tends to have a work plane looking darker that the rest of the room. Requires about 2x35 W fluorescent tubes per work place.

5 REFERENCES

1. VEITCH, J.A. & NEWSHAM, G.R., Lighting quality and energy-efficiency effects on task performance, mood, health, satisfaction and comfort, Journal of the Illuminating Engineering Society. 1998, Vol.27, n°1, pp.107-129.
2. CHARTON, V., Etude comparative de la perception d'ambiances lumineuses en milieu naturel réel et en milieu virtuel, Thèse de doctorat, Mécanique, Energétique, Génie Civil, Acoustique, INSA Lyon, ENTPE, 263 p., 2002.
3. COUTELIER, B., Caractérisation de la qualité d'un environnement lumineux à l'aide d'outils de mesure vidéo-photométriques et de simulations en milieux virtuels., Thèse de doctorat, Ecole doctorale MEGA, spécialité Génie Civil, INSA de Lyon, ENTPE, 300 p., 2006.
4. IEA ANNEX 45, Energy Efficient Lighting, http://www.lightinglab.fi/IEAAnnex45/

6 ACKNOWLEGEMENTS

This study was conducted within a contract involving Ingelux Consultants, ENTPE, Sonepar Group for ADEME, the French Energy and Environment Agency. Equipment was kindly provided by some lighting manufacturers: Artemide, Flos, Luxo, Optelma, Osram, Philips, SLI, Targetti.

Naslov avtorja / Author's address:

Marc Fontoynont,
National Engineering School of State Public Works, Vaulx-en-Velin, Lyon, France

Liisa Halonen & Eino Tetri

IEA ECBCS ANNEX 45 – ENERGY EFFICIENT ELECTRIC LIGHTING FOR BUILDINGS

Summary

The Executive Committee of the Energy Conservation in Buildings and Community Systems (ECBCS) program established a new research project (Annex) in June 2004 called Energy Efficient Electric Lighting for Buildings. The objectives of Annex 45 are to identify and accelerate the use of energy-efficient high-quality lighting technologies and their integration with other building systems, to assess and document the technical performance of existing and future lighting technologies, as well as to assess and document barriers preventing the adoption of energy-efficient technologies, and to propose means to resolve these barriers.

Povzetek

***IEA ECBCS** ANNEX **45 – Energetsko učinkovita električna razsvetljava v stavbah**; Izvršni komite Programa za varčevanje z energijo v stavbah in komunalnih sistemih (ECBCS) je ustanovil raziskovalni program (Annex) »Energetsko učinkovita električna razsvetljava v stavbah« v juniju 2004. Cilji programa so: poiskati energetsko varčne visoko kakovostne razsvetljavne naprave ter pospešiti njihovo uporabo in povezovanje z drugimi sistemi v zgradbah, določiti in dokumentirati tehnično kakovost in zmožnosti obstoječe in prihodnje razsvetljavne tehnologije ter določiti in dokumentirati ovire, ki preprečujejo uporabo energetsko učinkovitih tehnologij in predlagati ukrepe za odpravo teh ovir.*

1 Introduction

International Energy Agency (IEA) is an intergovernmental body committed to advancing security of energy supply, economic growth and environmental sustainability through energy policy co-operation. IEA has Implementing Agreements (IA) to organize research. One of these IAs is Energy Conservation in Buildings and Community Systems (ECBCS). The function of ECBCS is to undertake research and provide an international focus for building energy efficiency. Tasks are undertaken through a series of annexes that are directed at energy saving technologies and activities that support their application in practice. Results are also used in the formulation of energy conservation policies and standards.

The Executive Committee of the ECBCS program established a new Annex in June 2004 called Energy Efficient Electric Lighting for Buildings. Professor Liisa Halonen from Lighting Laboratory of Helsinki University of Technology was elected for the Operating Agent of the Annex 45.

2 Background

Lighting is a large and rapidly growing source of energy demand and greenhouse gas emissions. In 2005 grid-based electric lighting consumed was 2 650 TWh. That means 133 petalumen-hours (Plmh) of electric light was used, an average of 20 megalumenhours/person. In addition each year 55 billion litres of gasoline and diesel are used to operate vehicle lights. More than one-quarter of world's population uses liquid fuel (kerosene) to provide lighting. [1] Global lighting electricity use is distributed approximately 28 % to the residential sector, 48 % to the service sector, 16 % to the industrial sector, and 8 % to street and other lighting. For the industrialized countries national lighting electricity use ranges from 5 % to 15 %, while in developing countries the value can be as high as 86 % of the total electricity use. [2]

More efficient use of lighting energy would limit the rate of increase of electric power consumption, reduce the economic and social costs resulting from constructing new generating capacity, and reduce the emissions of greenhouse gases and other pollutants. At the moment fluorescent lamps dominate in office lighting. In domestic lighting the dominant light source is still the more than a century old, inefficient incandescent lamp. New aspects of desired lighting are energy savings, daylight use, individual control of light, quality of light, emissions during life cycle and total costs.

The building sector in the EU consumes over 40 % of energy use in EU and is responsible for over 40 % of its carbon dioxide emissions. Lighting is a substantial energy consumer, and a major component of the service costs in many buildings. The percentage of the electricity used for lighting in European buildings is 50 % in offices, 20-30 % in hospitals, 15 % in factories, 10-15 % in schools and 10 % in residential buildings [3]. To promote the improvement of the energy performance of buildings within the community, the European Parliament has adopted the Directive 2002/91/EC on the energy performance of buildings. [4]

3 Trends in energy efficient lighting

Electric light is obtained as a result of combination of lighting equipment. Modern lighting system needs light sources, ballasts, luminaires and controls. Part of the power input to the lighting unit is transformed into light, while the rest is considered as loss. Energy is lost in lamps, luminaires and ballasts in the form of heat. The saving of lighting energy requires the use of energy efficient components as well as the application of control, dimming, and the use of daylight.

A 35 % improvement has been presented in efficiency of T5 fluorescent lamp using mirror louvre fixture over an equivalent T8 mirror louvre fixture while using a high-frequency ballast and a standard aluminum reflector. The corresponding improvement in efficiency shown over a luminaire of the same type with conventional ballast was about 65 %. [5]

As part of the IEA Annex 45 pone objective is to develop a lighting control system with high level of intelligence and multiple levels of control that learn and adapt to user's preferences and behavior. The usage of wireless sensors and actuators is a key component for new lighting control systems. This is justified by the fact of the easy installation in a way that you do not have to lay cables and damage walls. In this sense it is also possible to integrate such a system into existing buildings. On the other hand is it impossible to realize an intelligent lighting system without a lot of sensors and actuators to capture and control the environment.

Directive 2000/55/EC gives energy efficiency requirements for ballasts for fluorescent lamps. The maximum power of ballast-lamp circuit, for example, of a 36 W fluorescent lamp should be less than 45 W after 21 May 2002 and less than 43 W after 21 November 2005. [6]

High pressure discharge lamps are very energy-efficient lamp types. Their small discharge body allows an efficient reflector design for luminaires so that the luminous flux leaving the luminaire can be distributed effectively in the room. Typically, it takes 3 minutes to reach 80% of the nominal luminous flux of a high pressure discharge lamp. For automotive lamps, this time has been reduced to 3 seconds already [7]. At present, high pressure discharge lamps cannot replace other lamp types. Reasons are given in the start performance and in restricted dimming performance. Research on the interaction of ballast electronics and high pressure discharge lamps may significantly improve the performance of this lamp type.

LEDs (Light Emitting Diodes) are new alternative light sources, which are foreseen to revolutionise the lighting technology in the near future. According to Agilent Technologies the lumens/package value of red LEDs has been increasing 30 times per decade whereas the price is decreasing 10 times per decade [8]. The use of LED based lighting could decrease the lighting energy consumption by 50 % by 2025 [9]. The future entrance of LEDs in the lighting market is dependent on improvements in conversion efficiency and optical power per package. Although most of the high-power LEDs (HP-LEDs) nowadays convert between 15 to 20% of the input power into light, their efficiency potential is far better. In fact the best AlInGaP (aluminum indium gallium phosphide) red LED and InGaN (indium gallium nitride) green and blue LEDs can have internal quantum efficiencies which can reach almost 100% and 50%, respectively. To achieve external quantum efficiencies close to that magnitude, the light extraction has to be improved. By allowing more photons to escape from the LED chip without been absorbed by the surrounding structure, is one of the main design challenges which has to be addressed in order to increase the device conversion efficiency and the radiant power per device. New technologies have been developed in order to address this issue. The most promising one is the use of quantum dots or nanoparticles. Quantum dots are characterized by having a large absorption spectral range characteristic and a tunable spectral emission. This makes them ideal to substitute conventional and inefficient phosphors used on today white LEDs. However improvements have to be done especially in the quantum efficiency of quantum dots.

The importance of LED lighting was acknowledged this year also by the Millennium Prize Foundation. The 2006 Millennium Technology Prize of one million euros, the world's largest technology award, was awarded to Professor Shuji Nakamura for his invention of the blue LED. [10]

4 Objectives

The goal is to identify and to accelerate the widespread use of appropriate energy efficient high-quality lighting technologies and their integration with other building systems, making them the preferred choice of lighting designers, owners and users.

The aim is to assess and document the technical performance of the existing promising, but largely underutilized, innovative lighting technologies as well as future lighting technologies and their impact on other building equipment and systems (ie: daylighting, HVAC). These novel lighting system concepts have to meet functional, aesthetic, and comfort requirements of building occupants.

The aim is to assess and document the barriers preventing the adoption of these promising existing and future technologies (ie: technical, economic, risk factors, resistance to change, legislative, etc.) and propose means to resolve these barriers.

5 Structure

The Annex 45 will run between 2005 and 2008. The work of Annex 45 is divided to four Subtasks.

- Subtask A Targets for energy performance and human well-being
- Subtask B Innovative technical solutions
- Subtask C Energy-efficient controls and integration
- Subtask D Documentation and dissemination.

Subtask A: Targets for Energy Performance and Human Well-Being

The objective are to document the effect of design and targets for energy use, lighting quality and human well-being. To propose an upgrade of lighting recommendations and codes to improve the energy performance of indoor lighting installations.

The performance criteria include the spectral, electrical and user related issues. The energy criteria include energy efficiency, life cycle energy considerations, maintenance and operation. The economical criteria include cost of devices and of application.

Subtask B: Innovative Technical Solutions

The objective is to identify, assess and document the performance, energy and economical criteria of the existing promising and innovative future lighting technologies and their impact on other building equipment and systems. The purpose is to reduce the energy use of buildings by investigating the saving potential by comparing the existing and future technologies and by applying information on concepts, products and lighting solutions. The technical solutions cover power supply, light sources, luminaries and concepts of controls.

Subtask C: Energy-Efficient Controls and Integration

The Subtask C focuses to optimal use of controls that enables energy savings whilst the user (occupant, facility manager, operation and maintenance team…) has the possibility to modify the electric lighting according to personal needs and preferences, within acceptable building operative requirements. Subtask C gives guidelines to designer, installers, manufacturers to achieve the above-mentioned aim.

Subtask D: Documentation and Dissemination

The objective of Subtask D is to improve current lighting practices in a manner that accelerates the use of energy efficient products, improves overall building performance and enhances the occupants' environmental satisfaction. The objective of Subtask D is to compile and widely disseminate the Annex research results of Subtasks A, B and C and to identify the means to influence the energy policies and regulations in order to promote the use of energy efficient lighting. The main deliverables of the Annex will be Energy-Efficient Lighting Guidebook, semi-annual Newsletter, seminars and a website (http://lightinglab.fi/IEAAnnex45).

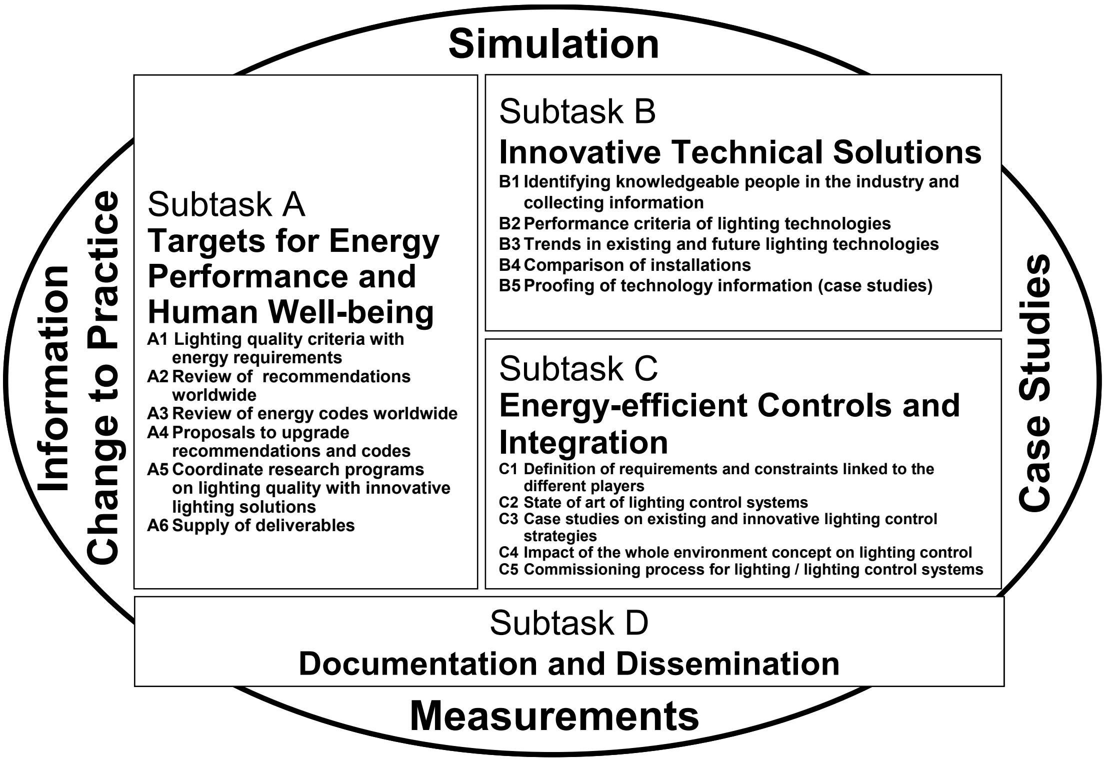


Figure 1. Structure of the Annex 45.

6 Management of the Annex

The Annex is managed by the Operating Agent with the assistance of the Subtask Leaders. Currently there are 20 participating and corresponding countries and 37 organizations in the Annex.

- Operating Agent
  Helsinki University of Technology, Finland
  Professor Liisa Halonen
- Subtask A Leader
  École Nationale des Travaux Publics de l'État, France
  Professor Marc Fontoynont
- Subtask B Leader
  Bartenbach LichtLabor, Austria
  General Manager Wilfried Pohl
- Subtask C Leader
  Centre Scientifique et Technique du Batiment, France
  Mireille Jandon and Ahmad Husaunndee
- Subtask D Leader
  Helsinki University of Technology, Finland
  D.Sc. Eino Tetri.

7 Deliverables

Deliverables of the Annex 45 will be Newsletter (published twice a year), seminars, website and guidebook of energy-efficient lighting.

More information of the Annex can be found from the Annex web-site: http://lightinglab.fi/IEAAnnex45 or from Liisa Halonen (liisa.halonen@tkk.fi) or Eino Tetri (eino.tetri@hut.fi) from Helsinki University of Technology.

8 REFERENCES

5. International Energy Agency. 2006. Light's Labour's Lost. IEA Publications, France. 360 p.
6. Mills E. 2002. Why we're here: The $320-billion global lighting energy bill. Right Light 5, Nice, France. pp. 369-385.
7. http://www.europa.eu.int/comm/energy_transport/atlas/html/lightdintro.html, accessed on 24.4.2004.
8. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings,
9. Govén T. 1997. Energy savings through improved lighting design and engineering. Right Light 4. Proceedings of the 4th European Conference on Energy-Efficient Lighting. Copenhagen, Denmark.. pp. 17-22.
10. Directive 2000/55/EC of the European parliament and of the council of 18 September 2000 on energy efficiency requirements for ballasts for fluorescent lighting.
11. Kaase H. 2004. Entwicklungstendenzen, Strategien und Visionen der Lichttechnik; LICHT 4/04; Germany.
12. Haitz R. 2001. Another Semiconductor Revolution: This Time it's Lighting; Proceedings of 9th International Symposium on the Science and technology of Light Sources; Ithaca, NY, USA.
13. Edited by Tsao J. Y. 2002. Light Emitting Diodes (LEDs) for General Illumination An OIDA Technology Roadmap Update 2002 September 2002 Optoelectronics Industry Development Association (OIDA) Sandia National Laboratories.
14. The Millennium Technology Prize. http://www.millenniumprize.fi/ accessed on 12.9.2006.

Naslov avtorja / Authors' address:

Liisa Halonen, Professor, D.Sc.(Tech.)
Helsinki University of Technology
Lighting Laboratory
P.O.Box 3000, FIN-02015 TKK, Finland
Tel. : +358 9 451 2418
Fax : +358 9 451 4982
Email : liisa.halonen@tkk.fi

Eino Tetri, D.Sc. (Tech.)
Helsinki University of Technology
Lighting Laboratory
P.O.Box 3000, FIN-02015 TKK, Finland
Tel. : +358 9 451 2420
Fax : +358 9 451 4982
Email : eino.tetri@tkk.fi

Florin Pop, Dorin Beu

ENERGY EFFICIENCY IN INTERIOR LIGHTING – A ROMANIAN CASE STUDY

Summary

The paper analyses the concordance between the regulations concerning the energy efficiency of interior lighting in buildings and the state-of-the-facts of the existing installations.

On the first part are presented the outcomes of a study based on the data revealed by the measurements in some residential and commercial buildings and the statistics and peoples' opinions (designers-constructors-owners surveys). There are also presented two studies related with the impact of the obstructions on the day-light illuminance level on the interiors and with the evaluation of interior lighting systems quality.

The second part is targeted to the involvement of the Lighting Engineering Center of the Technical University of Cluj-Napoca, Romania in two programs for promoting the lighting energy efficiency and saving measures in residential buildings: EnERLIn - European Efficient Residential Lighting Initiative, an EIE - SAVE program to promote the compact fluorescent lamps in the residential area, and CREFEN – Integrated Software System for Energy Efficiency and Saving in Residential Sector, a Romanian CEEX program. The efficient use of electric energy is still a neglected issue in residential sector, with a lack of both the necessary statistic data and the methodologies and tools for assessing, prognosis and training the specialists and consumers.

Povzetek

Energetska učinkovitost notranje razsvetljave – romunski primer*; Članek analizira skladnost predpisov na področju učinkovite rabe energije pri notranji razsvetljavi v zgradbah z dejanskim stanjem obstoječih inštalacij. V prvem delu so predstavljeni rezultati raziskave, temelječe na meritvah v stanovanjskih in poslovnih stavbah ter na statistiki in mnenju ljudi (načrtovalec – izvajalec – lastnik). Predstavljeni sta tudi dve študiji o vplivu ovir pred stavbo na nivo osvetljenosti z dnevno svetlobo v stavbi ter o oceni kakovosti notranje razsvetljave. Drugi del članka pa predstavlja vključevanje Centra za razsvetljavo na Tehnični univerzi v Cluj-Napoca, Romunija v programe za promocijo energetsko učinkovite razsvetljave in varčevanja z energijo v stanovanjskih stavbah: EnERLIn – Evropska iniciativa za učinkovito razsvetljavo v stanovanjskih prostorih, EIE-SAVE – program za promocijo uporabe kompaktnih fluorescenčnih sijalk v stanovanjih in CREFEN - integrirani programski sistem za energetsko učinkovitost in varčevanje z energijo v stanovanjskem sektorju, romunski CEEX program. Učinkovita raba električne energije v stanovanjskem sektorju je še vedno zapostavljeno področje, kjer primanjkuje tako ustreznih statističnih podatkov kot tudi metodologij in orodja za določevanje in napovedovanje razmer kot tudi za šolanje strokovnjakov in potrošnikov.*

1 Introduction

The building sector, particularly that of civil buildings, shows promising prospects of future development. The energy consumption for buildings systems - heating, cold and/or warm water supply, lighting and electric households - are two – two and half times greater in Romania then in EU countries. In the last years, there were developed specific regulations and norms to improve the thermal insulation of the building envelop. Many projects were and are financed by the WB (World Bank), BERD (European Bank for Reconstruction and Development), PHARE and ISPA programs to improve or refurbish the water supply network in many Romanian cities, the thermal insulation of the buildings, to enhance the thermal energy savings, the modernization of the schools, to improve the quality of the environment. Special laws were adopted by the Romanian Parliament to guarantee the obtaining of a higher level of the buildings quality – the Law nr. 10/1995 concerning the quality in constructions field and the Law 199/2000 concerning the energy efficiency in buildings. The legal frame for rehabilitation and modernisation of the buildings and their installations/services is a main component of the State Energy Policy of the government and it has to be harmonized with the international conventions related to the energy efficiency and environment protection. Based on the State Energy Policy, there will be established annually National Programs for the buildings rehabilitation, together with their installations/services. Therefore, there is a great demand for up-to-date technology and know-how for a resource-conscious building, renovation and energy planning.

2 A status of energy efficient lighting in Romania

Performances on efficient lighting in European Union. The EN 12464 (Lighting of work places) and EN 12665 (General terms and criteria for specifying lighting requirements) offer a new quality of further lighting installations – responsibility of the illumination design author for results of his work and responsibility of the users for proper maintenance of the installations. Their responsibilities will be under the legally and financially pressure. A minimum daylight factor is specified on the work plane so that at 3 m from the windows does not fall below 1%; this daylight will allow the use of suitable lighting controls to help manage and limit the energy use by electric lighting. The standard considers two zones on the working area – respectively the task and its immediate surrounding, the second being illuminated to at least 60% of that on the task. Comparative with a lighting system based on general lighting, a localised lighting system (for task area) with additional ambient lighting (for immediate surrounding) may fall the specific power from 10-15 W/m^2 to 6-10 W/m^2, representing about 50% savings (Govén 2001). Four EU countries - Belgium, France, Greece, and Netherlands – had a detailed calculation procedure for lighting as part of their building energy requirement (Littlefair & Slater 2002).

Lighting represents an important part of building energy consumption in the EU – around 10% of the total electricity consumption, ranging from 5% (Belgium, Luxemburg) to 15% (Denmark, Netherlands, and also Japan). The global electric lighting energy use may be split in four sectors: services 48%, residential 28%, industrial 16% and street lighting and other 8% (Mills 2002). Lighting systems design trends are dynamics both in time and between countries. The recommended illuminance level represents only one of the design parameters, but it is determinant for a lighting system and its energy consumption (Mills & Borg 1998)

Lighting electricity consumption accounts for about 20 to 30% of the total energy required by an office building (Fontoynont, Escaffre & Marty 2002). On average, the investment cost of lighting facilities for an office building works out at around 1 to 2% of total investment. The power density for standard fluorescent lighting installations varies from 13 to 20 W/m^2. Recent progress in equipment and design demonstrates the possibility to reduce these values in the range of 7 to 10 W/m^2 (Fontoynont, Escaffre & Marty 2002). A minimum acceptable lighting power density of about 7 W/m^2 will leads to annual lighting consumption of 16 kWh/m^2. Dimming or extinction of lamps of ambient lighting may lead to annual consumption below 10 kWh/m^2 (Fontoynont, Escaffre & Marty 2002). Based on the few comprehensive estimates studies, there is stipulated an approximate commercial sector lighting savings potential in the range of 25% to 40% (Mills 2002). In practice savings will vary by country, depending on existing baseline conditions. Energy saving measures in lighting must be accepted by the users and must be associated with an improvement of their standards working condition, having in mind even the fact that the annual lighting consumption of an office worker is of the order of one hour of the his/her salary cost (Fontoynont, Escaffre & Marty 2002).

National building energy regulations. The legal frame for an energy efficient lighting approach is constituted by the general set of laws, referring to the whole building or energy consumer: • Law 10/1995 “The Quality in Constructions Act” which establish the quality system, one of its compulsory regulations to be achieved and maintained during the entire life of construction referring to the law energy level of consumption and energy savings. • Law 199/2000 “The Energy Efficiency Act” according to the national policy on efficient use of energy, in conformity to the Energy Charta and Energy Efficiency and Environmental Protocol, which establish duties and stimulating measures for the energy producers and consumers regarding to its efficient use. The interior lighting installations are guided by two national recommendations – SR 6646-97 - *Artificial lighting* and NP-061-02 - *Guide for design and execution of the buildings artificial lighting systems*, following the CIE recommendations. Romanian norms include the recommended values of the illumination levels, maintenance factors and other parameters, but do not stipulate the specific requirement on energy efficiency for lighting equipment and systems, only the functional performance statement mentioned before: ‘to provide lighting systems which are energy efficient’.

Energy aspects. The average electric energy consumption was 515 kWh/person in 2003. At the level of the EU, according to “Energy efficiency indicators in Europe” – Odysee [1], the residential consumption in 2003 was 2533 kWh/household/year. We remark that in Romania this consumption is of about 40% of the EU level (see Figure 3 a). There is currently no information with respect to the electric lighting use in offices.

A measurement campaign at the local area in schools and offices (Pop&Beu 1998) stated a critical situation of the lighting systems, very old and out of right norms. Then, we promoted a long term information campaign through designers and building/electrical installations constructors, with the support of the national dealers and manufacturers, to improve their knowledge and to disseminate the results of the European programmes Thermie, Peco-Joule, Save.

A questionnaire related with the energy efficiency in lighting was spread through the local area of the Lighting Engineering Center U.T.C.-N., at about 50 lighting designers and dealers, receiving back 30 of them (Pop 2003). The answers refer to the offices and small manufacturers. The installed specific power was in the range of 13–22 W/m^2, and 3-5 W/m^2/100 lx for offices, too higher than standard values. There was no correlation with the daylight availability and users needs/presence due to the lack of interest from the owners. Some designers did not know the infrared control system. The weighted factors (in a 1-3 scale) for lighting features were the following: • *importance of the control facilities* – individual or building central - 1, zones of activity - 3; • *mention the specific power* – 3; • *high tech ballasts and lamps* – 2 to 3; • *mention/use of the proper lamps* (efficiency, colour temperature, colour rendering index) – 3; • *energy labels* – 1; • *maintenance schedule* – 1; • *photometric measurements* – 1 to 2; • *lighting installation history book* – 1. The national norms were considered unsatisfactory to acceptable.

This bad image of lighting efficiency is currently changing. The electric projects for modern buildings - offices, showrooms, commercial centres, schools - promote state of the art electric and lighting equipments, with high tech lamps, luminaries, control systems. High efficiency, standard levels of illuminances, the Buildings Energy Managements systems are the proof of this evolution. Romanian Educational Ministry promotes an intensive campaign, with the financial support of EU and WB, to modernise all the schools, at city or county locations.

3 Obstructions impact on office day-lighting illuminance

The design of an office lighting systems has to take into account the increasing number of furniture and equipment (obstructions) and the flexibility to suit to frequent changes. New design methods considering obstructions, were analysed under the frame of the CIE Technical Committee TC 3-31 ‘Electric lighting for real interiors’, chaired by Dr. Carter. Based on surveys and computer simulation, it was proposed a modified lumen method by using an obstruction factor. It is a function of the luminaries class and the ratio between vertical surface of obstructions and room area, being defined three kind of standard obstructions: light, medium and heavy (Carter, Leung & Lupton, 1995).

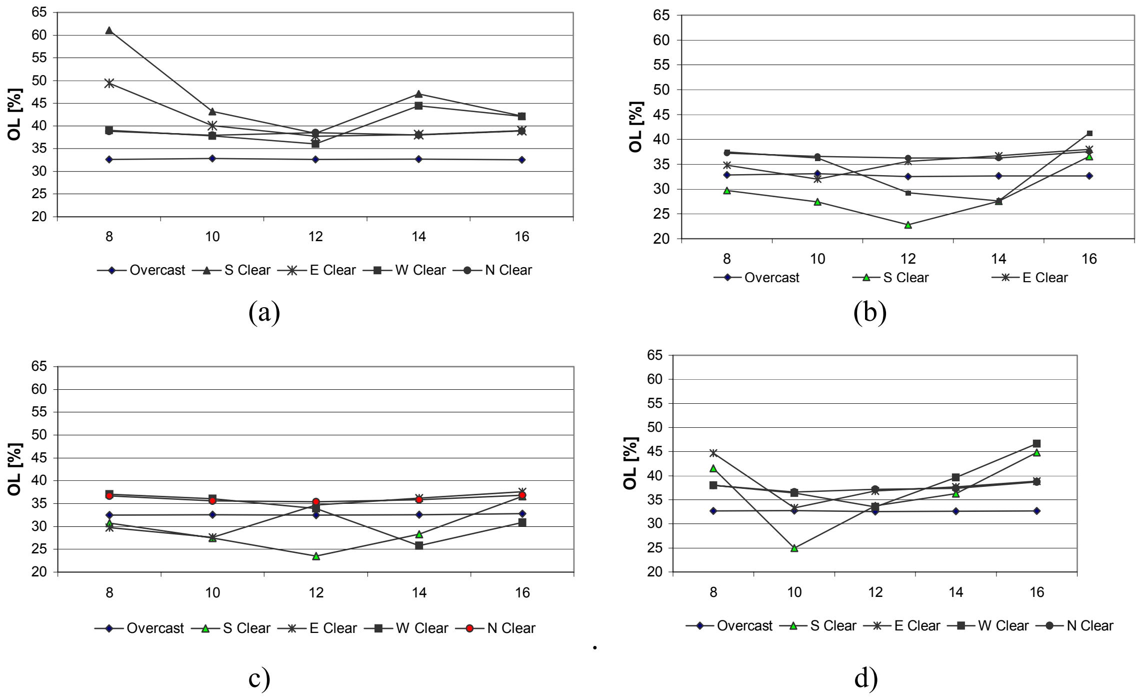


Figure 1: Obstruction Losses from 8 to 16
(a) on January 15th; (b) on April 15th; (c) on July 15th; (d) on October 15th

A research was targeted to the impact of obstructions on daylight average illuminance in offices based on computer simulation, using Lumen Micro software (Beu 2000, Beu & Pop 2002). *Obstruction Losses (OL)* factor was defined as the percentage reduction of the average working plane illuminance of furnished rooms compared with empty situation. The study was concerned to several parameters: standard obstructions; CIE sky conditions: clear, cloudy and partially cloudy; windows orientation: North, South, East and West; time of the day: 8, 10, 12, 14 and 16 for January, April, July and October 15th; presence or absence of electric lighting; obstructions orientation in relation with the windows; obstruction density and reflection; windows transmittance and dimensions; windows on one or two sides of the room. The results show important drops in average illuminance till 60%, which is a factor of concern for offices real illuminance.

Influence of the time of the year and obstruction type. Figure 1 shows the *OL* fluctuations during a day, from 8 a.m. to 4 p.m. for January, April, July and October 15th. It can be seen from these charts that *OL* for overcast sky is constant, but for clear sky there are high fluctuations. It also can be noticed that no matter the sky type, the *OL* are lower around 10 and 12 a.m., when sun altitude is near the maximum. From here a dependence relation between sun altitude and *OL* for South and West windows. For North windows there are minor daily fluctuations for clear and partially clear sky.

The chart shapes are changed for each period of the year. In some periods of the year, at 8 a.m. there are the highest *OL*, and in other periods there are the lowest *OL* The illuminance level reduction for overcast sky is not dependent of the time of the year, with average values of 32.81% for heavy obstructions, 27.37% for medium obstructions and 12.3% for light obstructions. In the morning, for partially overcast or clear sky and for North or West window orientation, illuminance reduction is not significantly influenced by the time. The highest fluctuation of illuminance reduction for 10 a.m. appears in the case of South or East windows, with a peak in the winter.

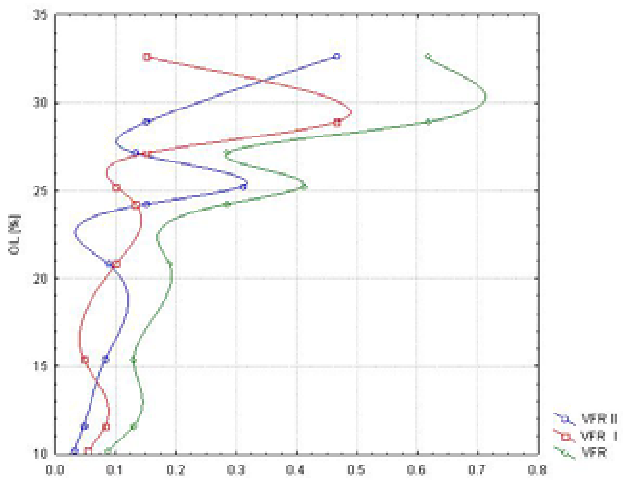


Figure 2: Obstruction Losses as function of $VFR_{||}$, $VFR_{\perp}$ and VFR (for overcast sky)

Influence of obstruction orientation in relation to the window. In the studies about obstructions in the case of electric lighting the *Vertical to Floor Ratio – VFR* factor was introduced as an expression of room content [5]. *VFR* is the ratio between obstructions vertical surface area above the floor area. We proposed for daylight to decompose *VFR* in $VFR_{||}$ for parallel surfaces with windows, and $VFR_{\perp}$ for perpendicular surfaces with windows. (NB: $VFR_{||} + VFR_{\perp} = VFR$). When the obstructions are rotated with 90°, the $VFR_{||}$ and $VFR_{\perp}$ swap, *VFR* remains constant, but *OL* drops in average with 3.6% for overcast sky and heavy obstructions and with 4% for partially overcast and heavy obstructions. So, the *OL* for overcast sky can be interpreted as function of $VFR_{||}$, $VFR_{\perp}$ and *VFR*. The chart from Figure 2 shows that the trend is different from the linear slope of *OL/VFR*, which is characteristic for electric lighting. However there is a relation of proportionality between *VFR* and *OL*, especially for light and medium obstructions, but which is no longer valid for heavy obstructions (presence of partitions). Despite these problems, the simulations have proved that a reduction of obstruction density lead to smaller *OL*, as the orientation of partitions from parallel to perpendicular to windows wall.

4 The Interior Lighting Evaluation System - ILES

The quality of a lighting installation would be described by several parameters: illuminance level and uniformity; direct glare control or avoidance (luminance distribution); appearance colour and colour rendition; modelling. The qualitative parameters have different weight, related to the room destination and architecture. The accent should be on: *visual performance*, choosing the right illuminance level and the glare avoidance; *visual comfort*, by the colour rendering and the luminance distribution; *visual environment,* by the selection of the light colour and direction and modelling.

Lighting quality is a multi-faceted concept. We assess it *directly*, by measuring its photometrical parameters, and, *indirectly*, using behaviour measures – for instance, responses to semantic differential scales or Likert-scale responses to statements of opinion. There are also many research studies proposing new methods and surveys devoted to identify a proper modality to refine visual performance and comfort models. However, since there are yet no comprehensive and objective measures of visual comfort; occupant surveys remain the most accurate way to assess the lighting installation not only by its photometric properties, but also by economic parameters and human behaviour. It is useful to simultaneously estimate photometric and economic (cost and energy) parameters, maintenance program and subjective evaluation of visual comfort.

Energy efficiency and quality do not automatically go hand in hand Greater lighting comfort for people in offices, for example, is often combined with a higher energy consumption. If a measurable (energy consumption) and a non-measurable (lighting comfort) parameter have to be weighted against each other, the non-measurable parameter comes under pressure (Zeguers, Jacobs 1997).

A lighting installation with good quality is energy-efficient whether permits a high level of performance without creating discomforts. *The light quality is not directly measurable, but it is a state generated by the link between environment and users.* A lighting has a good quality when: (1) there is a good visual condition; (2) it permits the accomplishment of the task or determines the behaviour in accordance with the environment; (3) assures the availability of the interactions and desired communication between the participants; (4) contributes to the aesthetics of the space. The evaluation of the lighting quality has to be made by the evaluation of its effect on the people, having in mind all the characteristics of the room space and the users.

Designed to be inexpensive, simple to administer, to score, and easy to interpret, the ILES covers a reduced number of parameters, but most important ones, and a rough scale of preferences. The system has two components - an objective photometric and energetic analysis LQED - Lighting Quality & Economic Diagnose and a subjective survey ULCS - Users' Lighting Comfort Survey.

(a) Its **objective component – LQED** – evaluates the photometric and energetic of the lighting system. This module may be used for in design to compare different variants and to offer an objective criterion to choose the better one.

Photometrical measurements. The physical data collection includes a general space inventory as well as measures of lighting – illuminance, luminance, daylight factor, and surface reflectance following the CIE standards.

Questionnaire concept. It is proposed a questionnaire following the reference models and answering to the specific questions, presented below:

Room: Destination; Dimensions; Daylight factor – average value; Ceiling/walls reflexivity
Equipment: Luminaries; Lamps - type, power, colour; Ballast; Installed power = Number of lamps x (Power + Ballast loses)

Photometric measurement: Average illuminance - norm/measured (designed); Illuminance uniformity - min/av.; Lighting source luminance; Luminance contrast - source/ceiling
Electric measurement: Voltage
Technical state: Lighting source - clean/dirty/painted; Installed power per unit - W/m^2 and/or W/(m^2·100 lx); Switching control – wall mounted/local, manual/automatic control
Maintenance programme: Is there a scheduled activity? Last date of the change of the lamps/luminaries - Yes / No; Cleaning period of the room/installation - Yes / No

The Quality Value Method. The quality of the lighting installation is influenced by different parameters. They cover the lighting quality – referred by its photometric parameters -, the lighting energy-effectiveness – referred by its economic parameters -, and the benefit of final users – referred by their comfort, pleasantness and productivity. The importance of different parameters varies inside of each of these groups and also between them. Following the Krochmann study (1990), there are proposed a method and a model for quantifying them into a final “quality value” number, by weighting the meaning of parameters and by evaluation of their levels.

The photometric parameters targeted to the lighting quality are: average illuminance, illuminance uniformity, modelling (cylindrical illuminance), lighting source luminance, luminance distribution (contrast) on the visual field, reflectance of the room surfaces – walls, ceiling, ground, luminaries protection angle, correlated colour temperature, colour rendering index and a lot of many others. Each of the parameters – noted with x – has a certain importance on the quality assembly, noticed by the *weighting factor* ***w(x)***, valued from 1 (lowest) to 10 (highest importance). Each of the parameters is evaluated in function with its effective value, compared with the standard, recommended or optimum value by the *scaling factor* ***s(x)***, valued from 1 to 10. Each of the parameters contribute to define the quality value of the lighting installation by the *quality factor* ***q(x)***, product of both specific factors

$$q(x)=w(x)\cdot s(x).$$

The effective quality factor of the installation is the sum of the quality factors of each component parameters $q_{ef}=\sum w(x)\cdot s(x)$, having the minimum - $\min q_{ef}=\sum w(x)$ -, and, respectively, the maximum value - $\max q_{ef}=10 \sum w(x)$.

The optimum quality factor of the installation is corresponding to the standard, recommended or optimum values, being the maximum value $q_{opt}=\max q_{ef}=10 \sum w(x)$.

The Quality Value, describing the overall quality of the lighting installation, is the ratio:

$$Q=\frac{q_{ef}}{q_{opt}}\cdot 10=\frac{\sum w(x)\cdot s(x)}{\sum w(x)}.$$

The scaling factor of each parameter x is defined by comparing the effective value, measured or designed, to the normalised value, recommended or admissible, and introducing the minimal/maximal values ratio:

$$s(x)=10\cdot\frac{\min\left(s_{eff},s_{norm}\right)}{\max\left(s_{eff},s_{norm}\right)}.$$

By using the ratio of the two illuminances, we take into account the following aspects: on one side, an installation which assures an illuminance level lower than the normalised value is under standard, but the rules concerning the illuminance are, as we all know, very elastic and conjectural (there are many working installations with illuminance levels well under the normalised values, accepted by the users); on the other side, an installation which assures an illuminance level higher than the normalised value does this by consuming extra electrical energy over the right balance. In both cases, the lighting installation will be qualitatively under-marked due to the involvement either of the photometrical aspect, or of the energetically aspect. The illuminance measured in a new installation is of 600 lx, designed for a normalised level of E_{norm}=400 lx. Introducing the maintenance factor of 0.8, the effective illuminance is considered E_{eff}=0.8·600=480 lx. The scaling factor becomes *s(E)*=10·400/480=8.3.

Of course, we may suppose that an installation is designed, executed or maintained so that its parameters should conform to the admissible/reasonable specific limits. For example, for offices it is recommended the use of some electrical (fluorescent) lamps with a colour rendering index of at least 80; it is absolutely improbable to design or keep in working state an installation equipped with lamps with an index of 50...60, because we may easily obtain the necessary lighting sources.

Evaluation of the weighting factors. The importance of different parameters is variable. The ILES user, according to the particular data of the room and the importance of the relevant component fixes the values of the weighting factors for the lighting system analysed.

A simple computer program allows us to obtain quickly the information necessary to evaluate the analysed lighting installation and its energetic balance.

A survey (Pop Mihaela&Pop 2002) with 100 people revealed the following values for the weighting factors of the quality parameters submitted to their attention:

1) Illuminance level on the working plane	9
2) Illuminance uniformity on the working plane	8
3) Space modelling	7
4) Luminance contrast - light source/ceiling	7
5) Luminance contrast - visual task/background	8
6) Distribution of illuminances in the visual field	8
7) Reflectance of the room surfaces (average weighted value)	6
8) (Correlated) Colour temperature of the lighting sources	8
9) Colour rendering index	7
10) Energetic efficiency	9

We would like to identify how lighting condition affect lighting economics and visual comfort of the users. The LQED module will be used to evaluate different variants of designed installations, to compare them on multiple aspects for having an objective criterion for choosing the best one.

(b) The **subjective component – ULCS** – must be simple to administer and score. For this a large number of former proposals have been analysed (some of them are presented in the mentioned bibliography) to identify the most important questions for defining a visual performance and comfort model. The complexity level of the corresponding parameters, and, implicitly, of the questions asked to the users, are determined by the knowledge level and, respectively, of education. It is useless to ask an uninformed user about certain aspects related to illuminance contrasts, colour rendering or interior space modelling.

The fulfilment of the comfort from a lighting installation is determined by parameter values that affect the visual task, visual comfort and environment. Some of them may be accurately measured, but others should be very subjective. *The visual satisfaction* describes on which measure the real visual conditions of the lighting are accepted by the users; it is determined the easiness which the work is performed and the pleasantness of the environment, both in the period when the attention is targeted to the visual task, and in the relax time. Of course, the luminous environment and the individual preferences affect the visual satisfaction.

To obtain the subjective opinions of the users there were selected the following questions. The answers are included in five options: inadequate, acceptable, good, very good, excellent or with two options: Yes/No, Comfortable/Uncomfortable, Disagree with/Agree with:

Is the day lighting sufficient?
Is the electric lighting sufficient?
The illuminance (light) is uniform on the working room surface?
Are you satisfied by the switching on/off modality?
Is the light appearance (brightness) of the luminaries adequate?
How do you appreciate the maintenance schedule of the lighting installation (cleaning, replacement of the failed equipment)?
Is the available light sufficient to read/write by hand/computer use/draw?
How do you appreciate the light environment of the room?
How do you appreciate the work lighting at your place (stand, desk)?
How do you appreciate the lighting in your working room comparing with the others?
Please notify on which room would you like to work/do you like the lighting installation?

5 EnERLIn - European Efficient Residential Lighting Initiative

The European Climate Change Programme (ECCP) identified residential lighting as an important area to CO_2 emission reductions. After a considerable number of promotion and rebate schemes, about 135 million CFLs are used today in European homes. However, only 30% of EU households have at least one CFL, with those households that own them having an average of three or four. The EnERLIn EIE SAVE program is aiming at promoting to all the stakeholders a quality charter to assure that the CFL that are marketed and promoted can deliver savings which last overtime and meet the customer expectations of high quality lighting, and the ultimate objective of the program is to substantially increase the efficiency of residential lighting in a number of Member States and Candidate Countries.

The residential lighting market is still dominated by inefficient Incandescent Lamps (GSL – General Service Lamps). The EnERLIn EIE SAVE program proposes to develop and validate robust scenarios for CFL promotional campaigns in European, national and regional levels. Concerning energy savings from CFLs, assuming that there is 150 million households in Europe the energy economy by replacing only one additional 75 W GSL by one 15 W CFL is in the order of 22.5 TWh or 4 MTEP per annum, this corresponds to 1.2 Mtonnes of less CO_2 per annum. We should add at these savings that a high quality CFL has a life span higher than 10,000 work hours, compared to 2000 work hours for a GSL.

The European Union initiated numberless campaigns to promote compact fluorescent lamps with the purpose of increasing the market share of compact fluorescent lamps at 15%. In this case, the estimated energy saving would amount to 15 TWh per year. This energy saving is similar to a reduction of annual CO_2 emissions of about 800 kTones CO_2.

Objectives of the EnERLIn action. Improving the energy efficiency is a central theme of energy policy within the European Community, as indicated in the White Paper "An Energy Policy for the European Union", since improved energy efficiency meets all the three goals of energy policy, namely security of supply, competitiveness and protection of the environment. Lighting represents an important part of building energy consumption in the EU – around 10% of the total electricity consumption, ranging from 5% (Belgium, Luxemburg) to 15% (Denmark, Netherlands, and also Japan).

The global electric lighting energy use may be split in four sectors: services 48%, residential 28%, industrial 16% and street lighting and other 8% (Mills 2002).

Overall electric appliances in households, industry and the tertiary sector represent 40% of the EU’s total electricity consumption, its generation being one of the most important sources of CO_2 emissions. Within the EU, the households and private and public services sector buildings are important power consumers. In both cases lighting represents a large part of their energy consumption. Several EU and National Initiatives and Directives tented to promote energy efficient lighting for services sector buildings. These efforts can be judged as very successful because nowadays the Compact Fluorescent Lamp (CFL) market share represent 20% of the global European market whereas the same figure in world scale is limited to 17%. The rate of the households owning a CFL covers the range from 0.8 CFLs per household in UK to more than 3 CFLs per household in Denmark; the SAVE projects have found that there is at least room for 8 CFLs per home (Kofod 2002, Loe & Jones 2002, *DELight* 1998). An analysis on the lighting pattern in 100 Danish homes denotes that the monthly average lighting consumption varies between 5% and 21% of the total respective monthly consumption, and 24% of the lamps are energy efficient lamps (linear fluorescent lamps or CFLs). However, the same market analysis from Lighting Companies show that in Western Europe energy inefficient incandescence lamps (including halogens) still represent 30% of the sales [13]. The bulk of these inefficient light sources concern the residential sector. In Romania there are two natural barriers to implement an energy efficient lighting by using CFLs: economical - the low level of average people income - and educational - the lack of common lighting knowledge even through educated people.

There are several reasons explaining that residential sector still use a large amount of GSLs:

- It seems difficult to convince individual customers that the payback time is so rapid.
- There are still many customers unaware of the environmental and economic benefits of CFLs.
- Low quality (and probably lower cost) CFLs are widely available in the European markets, the customers buying these devices due to the attractive price are very rapidly disappointed by the reduced lifetime, bad lumen output due to wrong information from manufactures about how to replace incandescent lamps, and bad lumen maintenance of these lamps.
- Older generation of CFLs were almost unable to offer to customers an acceptable ambiance within the residence, this due to poor colour rendering index, limited choice of colour temperatures, ungracious shapes and aesthetic incompatibility with luminaries; most of these inconveniences are now overcame but there is still a large part of customer unaware of that progress.
- For households lighting can be purely practical or a very architectural feature or a combination of both, therefore energy efficiency is often just one consideration and probably not the prevailing one.
- CFL lamps are not suitable for applications with short on-off cycles as this reduces lamp life; therefore it is necessary to educate the customer on how to use them effectively.
- The warm up time of the CFL before full lumen output does that the user should not use in a staircase or elsewhere where they need the full lumen output immediately.
- The common CFL lamps are very sensitive to voltage variation; of course, in many countries the mains voltage is very well regulated, but in other countries and especially eastern European regions the voltage may fluctuate and this is still an important issue for CFLs.
- Finding luminaries with nice design, suitable for CFLs, is in nearly all countries, a difficult issue; many nicely designed luminaries for incandescent lamps do not look equally nice if they are used with CFLs.

Promoting CFLs by using solid argumentation, which answer to the specific individual questions and fears of the customer and then add imitative measures seems to be the right way to act. It should be noticed here that “rational” arguments are not appropriate for all customer segments. To reach the last customer segment we need new CFL solution and new control features that create added value. To identify all possible reasons of using CFLs, compile them and provide the good answers (scientifically proved) and then translate them to a clear and understandable argumentation for the non-specialist, is the main barrier that needs to be addressed. Furthermore, barriers to information about energy-efficient technologies (including lighting) exist on several levels, each of which has implications for penetration rates. The most widespread problem in many countries, to varying degrees, is that of a lack of awareness of energy efficiency. Members of the general public simply cannot define what it means for a technology to be energy efficient. Information barriers are important to policy makers as well.

The ultimate objective of this program is to substantially increase the efficiency of residential lighting in a number of Member States and Candidate Countries, and this can be done by offering them good arguments necessary to overcome the above cited barrier. It is also important to promote the wide-scale availability of a high spectrum of low-cost CFLs suiting a wide range of needs including different sizes, shapes, colour rendering, wattage (particular problem in some counties like Hungary is that the typical good CFLs are of lower wattage and therefore provide limited illumination levels), and bases. Furthermore, to achieve successful residential market transformation we should promote that both light fixture outlets as well as design and specialty stores display their luminaries with CFLs (good and aesthetic ones) rather than GSL. At the same time the program is aiming at promoting to all the stakeholders a quality charter to assure that the CFL that are marketed and promoted can deliver savings which last overtime and meet the customer expectations of high quality lighting.

The major part of the program will design implement and evaluate a common promotional campaigns for CFLs that meet the European CFL Quality Charter along with dedicated fixtures. These national or regional campaigns shall be conducted in collaboration with lamp manufacturers, retailers, consumer and environmental organisations, and electricity utilities. On the other hand the elaboration of the argumentation should be based as deep as possible to quantitative and scientific arguments. This last, may lead to the creation or/and use of independent test facilities allowing to examine different proposed solutions before adopt them in the final argument list.

All the program objectives will lead to a higher market share for the most efficient CFLs and dedicated luminaries. The main stakeholders concerned by this program are manufacturers’ associations, consumers’ associations, buyer’s groups, energy agencies and other intermediates, utilities, training institutes, retailers, installers and other professions. The final beneficiaries will be end-users of equipment mainly in domestic sector.

EnERLIn Consortium. 14 partners from 14 countries constitute the proposed consortium, covering a large part of Europe form north to south and from east to west. This is an important issue; because, concerning lighting the reaction of the individual customers is quite different form a country to the other (north countries prefer low colour temperatures lamps –hot ambiance- and south countries are more sensitive to high colour temperatures –cold ambiance). The consortium includes western countries with high GDPs compared to eastern countries that they just integrated EU (Poland, Hungary, Czech Rep., Latvia and Estonia). These countries are in full market transformation at this moment. Finally, two candidate countries (Bulgaria and Romania) are also members of the consortium. The EnERLIn consortium is strongly cross-disciplinary including, National or Regional Energy Agencies (ADENE, KAPE, ENEA, SEC, SEVEn, BE), one ESCO in Belgium, academic institutions (France – the coordinator CPAT - University Toulouse 3, Hungary and Romania), a values-based consultancy focusing on sustainability (Respect) as well as independent consulting

SMEs (Ekodoma, Energy Saving Bureau). Each partner has solid experience with EU projects (especially from DG TREN), and strong links with international organisms like CIE and projects like ELI, other European networks (COST-529) and programs (GreenLight). Some consortium partners are quite influential for policy-making bodies in both national (regional) and European levels.

6 CREFEN – integrated software system for energy efficiency and saving in residential sector

The **CREFEN project** aims to creating an integrated software system-tool focused on the applications concerning the electric energy efficient use and saving in residential sector in Romania. The project integrates the consumption assessment and prognosis methodologies, consumption scenarios, consumers' guidance and training to the advanced technologies, sustainable electric energy management and the economical, social and environment impact, as well. A special issue is to develop the necessary databases of equipment and endowments from residential sector, using the market surveys and questionnaires.

The project aims to develop an advanced modeling and simulation software system-tool of electric energy consumption in residential sector and of economical effects, to implement an application with databases, an interactive educational application and electronic book related to the energy efficiency use in order to influence the consumers' options in selecting energy efficient appliances for environmental protection by reducing the CO_2 emissions.

The **National Strategy in the energy efficiency field** adopted by the HG 163/2004 underlines that the residential sector has a primary energy saving potential at 3.6 millions tones equivalent petrol through 6.8 million tones of the total final consumers; it means more than 50%. This potential can be capitalized by the rehabilitation of the buildings heating insulation, the improvement of the heating and lighting systems and of the electric domestic appliances. The legislative frame was created and is on line with the EU acquis, the EU Directives related to labelling of the energy parameters for many electric appliances.

The **Governmental Program** on the following years 2005-2008 states the necessity to accomplish the legislative and institutional frame in order to apply the flexible mechanisms adopted by the Kyoto Protocol, to pursue the implementation of the technical and economical measures for the reduction of the gas emission with the greenhouse effect, in accordance with the features of the National Plan for the Allocation of the Emission Quotas, the development of the National Plan for Climatic Changes Action, the improvement of the energy efficiency and the promotion of regenerate energies.

The **specific objectives** of the CREFEN project are:

- Drawing up of scenarios and prognosis of electric energy consumption in residential sector;
- Achievement of an advanced modelling and simulation software system-tool of electric energy consumption in residential sector and of economical and environmental effects;
- Using a tool for defining the potential of energy saving, prognosis and scenarios of consumption evolution;
- Improvement of the degree of taking into consideration by the consumers, decision factors and specialists of the opportunities, advantages of promoting new technologies in electric energy consumption in residential sector, in the framework of a sustainable development integrated at the European level;

- Designing and implementation of a web application with databases for domestic and lighting appliances available on the Romanian market, which include information from the energy label and sheet;
- Designing and implementation of the software for an interactive system and an electronic book.

The project is connected with energy efficient use according to EU directives from one side and with the implementation of database applications using web-based technologies for assisting and influencing the consumers decision in selecting the domestic and lighting appliances from the other side, that leading to sustainable environment management. The last aim of the project is for environmental protection by reducing the CO_2 emissions.

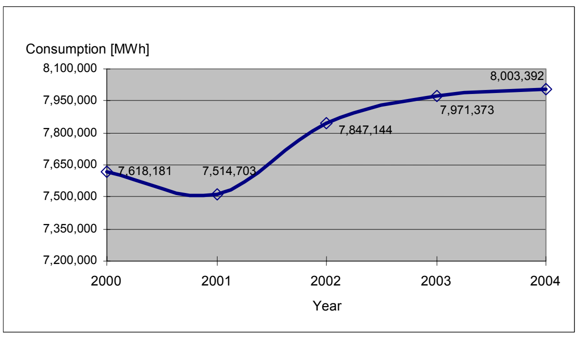
The software application architecture will be a modular one, with the possibility of its extension with new functionalities, without perturbing the other components or requiring the reorganization of the system data.

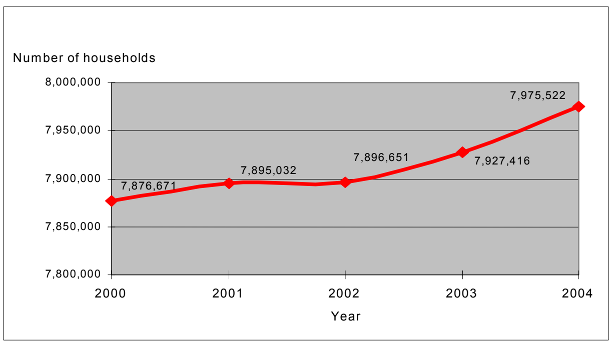
Lighting Engineering Center UTC-N work in the CREFEN project aims: (1) to analyze the Electric Lighting component in the energy balance of the dwelling; (2) to elaborate a simplified mathematical model for calculation of the inside electric lighting; (3) to present the IT system to technical background users groups (students, designers, dealers and retailers); (4) to contribute with the chapter Electric and Natural Lighting of the design specification for IT system; (5) to analyze the direct energetic and educational benefits and evaluate the importance and the impact of the improvement of the domestic users education; (6) to design consumption evaluation scenarios based on the evolution of the technological performances of the new lighting equipments (for 5 and 10 years); (7) to print an informing flyer concerning the electric and natural lighting component; (8) to promote the project achievements by workshops, the ‘Ingineria Iluminatului’ (Lighting Engineering) journal and the ILUMINAT international conference.

7 Analysis of electric lighting energy consumption in the residential sector in Romania

The statistic data [15] for the period 2000 – 2004 allow us to determine the variation of total household consumption – Figure 3 a –, total number of household consumers – Figure 3 b –, average consumption per household consumer – Figure 4 – and of the specific consumption per m^2 – Figure 5.

The analysis of the presented data allows us to estimate a few characteristics of electric energy consumption of households – Table 1.





a) b)

Figure 3 Variation of total household consumption (a) and total number of household consumers (b) in Romania 2000-2004

At the level of the EU, according to “Energy efficiency indicators in Europe” – Odysee [1], the residential consumption in 2003 was of 2533 kWh/household/year. We remark that in Romania this consumption is of about 40% of the EU level. e currently have little information with respect to the electric lighting contribution to the total energy consumption of the households in Romania. As estimation, we may count on the results of the study [4], according to which the electric lighting consumption represents around 25% of the total electric energy consumption of the studied households.

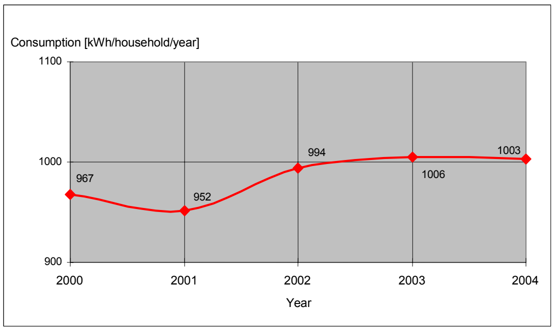


Figure 4 Average energy consumption 2000-2004

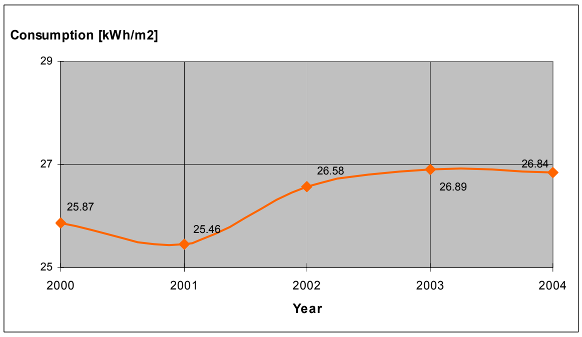


Figure 5 Household consumption per m^2 in Romania
* the average value of 37.39 m^2 per household in Romania has been considered.

Table 1 Characteristics of electric lighting energy consumption in households in Romania.

Year		**2000**	**2001**	**2002**	**2003**	**2004**
Total annual electric lighting consumption	[x10^3 MWh]	1,938	2,028	1,996	2,028	2,036
Annual electric lighting consumption per household	[kWh/household/year]	246	257	253	256	255
Annual electric lighting consumption per m^2	[kWh/m^2/year]	6.58	6.87	6.76	6.84	6.83
Annual cost of electric lighting consumption per household	[Euro/household/year]	38.57	39.57	39.19	39.47	39.42

Note: The total annual household consumption in Romania has been determined considering the sales of Electrical National Company towards the household consumers and the average contribution of the consumption on the lighting circuits (25%); The annual electric lighting household consumption per m^2 was determined based on the average household surface in Romania in 2002 – 37.39 m^2/household; an average exchange rate of 3.50 RON/Euro.

A comparison of the information presented in [7] to the data presented in this study is shown in Table 2. The increase in the annual household electric lighting energy consumption in 2004 vs. 2000, of 3.61%, correlated with the continuous increase of the number of household subscribers in Romania of 1.24% (2004 vs. 2000) – Figure 3 a, determine the necessity to adopt measures of energy efficiency in the household lighting of Romania.

The total energy consumption dropped from 60 TWh/year in 1996 to 33.8 TWh/year in 2005, according to the data received from the national company of electricity. For the same period, the weight of the residential consumption increased significantly, partly due to the massive reduction of industrial consumption after 1989, but as well, to a continuous increase of the number of household subscribers.

Table 2 Characteristics of electric lighting energy consumption in the residential sector in Romania; comparative study based on data in [1] and [7].

	DELight 1998	UTC-N 2005
Electricity consumption		
Total electricity consumption (TWh/an)	60.0 (1996)	33.8
Residential electricity consumption (TWh/an)	7.1	8.001
Residential lighting electricity consumption (TWh/an)	n.a. (1996)	~2.036
Household lighting – Information		
Household lighting electric energy consumption (kWh/an)	n.a. (1995)	~255.3
Number of lamps per household	9	11.5
Average number of CFL per household	0.006 (1995)	1.11
Household ratio using CFL	0.5 (1995)	0.47
Average number of CFL per household using CFL	1.1 (1995)	4.02
Number of luminaries per household	5.5	7.16
Households – Information		
Number of households ($x10^6$)	7.78 (1995)	7.97
Number of persons per household	2.91 (1994)	2.63 (2002)
Average surface (m^2)	n.a.	37.39
Prices	1996 (ecu)	2005 (Euro)
Price of electric energy per kWh 0 – 50 kWh	0.008	0.38
50 – 100 kWh	0.019	
>100 kWh	0.041	0.0921
Price of GSL	0.3 ecu	0.43 Euro
Price of CFL	13.2	4.3

Note: The average exchange rate of 3.50 RON/Euro has been used

The cost of CFLs mainly depend on their life span, the cheapest having a life of 3 years, the typical cost in Romania being between 2.9 – 4.3 Euro, and the more expensive ones have a life span of 8-10 years and a price of 8.6 – 11.4 Euro. Since the electric energy consumption of these lamps is much lower and has a much smaller cost (only 20% of the cost of GSL, the cost of the initial investment may be recovered in 3 – 12 months, depending on the cost of the CFL, after which up to 8.0 – 9.0 Euro per lamp per year is saved.

The use rate of CFLs is from 0.8 units per household in Great Britain up to over 3 units per household in Denmark. Projects from the SAVE programme consider as a reasonable upper limit the use of up to 8 units per household. An analysis of the residential lighting, realized in 100 households in Denmark, shows a lighting consumption of between 5% and 21% of the total monthly electric energy consumption of the household and the use of 24% saving lamps – linear fluorescent lamps and compact fluorescent lamps.

During November 2005 a study has been realized using feed-back reply forms concerning the usage degree of GSL and CFLs in households in Western Romania. We received 295 replies, namely 220 apartments (with 1–4 rooms) and 75 houses (with 2–more than 7 rooms). The light source equipment in these households is presented in Table 3.

Table 3 Light source usage statistics for GSL and CFLs in Romanian households.

Household		GSL		CFL		Installed power
Type	No.	Units	Average	Units	Average	kW
Apartment	220	2624	11.98	367	1.67	0.770
Single-family house	75	1088	14.51	196	2.61	1.028
Total	295	3712	12.58	563	1.91	0.835

The installed lighting power has an average value of 0.835 kW/household.

From the analysis of the data presented above we may conclude that the CFL energy saving lamps are bought by people with high earnings, which own houses. We consider the equipping degree with CFLs of approximately two units per household is high, and this denotes the interest of Romanian consumers for buying energy saving lamps.

8 REFERENCES

[1] Alexandru Adriana, coordinator. *CREFEN – Informatic integrated system for energy efficiency and saving in residential sector* – CEEX programme, Contract C608/2005, 2005-2008.

[2] Atanasiu B., Bertoldi P. *Report on Electricity End Use Consumption in New MS and CC in Tertiary and Residential Sectors*, July 2005, JRC - Ispra.

[3] Berrutto V., Bertoldi P. *European Commission energy-efficient lighting initiatives*. Proceedings of the 25th Session of the CIE (San Diego, USA, 25 June - 2 July 2003). ISBN 3901-90621-5.

[4] Beu D., coordinator. *Study concerning the energy efficiency of the residential electric appliances* – SEEC – Universitatea Tehnica Cluj-Napoca (RO), grant Gr 6113/2000

[5] Beu, D. *Lighting systems in obstructed spaces*. Ph.D. Thesis, Technical University of Cluj-Napoca, 2000

[6] Beu, D., Pop F., *Residential and Commercial Survey for a Romanian Energy Efficient Lighting Program*, ENEF 2002, Banska Bystrica, 2002

[7] Environmental Change Unit. *Domestic Efficient Lighting (DELight)*, University of Oxford (UK), 1998. ISBN 1-874370-20-6.

[8] European Commission. Commission Directive 98/11/EC of 27 January 1998 implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps, Official Journal L71, 10.03.1998, pp. 01-08.

[9] Leslie RP, Conway Kathryn M., 2000, The Lighting Pattern Book for Homes, Lighting Research Center, Reansealer Polytechnic Institute

[10] Lewis J.O., coordinator. *EnerBuild RTD Network* - FP5 programme, 2001-2003.

[11] Pop F. *Energy efficiency in lighting between regulations and reality*, Proceedings of Workshops Budapest, Prague, Warsaw, Newly Associated States EnerBuild RTD, 2003, ISBN 80-239-0742-5, pp. 38-42

[12] Pop F., Beu D., Ciugudeanu C. *Promoting actions for lighting energy efficiency and saving in residential buildings in Romania*, International Conference on Energy Efficiency in Domestic Appliances and Lighting – EEDAL'06, London, June 2006

[13] Zissis G., co-ordinator. *European Efficient Residential Lighting Initiative - EnERLIn*, EIE "Intelligent Energy – Europe" programme Grant EIE/05/176/SI2.419666, 2006-2008.

[14] Zissis G, Progress accomplished in the frame of EnERLIn project during the first 6-month operation, Ingineria Iluminatului, vol. 8, No. 17 - Summer, 2006

[15] Statistic data 2003. Romanian Statistic National Institute.

[16] U.S. Department of Energy, EERE Consumer's Guide Compact Fluorescent Lamps, Energy Efficiency and Renewable Energy

9 Naslov avtorja / Authors' address:

Dr. Florin Pop, professor
Dr. Dorin Beu, reader
Lighting Engineering Center, Technical University of Cluj-Napoca
RO 400020 Cluj-Napoca, 15 C. Daicoviciu Street
Romania
Tel.: +40745. 516276 (Pop); +40723. 661536 (Beu)
Fax: +40264. 592055
Email: florin.pop@insta.utcluj.ro
dorin_beu@cluj.astral.ro

Schanda J. and Madár G.

COLOUR RENDERING INDEX OF LED LIGHT SOURCES

Abstract

LEDs are widely used in signalling applications and in large surface displays. In recent times white light emitting LEDs start to become used in general lighting as well.

The spectral power distribution of white LEDs differs considerably from the power distribution of traditional light sources, thus it is not to wonder that the colour rendering index developed for classical fluorescent lamps does not works properly for LEDs. In our Laboratory we have investigated the colour rendering of traditional light sources and of LEDs of different construction (blue chip plus yellow phosphor and Red-, Green-, Blue-LED combination), both determining the colorimetric characteristics and evaluating their visual colour rendering properties. We could determine the differences between the mathematical method and the visual one.

We have developed a number of new methods to investigate the colour rendering characteristics of LEDs, among others based on colour harmony and a preference type of study, also using simulation techniques. This paper will show the methods we used, together with some examples how light sources with different spectral power distribution influence the visual appearance of an environment, and how this could be described.

Keywords: colour, colour rendering, LEDs.

Povzetek

Indeks barvnega videza svetil s svetlečimi diodami*; Svetleče diode (LED) so široko uporabljajo v signalnih napravah ter v velikih svetlobnih panojih. V zadnjem času pa se bele svetleče diode vse bolj uporabljajo tudi v splošni razsvetljavi. Spektralna sestava svetlobe bele svetleče diode precej odstopa od spektralne sestave svetlobe tradicionalnih svetlobnih virov. Zato ni čudno, če se postopek določevanja indeksa barvnega videza, ki je bil razvit za klasične fluorescenčne sijalke, pri svetlečih diodah ne obnese najbolje. V našem laboratoriju smo raziskali reprodukcijo barve pri tradicionalnih svetlobnih virih ter pri belih svetlečih diodah različnih tipov (modra LED z oranžnim fosforescenčnim premazom ter kombinacija modre, zelene in rdeče LED). Določili smo kolorimetrične lastnosti in ovrednotili njihovo vidno reprodukcijo barv ter prišli do ugotovitve, da obstaja razlika med matematično in optično metodo. Na podlagi tega smo razvili več novih metod za proučevanje barvne reprodukcije pri svetlečih diodah, med drugim temelječe tudi na barvni harmoniji in simulacijah. Članek prikazuje metode, ki smo jih uporabili, skupaj z primeri, kako svetlobni viri z različnimi spektralnimi vsebinami svetlobe vplivajo na vidno zaznavanje okolice in kako je ta vpliv možno opisati.*

Ključne besede: barva (svetlobe), barvna reprodukcija, indeks barvnega videza, svetleče diode

1 Introduction

The light source industry is currently in a major revolution, changing the light source construction from a glass (or ceramic) bulb and some gas filling construction to solid state. Several nations (Japan, USA) have started centrally funded projects to develop efficient solid state light sources: Light emitting diodes (LEDs) and organic light emitters (OLEDs). These sources have very different spectral power distributions (SPD) compared with traditional light sources, and to optimise these SPDs one needs the understanding not only of the technological questions of producing these sources, but also the lighting and visual perception issues coupled to these special SPDs. In the present paper we will deal only with inorganic LEDs, as these are already in the phase of development where they provide important competition to traditional light sources, but their application might end up in frustration if their special spectral characteristics are not well taken into consideration.

The three most important photometric and colorimetric characteristics of a general purpose lamp are: efficacy (output lumen per input watts), lamp-light colour (correlated colour temperature) and colour rendering (colour rendering index). While the first two of these descriptors provide the possibility to compare LEDs with traditional light sources without any difficulty, colour rendering is a different issue, due to the very different SPDs of the LEDs.

2 Colour rendering and its traditional descriptor

The CIE defined colour rendering in the International Lighting Vocabulary[1] as:

“Effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant.”

The first and most difficult problem of this definition is that it requires “a reference illuminant”, but leaves open the selection of the reference illuminant. The CIE Technical Committee that was responsible to develop the test method had long discussions on this question, because the selection of the reference illuminant has profound influence on the calculation result[2]. Finally it was decided to use black-body radiation of the same CCT as the test source CCT below 5000 K and phases of daylight above this CCT. This meant on one side that there are an infinite number of reference illuminants, and that e.g. an incandescent lamp with a CCT of 2900 K will have the same good colour rendering as natural daylight. Ever since making this decision, the question has been debated, but no acceptable solution was found.

A second problem was that the definition calls for colour appearance comparison, but no colour appearance difference metric has been accepted internationally up to now.

For practical reasons the CIE finally decided to describe colour rendering in the form of average colour differences – in those days in the U*, V*, W* colour space[3], defining eight test samples with low chroma and six further ones (high chroma and often encountered colours). A short description of the history of the colour-rendering index (CRI) can be found in [4].

First major problems of the current colour rendering index method were encountered at the time when the three-band fluorescent lamps were introduced: the narrow band emission spectra of these lamps, developed specially to achieve a high colour rendering index and efficacy, did not give good visual colour rendering[5,6,7,8,9,10]. As LED sources have also narrow band emission it was not surprising that the current colour rendering index determination method does not work well with LEDs.

3 Types of white LEDS

LEDs are characteristically narrow band emitters, with spectral bandwidth of 30 nm to 50 nm. White light can be produced with such sources in two forms: using a short wavelength emitting LED (near UV or deep blue emitting one) and a phosphor that converts part of this light into longer wavelength radiation (p-LED), so that the mixture of the radiation of the LED itself and that of the phosphor layer produce white light. The other possibility is to mix the light of three well selected LEDs, a red-, a green- and a blue-emitting one (RGB-LED), eventually taking also a fourth, orange-yellow LED (RYGB-LED) to fill up a gap in the emission spectrum between the green and the red emission. Spectra of such representative LEDs of high CCT is seen in Figure 1. The p-LED and the RGB-LED have low CRI, the RYGB-LED has a much higher CRI.

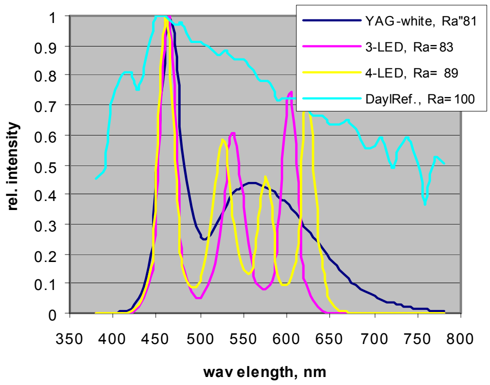


Figure 1: *Representative spectra of a p-LED and an RGB-, as well as RYGB-LED, together with the reference daylight spectrum.*

At this place we can not deal with the problems of colour stability of 3 and 4 LED combinations, we just would like to mention that this needs active feed-back circuits, but from the colour rendering and efficacy point of view the RYGB-LEDs are very promising.

4 Colour rendering index of the LEDS

Figure 2 shows approximate colour reproductions of the eight basic CIE test samples if illuminated by the reference and the three LEDs. Figure 3 shows similar colours for the six supplementary colours: strong red, yellow, green and blue, as well as complexion and leave green. In every sample the $\Delta E_{ab}*$ colour differences between the test sample illuminated by the reference illuminant and the particular test source can be seen. (The author is indebted Dr. Yoshi Ohno for lending the program that enabled the reproduction of these colours.)

Figure 2*: Approximate colour reproduction of the eight basic CIE test samples by the three selected LEDs, who's SPDs are shown in Figure 1.*

	TCS09	TCS10	TCS11	TCS12	TCS13	TCS14
Ref.						
p-LED	8.5	0.9	8.3	15.2	1.1	1.1
RGB-LED	16.8	3.8	2.3	23.0	1.3	3.2
RYGB-LED	7.3	0.4	4.5	15.7	1.7	1.3

Figure 3: *Approximate colour reproduction of the six supplementary CIE test samples by the three selected LEDs, who' SPD is shown in Figure 1.*

As it can be seen the RGB-LED is particularly poor in case of the reddish and blue hues. Visual inspection not always supports this statement, especially if the reflectance spectrum of the test sample differs from that of the CIE test sample's reflectance spectrum, as is often the case if real life samples are considered. To test this we have prepared metameric samples by printing on two different ink-jet printers and a laser printer. An example is seen on Figure 4..

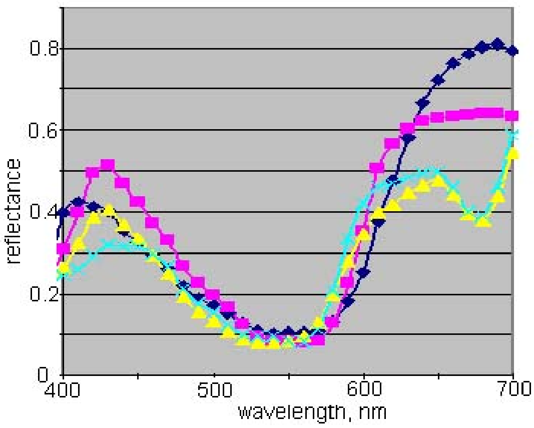


Figure 4: *Metameric samples used in colour rendering calculations.*

Using such metameric samples colour rendering indices were calculated for a number of light sources[11]. As can be seen in Figure 5 just in case of the critical R_a=75 to 80 range the sample spectrum has a profound influence on the CRI.

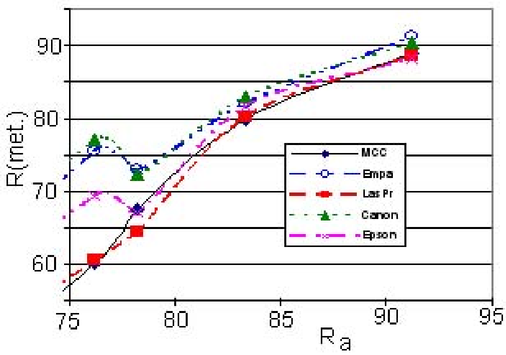


Figure 5: *Metameric CRI versus classical CRI for a number of sources.*

5 Updating the CIE test method

During the past decades several attempts were made to update the test method for colour rendering determination.

Investigations were carried out to test the usefulness of the CIE Test Samples[12,13,,14,15] and the chromatic adaptation formulas[16,17], testing the method for practical sources as well[18]. CIE tackled the question several times, technical committees were established, and after five to ten years closed down, as they could not find a solution that every party would have agreed upon. The last such committee, CIE TC 1-33, was established in 1991 and closed down in 1999. It was unable to recommend a new colour rendering index formula, but published its closing remarks[19], and in this publication formulated some ideas that could provide guidance for future research.

Visual experiments were performed already before the new proposal (see e.g. [20]) and further experiments were started[21,22] partly to get an alternative description of colour rendering[23]. These experiments have shown that there are certainly better ways to describe the colour rendering properties of light sources, especially of white LED sources, where the white colour is produced by mixing the light of some red-, green- and blue LEDs. The CIE Division 1, responsible for light, colour and vision decided not to change the current colour rendering index calculation method, but to develop a new descriptor, such as “colour appearance rendering” or “colour quality index”. A Technical Committee was established in 2006 to investigate this question.

6 Supplementary methods to describe colour quality of light sources

The wish to supplement colour rendering with further quality descriptors is not new. Judd coined the term flattery index already in 1967[24]. The flattery index was intended to describe whether a light source renders colours in a more pleasant (flattery) way then an other source. Jerome discussed the differences between flattery and rendition in detail[25]. Later the word *preference* was used instead of flattery[26]. Thornton’s calculation showed that colour rendering and colour preference indices do not have their optimum value at the same spectral distribution[28]. Some experiments tried to combine the colour preference and colour rendition aspect in such a way that the maximum of colour rendition remained if the test source had the same SPD as the reference illuminant, but the worsening of the index was slower if the colour difference between the sample illuminated by the test source compared to the illumination by the reference illuminant deviated in the direction of higher chroma, or e.g. in case of complexion towards redder hues[27]. Other ideas went into the direction to develop a colour discrimination index, as there are a number of tasks where the discrimination between small colour differences is important[28,29]. All these can be supported by simulation experiments[30]. Also Davis and Ohno published on improved colour quality metrics[31].

The comfort experience in an interior setting is also influenced by the colour quality of the lighting. Bellchambers investigated visual clarity[32] and found correlation between visual clarity, illumination and colour rendering. Other investigations tried to correlate the different aspects of lighting quality as well (see e.g.[33]).

An interesting new approach is based on the hue shift of many colours that shows which hues are highly distorted compared to a reference and which are rendered correctly[34,35].

7 Colour quality simulation

Our recent studies go in a similar direction by starting from the supposition that if a designer has carefully chosen the colours of an environment to be pleasant under one light source, i.e. the observer gets a harmonious impression of the environment, then an other light source will be accepted if after chromatic adaptation the colours of the environment stay harmonious[36]. We based our experiments on McCann's observation that when the shift of each colour in a set goes in a systematic order (e.g. all hues shift in the same direction, or all colours get lighter or darker, or all chroma increases or decreases) the result is more acceptable compared to a colour distortion when the colours move in different directions in colour space.

Figure **6** shows this on an example of McCann[37]: Compared to the original the copy on the right side was made lighter and more yellow; in the copy on the left the average colour difference to the original is of the same value, but hue, lightness and chroma of the single patches was moved in arbitrary directions.

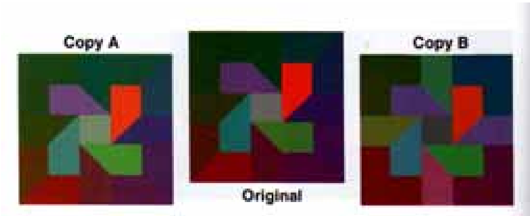


Figure 6: *McCanns experiment demonstrating that a systematic change in colours (Copy A) looks better then a random one (Copy B).*

Similar effects are produced by changing a reference source to a test source in illuminating a multi coloured test sample.

Figure 7 shows the shift in hue and chroma for a harmonious set of colours (Munsell "diminshing series"), due to changing the illumination from the reference illuminant to an LED test illuminant[38].

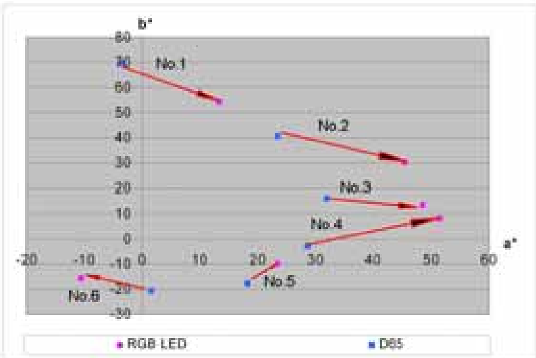


Figure 7: *Color coordinates of a Munsell harmonious set called "Diminishing series" under a reference illuminant (blue squares), and under a white RGB LED light source (pink circles).*

While the rather large change in colour for the yellow and reddish hues would not be perceived as unpleasant if only the patches Number 1 to 3 would be seen, but the colour shift of patch Number 4, 5 and 6 distorts the harmony of the arrangement.

The development of a reasonable colour appearance model[39] enables the display of scenes transformed to that under a reference illuminant on a visual display unit. We have performed such simulated scene comparisons, requesting observers to compare a scene as would look under a reference illuminant (CIE D65) and under a test illuminant. Table 1 shows the selected sources and their correlated colour temperature

Table 1: *Light source characteristics used in the present experiment*

Description of light source	Correlated colour temperature, K	Ra
CIE A	2856	100
CIE D65	6505	100
FL 3.5	4086	96
FL 3.12	2984	93
FlLamp	7226	87
CIE FL 7	6497	86
CIE FL 11	3999	83
p-LED (cool)	9310	80
p-LED (warm)	2976	77
CIE FL 2	4225	64
CIE FL 4	2938	51
RGB-LED1	2788	44
RGB-LED2	2788	27
RGB-LED3	2788	-17

In this new experimental paradigm the image of a scene was selected, where the spectral reflectance was known for every pixel. In the present experiment we used an image kindly supplied by Nascimento and co-workers[40]. Figure 8 shows the image rendered as it would look under D65 illumination. The test images were calculated from this hyperspectral image, using the SPDs of the sources enumerated in Table 1.

Figure 8: Image used in the present experiment.

The white point of the generated test image is the white point of the test illuminant it was calculated under. The main concept of the simulation is that all images are shown in the same chromatic adaptation environment (CRT display) to eliminate factors such as colour memory effects that can affect the result of the experiments negatively. The CIECAM02 colour appearance model was used to transform both images (illuminated by the test and the reference illuminant) to D65, the white point of the monitor. This way the differences between the colour appearances produced by the test illuminants, independently of the CCT of the source could be observed and judged.

7.1 Experiment

In the experiment to be discussed here three images were shown simultaneously on the screen at one time in two rows. There were two images in the upper row and there was one in the middle of the lower row. The lower image was fixed and showed the reference image. The observers’ task was to answer the question that from the two test images shown in the upper row which one was more similar to the reference image than the other one.

For each test person all images were shown in random order paired with all other images. This enabled to rank order the light sources, using Thurstone's method of paired comparisons[41], to evaluate lamp-light quality compared to an ideal illuminant (Illuminant D65, as it is generally accepted that best colour fidelity is achieved under daylight illumination)[*].

Table 2: *Result of the experiment*

Visual Rank Order	Description of light source	Correlated colour temperature, K	Colour rendering, Ra
Ref.	CIE D65	6505	100
1	FlLamp	7226	87
2	CIE FL 7	6497	86
3	CIE FL 11	3999	83
3	FL 3.5	4086	96
5	p-LED (cool)	9310	80
6	CIE A	2856	100
7	p-LED (warm)	2976	77
8	FL 3.12	2984	93
9	CIE FL 2	4225	64
10	CIE FL 4	2938	51
11	RGB-LED1	2788	44
12	RGB-LED2	2788	27
13	RGB-LED3	2788	-17

Statistical significance of above data will be discussed in a more detailed report.

8 Discussion

Analysing the results shown in Table 2 one can draw the following conclusions:

Sources with high CCT got high ranking, although CCT is not the only factor influencing the quality index: warm white sources, as p-LED (warm) and FL 3.12 got higher ranking than CIE FL 2, a source of higher CCT, but with relatively low CRI.

But colour rendering index is also not the ordering parameter: CIE FL 11 and FL 3.5 have almost the same CCT, but the source with lower CRI was ranked higher than the other. The same can be seen in case of the p-LED and FL 3.12.

The relatively good ranking of the two p-LEDs shows clearly that CRI is not a good descriptor of lamp-light quality, a statement often heard as anecdotic remark.

The three RGB-LEDs rank at the bottom of the scale, having also low CRI values.

[*] A second experiment, dealing with colour preference, will be discussed in an other paper.

9 Conclusions and work in progess

Our simulation experiment showed clearly that the method of showing the images of one scene as it would look under different illuminants – but after chromatic adaptation – is a valid method to investigate lamp-light colour quality.

Experiments are under way in three directions:

1. Using other scenes, especially one where humans are also in the picture, as complexion colour is one of the most significant colours for both colour rendering and colour preference.
2. Selection of sources will be slightly modified: four colour (RYGB) LEDs will be included, and both at low and high CCT three and four colour LEDs will be simulated.
3. With the most critical sources the simulation experiment will be supplemented with real-life situations, using our double booth experimental set-up, that we used to show that the present CRI test method fails for quite a number of sources, and that the colour difference evaluation in the CIECAM02 space gives better correlation with visual observation[42].

We hope that based on such experiments, and using our colour harmony experiment results as well, it will be possible to come up with a lamp-light quality index that correlates better with visual evaluation than the present CIE CRI Test Method.

10 Acknowledgements

Authors would like to thank the Miescher Foundation for its continuous support. They are also indebted to OSRAM Opto Semiconductors for kindly supplying some LEDs used in the oral demonstration of this paper.

11 References

1 CIE International Lighting Vocabulary. Publication. *CIE* **17.4**-1987.

2 Ouweltjes JL. (1969) Chromatic adaptation and colour rendering of light sources. *Compte Rendu 1st AIC Colour Congress „Color 69" Stockholm* 831-838.

3 CIE (1974) Method of measuring and specifying colour rendering of light sources. Publication *CIE* **13.2** (TC-3.2) 1974.

4 Schanda J (2006) Colour rendering of light sources. Chapter 8 in Colorimetry – Understanding the CIE System, ed.: J Schanda, Wiley under print.

5 Thornton WA. (1971) Luminous and colour-rendering capability of white light. *J of OSA* **61** 1155-1163.

6 Koedam M, Opstelten JJ, Radielovic D (1972) The application of simulated spectral power distributions in lamp development. *J. IES* 285-289.

7 Opstelten JJ, Radielovic D. Wanmaker WL (1973) The choice and evaluation of phosphors for application to lamps with improved color rendition. *J. Electrochem. Soc.* **120** 1400-1408.

8 Walter W (1977) Optimum lamp spectra. *IES Techn. Conf.* Aug. 1977 New York.

9 Verstegen J. Radielovic D, Vrenken LE. A new generation of "deluxe" fluorescent lamps combining an efficacy of 80 lumens/w or more with a color rendering index of approximately 85. A Survey of Phosphors, **121**/12, 1627-1631.

10 Valberg A; Seim T; Sällström P (1979) Colour rendering and the three-band fluorescent lamp. Annex 6 to Circular 2/80, Meeting of the CIE 1979, Kyoto, August, 26 p.

11 Schanda J and Sándor N (2003) Colour rendering, Past - Present – Future. Cap Town Colour Conf.

12 Opstelten JJ (1980) The dependence of the general colour rendering index on the set of test colours, the standard observer and the colour-difference formula. *Lighting Res. & Technol.* **12** 186-194.

13 Schanda J (1985) The influence of the test samples used for calculating colour rendering indices. *AIC Congress COLOUR* Monte Carlo, 6 p.

[14] Rea MS, Robertson AR, Petrusic WM (1990) Colour Rendering of Skin under Fluorescent Lamp Illumination. *COLOR Res. & Appl*. **15** 80-92.

[15] Hisdal B (1993) Colour samples and colour rendering of light sources. *Lighting Res. Technol.* **25** 13-17.

[16] Fuchida T, Mori L (1982) Comparison of correcting methods for chromatic adaptation used for color-rendering specification. *COLOR Res. & Appl.* **7** 294-301.

[17] Schanda J (1982) Chromatic adaptation and colour rendering. *CIE Journal* **1**/2 30-37.

[18] Guo X, Houser KW (2004) A review of colour rendering indices and their application to commercial light sources, *Lighting Res. Technol.* **36** 183-197.

[19] Commission Internationale de l'Eclairage: *Colour rendering*, TC 1-33 closing remarks. *Publ. CIE* **135**/2 1999.

[20] Kambe N, Mori L (1971) Visual judgements of color rendering properties of light sources. *Proceedings of CIE*, Barcelona **21A**, 135-140.

[21] Sándor N, Bodrogi P, Csuti P, Kránicz B, Schanda J (2003) Direct visual assessment of colour rendering. *Proc. CIE Session San Diego* 2003, CIE Publ. CIE **152:2003** D1-42-45.

[22] Sándor N, Csuti P, Bodrogi P, Schanda J. Visual observation of colour rendering. *Proc. CIE Symposium '04*, LED light sources. CIE **x026:2004** 16-19.

[23] Yaguchi H, Takahashi Y, Shioiri S (2001) A proposal of color rendering index based on categorical color names. *Internat. Lighting Congress,* Istanbul 2001.

[24] Judd DB (1967) A flattery index for artificial illuminants. *Illum. Engng* **62** 593-598.

[25] Jerome CW (1972) Flattery versus rendition. *J. of IES* April 1972 208-211.

[26] Thornton WA (1974) A validation of the color-preference index. *J. IES* 48-52.

[27] Schanda J (1985) A combined colour preference-colour rendering index. *Lighting Res. & Technol.* **17** 31-34.

[28] Thornton WA (1972) Color-discrimination index. *J. of OSA* **62** 191-194.

[29] Schanda J, Czibula G (1980) New description of color discrimination properties of light sources. *Acta Chromatica* **3**/5 209-211.

[30] Davis W, Gardner JL, Ohno Y (2005) NIST facility for color rendering simulation. *Proc. AIC Colour 05* Part 1. 519 - 522.

[31] Davis W and Ohno Y (2005) Toward an Improved Color Rendering Metric, *Proc. Fifth International Conference on Solid State Lighting,* SPIE Vol. **5941**, 59411G.

[32] Bellchambers HE (1972) Illumination, colour rendering and visual clarity. *Lighting Res. & Technol.* **4** 104-106.

[33] Schanda, J (1978) Colour rendering and the impression of comfort with artificial illumination. *Information Couleur*, **3**/2 23-28.

[34] Kemenade JTC, Burgt PJM (1988) Light sources and colour rendering: additional information to the Ra-index. *Nat. Lighting Conf.* Cambridge – 1988.

[35] Kemenade van JTC, Burgt van der PJM (1995) Towards a user oriented description of colour rendition of light sources. *Proc. 23rd Session of the CIE*, CIE**119**/1. 43 - 46.

[36] Schanda J, Madár G, Sándor N, Szabó F. (2006) Colour rendering - colour acceptability *6th Internat. Lighting Res. Symp.* On Light and Color, Florida Feb. 2006.

[37] McCann J (2002) A spatial colour gamut calculation to optimise colour appearance. In Colour Image Science, Exploiting Digital Media, ed.: LW MacDonald and MR Luo, John Wiley & Sons, Ltd. Chichester UK.

[38] Szabó F, Bodrogi P, Schanda J (2006) Comparison of Colour Harmony Models: Visual Experiment with Reflecting Samples Simulated on a Colour CRT Monitor. CGIV2006 Conf. Leeds.

[39] CIE (2004) A colour appearance model for colour management systems: CIECAM02. CIE Publ. **159:2004**.

[40] Nascimento SMC, Ferreira F and Foster DH (2002) Statistics of spatial cone-excitation ratios in natural scenes. *J. Opt. Soc. Am. A*, **19** 1484-1490.

[41] Thurstone LL (1927) The Method of Paired Comparisons for Social Values. *J. Abnormal and Social Psychology* **21** 384-400.

[42] Sándor N, Schanda J (2005) Visual colour-rendering experiments. *Proc. AIC Conference*, Granada pp.: 511-514.

Authors address:

dr. Madár, Gábor
dr. Schanda, János
University of Pannonia
Egyetem u. 10.
H-8200Veszprém, Hungary

Anna Pellegrino

LIGHTING CONTROL SYSTEMS TO IMPROVE ENERGY PERFORMANCE AND ENVIRONMENTAL QUALITY OF BUILDINGS: LIMITS AND POTENTIALS

Summary

Over the last few years, the use of electric lighting controls and, in particular, daylight responsive controls, has become widespread thanks to growing interest in strategies and technologies aimed at realising “sustainable” buildings, where the goal of reducing energy consumption is associated with achieving high environmental quality. Furthermore, new international standards underlining the need to reduce energy consumption as well as the importance of considering lighting control, have increased interest and attention to these systems - from designers, building owners and public authorities. Unfortunately, expected results in buildings are rarely obtained, partly due to technical limits or design, installation or commissioning mistakes and these systems often prove difficult for users to accept.

A review of lighting control is covered in the paper.

Povzetek

***Sistemi za regulacijo razsvetljave z namenom izboljšanja izkoristka in okoljske kakovosti stavb**; V zadnjih letih se uporaba sistemov za regulacijo razsvetljave povečuje, še posebej sistemov za regulacijo razsvetljave v odvisnosti od dnevne svetlobe. Razlog za to je povečan interes za strategije in tehnologije, povezane z razvojem in izvedbo trajnostnih stavb, kjer je glavni cilj zmanjšanje porabe energije in doseganje visoke okoljske kakovosti. Poleg tega je povečan interes za tovrstne stavbe pri načrtovalcih, lastnikih in javni upravi tudi posledica novih mednarodnih standardov, kjer se poudarja potreba po varčevanju z energijo ter pomembnost uporabe regulacije razsvetljave. Na žalost pa je zelo težko doseči pričakovane rezultate, tudi zaradi tehničnih omejitev, slabega načrtovanja ter napak pri izvedbi. Tovrstne sisteme pa dostikrat zavračajo tudi uporabniki stavb. V članku je podan pregled sistemov za regulacijo razsvetljave.*

1 Introduction

Use of automatic systems to control buildings, plants and services, in particular in non-residential buildings, has been proposed as a natural evolution of automation processes developed for industrial production, since the eighties. The introduction of automatic control systems seemed to offer real opportunities to raise the overall building quality, in particular concerning the improvement of building functionality and environmental conditions.

Interior lighting came out as a possible application field for automation systems: lighting requirements of a space can change during the day or year in relation to its functions, activities carried out, daylight availability or actual space usage. In order to respond to different lighting requirements users can manually switch on, off or dim luminaires, but being able to automatically control lighting, independently from the occupant’s actions, seems to be a potentially interesting challenge.

Introducing partially or completely automatic systems to control or integrate electric lighting and daylighting might help, from a theoretical point of view, in getting advantages such as the increase of visual and thermal comfort or decrease of energy costs. Energy savings can be achieved thanks to both a reduction of luminaires electrical energy consumption and, in air-conditioned buildings, a lowering of the thermal load produced by electric light sources.

The problem of energy conservation has been a recurrent topic since the seventies. Over the last few decades the importance of reducing energy consumption has achieved new implications concerned with both the need of preserving natural resources and the link that exists between energy consumption and climatic changes.

Over the last few years, there has been a growth of interest towards strategies and technologies aimed at realising “sustainable” buildings, where the goal of reducing energy consumption is associated to achieving high environmental quality. Furthermore, this trend is supported by new international standards that underline the need to reduce energy consumption as well as the importance of achieving high environmental quality levels.

Lighting control products have been available on the market since the eighties, however their popularity has so far been limited and often restricted to industrial or large office buildings.

Recently, interest towards new solutions for electric lighting and daylighting control has been increased by the diffusion of new architectural design trends and accessibility of new technologies and products. In building design trends, there has been a significant and growing interest in the use of highly glazed facades, implying more daylight availability inside buildings and, consequently, the need for more control of a resource that, beyond its many advantages, can lead, when not controlled, to considerable discomfort from both visual and thermal points of view (glare, overheating, etc). With control technologies, the steady diffusion of dimmable electronic ballasts for discharge lamps, evolution of communication protocols and growing diffusion of new lighting trends such as dynamic lighting and coloured lighting, have boosted the choice in new control lighting products. At present, most luminaires manufacturers have a line of products for lighting control in their catalogues. Depending on the size of the company it can range from very simple devices to complex building automation systems, and this demonstrates that there are further expectations of growth for the lighting control systems market.

2 Lighting control and the quality of lighting design

A new phase of the cultural debate on the significance of a lighting project began in the nineties: the definition of the concept of lighting quality took on a value that went beyond purely illuminating engineering aspects [1] [2] [3] [4].

Agreement has traditionally been reached on recognising that light has an influence on:

- vision;
- visual performance in carrying out a task;
- subjective behaviour;
- determination of a state of mind;
- health;
- formulation of an aesthetical evaluation.

An illuminated environment, characterised by a good quality, should therefore:

- create optimal perception conditions;
- create optimal conditions for carrying out an activity or precise visual task;
- favour correct behaviour;
- contribute to the determination of appropriate states of mind;
- favour healthy conditions and avoid phenomena that are dangerous for one's health;
- contribute to the creation of an appreciable aesthetic environment, taking into consideration and valorising the architectonic characteristics.

Considerations from the 1998 CIE Symposium on Lighting Quality [1] have made the concept of lighting quality a more holistic approach, apart from falling back on the sphere of visual comfort and related criteria (illuminance, light distribution, glare, etc.), greater importance has been given to the role of aspects, not directly dealing with lighting, underlying the multidimensional nature of the lighting design. In the proposed model (Fig. 1) the definition of lighting quality encompasses the spheres of human needs, architectural integration, and environmental/ economic constraints.

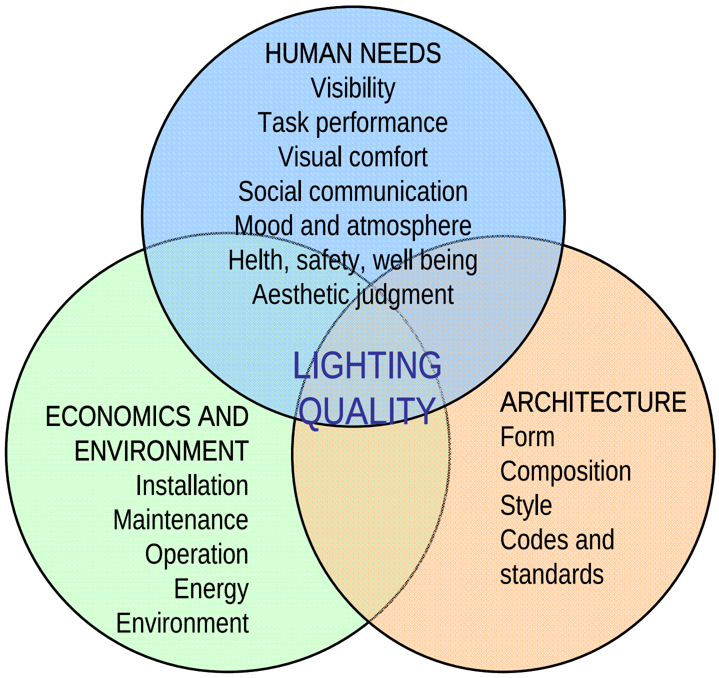


Fig. 1 – Lighting Quality definition developed at First CIE Symposium on Lighting Quality [4]

Within this framework it is clear that the use of lighting controls might have a positive influence on the global quality of lighting design. These systems are intended to increase the flexibility of lighting and optimise energy consumption, taking into account actual space occupancy and daylight availability during different hours of the day or different periods of the year. In modern buildings lighting needs and preferences may change from hour to hour and from day to day, different tasks may occur in the same space, a number of different people may use the same workplace and this requires a flexible lighting system able to provide variable lighting levels.

An ideal lighting control system increases the quality of lighting design ensuring proper and constant lighting conditions for different requirements, and eliminating energy waste, with positive consequences on both the sphere of human needs and the sphere of environmental/economical implications.

If we move from a theoretical to a practical analysis, we see that the use of control systems implies greater complexity: their operation depends on the presence of distributed and centralised “intelligences” (sensors, pc and software etc.) that regulate the behaviour of controlled components (luminaires, shading devices, etc.). Control device characteristics, installation and commissioning can heavily influence system performance and then later the actual quality of lighting design.

When assessing the implication of control systems on lighting quality, we should consider users’ response and their degree of acceptance. Lighting conditions automatically generated by control systems may not correspond to occupants’ requirements; it could lead to physiological or psychological discomfort and, consequently and in many cases, to deactivating automatisms.

If we take possible design, installation and commissioning errors to the extreme we could easily imagine cases for which control systems do not ensure comfort conditions and energy costs are increased, rather then reduced.

3 Lighting control and European energy codes requirements

The issuing of European directives and technical standards underlying the need to reduce energy consumption in buildings is one of the main factors that contributed, over the last few years, to increasing the development and application of lighting control systems.

Directive 2002/91/EC of the European Parliament and Council on the energy performance of buildings, came into force at the beginning of 2003 [5]. The directive was inspired by considerations on the importance of energy consumption in Europe and aims to contribute to reducing consequent polluting emissions in order to meet the Kyoto agreed targets. Buildings in Europe use over 40% of the global amount of energy and, according to the European energy commissioner, a cost-effective savings potential of around 22% of present consumption can be realised by 2010 [6].

The Directive objective is to improve energy performance of buildings, by requiring:

- a methodology to calculate integrated energy performance of buildings
- minimum energy requirements for new buildings
- minimum energy requirements for large existing buildings being renovated
- energy certification of buildings
- regular inspections of building’s plants (heating and air-conditioning) [7]

As far as a methodology to calculate energy performance of buildings is concerned, every government shall establish a calculation method based on a general framework incorporating several aspects: thermal characteristics of the building, heating installation, air-conditioning installation, ventilation, built-in lighting installation, etc. Where relevant in the calculation, the positive influence of free contributions shall be taken into account and daylight availability in buildings can significantly contribute to improving energy performance of electric lighting installations.

The European Committees for Standardisations (CEN, CENELEC and ETSI) are currently working on implementing methodologies to calculate the integrated energy performance of buildings. As far as energy consumption related to electric lighting is concerned, the CEN TC169 is preparing a standard (prEN 15193: Energy performance of buildings – Energy requirements for lighting) [8] devised to establish conventions and procedures for the estimation of annual energy requirements of lighting in buildings. The standard can be used for existing buildings, newly designed or renovated buildings and it takes a "dynamic" use of electric light into account, considering both daylight availability and space occupancy. According to European Directive guidelines, the TC 169 is implementing a method that - despite maintaining the simplification necessary to guarantee design applicability - sharpens the calculation of energy consumption concerning use of artificial light management systems based on the integration of natural light or user presence. Once obtained, the estimate of energy consumption of the lighting plant contributes to defining world energy performance regarding certifying the building.

Still within the overall framework of tools to implement the indications in the European Directive, a technical procedure is included that establishes the provisions and methods for estimating the impact of "building automation" systems on energy performance and energy use in buildings (prEN 15232: Calculation methods for energy efficiency improvements by the application of integrated building automation systems) [9]. The standard underlines the role of building automation systems in increasing functionality and energy efficiency systems, including obviously artificial lighting plants and screening systems of direct sun radiation.

In addition to indications emerging on energy certification of buildings, greater awareness about adopting lighting control systems is also due to indications published in a recent technical set of rules disseminated in lighting-technique circles. The standard CEN 12464 "Light and lighting – Lighting of work places – Part 1: Indoor work places" [10], in the section *Criteria for lighting technique design* at point 4.9 – energy saving – cites that a lighting plant must correspond to lighting requirements of a particular area without wasting energy. While in the section *Lighting requirements for indoor, visual tasks and activity*, use of equipment with adjustable light flow is recommended for school buildings facilities (school classrooms, evening classrooms and reading rooms).

4 Limits to the popularity of lighting control systems

Despite the potential benefits of using lighting control systems to reduce lighting energy and enhance lighting quality, their application on a large scale has not yet been achieved, and this lack of diffusion is particularly true in Italian buildings. Furthermore, it is quite common to come across buildings where the controls have been disabled because of occupants' complaints against their use.

Going further into the analysis, it is possible to outline the most relevant aspects that may have had a negative influence on the use of lighting controls [11]. Often architects or lighting designers are not well informed about existing control technologies (features and potentials of different solutions, operating characteristics of each component, etc.). Lighting controls must be compatible with existing lighting equipment (luminaires, lamps, ballasts and wiring) and since lighting and control components can be obtained from multiple vendors, the designer must be knowledgeable about their interactions. Lack of awareness implies a difficulty in choosing and designing appropriate solutions for each specific application (offices, schools, hospitals, etc.) and, as a consequence, the necessity to rely completely on systems manufactures' technical staff.

Other influencing factors can be related to the complexity of the commissioning phase and occupants' response. Controls must be reliable and work correctly virtually all the time and most of them require careful commissioning to ensure that they operate according to design intents. Simple sensors such as occupancy sensors or daylight sensors should be calibrated in their sensitivity or delay time; building automation systems, controlling for instance both electric lighting and shading devices should be carefully programmed, taking into account all influencing factors (building orientation, obstruction, shading characteristics, space functions, space occupancy, user needs and preferences, etc.). Initial commissioning is usually done by the system supplier's technical staff but, considering the complexity of the application field, it is quite hard to believe that a single intervention could optimise the system operation. The need for continuous intervention from external professionals could sometimes induce facility management staff to disable control systems, in particular if their efficacy in reducing lighting energy costs is not demonstrated or their use causes occupant complaints.

Occupant complaint is the other relevant issue for successful use of lighting control systems. As far as environmental conditions are concerned, user needs and preferences are always different, but this is particularly true for lighting. An automatic lighting control, based on preliminary or standard calibration, may not take into account the complexity of space articulation, tasks and activities, or user needs, and may easily fail in achieving the expected results. Over the last few years the issue of matching users preferences, as far as environmental conditions are concerned, and control behaviour, has been faced by several research centres with the idea of developing autoadaptive systems, able to “learn” from occupants behaviour how to control environmental parameters (thermal and lighting conditions, glare protection, etc.) [12] [13] [14].

Although lighting controls are increasingly considered not just for saving energy, but also for improving visual comfort, occupant mood and generally as a real amenity for people living and working in buildings, their efficacy is still mainly assessed on economic benefits related to building operation costs. Designers, however, can't easily evaluate actual savings achievable by adopting a lighting control system, and this may further discourage from introducing them in new projects or existing buildings.

5 Assessment of lighting control systems performance

Generally speaking, information available to designers to assess a control system's performance in saving energy is strictly based on advertising material from manufacturers. Catalogues and technical product literature frequently publish the percentage of reduction in consumption compared to the installation of a completely manually controlled plant. This information is very general concerning the chance of saving energy through using control systems, but it is obvious that it is not enough to estimate real performance resulting from applying the system to one specific case.

An accurate estimate of energy performance, and therefore the efficiency of a lighting management system, depends on several factors, linked to the specific characteristics of the building it is being designed for, as well as the characteristics of the system itself (control strategies, type of control devices, etc.).

When the system includes interaction by natural and artificial light, the following come into play:

- exterior daylight availability, that depends on:
  - the space's latitude and longitude,
  - day of the month and hour of the day,
  - sky conditions (overcast, clear, intermediate, etc.)
- amount of natural light present, that depends on:
  - exterior daylight availability,
  - presence of exterior obstructions,
  - orientation of the environment (if necessary, the presence of direct solar radiation should be considered)
  - presence of shading devices,
  - configuration of the environment and layout of work places,
- usage characteristics, eg:
  - occupation profile,
  - interaction between users and screening components,
  - interaction between users and lighting plant,
- characteristics and performance of lighting plant (typologies of luminaires, distribution of light in the environment, etc.)
- typology and architecture of the control system (control based on occupation, presence of natural light, user interest, pre-defined settings, etc., typologies of adopted sensors, groupings of terminals, etc.).

Every estimation method is based on the assumption that energy use depends on power, which is the rate of electricity consumption, and time, which is the period of consumption.

When the control system includes integration of natural and artificial light, the estimate of its performance is based on calculating the amount of natural light in the environment and, consequently, on the estimate of the amount of artificial light necessary for correct integration (ie to guarantee constant luminance corresponding to conditions of visible comfort).

A simplified calculation can be done starting from the average daylight factor, and availability of diffused external light, gathered from data concerning the locality in consideration or through specific calculation algorithms. Comparing the availability of natural light with occupancy times, it is possible to determine the amount of light that should be emitted from the lighting plant on a time basis and consequently the electrical power absorbed (having previously defined the artificial lighting plant's characteristics). Summing up hour consumption concerning each environment under control, it is possible to determine the building's overall annual consumption.

A simplified approach of this type depends on many influencing factors, previously listed like:

- contribution due to direct solar radiation,
- influence of movable shading devices,
- variations linked to different orientation of the space,
- different obtainable performance with different typologies of control systems (eg. combined presence of day light sensors and occupation sensors)
- user interaction with the space and system.

On the other hand, it makes a simple and relatively quick, general confrontation between design solutions with and without natural and artificial light integration systems.

A more complete approach is that proposed by the draft European standard (prEN 15193: Energy performance of buildings – Energy requirements for lighting). This also deals with a relatively simplified, manual calculation method for the estimate of an indicator of annual energy performance of a building’s artificial lighting plant.

The draft standard proposes two assessment methods that include the occupation profile of the environments and potentialities of control systems in exploiting free contributions from natural sunlight:

- *a quick method* which allows the estimation of annual lighting energy consumption of a building. The luminaires power is “weighted” on the basis of dependency factors related to occupancy, daylight availability and type of control system, and default values for each factor are provided for different types of buildings.

- *a comprehensive method* which allows for a more accurate determination of the lighting energy estimation for each building room or zone and for different periods (monthly or annual). Here too, the luminaires power is “weighted” on the basis of dependency factors related to:

- natural light coming into the environment (diffused component); determined on the basis of the real calculation of numbers of hours of daylight autonomy and referring to geographic position, taking into consideration the building’s geometry, obstructions, transparent component characteristics, and identifying the spaces that most benefit effectively from natural light;
- occupation profile; assessed considering environment purpose, possible user behaviour, plant characteristics, etc.;
- criteria covering light control (manual, automatic, automatic shading, with sub-division of equipment groups, etc.)

Even though there is greater detail in analysing the building characteristics and designed control system, the influence of the factors cited is considered in the calculations through use of table values, referring to certain building typologies, location and control criteria.

Both methods consider the luminaires power, which provide power for functional illumination, and the parasitic power, which provides power for lighting control systems and charging batteries for emergency lighting.

Both the methods proposed by the standard depend on some of the aspects that contribute to determining the system’s performance, ie:

- the influence of components for controlling natural light, (eg. movable shading devices);
- the influence connected to the ways a user interacts with the artificial lighting plant and shading devices.

Also the availability of natural light and control system characteristics are estimated according to a tabular approach and therefore a high level of approximation.

On the other hand, the methods proposed by the draft standard provide a standardised approach, useful for a general estimate of the performances of a lighting plant in the presence of a control system (quick method), or for a more detailed calculation and a comparison with different design solutions (comprehensive method).

As well as manual calculation methods, designers can turn to calculation software, developed at international research centres. These include, by the way, Lightiswitch [15] [16] and Energy Plus [17]. Despite the fact that this software considers aspects of the problem that are generally neglected in manual calculation methods, like user control of the systems or the presence of solar screening, none allows the user to thoroughly assess all possible variables that, in real buildings, compete to determine lighting plant consumption in the presence of control systems.

Determining real energy saving potentials of any lighting control device or system is not an exact science, since their performance depends on how they are applied and used. However more accurate information on actual potential energy savings and availability of easy and reliable evaluation methods could increase designers’ awareness and confidence in choosing lighting control systems for both new or renovated buildings.

6 Conclusions

Interest in control systems and natural and artificial light integration has recently increased, as has choice in products and solutions by lighting system manufacturers and companies from the automation sector.

Nevertheless, frequently systems installed in tertiary buildings (office blocks, schools, etc.) have been deactivated or tampered with following users’ non acceptance and dissatisfaction with performance, but also by the impossibility or difficulty to interact with the system. This lack of success is due to an uninformed choice of system or to it being unsuitable for tasks carried out in the environment or user characteristics, incorrect design of system architecture, choice of components that don’t always communicate, or not last, the difficulty to programme each component or entire system. Customers and designers are often doubtful about these systems’ real efficiency when considering the frequently high installation costs.

The Politecnico di Torino’s Department of Energy research in this sector is in fact inspired by these considerations. The last objective in this activity is to draw up guidelines for the light control systems project mostly for use by architects and lighting designers. The guide will cite results of both specific theoretic and trial studies currently underway as well as aiming at providing support for designers on:

- state of the art of currently available control systems;
- calculation methods for energy performance;
- information on environmental and energy performance, degree of acceptance and ways of interaction between systems and user, in real situations.

7 References

1. CIE x015-1998, Proceedings of the First CIE Symposium on Lighting Quality, 9-10 May 1998, National Research Council Canada, Ottawa/Ontario, Canada
2. Veitch J.A., 2001, Psychological processes influencing Lighting Quality, Journal of the Illuminating Engineering Society, Vol 30, n.1, pp124-140
3. Boyce P.R., Human factors in lighting, 2nd Edition, Taylor & Francis, London, 2003
4. REA, M. S., The IESNA Lighting Handbook. Reference & application, Ninth Edition, FIES editor in Chief , New York, 2000
5. http://ec.europa.eu/energy/demand/legislation/buildings_en.html,
6. CIBSE Briefing 6, The Energy Performance of Building Directive, Chartered Institution of Building Services Engineers, 2003, London (www.diag.org.uk/pdf/CIBSE_Briefing.pdf)

7. Corrado V., Serraino M., Applicazione della nuova normative sull’efficienza energetica degli edifici. Commenti al nuovo quadro legislativo e alla normativa, Rockwool Italia S.p.A., Milano, giugno 2006, (www.rockwool.it)
8. CEN-TC 169, prEN 15193 – Energy performance of buildings – Energy requirements for lighting, Bruxelles, 2006
9. CEN-TC 247, prEN 15232 – Calculation method for energy efficiency improvements by the application of integrated building automation systems, Bruxelles, 2005
10. CEN 12464, Light and lighting – Lighting of work places – Part 1: Indoor work places
11. AAVV, Advanced lighting guidelines, New Building Institute, California, 2003, *http://www.newbuildings.org/lighting.htm*
12. Guillemin A., Morel N., An Energy-Efficient Controller for Shading Devices Self-Adapting to the User Wishes, Building & Environment 37(11), pp 1091-1097 (2002)
13. Guillemin A., Using genetic algorithms to take into account user whishes in an advanced building control system, These n° 2778, Ecole Polytechnique Fédérale de Lausanne, (2003)
14. http://www2.polito.it/ricerca/ftarch/symp_IEA/3%b0%20sessione/pdf/Rosemann.pdf
15. Reinhart C., Lightswitch-2002: a model for manual and automated control of electric lighting and blinds, Solar Energy, 77 (2004)
16. http://www.buildwiz.com/lightswitch/
17. www.eere.energy.gov/buildings/energyplus

Avtorjev naslov / Author's address:

dr. Anna Pellegrino,

Professor at politechnica di Torino,

Italy

Christian Bartenbach

LIGHTING OF SPACES WITH VDT´S CONSIDERING THE REQUIREMENTS AND PROCESSES OF VISUAL PERCEPTION

RAZSVETLJAVA PROSTOROV Z VDT UPOŠTEVAJE ZAHTEVE IN PROCESE VIDNEGA ZAZNAVANJA

Le Corbusier once said: „The right light at the right place at the right time.“

It is not certain if he intended to differentiate between day-lighting and artificial lighting. But one thing is certain: the appearance of any interior depends largely on the lighting – and most of the time it is daylight.

Why do we spend so much effort in designing functional and aesthetically pleasing electrical lighting? Nevertheless, most spaces appear to be quite different at night – when there is no daylight.

Day-lighting is without doubt the preferred option. At least subconsciously we move closer to the windows whenever we can. Transparent openings should, however, comply with a wide range of very particular requirements. They should contribute to optimal visual conditions at the work place, e. g. they have to assure the appropriate amount and distribution of daylight, provide protection against direct sun, provide optimal conditions regarding glare and visual connection to the outside, and finally they have to perform the conflicting task of permitting sufficient visible transmission while blocking out heat.

A number of project examples highlight the different options of how to control daylight by means of reflectors, louvers and various types of prismatic panels. These examples range from air terminals, to subway stations, from museums to exhibition halls, from a plenary hall to office buildings, and even underground parking lots.

A study with the aim to utilise direct sun light in underground spaces shows how to use heliostats tracing the sun to redirect sunlight via mirrors and lenses for the benefit of people working in windowless spaces. It is possible to illuminate a room of about 60 – 80 m2 with about 600 – 800 lx with one heliostat of 1m2 surface area.

Another potential use of sunlight has been realised in narrow courtyards. By using reflectors at the bottom as well as on the window cladding a virtual image of the sky can be reflected into the lower floors of a building contributing greatly to the natural illumination of the interior.

One of the difficulties when using computer screens near windows is to find a balance between the low intrinsic brightness of the screen compared to the high luminance values of the unprotected window. Besides fixed or adjustable shields installed outside, there is a range of options utilising re-directing blinds or prismatic panels installed in the windows which provide glare control, sun protection and plenty of daylight where it is needed – across the entire room.

In some cases it is possible to do away with the cooling system altogether. This requires an intelligent system and excellent collaboration between the architects, lighting designers and the engineers responsible for the air conditioning system.

During a period of four years Bartenbach LichtLabor has carried out a series of tests with about 1600 persons to establish a correlation between different types of windows respectively systems controlling daylight and their effect on people. The results show a considerable increase in efficiency when intelligent day-lighting systems are employed compared to unprotected windows. Visual perception is a mental process and the less mental effort we have to make to correct the negative effects of unsuitable blinds the more mental energy is available to carry out the task at hand.

Currently we are working on a number of research projects with the aim to improve the utilisation of daylight. We expect that such systems will become the norm in the not too distant future. The combined benefits of the effects of daylight on humans and the considerable savings on the refrigeration load of the AC system will be the drivers for this development.

Needless to say, such intelligent systems can best be utilised in conjunction with a state-of-the-art lighting control system. But that appears to be part of the standard design brief already.

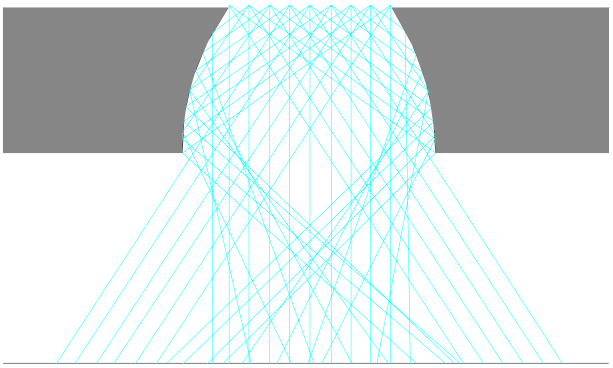


Fig. 1

(Ray tracing of natural light controlled by skylight with parabolic reflectors assuring high efficiency, perfect shielding and glare prevention and controlled light distribution.

Fig. 2

Integral daylighting and artificial lighting at Zurich Airport (Arch. Keller, Bachmann + Partners, CH).

The suspended annular ring serves to redistribute some light to the ceiling. At night a warmtone light source is used to generate a higher comfort level.

Fig. 3

The stations of the Metro in Copenhagen (Arch. KHRAS Architects, DK), are located underground and are illuminated – at least partially – with natural light.

Fig. 4

For the Design Center in Linz a special sun protection system was developed together with Prof. Herzog. With a g-value (energy transmission) of 0.15 and a light transmission of 45% it meets all requirements. It consists of a specular louver that is located between the glazing of the insulating glass of the roof structure.

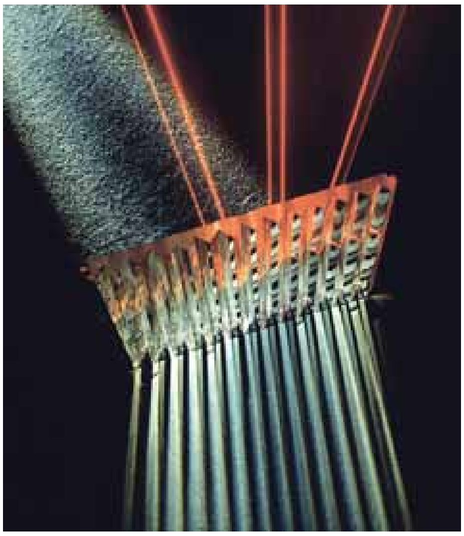


Fig. 5

In the "House of German History" in Bonn – an exhibition hall with a glazed roof - designed by the architects Rüdiger + Rüdiger, prismatic panels were integrated into the glass roof. Thus daylight is allowed to enter the building without causing glare or permitting direct sunlight to enter. Also, UV rays had to be blocked to meet the stringent requirements regarding conservation.

Fig. 6

The plenary hall of the German Federal Government in Bonn by architects Behnisch & Partners, was realised with exterior sun-shading lamellas. These prismatic panels trace the movement of the sun and thus allow skylight to enter the building without any glare while blocking direct sunlight.

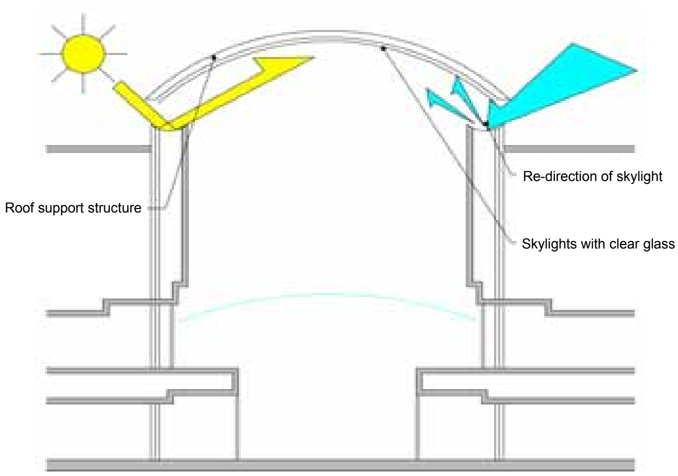


Fig. 7

A principal study of a building providing a suitable geometry for daylighting requiring only one reflector.

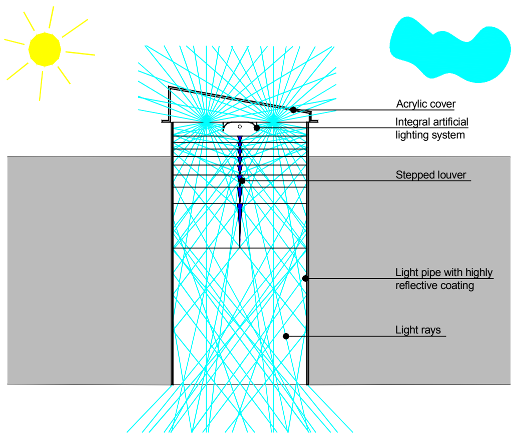


Fig. 8

A system developed by BLL incorporating mirrors and prismatic panels allows the utilisation of sunlight and skylight. This so called solar utilisation results in a higher light transmission while keeping the total energy transmission low. Excellent light distribution and glare-free lighting are assured with the dynamics of natural light in the interior.

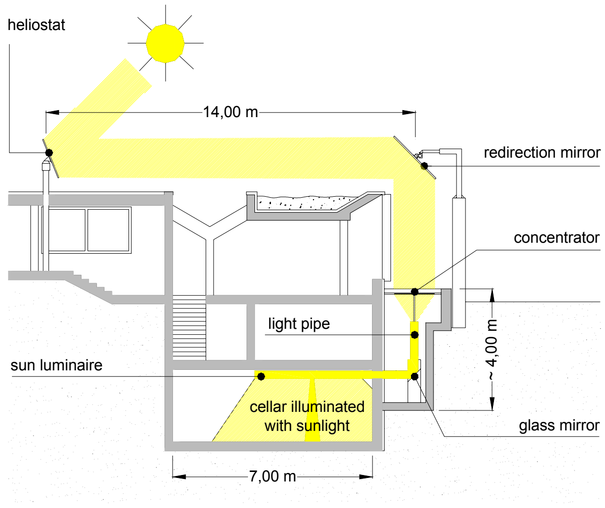


Fig. 9

It is possible to illuminate about 60 to 80 m² to about 600 – 800 lx with 1m² surface area of a Heliostat. Sunlight can be transported up to 60 m into a building. One possible solution is an "artificial window" as shown in the sketch.

Fig. 10 + 11

The left picture shows the problems related to screen based tasks next to a window. One possible solution is to divide the window in an upper and lower part with different functions. The top is used for re-directing natural light while the lower part provides a visual connection to the outside.

Fig. 12

A similar technique is used at the office building of the UBS in Biel (Arch. Mark + Yvonne Hausamann, CH). Prismatic panels for sun-shading and light-guiding prismatic panels in the upper part of the windows result in low energy transmission (0.08). No additional cooling is required in this building. Natural light entering the building is reflected onto metal ceiling panels (perforated for acoustic purposes) that in turn reflect light into the room without glare. Artificial lighting is an integral part of the day-lighting system.

Fig. 13

Specular light guiding blinds provide optimal sun-shading (g = 0.1 to 0.15), re-direction of light and glare control and the visual link to the outside due to perforations in the blinds.

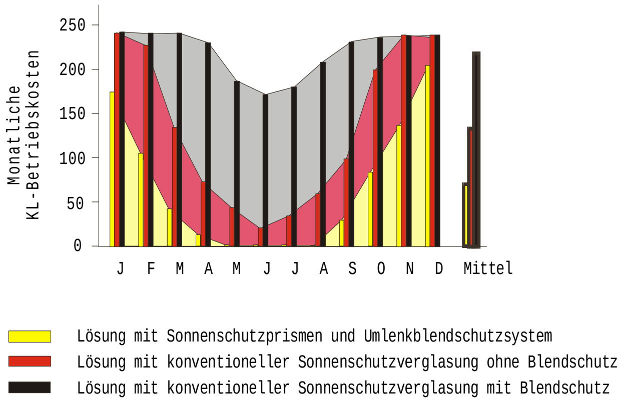


Fig. 14

With suitable systems such as blinds it is possible to reduce the requirement of artificial lighting during normal working hours to 20% - 30% over the year. This represents a reduction of up to 60% compare to conventional window systems.

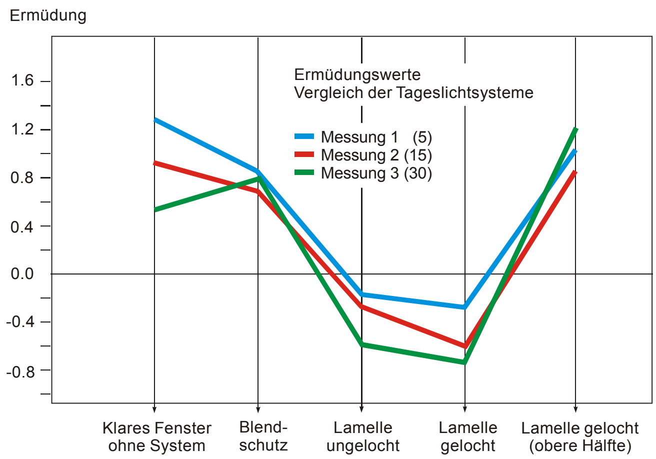


Fig. 15

Over four years Bartenbach LichtLabor has carried out research in terms of perception psychological issues related to screen-based tasks in offices with about 1,600 test persons. It has been shown that suitable systems result in improved visual performance and thus increased productivity. Accordingly fatigue is lowest whenever there is a harmonious brightness distribution.

Avtorjev naslov / Author’s address:

Christian Bartenbach
Bartenbach LichtLabor

Henri Juslén,

LIGHTING AND PRODUCTIVITY IN THE INDUSTRIAL WORKING PLACE

Abstract

Lighting-related parameters like visual performance and alertness, together with motivation, are assumed to influence productivity, wherever productivity is related to human performance. To test the impact of lighting level on productivity five case studies were started in 2003 and 2004. Studies have been finalized and a number of conclusions can be drawn. Lighting influences productivity if productivity is related to human performance. Productivity increases as illuminance levels rise. This paper considers also the question: “What happens if we change and improve the lighting in an industrial workplace?” Installing a new system of illumination in the workplace can affect the individual’s performance level in a variety of ways. The following mechanisms are described and discussed: visual performance, visual comfort, visual ambience, interpersonal relationships, biological clock, stimulation, job satisfaction, problem solving, the halo effect and change process.

Povzetek

Razsvetljava in produktivnost na industrijskih delovnih mestih*; Za parametre, povezane z razsvetljavo, kot sta na primer vidna sposobnost in budnost oziroma motivacija, velja da vplivajo na produktivnost v kolikor je le-ta povezana z človeškim delom. Da bi preverili povezavo med nivojem osvetljenosti in produktivnostjo, smo v letih 2003 in 2004 izvedli pet študij. Iz rezultatov študij lahko zaključimo: razsvetljava vpliva produktivnost, če je le-ta povezana s človeškim delom ter produktivnost se poveča s povečano osvetljenostjo. Članek pa obravnava tudi vprašanje: »Kaj se zgodi če spremenimo oziroma izboljšamo razsvetljavo industrijskega delovnega mesta?« namestitev nove razsvetljavne naprave na delovnem mestu lahko vpliva na delavčevo delovno sposobnost na različne načine. V članku so opisani sledeči mehanizmi: vidna sposobnost, vidno udobje, vidno okolje, medčloveški odnosi, biološka ura, stimulacija, zadovoljstvo ob delu, reševanje problemov, odmevni učinek in proces sprememb.*

1 Mechanisms in the description of the effect of changing the lighting

In order to determine the size of the effect that a lighting change might have on productivity and viability, particular attention can be drawn to the possible reasons for an increase in productivity. Previous field studies (Ruffer, 1925 and 1927; Schneider, 1938; Goldstern and Pudnoky, 1931; Bitterli, 1955; Stenzel, 1962a and 1962b; Crouch, 1967; Lindner, 1975; Carlton, 1980; Buchanan et al, 1991; Völker, 1999) have indicated an increase in productivity levels following an improvement in the system of illumination. Of course the reason for this increase is not necessarily only to be found in the improvement in visual performance levels.

On the basis of a literature search with the focus on light, biology and psychology, it has been possible to develop a model to describe the effect of a lighting change on profitability (Juslén and Tenner, 2005).

The model is illustrated in Figure 1. Light can affect human performance levels through visual and psycho-biological channels. In addition, changing the lighting affects the performance level when emotional and psychological reaction is taken into account. Just how much effect the mechanisms have on performance levels may be different for different people. In industrial work environments human performance level is linked directly to profitability. The costs for the installation and the effect on visiting customers will also influence the profitability of the lighting change.

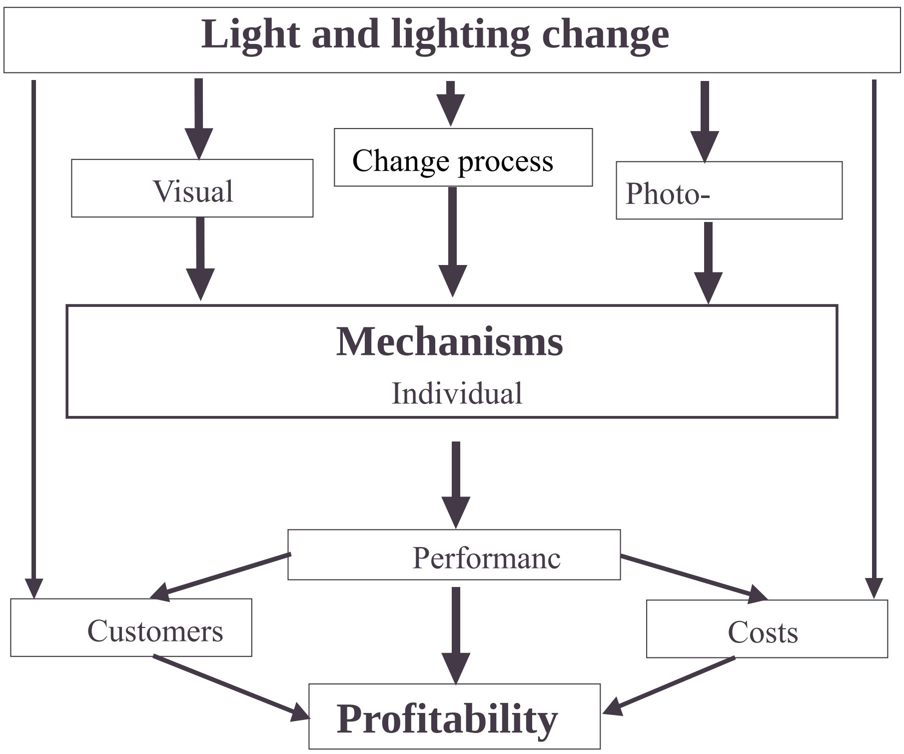


Figure 1. Model showing the effect of a change of the lighting on the profitability in a work environment. (Juslén and Tenner 2005)

A change in the lighting can be effected by modifying the artificial light as well as the quality of natural daylight. Many previous studies show the effect on worker performance level of a change of illumination. This effect is the combination of a variety of mechanisms. When lighting is changed (improved), increased performance level can be achieved using the mechanisms described below. Using the above-illustrated model these can be categorised as visual and photo-biological mechanisms and mechanisms related to the process of change. However, this categorization is conceptual and the origin of mechanisms might vary. For example, stimulation might be sometimes resulted via the visual channel, not biological.

Visual

1. Visual performance
   People are more productive when they can better see what they are doing

2. Visual comfort
   Reduced glare improves performance level through higher levels of concentration

3. Visual ambience
   Illumination has an effect on visual surroundings which are part of the work environment. In turn this affects performance level.

4. Interpersonal relationships
   The way people physically see each other will influence their opinions of each other and this can impact teamwork and therefore productivity.

Photo-biological

5. Biological clock
   Light has an effect on the biological clock, which controls the circadian rhythm and thus at particular periods of time performance levels.

6. Stimulation
   Light stimulates psychological and physiological processes which will affect performance levels.

Process of change

7. Job satisfaction
   Improving the illumination as a means of recognising someone’s work can in some circumstances improve work satisfaction. Further more, improvement can result by providing individual control of the system of illumination (“autonomy”). Job satisfaction affects productivity.

8. Problem solving
   By solving problems which have led to complaints improves the feeling of wellbeing and helps motivation. These feelings are directly linked to performance levels.

9. The halo effect
   The halo effect derives from a belief in the superiority of new technologies or products resulting in improved productivity.

10. The change process
    Good change management supports the positive effects of a lighting change.

If improving the lighting situation has an effect on productivity, as demonstrated by most studies, how long does this effect last? The mechanism model can provide a first approximation. If the reason for an increase in performance levels is the visual or photo-biological aspect or a combination of these mechanisms, it can be concluded that the effect will be long-term, assuming that no other variables reduce the performance levels in this time period.

It is more likely that psychological effects resulting from the process of change will decrease with time, depending also of course on other influences on the person. The “autonomy” aspect (see point 7 – job satisfaction), i.e. the individual’s ability to control the lighting in the workplace, is more likely to have a lasting effect. If more positive steps are to be taken by an industrial business, these changes can be a link in the extended chain.

2 Case studies in an industrial environment

Five field studies were carried out in various European countries in order to determine the effect of the lighting change on productivity. Table 1 gives an overview of the study methodology and the results.

The studies are based on the mechanism model (Juslén and Tenner 2005). By selecting a variety of field studies, the mechanism to describe the effects of a change in illumination on productivity could be investigated in real industrial environments.

As already stated, the visual and photo-biological mechanisms which lead to an improvement in performance levels have a long-term effect. The effects from mechanisms associated with the process of change can decrease over time. For this reason long-term studys were carried out such that the effect of the “change process” (mechanisms 7 to 10) would be minimised. As a result the studys are focussed on the visual and photo-biological mechanisms.

The case studies treated communication with other people as a subordinate task, so that the point “interpersonal relationships” (4) was not investigated and is not included in the evaluation.

In each of the working environments investigated, normal industrial activities were carried out and no special arrangements were made. The methods of study and techniques for measurement of productivity were adapted to meet local conditions. For example productivity was measured by assembly time or number of errors. Fundamentally the results show an improvement in productivity with increased levels of illumination.

It is necessary to conduct long-term studys in order to obtain reliable practical data. In each study the productivity measurements were made under varying conditions of illumination and over a long period of time using a fixed group of employees. In 4 of the 5 studies ANOVA (Analysis of variance $r<0.05$) was used in order to determine the significance of the change in productivity. In the final field study (see E below), a before and after study, no statistical method was employed. A reference group was used in 3 of the 5 studies.

A. In study A the workstation of the employees in a Finnish luminaire factory were fitted with a new overhead controllable lighting system (task lighting). The old task lighting was not controllable. Each user could freely choose the level of illumination within the range 100 lx to 3000 lx. The productivity (in this case assembly time) of the test group was compared with the productivity of a reference group provided with a workplace illumination level of 700 lx (Juslén et al, 2006). The productivity of the test group was significantly increased (4.6%) when measured against the reference group. There was a weak statistically significant correlation between the level of illumination and the productivity of the test group.

B. Study B was carried out in a German luminaire manufacturing company. A section of the employees was provided with a new, controllable lighting system for their workplaces (task lighting), allowing them to adjust the illumination level in the range 100 lx to 900 lx in addition to the general illumination level of 250 lx. The illumination was selectable as a colour temperature of 3500 K or 4400 K. The lighting situation at switch-on was varied at intervals of several weeks using the following combinations: high level of illuminance with low colour temperature, high level of illuminance with higher colour temperature, low level of illuminance with higher colour temperature and low levels of illuminnce with low colour temperature. The users could modify the level of illuminance but not the colour temperature. The result was that the illuminance levels chosen by the users were set 5% higher at higher colour temperatures. Productivity (assembly time) was recorded for each preset switch-on value. In this study the higher colour temperature had a positive effect on productivity (5.7%), the illuminance did not.

C. Study C was carried out in a Dutch electronics company (assembly of electronic components). Work was done in shifts. The illumination levels at the assembly desks came from the general illumination and were re-set for each shift to a level of 800 lx or 1,200 lx. Productivity (assembly time and number of errors) was measured on scanners, which recorded production time and errors (Juslén and Fassian, 2005). On both shifts productivity increased with increased illumination (3% and during night shift 7%).

D. Study D was carried out at the packing line of a Dutch food manufacturing company. The general illumination level before and during the study was approximately 300 lx. An additional, local lighting was installed and the level of local lighting set alternately to 50 lx or 1,700 lx on a weekly basis. The rate of absenteeism of the test group was compared with that of the reference group (no additional workplace lighting). The rates of absenteeism of the test group were 17% lower than that of the reference group. In order to measure productivity the repair time on the machines was recorded as representative of the productivity levels of the employees. The test group increased productivity by 3%, although it should be noted that the difference was only significant for one particular type of error and for one of the shifts only.

E. In study E the lighting conditions in a Dutch luminaire factory were modified. Local illumination was introduced and the level increased from 500 lx to 1,050 lx. Productivity and absenteeism were measured for the test group and compared with the reference group before and after the change (Juslén und Kremer, 2005). In this study, carried out before and after the change, productivity increased by 5.5%.

	A	B	C	D	E
Type of work	Luminaire assembly	Luminaire assembly	Electronics assembly	Machine maintenance	Luminaire assembly
Location	Finland	Germany	the Netherlands	the Netherlands	the Netherlands
Number of people in test group	21	25	35	26	42
Local Illumination levels	100 – 3,000 lx	100 – 900 lx	-	50 – 1,700 lx	700 lx
General Illumination levels	250 lx	250 lx	800 lx / 1,200 lx	300 lx	350 lx
Reference group	Yes	No	No	Yes	Yes
Reference group illumination	700 lx	-	-	300 lx	500 lx
Changes on local illumination	User selection	User selection	-	Regular changes	Increased once
Changes on general illumination	-	-	Regular changes	-	Decreased once
Shifts	Day	Day	Day/eve/night	Day/eve/night	Day
Length of study	1 year	8 months	2 x 2 months	5 months	Before/after
Change in productivity as a result of changing illumination	4.6 %	Not significant	Morning: 3 % Evening: 3 % Night 3%	3 %	5.5 %
Change in productivity as a result of colour temperature	Not measured	5.7 %	Not measured	Not measured	Not measured
Change in error rate	Not measured	Not measured	Not significant	Not measured	Not measured
Change in absenteeism	Not measured	Not measured	Not measured	-17 %	-2.5 %

Table1. Overview of the methodology and the results of the productivity studies

3 Discussion

The variations in the studies were designed so that the mechanisms for defining the effects of changes in illumination on productivity could be investigated in real industrial environments. However, it appears difficult in practice to determine the effects of different mechanisms on worker productivity independently of one another.

Nonetheless, the effect of some mechanisms can be evaluated on an approximated basis or rejected. The evaluation for each study is considered individually below.

The test subjects in study A were provided with a new system of illumination for their workplaces and according to the questionnaire (Juslén et al 2005) expressed themselves as satisfied with it. Although the lighting installation was changed, and the initial increase in productivity could be related to the “process of change” or the “halo effect”, these effects could not be long term and would become ineffective during the study time of 1 year.

The employees were able to set their own levels of illumination and thus the “autonomy“ aspect (work satisfaction) could have an influence on productivity.

It is also possible that the photo-biological mechanisms, “biological clock” and “stimulation”, could have an effect in this case. The effect of using higher levels of illumination during daytime could strengthen the circadian rhythm thus improving sleep and thereby performance levels during the day.

In study B productivity increased when the colour temperature was increased. The “change process” mechanism within the framework of various test situations is discussed below. Since the illumination levels set by the users for different colour temperatures were almost the same, we can conclude that the “visual” mechanisms most probably did not have strong effect. This study therefore concentrates on the “photo-biological” mechanisms. This is in agreement with the results of previous studies, which indicate that a higher colour temperature increases the attention span of the worker (Fleischer 2001).

The results of study C are relatively clear. The increase in productivity at higher illumination levels (1,200 lx as against 800 lx) was observed on all shifts. Since the general level of illumination was only changed between shifts, it is very unlikely that the “visual surroundings” and the “visual comfort” have had any influence. For the same reasons (varying levels per shift), and because the test persons were unaware of the studies and the methodologies, the “process of change” can also be eliminated. The most likely effective mechanisms in this study are “visual performance levels” and “stimulation”.

The work carried out in study D deviates considerably from the work carried out at the other locations. Small reduction in repair time was observed. In retrospect it has been established that the repair time – the only possible measure of productivity – is not necessarily a representative yardstick for performance.

However a large decrease in absenteeism was observed. This would suggest some effect from the mechanisms “job satisfaction” and “stimulation”. Both have an indirect effect on the total performance of the department.

Study E is a typical “before and after” study. The illumination was changed once and the measurements made before and then after the change. The reasons for the increase in productivity in this study is not discussed here, since not all aspects could be brought under complete control, even by bringing in a reference group.

4 Conclusions and recommendations

From the evidence of the studies described above, it can be concluded that a change and improvement in lighting can have an effect on productivity. By increasing illumination levels it is possible to increase a person's productivity. It is difficult to predict the extent of this effect since the starting conditions, the final installation, the people involved, the nature of the work and the process of change all influence the result. Nonetheless taking account of the mechanisms can help to evaluate the importance of various aspects and to channel the applied effort in the correct direction. Changes in illumination can be implemented by various means and an increase in productivity achieved using the above-mentioned ten mechanisms. Lighting changes should be an integral part of a management process. It can have direct and indirect effects on productivity. Indirect effects such as wellbeing, alertness and reduced absenteeism are important goals. However, it is the direct goals such as reduced process times, higher output or increased production quantities which are the priority, since they are on the one hand more easily measured and on the other provide quick commercial gains. The following recommendations are intended for practitioners involved in lighting change.

1. **Study the present conditions.** Inform people that the planning of the lighting change is going on. Give them a possibility to influence, use unofficial interviews, questionnaire with also open questions or presentation in workers meeting. Using only questionnaires with multiple choices is not reliable way to estimate if people will benefit of the lighting change. Important questions to be answered are: What kind of lighting there is now? Is there something complained by people? Is something blocking the productivity (speed of the machine, salary system etc.)? What and where are the tasks?
2. **Create a plan.** In case something is blocking the productivity increase, try to find way to overcome the reason or take into account that direct productivity results cannot be achieved. Use mechanism model to evaluate the effects (direct and indirect) of the lighting chance and to plan a new lighting. Take into account possible needs for presenting working areas to customers as well as the needs for flexibility together with good energy management. Figure 2 shows a form that could be used as discussion tool with customer or as a check list. Consider using localized lighting and giving control to workers. Use norms and codes, but do not afraid to make better lighting installation than minimums according norms.
3. **Make a change.** In case lighting change seems to be a reasonable investment, do it by involving people and follow the process to be able to correct possible misunderstandings or installation errors.
4. **Evaluate the results.** Evaluating the results is important since maybe something was forgotten during the process and can be corrected also later. On the other hand designers or other parties involved the change, need feedback to be able to learn from the process.
5. **Make corrective actions and/or close the project**

Check list for the base of the lighting design **(workplace lighting)**

Mark the importance of the following items to the list

0 Not important at all
3 Very important

Visual performance	0	*(Use lower maintained lighting level than defined in norm)*
(How well we are able to see)	1	
	2	
	3	*(Use higher maintained lighting level than defined in norm.)*
Visual comfort	0	*(Use solution, which is just according minimums in norm.)*
(How comfortable it is to look)	1	
	2	
	3	*(Concentrate on optics and glare limitation & indirect lighting)*
Visual ambience	0	*(Do nothing special for this purpose)*
(How the environment looks like)	1	
	2	
	3	*(Add some ambience and accent lighting)*
Interpersonal relationships	0	*(Do nothing special for this purpose)*
(How people work together)	1	
	2	
	3	*(Concentrate on vertical illuminance and colour rendering)*
Biological clock	0	*(Do nothing special for this purpose)*
(when we are awake)	1	
	2	
	3	*(High lighting levels and/or special spectra as on option.)*
Stimulation	0	*(Do nothing special for this purpose)*
(How alarm we are)	1	
	2	
	3	*(High lighting levels and/or special spectra as on option.)*
Job satisfaction	0	*(Do nothing special for this purpose)*
(How happy we are for our work)	1	
	2	
	3	*(Clear lighting improvements and consider using personal control)*
Solving problems	0	*(Do nothing special for this purpose)*
(Is there something so wrong)	1	
	2	
	3	*(Correct the problem and make note of it)*
Change process	0	
(How to do the change)	1	
	2	
	3	*(Always important to inform and involve people)*
Flexibility	0	*(Do nothing special for this purpose)*
(is the purpose of the	1	
space always same)	2	
	3	*(Take flexibility under the consideration)*
Customers	0	*(Do nothing special for this purpose)*
(Does it matter	1	
how visitors see the space)	2	
	3	*(Use higher lighting levels and consider shop type solutions)*

Total ☐

0 Standard 11 — 22 Demanding 33

Figure 2. Lighting change estimation form. (Customer and designer can together estimate if presented issues are important in the premises where people are working. It gives also some very simple recommendations if the importance of the issue is clear. Total points give an indication of complexity of lighting design.)

5 References

1. Bitterli, E. (1955) Licht und arbeit (Light and work). Bull. Ass.Suisse electr. T. 46, n° 12, 559-563
2. Buchanan, T.L., Barker, K.N., Gibson, J.T., Jiang, B.C. and Pearson, R.E (1991) Illumination and errors in dispensing. AM J Hosp Pharm. 48, 2137-45.
3. Carlton, B. (1980) Industrial lighting must be tailored to real-life working conditions. Electrical times, issue 4562 (14 March 1980)
4. Crouch, C.L., (1967) Working and living in a luminous environment. Trans. Illum. Eng. Soc vol. 32 No. 1, 41-53
5. Fleischer, S. E. (2001) Die psychologische Wirkung veränderlicher Kunstlichtsituationen auf den Menschen (The psychological effect on humans of changing artificial light conditions). PhD Thesis Eidgenössische Technische Hochschule Zürich
6. Goldstern, N. and Putnoky, F. (1931) Die wirtschaftliche Beleuchtung von Webstuhlen; neue arbeitstechnische Untersuchungen (The economic illumination of weaving looms; new technical work studies). Licht und Lampe 22, 5-9 und 25-28.
7. Juslén, H., und Kremer, E., 2005. Localised lighting for efficient use of energy and better performance – Field Study in the factory. CIE mid-term meeting and international lighting Congress, León 2005, Proceedings
8. Juslén H., Fassian M., Lighting and productivity – Night shift field study in the industrial environment. Light & Engineering, Vol. 13, No. 2, pp. 59-62, 2005
9. Juslén HT, Wouters MCHM, Tenner AD. The influence of controllable task-lighting on productivity: a field study. Applied Ergonomics. in press
10. Juslén HT, Tenner AD. Mechanisms involved in enhancing human performance by changing the lighting in the industrial workplace. International Journal of Industrial Ergonomics. 35 (2005) 843-855.
11. Lindner, H., (1975) Beleuchtungsstärke und Arbeitsleistung – Systematik experimenteller Grundlagen (Illumination levels and work performance – systematic experimental principles). Zeitschrift für die gesamte Hygiene und ihre Grenzgebiete (Journal of hygiene and related disciplines) 21, 2, 101-107
12. Ruffer, W. (1927) Licht und Leistung (Light and performance). Licht und Lampe , 242-245.
13. Ruffer, W. (1925) Leistungssteigerung durch Verstärkung der Beleuchtung (Improved performance by increasing illumination). Die Lichttechnik, 53-58.
14. Schneider, L. (1938) Förderung der menschlichen Arbeitsleistung durch richtige Beleuchtung (Improving human work performance using appropriate illumination). Das Licht 8, 286-96.
15. Stenzel, A.G. (1962) Erfahrungen mit 1000 lx in einer Lederwarenfabrik (Experiences with 1000 lx in a leather factory). Lichttechnik 14. Jahrgang Nr. 1/1962, 16-18
16. Stenzel, A.G. (1962) Erfahrungen mit 1000 lx in einem Kamerawerk (Experiences with 1000 lx in a camera factory). Lichttechnik 14. Jahrgang Nr. 7/1962, 351-353
17. Völker, S. 1999 “Eignung von Methoden zur Ermittlung eines notwendigen Beleuchtungsniveaus” (Application of methods to determine the necessary level of illumination). PhD Thesis Technical University Ilmenau
18. Wyon, D. P. (1996) Indoor environmental effects on productivity, In: Proceedings of IAQ 96- Paths to better building environments, (edited by K. Y. Teichman), ASHRAE, Atlanta, 5-15.

Avtorjev naslov / Author's address:

Henri Juslén, Philips Lighting BV, IDMAN Oy,
Mattilantie 75, PL 4, Mäntsälä, Finland

Martine Knoop

DYNAMIC LIGHTING FOR WELL-BEING IN WORK PLACES: ADDRESSING THE VISUAL, EMOTIONAL AND BIOLOGICAL ASPECTS OF LIGHTING DESIGN

Abstract

Light can be used to increase alertness, evoke relaxation and suppress sleepiness. Therefore, it can be deployed to support the well-being and performance of people in working places. These so-called ‘non-visual’ or ‘biological’ effects have become an increasingly important topic in lighting design over the last few years. Research on the physical effects of light on our body, as opposed to effects on visual perception and emotion, is still on-going. This paper will discuss the implementation of current research results into practical applications.

Furthermore, this article will discuss opportunities and benefits for lighting designers to apply this research by suggesting methods of application in lighting solutions for various work places. Those are driven by biological aspects of lighting, but take into account visual and emotional attributes, to aim at overall well-being in work places.

Povzetek

Dinamična razsvetljava za dobro počutjena delovnem mestu: upoštevanje vidnih, čustvenih in bioloških vidikov razsvetljave. S pomočjo r*azsvetljave lahko izboljšamo budnost, prikličemo sproščenost in preprečimo zaspanost. Torej jo lahko uporabimo za izboljšanje dobrega počutja in učinka na delovnem mestu. Ti takoimenovani »nevizualni« ali »biološki« učinki postajajo vedno pomembnejši dejavniki načrtovanja razsvetljave. Raziskave na področju fizikalnih učinkov svetlobe na naše telo, ki so lahko popolnoma drugačni od učinkov na vidno zaznavanje in čustva, še vedno potekajo. Ta prispevek bo prikazal uporabo trenutnih raziskovalnih dosežkov v praktičnih aplikacijah.*

Razen tega bodo prikazane priložnosti in prednosti za oblikovalce svetlobe pri uporabi dosežkov teh raziskav s predlogi metod za njihovo uporabo za razna delovna mesta. Ti predlogi so narejeni na osnovi bioloških aspektov razsvetljave, vendar ob upoštevanju vidnih in emocionalnih lastnosti, s ciljem splošnega dobrega počutja na delovnem mestu.

1 Introduction

Lighting is a powerful tool in architectural design. It addresses both functional as well as emotional needs in indoor and outdoor environments. Over the last two decades it has become clear that light has a biological effect as well. Light reaching the retina is not solely processed by the cones and rods, but also by intrinsically photosensitive retinal ganglion cells called the ‘3rd receptors’. From these cells, signals are sent to the suprachiasmatic nucleus (SCN) of the hypothalamus, our main body clock. From the SCN, information is send to the pineal gland, where the information is used for the production of hormones and the modulation of body temperature (Figure 1).

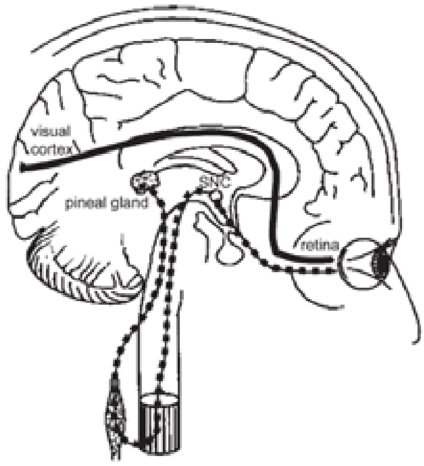


Figure 1: Visual and biological pathways in the brain: nerve connections between the retina of the eye, with its cones and rods, and the visual cortex on the one hand (continuous line) and between the retina, with the novel photoreceptor cell, and the SNC and the pineal gland (broken line) (Source: van Bommel and van den Beld 2004)

Both play an important role in the regulation of our circadian rhythms. Circadian rhythms are cycles of approximately 24 hours (‘circadian’ finds it’s origin in Latin, ‘circa’ = about, ‘diem’ = day). Such rhythms can be found in human beings, animals and plants. They regulate our daily life: sleep/wake and feeding patterns, hormone production and brain activity are typical examples of circadian cycles (see Figure 2 for examples of circadian rhythms). To put this into practice for work places, circadian rhythms determine when we feel sleepy, active or alert.

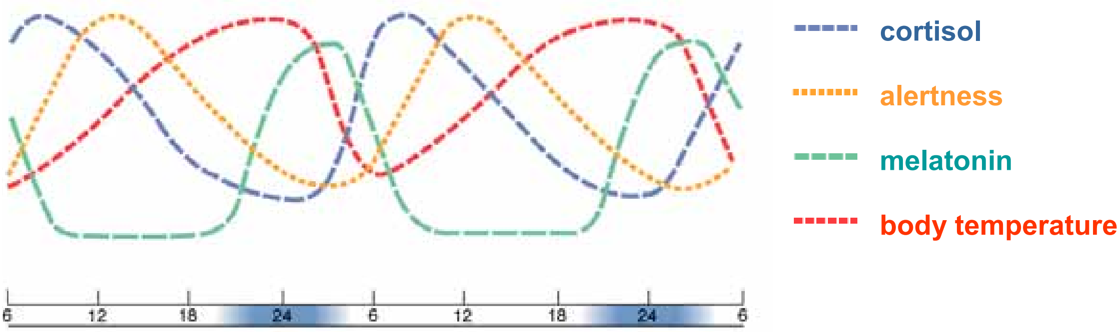


Figure 2: Circadian rhythms of production of cortisol and melatonin, of alertness and body temperature

2 General ‘principles’ for biological aspects of lighting

Hormone production, responding to light during day and night

Light is the most powerful time cue for circadian rhythms. Increasing light levels in the morning (sunrise) signals the human body to start its active cycle. A number of hormones, like adrenaline, cortisol and serotonin are produced. Cortisol is the hormone that wakes us up and gets us out of our sleep-mode (see Figure 3). Whereas serotonin and adrenaline production continue over the day, cortisol is only meant to be in the system for a shorter time period; the cortisol level drops during the day.

The reduction of daylight intensity in the evening (sunset) is an indication for the human body to prepare the body to slow down. Hormones play an important role in this as well. Melatonin is the hormone produced during the night, and in combination with darkness, the body identifies this as nighttime. For human beings, nighttime cues lead to a reduction in body activity, slowing of metabolism and preparation for sleep; for nocturnal organisms, like owls, nighttime signals cause increased activity.

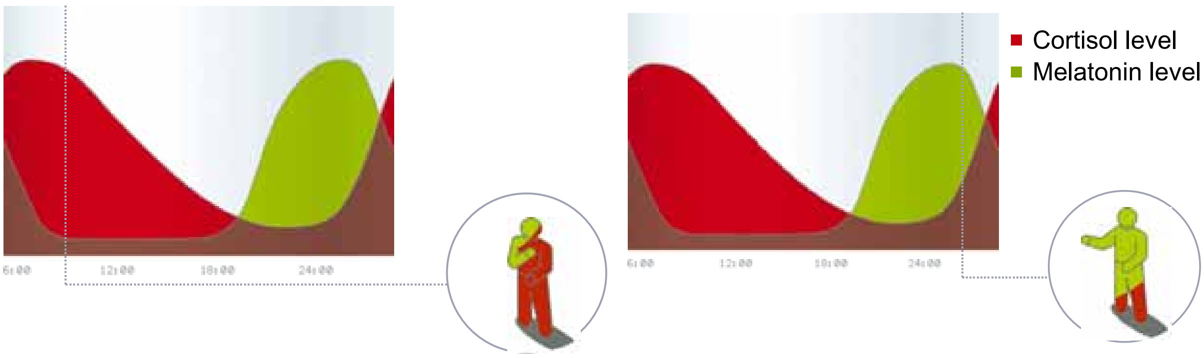


Figure 3: Hormone production and activity level
Left picture: **9 am**, daylight makes the cortisol level raise, we feel awake and active
Right picture: **1 am**, lack of daylight makes the melatonin level raise, we feel sleepy

Light for circadian, phase shifting effects

Since light is such an important time cue for circadian rhythms, it can be used to adjust to situations where activities take place that do not coincide with our circadian rhythms. This is the case for people working in a night shift or traveling across several time zones in a short time period: they need to be awake when the body is programmed to sleep and the other way around. Offering higher light levels at times when the body is not expecting them will cause a biological effect. Evening light will give the body a signal that it is still daytime, and sleepiness will occur later. Light in the morning, on the other hand, will cause sleepiness earlier in the evening. This is called phase shifting (see Figure 5, next page).

The minimum core body temperature (CBT) is crucial in phase shifting, since it determines the body’s interpretation of ‘evening’ and ‘morning’ as mentioned above. Although there is a wide spread in timing of the individual minimum core body temperature, in most adult working people the core body temperature will reach its minimum between 03:00 and 06:00 a.m. In this time period the urge to sleep is strongest.

In realizing a phase shift, timing is crucial (see Figure 4). Before the minimum CBT the light will be seen as 'evening' light; after the minimum CBT the light is seen as 'morning' light. Note, however, that the above-mentioned time period of 03:00 to 06:00 a.m. cannot be applied as a standard; the CBT differs individually, and may well occur beyond or before this mentioned period. The minimum CBT of teenagers for example, may occur in the early morning. 'Early morning' light could - in this case - be perceived as 'late evening' light and cause an opposite reaction as intended to achieve. As can also be seen from Figure 4, the effect of light on our circadian rhythms is largest when the body is normally not expecting any light.

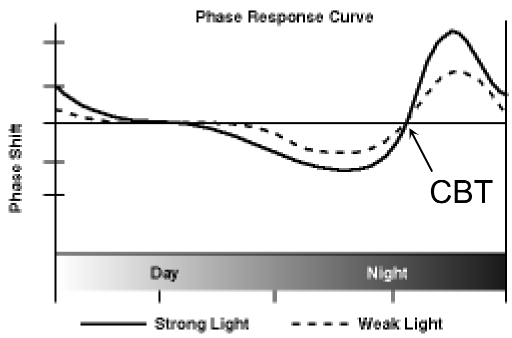
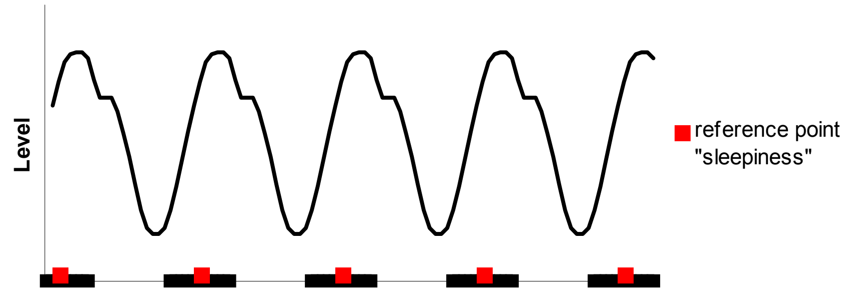


Figure 4: Phase response curve. Source: „Light, Sight, and Photobiology" by Peter Boyce (http://www.lrc.rpi.edu/programs/Futures/LF-Photobiology/index.asp)

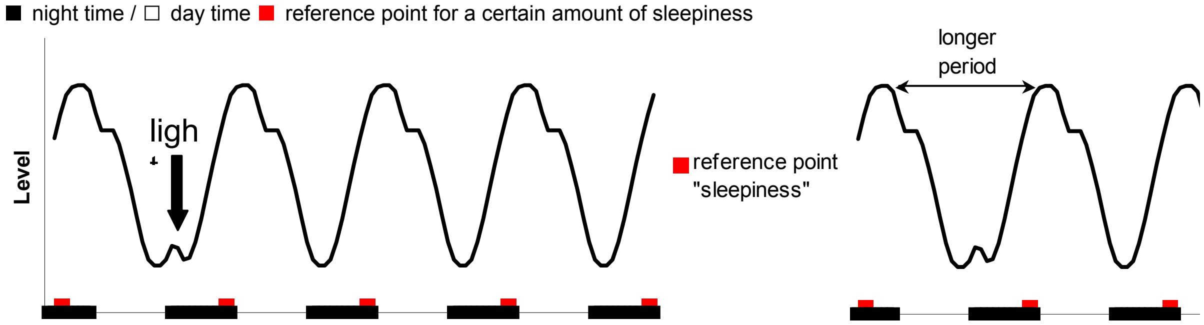
Important parameters in the phase shifting effects of light include size and position of the light source, duration and timing of exposure, light wavelength and light intensity. Research is still on-going, but a few results, focusing on duration and wavelength, give directions to lighting solutions that can be offered in practice already.

- Research has shown that light with wavelengths between 440 and 475 nm is most effective in causing a circadian shift. For example, Lockley, Brainard and Czeisler (2003) found that humans exposed to 6.5 h of monochromatic blue light (460 nm) had a two times greater circadian phase delay than with 555 nm light. At the same time, melatonin was suppressed twice as much with 460 nm light than with 555 nm light.
- There are indications that pulses of light result in phase shifting effects comparable to those realized with continuous exposure to the same level of bright light (Rimmer et al. 2000). Research by Gronfier et al. 2000 showed that a 6.5 h continuous exposure to bright light (9500 lx at the eye) had about the same phase shifting effect as six 15 minutes pulses of the same light separated by 1 hour.

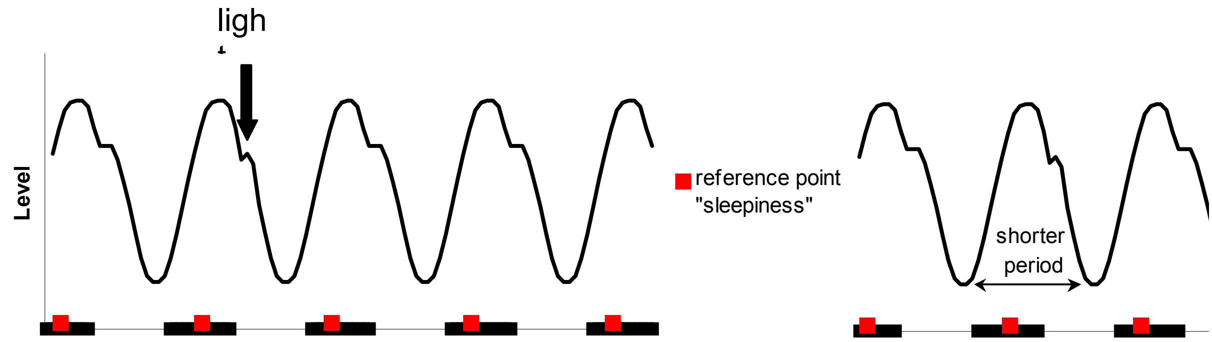
The use of phase shifting in applications and the resulting lighting solutions will be discussed later, in the section on nighttime work places.



■ night time / ☐ day time ■ reference point for a certain amount of sleepiness



Phase delay: Evening light. The 'day' is artificially lengthened, sleepiness will occur later



Phase advance: Morning light. The 'day' starts earlier, sleepiness will occur earlier

Figure 5: General principles of phase shifting for **a typical circadian rhythm**, like blood hormone levels or activity levels. Adapted from "Overview of Circadian Rhythms" by Hotz Vitaterna, Takahashi and Turek

Direct, non-circadian effects of light

Next to the circadian, phase shifting, effects, light can cause **direct** biological effects as well, of which a few are listed below. The direct effects of light are independent of circadian rhythms. In principle, these responses to light exposure could occur at any time, day or night, by introducing bright light (de Groot et al. 2006):

- Light at night results in an immediate suppression of melatonin and a reduction of sleepiness (Figure 6). This effect is greater under blue light compared to red light (Rüger 2005).
- Daytime bright light can reduce sleepiness and fatigue even though melatonin is virtually absent and core body temperature is nearly constant (Rüger 2005).
- Kayumov et al. (2005) found that blue deficient light, as a result of wearing goggles blocking wavelengths < 530 nm, did not suppress melatonin at night, which was the case with white light of the same lighting level (800 lux).
- Bright light in the early morning results in an immediate increase of cortisol (Leproult et al. 2001), whereas afternoon bright light does not have this effect on the cortisol production (Leproult et al. 2001, Rüger 2005).
- A temporary increase of light levels, and/or an increase of the direct component, can raise vigilance and thus enhance work performance (Fleischer 2001).
- Warm white light facilitates relaxation, while daylight-white light is stimulating (Fleischer 2001).
- Average pupil size was significantly smaller under 5500 K compared to 3600 K (Berman et al. 2006), resulting in an increase of visual acuity.

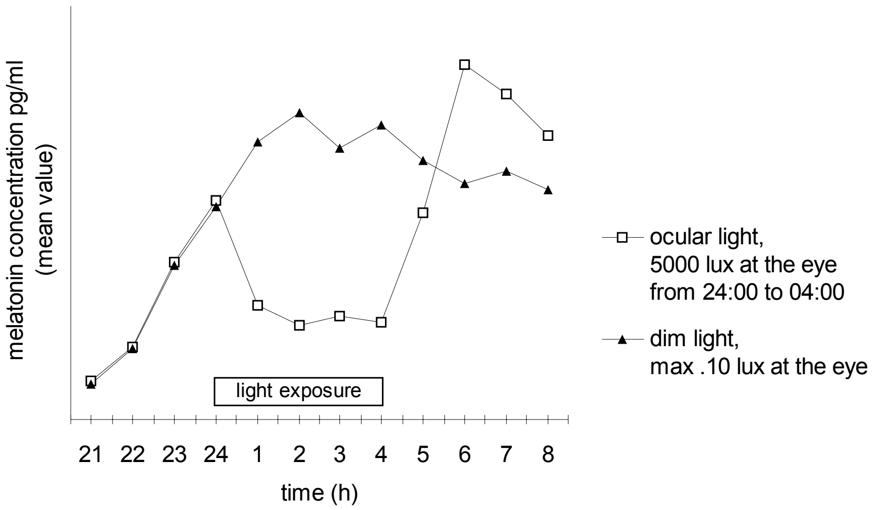


Figure 6: An example of a direct, biological, effect of light: melatonin suppression during the night
Adapted from Rüger 2005

Consequently, light can be used to cause a direct effect to activate the human body, to reduce sleepiness during day- and nighttime and to increase visual acuity, all of which will indirectly enhance working conditions. High light levels and light with a high blue component (cooler color temperature) are most effective.

3. Applications and lighting solutions

A distinction between direct biological and phase shifting effects of light can be made, as described above. The direct biological effects of light can be caused during day- and nighttime, with the strongest phase shifting effects of light induced during nighttime.

As a result, the lighting solutions for day- and nighttime might differ from each other. These distinct approaches will be discussed in the following section, focusing primarily on lighting solutions for healthy working people.

Daytime work places

During daytime, the only biological effects to reach with lighting are the reduction of sleepiness and the increase of alertness.

Bright light with high color temperatures will provide a good start of the day, due to suppression of the remaining melatonin in the body and the increase of cortisol level (Rüger 2005, Leproult et al. 2001). The circadian rhythm of alertness peaks in the morning and in the early evening, where additional support of light is not necessary.

The so-called 'post lunch dip' is a time period of decreased alertness that occurs between 1 p.m. and 4 p.m, taking into account individual differences. For those workers that will not be able to take a long lunch break or a nap, lighting is a solution. In contrast to the morning, we cannot address the post lunch dip by means of hormone production (Rüger 2005, Leproult et al. 2001). Although not clarified yet, it is clear that other pathways besides the mechanisms of hormone production affect alertness; research has shown an increase of alertness in the afternoon induced by the use of higher color temperatures and higher light levels (Fleischer 2001, Rüger 2005).

Based on the above-mentioned biological effects, 'Dynamic Lighting' has been developed. Dynamic Lighting is a concept to increase well-being, motivation and performance of people, by supporting the natural rhythm of activity. High light levels with cooler color temperatures are used to stimulate, while lower light levels with lower color temperatures have a less stimulating, more relaxing effect.

These principles are shown in Figures 7 and 8.

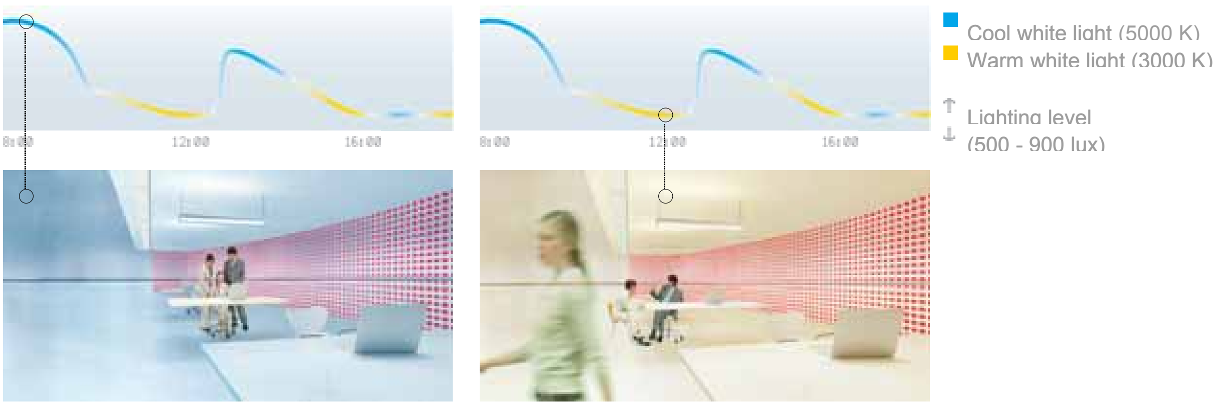


Figure 7: Left picture: Start of the working day. Cool light, increased lighting level, to raise the energy level and provide a good start of the day
Right picture: Lunch time. Warm light, decreased lighting level. Time to recharge batteries

Figure 8: Left picture: After lunch. Cool light, increased lighting level, to counter the ’post lunch dip’
Right picture: Happy hour. Cool light, lower lighting level, to raise concentration before going home

Application

Dynamic Lighting maintains optimal alertness levels during the day, with clear applications in offices, industry, hospitals and schools.

Figure 9: Application of Dynamic Lighting in a conference room

Figure 10: Application of Dynamic Lighting in an office room

Nighttime work places

During daytime, the focus is on achieving direct biological effects. This is not the case when we look at applications in which people have to work at night, like hospitals, control rooms and industry.

During nighttime, direct biological effects and circadian phase shifting effects can be realized as well as caused by use of light at night. People working on times conflicting with their normal circadian rhythms might want to shift the circadian rhythms when this is a long term condition. In case of fast rotating shift work, or single nights of work, a phase shift is not desired. This asks for a distinct approach for those two cases.

1. Long-term night shift

For applications with long-term night shifts, light at night increases alertness during nighttime and result in a controlled phase shift. Research shows that high light levels, in long pulses or continuous during the whole time period, suppress the production of melatonin and can be used to stimulate a phase shift. Most effective in this application is bluish light at high light levels. In the morning, light without biological stimulating effects should be offered, to prevent a discarded phase advance shift (see Figure 3).

The above-mentioned 'Dynamic Lighting' can be applied during night shifts as well. High color temperatures and (pulses of) high light levels should be applied in the beginning of the evening, changing to lower levels and color temperatures at the end of the night shift. This should be supported by reduced light exposure over the day. It is advised to wear sunglasses while driving home and sleep in complete darkness during the day. Dark/light rhythms are very important for health and circadian rhythms.

In view of the fact that light pulses might be as effective as continuous exposure to bright light, localized solutions in break rooms are especially suitable for industry applications, where break times are fixed and light exposure can be guaranteed.

Application

Dynamic Lighting for night shifts increases alertness during the night and causes a phase shift, with clear applications in industry, hospitals and control rooms.

Figure 11: Application of Dynamic Lighting in hospitals (left) and control rooms (middle, right)

2. Fast rotating night shifts & working single nights

In a number of European countries, fast rotating night shifts are common practice (de Groot, 2005). Under these circumstances, the lighting should increase alertness during nighttime, however without causing a phase and the suppression of melatonin. A phase shift would cause problems adjusting back to the normal daily schedule following the short night shift period.

Kayumov et al. (2005) showed no reduction of people's performance during work at night when using light with a low blue component, instead of white light. With blue deficient light, melatonin production was not suppressed, which was the case with white light of the same lighting level (800 lux). Blue deficient light might be a lighting solution for fast rotating shift work, however it has not yet been proven whether this effect lasts over a longer period. Furthermore, a number of additional aspects must be taken into account that might affect the circadian rhythm in another way. Insight has to be collected on the consequences of the use of blue deficient light in rapidly rotating night shift schedules on:

- sleep quality during daytime;
- alertness during night time; and,
- melatonin production in the consecutive nights.

Further research will have to focus on these aspects in order to develop carefully considered night-shift light plans for rapidly rotating shift schedules.

4 Overall well-being

Light for well-being of people takes into consideration visual, emotional and biological aspects. The biological aspects have been discussed in this paper.

Light for vision has been studied for years, resulting in recommendations for comfortable, glare free task lighting in work places. This has been taken into consideration in the choice of luminaires and minimum maintained illuminance levels for Dynamic Lighting.

The emotional aspects of lighting have become more important during the last decades. Lighting designers and architects use light to create atmosphere and effects in interior and exterior spaces. Individual taste, mood, culture and experiences are just a few parameters that will influence the appreciation of this subjective aspect of a lighting design, and with this the well-being of users. With Dynamic Lighting, level and color temperature of the light change. This will have a direct effect on the perception of the room. Dynamic Lighting can turn rooms into motivating areas to concentrate, as well as into homey spaces for relaxation, by changing light level and color temperature. It is a powerful tool in the design of modern office environments, where flexibility in atmosphere is desired.

5 Summary: Lighting solutions for well-being in work places

This paper discussed the implementation of current results of research on biological effects of light. These effects can be divided into (circadian) phase shifting effects and (non-circadian) direct effects. Light with a relatively high level and/or containing lower wavelengths has the strongest impact on these effects. Phase shifting effects can be utilized to adapt the circadian rhythm to working conditions that do not coincide with it, like long-term night shift work. Direct, non-circadian effects can be employed to increase alertness and reduce sleepiness, during day- and nighttime.

The discussed resulting lighting solutions are driven by biological aspects of lighting, but need to take into account overall well-being. Therefore, all requirements concerning a functionally and emotionally well balanced lighting installation must also be fulfilled. When dealing with light for well-being, the suitable solution seems to be dynamic lighting: change of lighting situations, adjusted to the requirements of the moment.

References

19. Berman SM, Navvab M, Martin MJ, Sheedy J and Tithof W (2006) Children's near acuity is better under high colour temperature lighting. Lighting Research and Technology, Vol. 38, No. 1, pp. 41-52.
20. Bommel WJM van, Beld GJ van den (2004) Lighting for work: visual and biological effects. Lighting Research and Technology, 36(4), 255 - 269
21. Fleischer SE (2001) Die psychologische Wirkung veränderlicher Kunstlichtsituation auf den Menschen. Ph.D. thesis Eidgenössiche Technische Hochschule (ETH) Zürich
22. Groot, EH de (2005) Voordelen van fotobiologische verlichtingssystemen tijdens de nachtdienst. NSVV Lichtcongres
23. Groot, EH de (2006) benefits of photobiological light exposure during night-shift work. CIE Light & Health conference – Ottawa, Canada.
24. Gronfier C, Kronauer RE, Wright KP, Czeisler CA (2000) Phase-shifting effectiveness of intermittent light pulses: Relationship to melatonin suppression. 7th Meeting of the Society for Research on Biological Rhythms – Jacksonville.
25. Hotz Vitaterna M, Takahashi JS and Turek FW (2001) Overview of Circadian Rhythms. Alcohol Research and Health
26. Kayumov L, Casper RF, Hawa RJ, Perelman B, Chung SA, Sokalsky S, and Shapiro CM (2005) Blocking low-wavelength light prevents nocturnal melatonin suppression with no adverse effect on performance during simulated shift work. J Journal of Clinical Endocrinology & Metabolism (90):2755-2761.

27. Leproult R, Colecchia EF, L'Hermite-Baleriaux M, Van Cauter E (2001) Transition from dim to bright light in the morning induces an immediate elevation of cortisol levels. J.Clin.Endocrinol.Metab. 86: 151-157
28. Lockley SW, Brainard GC and Czeisler CA (2003) High sensitivity of the human circadian melatonin rhythm to resetting by short wavelength light. Journal of Clinical Endocrinology & Metabolism 88(9):4502-4505
29. Rimmer DW, Boivin DB, Shanahan TL, Kronauer RE, Duffy JF, Czeisler CA (2000) Dynamic resetting of the human circadian pacemaker by intermittent bright light. Am J Physiol Regulatory Integrative Comp Physiol. 279: R1574–R1579
30. Rüger M (2005) Lighting up the human circadian clock. Ph.D. thesis University of Groningen

Avtoričin naslov / Author's address:

Dr. Martine Knoop
Senior Lighting Application Specialist, Lighting Design and Application Center (LiDAC), Philips Lighting and Visiting Professor, Eindhoven University of Technology, department of architecture, building and planning

Corresponding address:
Mathildelaan 1, Building EDW 618
5611 BD Eindhoven, the Netherlands
Email: martine.knoop@philips.com

Tommy Govén

THE BACKGROUND LUMINANCE AND COLOUR TEMPERATURES INFLUENCE ON ALERTNESS AND MENTAL HEALTH

VPLIV SVETLOSTI OZADJA IN BARVNE TEMPERATURE NA BUDNOST IN DUŠEVNO ZDRAVJE

Purpose of the study

”to lay down the appropriate luminance levels at different colour temperatures for ambient lighting within working areas”

New research in lighting has shown that light is not only influencing the visual centra – it also affects the whole body.

For more than 150 years we have considered rods and cones to be the only photo-receptors in the human eye and that these only affect the visual centra. Four years ago a new 3rd receptor was found by David Berson at Brown University USA which in fact was the missing link in how the human wealth is influenced by lighting.

It is now shown that light influences different hormones in the brain where the pineal gland plays an important role in controlling the sleep hormone melatonin which is provided to the blood in the body at low light levels or in darkness. At high light levels the stress hormone cortisol is produced by the adrenal cortex which contributes to alertness.

During the last years a lot of studies have been carried out on how the spectrum of the light (daylight and artificial) affects the hormone suppression and how colours and light distribution in the visual field brings emotional effects to the human being.

Colours and light distribution in the visual field brings emotional effects to the human being.

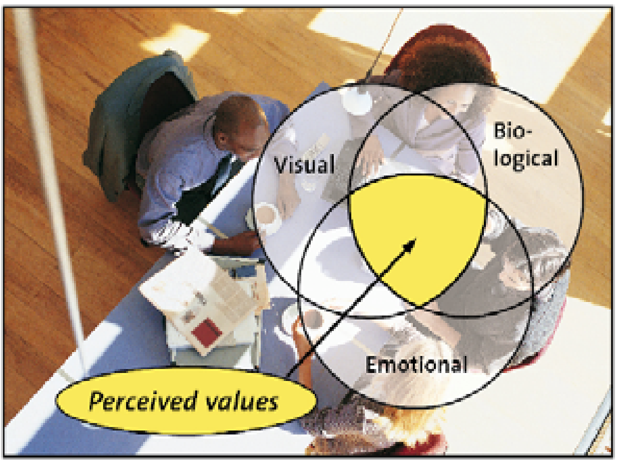
New legislations on the use of energy and findings in research will and have already created new more efficient lighting systems which are optimal for vision as well as for the human health.

Lighting design will in the future be more focused on visual, biological and emotional aspects and future lighting systems must at the same time be energy efficient. In order to evaluate the need a sufficient luminance level of ambient light over a working day and the influence of different colour temperatures from different artificial light sources within in the visual field a study is now going on in cooperation with the Lund University, Fagerhult and the Swedish Energy Agency. The main focus of this study is the impact of fluorescent light on endocrine and subjective indices of arousal.

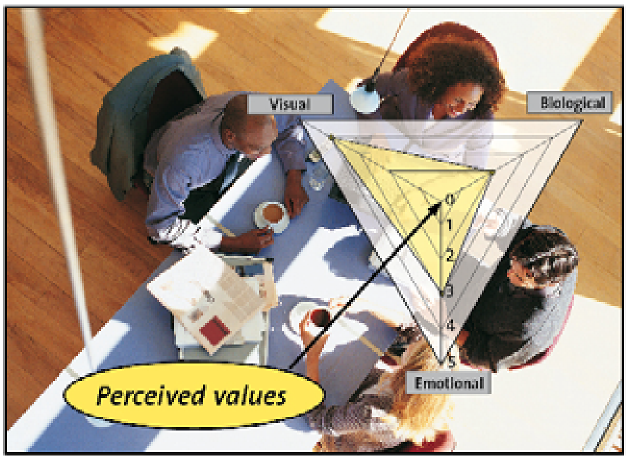
60 subjects of different age are participating in study. Some of the subjects will be diagnosed as SAD-patients (which are affective to the seasonal disorder of light). The study is carried out in two equal equipped office rooms where the ambient light in the visual field of view is set to different light levels and colour-temperatures.

The Human Aspects of Light

Lighting design will in the future be more focused on visual, biological and emotional aspects and future lighting systems. In order to describe the design purpose the following evaluation system can be used.



Evaluation of a lighting system.



Evaluation of lighting in a working area.

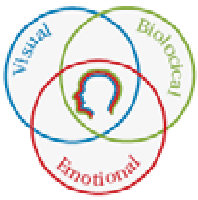
Evaluation of a lighting system

For example in working areas – at task – the visual aspects are of most importance. However, the emotional and biological aspects has also to be considered in order to create creativity and productivity. In classrooms all aspects could be of equal importance.

Visual
- Task light
- Visual performance
- Contrast
- Glare

Biological
- Ocular light
- Circadian effects
- Mental health
- Alertness

Emotional
- Comfort
- Dynamics
- Colours
- Colour of light



Method

The main focus of the study is the impact of fluorescent light on endocrine and subjective indices of arousal.

Initially two types of fluorescent T5-tubes were used – 3000K and 4000K – each at three different luminance levels of the ambient vertical light – initially 10 cd/m2, 100 cd/m2 and 350 cd/m2. The light spectrum was kept constant for all luminance levels for the different colour temperatures.

The vertical luminance was kept uniform within ±30° of the horizontal line of sight. The horizontal illuminance will be kept at 500 lux within the working area /task area for each ambient luminance level.

Exposure last for one whole day for each of the six combinations. The rooms are designed as ordinary office rooms. In a pilot study the luminance levels was checked to be reasonable. Thereafter the final luminance levels were decided. The subjects are randomly assigned to start at different levels of luminance.

Measurements concerning the endocrine indices (cortisol and melatonin) are obtained in the morning and in the afternoon on the day of light exposure, but also on the days preceding and following the experiment.

The morning samples were collected by the subjects around seven o'clock, which means that the obtained values will reflect the amount of melatonin excreted during night, as well as the pronounced diurnal rise in cortisol taking place in the early morning. The samples from the afternoon were taken around four o'clock, showing the suppression of melatonin during the day as well as the levels of cortisol.

Furthermore, the visual discomfort, subjective assessment of lighting quality was assessed by different forms shown on a VDU connected to a computer in the office room.

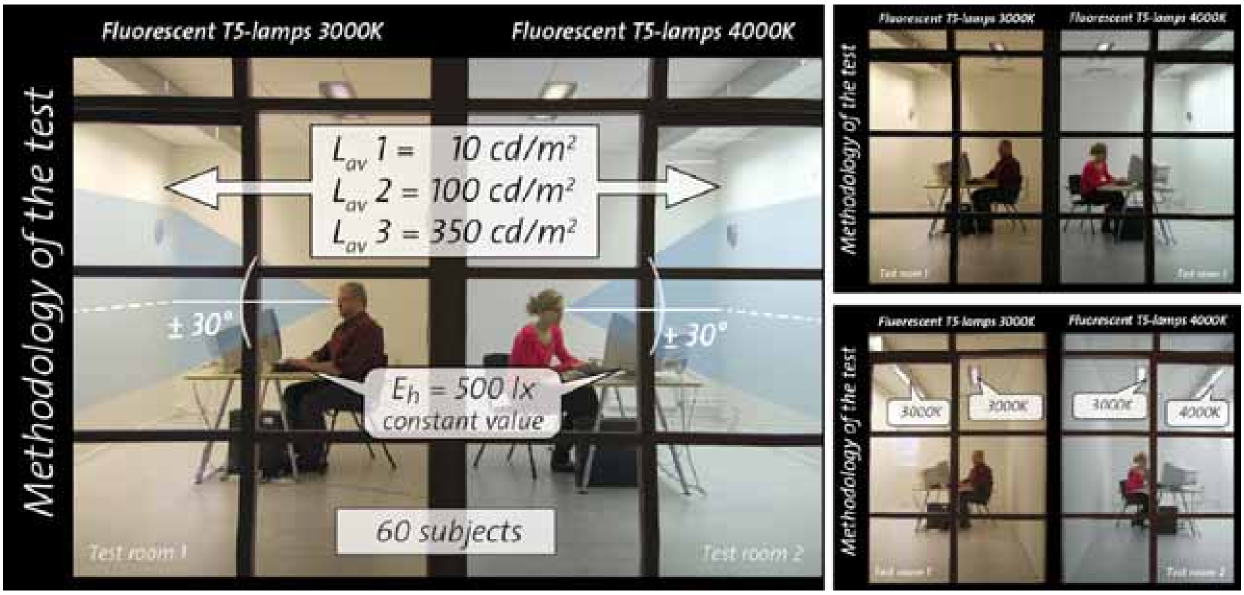
The affective state of the subjects described as general well-being, level of sociability and activation is also measured.

Additional measurements concerning personality and diurnal rhythm are also conducted by means of questionnaires and interviews.

The data were treated by means of a repeated measurement where every subject acts as their own control.

Design of the Study

In order to evaluate how the subjects reacted mentally each subject had to go through a two days test scheme. The subjects had to pass test scheme when exposed to the different ambient luminance levels at the different colour temperatures.



Time Schedule

Day 1 PM

14:45 Saliva – Cortisol 1

Urine – Melatonin 1

For each light setting endocrine indices on Cortisol levels was measured 5 times and on Melatonin 2 times. Subjective and emotional tests of the different light scenes was also carried out during the test as shown in the enclosed test schedule beside.

Day 2 AM

07:00 Wake-up time – Saliva Cortisol 2
08:45 Saliva Cortisol 3
09:00 PC-Computer welcomes
09:15 Subjective experience of lighting 1
09:30 Subjective emotional experience 1
10:00 Visual stress 1
10:30 Daily rhythm (subjective experience)
11:00 Subjective experience of lighting 2
11:30 SMB (subjective conception of the room)
11:45 Saliva – Cortisol 4
12:00 Lunch at site

Day 2 PM

13:15 Subjective experience of lighting 3
13:30 Subjective emotional experience 2
14:00 Visual stress 2 (eye strain – due to glare)
14:30 SQM (SAD-test questionnaire)
14:50 Personality test type AB
15:10 SIGH Revised (depressive ability)
15:30 Subjective experience of lighting 4
15:45 Subjective emotional experience 3
15:50 Saliva - Cortisol 5
Urine - Melatonin 2
16:00 Debriefing

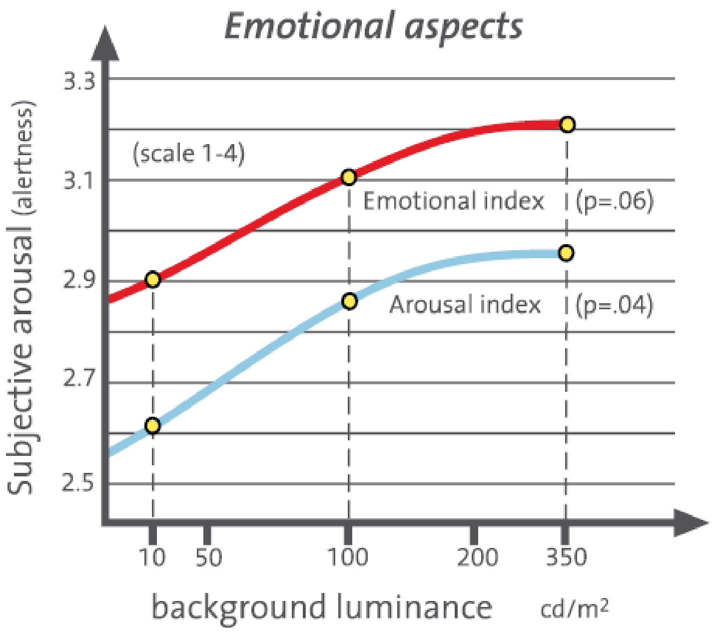
Preliminary results

Today 15 subjects out of 60 have completed the study. The preliminary results on the emotional and perceptual indices are shown below.

Emotional Aspects

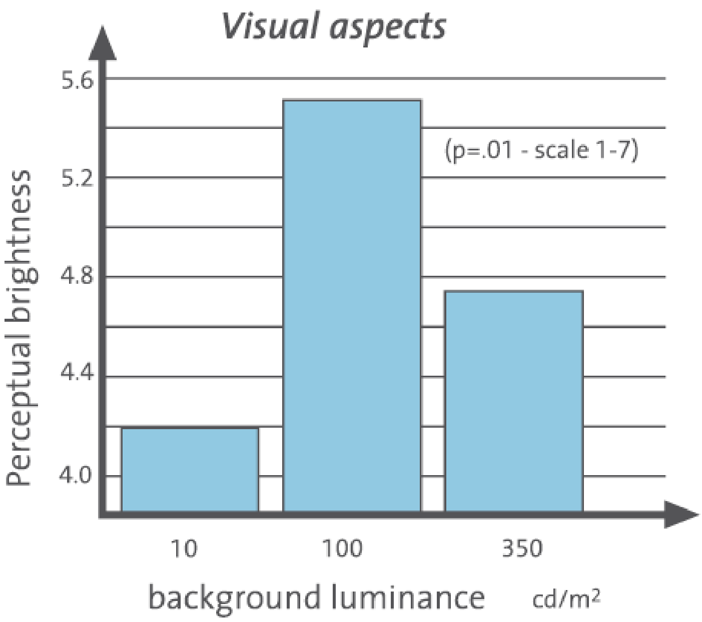
Subjective arousal – The awakeness showed a significant difference between the three lightness levels. The subjects showed more arousal when the ambient luminance was higher.

The same was true for the total emotional index, although the difference was not so pronounced. However, no differences were found between the two colour temperatures, according to arousal. (see figure).



Visual Aspects

Perceptual experience – Subjects sitting in the 4000K room experienced the room significant more cool than their counterparts in the 3000K room. The visual perception of brightness also showed a significant difference between the three lightness levels. However, the subjects experienced the 100 cd/m2 situation as the brightest, followed by the 350 cd/m2. The 10 cd/m2 situation was perceived as the least bright environment. This result may be caused by the fact, that when the lightness of the ambient light is higher than the lightness of the working area (desk lightness ~140 cd/m2) the eye is adapted to a higher level which results in a lower brightness of the desk. (see figure). No significant differencies were found between 3000K and 4000K.



Previous studies on preferred luminance distribution has shown that ambient light levels around 75 cd/m2 at a horizontal illumination level at task of 500 lux when using general lighting systems. (Preferred luminance distribution in working areas – T.Govén et al - Right Light 5, 2002 -Nice)

Further analyses

Biological aspects

During September and October the data collection will be completed. The final assessments will contain analyses of the endocrine measurements on cortisol and melatonin, the individual parameters such as diurnal rhythms and personality. Finally, more elaborated analyses concerning the subjective ratings including changes over time, will be conducted.

Avtorjev naslov / Author’s address:

Tommy Govén - Fagerhult, Sweden – 09/2006
tommy.goven@fagerhult.se

László Beke, Youngshin Kwak, Peter Bodrogi, Seong Deok Lee, Du-Sik Park, Chang Yeong Kim

OPTIMAL COLOR PRIMARIES FOR THREE- AND MULTI-PRIMARY WIDE GAMUT DISPLAYS

Summary

The paper presents a collection of principles to compare two sets of color primaries for three- and multi-primary wide gamut displays. A comprehensive set of design guidelines and a new, algorithmic 3 dimensional method to find optimal color primaries both for three-primary and multi-primary displays is described. The method was implemented in a computer program; the resulting optimal color primary sets are discussed. The paper shows that traditional two dimensional methods to find optimal color primaries by using a chromaticity diagram are theoretically inferior to 3 dimensional optimization techniques that include luminance information.

Povzetek

Optimalne osnovne barve za tri- in večbarvne ekrane s širokim barvnim obsegom *V članku so prikazani različni principi za primerjavo dveh kompletov osnovnih barv za tri- in večbarvne ekrane širokega barvnega obsega. Obširno so opisana navodila za njihovo dizajniranje, pa tudi nova tridimenzionalna metoda za iskanje optimalnih osnovnih barv za tribarvne in večbarvne ekrane. Prikazana je tudi uporaba nove metode v ustreznem računalniškem programu. Z njim smo določili različne nabore optimalnih osnovnih barv in jih podrobneje obravnavali. Pokazali smo, da ima nova, tridimenzionalna metoda za iskanje optimalnih osnovnih barv, ki vključuje tudi svetlost, precej prednosti pred tradicionalno dvodimenzionalno metodo, ki temelji na uporabi barnega diagrama.*

1. Introduction

Digital imaging in electronic commerce, telemedicine, etc., demands ever higher image quality. Image quality is formulated in many ways from pSNR through S-CIELAB [1] to iCAM [2]. There is a general agreement that color fidelity is of primal importance. Ideally, displaying or executing color fidelity enhancement transforms on realistic images requires such displays that do not place any restrictions on the range of displayable colors (i.e. the color gamut). In lack of these displays, gamut mapping methods of more or less complexity have been developed [3] but all of them distort image information in some way. It seems more desirable to design such displays that reduce the need for gamut mapping algorithms by enabling a wide color gamut.

For displaying a certain color, most displays utilize additive color mixing, by using three or more primary color stimuli, which either undergo spatial (CRT, TFT etc.) or temporal (DLP) integration, utilizing the limited resolving power of the human visual system, or are projected onto the same locus by three different sources (LCD projection).

The range of displayable colors depends on the colorimetric properties [4] of the primaries but the number of primary colors is also important. Classical three-primary color matching experiments show that for certain test colors negative amounts of a primary is needed to match a test color, that is this primary has to be added to the test color to match the other two primaries. A similar method (matrixing) can be (and in fact it is) used in cameras (and in other input devices), but it cannot be used for imaging purposes. One possible solution is to select three primaries to minimize the amount of out-of-gamut colors and another solution is to increase the number of color primaries.

Due to recent technological developments, unconventional (wide-gamut) 3-primary and multi-primary displays have gained much attention. However, the issue of selecting the number, chromaticity and luminance of the color primaries still needs a firm theoretical and practical basis in order to ensure that the most is gained by venturing the simplicity of using traditional primaries and traditional image rendering methods. The present article follows a more or less pragmatic approach based on several recent findings of color science to provide some guidelines to solve this issue.

Figure 1 shows the traditional approach of color primary design based on the CIE1931xy chromaticity diagram. In this approach, the colors were to be covered (that is to be inside the triangle or polygon spanned by the primaries) in the chromaticity plane only, regardless of the lightness information of the test colors.

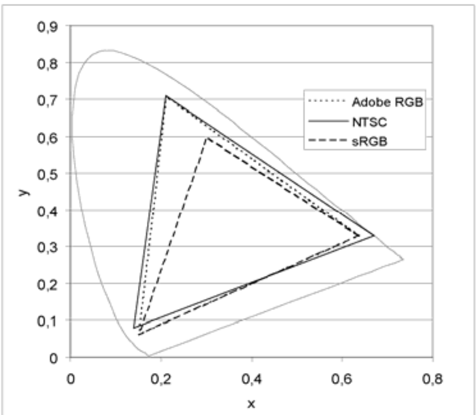


Figure 1. Primaries of NTSC, PAL, Adobe RGB and sRGB systems

In this work, we will show that two dimensional (2D) methods (i.e. using a chromaticity diagram) are not only inferior to 3D optimization (i.e. also using luminance information) but they can also be misleading.

Concerning the present paper, we introduce a new 3D approach based on a cost function (CF) by which two sets of primaries can be compared. In this CF we include the result of our own recent psycho-physical experiment regarding the minimal visually acceptable lightness of color primaries, for different hues. We briefly describe this experiment in this paper. Then, we will show a method by which the minima of our CF can be found. This method results in 'optimal' color primaries, optimal in the sense of those factors that we found to be important enough to incorporate in our CF. We will also show several computational results of the optimization method i.e. several optimal primary sets. By formulating the cost function and by searching for the primary sets we hope to answer the following questions: what visual and technical factors do we have to consider in designing primary sets?; how many primaries do we have to use?; and what are the 'optimal' primaries?.

2. Factors to set up the cost function and to design the optimal color primaries

There are various factors to consider when designing a color primary set and we must find, select and use only those factors that are important and useful. We have to ignore those factors that are irrelevant and/or redundant. Below, a number of factors are listed and analyzed from this point of view. The source of these factors are papers of different approaches regarding color imaging, patents of various imaging devices and solutions, and the CIE TC 8-05 Technical Report [6].

2.1 Volume ([6])

The total volume of the color gamut in a perceptual color space (such as CIELAB or CIECAM02[7]) seems to be an obvious factor.

However, the interpretation of an optimal gamut volume is not clear. While a large gamut is able to represent more colors, it remains a question what percent of all these colors will be actually used in the particular system, and, if quantization efficiency (see below) will be limited by an unnecessarily large gamut.

2.2 Coverage

The most important property of any primary set is to be able to represent the highest possible amount of colors of a so-called *target color gamut*. The usefulness of this criterion depends on the set of colors chosen that serves as the target color gamut.

The coverage of the TCS may be interpreted in at least two different ways:

Target gamut covered by the device gamut: This is the more important factor i.e. that percentage of the TCS that is covered by the device gamut. The testing of TCS coverage can be accomplished by computing the volume of the intersection of the convex hulls (see e.g. [11]) or by sampling the TCS and testing the device gamut for inclusion of the samples. The testing of TCS coverage has to be done in a perceptual color space such as CIELAB or CIECAM02 or CIECAM02-SCDUCS [12] by using a well chosen sample density.

Device gamut used to cover the target gamut: This is the less important factor but it can still be interesting to check the device gamut in order not to 'waste' gamut for colors outside the TCS.

2.3 Quantization metrics ([6])

Displays driven by digital signals unavoidably raise the issue of quantization. Though these metrics are not related so closely to the issue of color primaries, with careful co-optimization, they may have their value in the optimization process.

2.4 Number of color primaries

There are two qualitatively different issues that we must address when making a decision on the number of primaries: 1. using 3 or more primaries, and 2. if using more than 3, then how many of them shall be used.

2.5 White Point

Though it is possible to alter the white point of an existing device by scaling down certain primaries’ contribution to it, at the expense of the maximal brightness and gamut volume, it is obvious that the white point must lie in a certain color tolerance region. Both published [14] results and some of our own unpublished experimental results state that a white point around u’=0.1913 v’=0.4591 can be considered as visually optimal, with a tolerance region around it in a perceptually uniform chromaticity diagram, e.g. CIE1976u’v’. This region defines the range of acceptable device white points. (Such a region can be seen in Figure 4.)

2.6 Implementation constraints

If the objective is not only a theoretically optimal color primary set but also the manufacturing of an actual device then technological constraints, such as the distance from the spectrum locus, maximal luminance values, and the chromaticities that are attainable by filtering a specific lamp used in the device, must be considered.

2.7 P/W ratio

In the case of traditional displays, the ratio of the luminance of the primaries (P) related to the luminance of the peak white (W), i.e. the so-called P/W ratio, was determined so that a desired white point resulted from the mixture of the primaries. Among the very first problems occurring with the introduction of wide gamut displays was the too low brightness of yellowish colors when the red and green primaries of higher excitation purity were introduced[5]. The answer was to introduce a further primary i.e. Yellow. But the introduction of an additional primary or additional primaries increased the number of those parts that the peak white luminance had to be partitioned to, and the P/W ratio became less than for the case of traditional 3P displays. This partitioning occurs in subpixel area or in time-slot length in actual devices. The P/W ratio can be an important factor to consider in the design of new wide-gamut color primary sets. Our own experimental results on the visually acceptable P/W ratios are described in Section 3.2.

3. Implementation

3.1 The Target Color Set

According to the principles described in Section 2, a target color set (TCS) was constructed to be covered by the new color primary set during the computational optimization. The basis of this TCS was the sampled sum (union) of the SOCS database [10] under illuminant CIE D65, the Pointer surface colours database [9], plus the sRGB gamut using the complete lattice of DAC values in the gamma-linear model.

Throughout the computations below the CIE1931 2 degree standard observer was being used[8].

3.2 A psycho-physical experiment on visually acceptable P/W ratios

As described in Section 2, a common complaint against multi-primary displays is that users perceive yellowish colors (or other colors) to be too “dim”. To express these subjective acceptability judgments in terms of luminance or CIECAM02 lightness (J), we carried out a psychophysical experiment i.e. a series of visual observations.

In this experiment, an equi-distant sampling was carried out on a constant hue plane in the CIECAM02 *(J,s,h)* color space, and the observers were inquired if a displayed color sample was acceptable as a color primary of a display. Different values of saturation at a number of hues were investigated, finding the minimal lightness which was acceptable as a display primary.

The samples were displayed by a special 4-primary device consisting of a traditional 3 primary DLP projector and an exchangeable fourth primary of a monochromatic source. The task of the observers was to set that minimal lightness (CIECAM02 J) of the sample at each value of saturation which was still acceptable as a display primary.

Results showed that the minimal lightness – which is in fact conceptually very similar to the frequently used P/W ratio – appeared to be little influenced by the saturation of the sample and by the luminance level of the white background.

It is clear that if we have to introduce more than three primaries in a device then we must make a compromise between satisfying the minimal lightness condition and several other factors.

3.3 The Cost Function

A cost function which describes a primary set was introduced. In this cost function some of the elements described in Section 2. are incorporated: TCS coverage, P/W ratio, white point criterion and technological constraints. Other factors are omitted because of their relatively low importance in this view.

A cost function assigns a scalar to each primary set, which is specified by the XYZ coordinates of the primaries. The values of the cost function over the 3N dimensional parameter space are called the cost surface. The cost surface is a scalar field in the 3N dimensional space describing the ’goodness’ of the 3N dimensional point consisting of the CIE1931XYZ coordinates of the N primaries: that is a primary set.

The cost surface can be re-shaped by assigning different weights to the components with regards to the actual importance of the component.

The components are listed below.

TCS (Test Color Sample) Coverage

If we suppose that the device white point is a good approximation for “white” in any pictorial content displayed on the device (which is at least doubtful, see e.g. [15], but still the best approximation we have today) then it is quite straightforward to use a chromatic adaptation transform or a color appearance model in which coverage checking can be done.

Assuming that the gamut of a device is topologically equivalent in the CIE1931XYZ tristimulus space and in the CIECAM02 *(J,C,h)* perceptual color space, and using the fact that the N color primaries span a regular polyhedron in the former space, a coverage checking algorithm was developed, which avoids the huge computational burden of building a convex hull [11] onto the lattice of DAC values of the n-primaries in each optimization step but still allows for chromatic adaptation to the white point of the device.

P/W Ratio

To include the resulting P/W curve (see Section 3.2) in the computational optimization procedure to find an optimal color primary set, we can add a P/W term to the cost function, e.g. by summing up the differences between the P/W values of the new display’s primaries and the minimal P/W curve.

White Point Criterion

According to the principles detailed in Section 2.5, a tolerance region was determined in the form of an ellipse which fits into the tolerance region of [14].

Technological Constraint

In order to point out interactions and trade-offs between the quality of the color gamut and its feasibility, a pseudo-technological constraint was introduced on the primaries: They had to be no closer to the spectrum locus than a given value, otherwise a term was added to the cost function which contained this distance in inverse proportion.

3.4 The Optimizer

Minima of the scalar cost function correspond to those sets of color primaries which are optimal in the sense as argued in Section 2.

In the test implementation we used a $3N$ dimensional simplex method [16] to find the local minima of the cost function.

To find local minima closer to the global minimum, multiple restarts were initiated starting from different points of the parameter space, from which the best was considered as the “optimal” primary set.

4. Results and Discussion

In this section, example optimum primary sets are shown resulting from running the optimizer program.

The weights were tuned for the algorithm's best performance in agreement with the empirical expectations towards a primary set i.e. that the TCS coverage is the most important issue, while P/W ratios are of less importance. Other parameters of the optimizer – such as its exit conditions and its random initialization – were fine-tuned throughout the development and running of the program.

Two kinds of optimizations were carried out, for a three-, a four-, a five-, and a six-primary system, respectively: in Case I., the technological constraint (i.e. the S/L distance, see Section 3.3) was included, in Case II. it was turned off.

Table 1 shows the parameters of the eight optimal color primary sets.

Number of primaries	Case I.			Case II.		
	TCS Coverage [%]	White point		TCS Coverage [%]	White point	
		u'	v'		u'	v'
3	92.70	0.1982	0.4515	97.15	0.1868	0.4426
4	93.45	0.1947	0.4497	99.03	0.2014	0.4658
5	92.80	0.1933	0.4555	98.96	0.1990	0.4618
6	93.22	0.1877	0.4418	98.86	0.1904	0.4670

Table 1. Parameters of the optimal color primary sets

For comparison the TCS (the TCS defined in Section 3.1) coverage for some standard gamuts are presented in Table 2.

	TCS Coverage [%]
sRGB	77.20
NTSC	89.13
Adobe RGB	86.44

Table 2. Coverage of standard gamuts

Comparing the values of TCS coverage with the loci of the primaries in the CIE1976u'v' chromaticity diagram reveals that the criteria defined in Section 3.3 for TCS coverage yield significantly different results as compared to those of the "traditional" (i.e. those found in literature) gamut evaluations that are carried out in the chromaticity diagram. Firstly, significant differences in the area of the orthogonal projection of the color gamut onto the chromaticity plane (which was a traditional descriptor) yield much smaller differences of TCS coverage as defined in Section 3.3. Secondly, the polygon line connecting the color primaries in ascending order of hue angle, shown in Figure 2 is concave for the optimal primary sets found in the 3 dimensional approach of the present work. This finding would be a nonsense according in a "traditional" two dimensional approach.

However, in three dimensions, a number of test-color samples of high lightness at the border of the gamut between two primaries can be covered by introducing an additional primary. Possibly this additional primary will be of lower saturation, in order not to modify the white point of the device with a high-chroma primary.

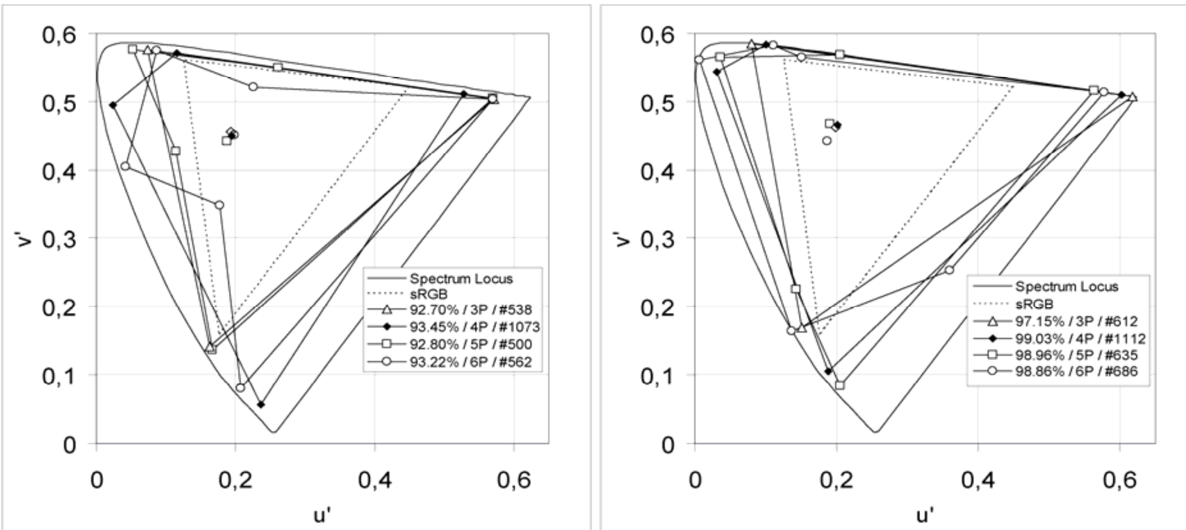


Figure 2. Chromaticity diagram based (“traditional”) representation of the gamuts of the eight optimal color primary sets, Case I. (left) and Case II. (right)

The primaries of the 3P systems satisfied the minimal lightness condition, which was defined in Section 3.3 in both cases (i.e. Case I. and Case II.), but the boundaries of the gamut fail to reach the minimal lightness level between 240 and 310 degrees (i.e. in the blue-magenta region) and slightly between 120 and 130 degrees (i.e. in the yellow-green region).

In general, the primaries of both the 5P and the 6P systems fail to reach the required minimal lightness level, and the gamut shows deficiency in lightness in the same regions as the 3P system plus in the red region for the 5P system and almost everywhere for the 6P system.

A supplementary run of the Optimizer Program showed that if the same weight was attributed to TCS coverage and P/W ratio checking, for the 5P system, the optimization yielded coverage values of 82-88% with primaries satisfying the minimal lightness condition. This means that there is a trade-off between TCS coverage and P/W ratios which can be decided by considering the target of any actual device development and further visual experiments on user preference.

The analysis of the gamut shape reveals that the 5P and 6P gamuts are able to render low lightness-high chroma samples, while 3P gamuts are better in representing high chroma-high lightness samples, and 4P systems are in between. Among the four tested primary sets (3P, 4P, 5P, 6P) the 4P system gives the highest TCS coverage in both cases. This is because a four primary system joins the flexibility of a multi-primary system with the fact that the 100-valued lightness (1-valued P/W) of the white point is distributed among only 4 primaries (see above).

5 Conclusion

A series of factors were listed which may be used as descriptors of a color primary set of a multi-primary display and by which factors two color primary sets can be compared.

We constructed a scalar cost function from these factors and some novel experimental results with the matrix of the color primary set as the independent variable. We considered those primary sets for which this cost function was minimal as optimal in the sense of the definition of the cost function and the empirically determined importance of its components. This was expressed by attributing weights to the components. A comprehensive target color set (TCS) was compiled and sampled in a uniform color space (CIECAM02). An algorithm was developed to test TCS coverage in device context for sets of an arbitrary number of color primaries. Examples for the three-, four-, five- and six primary sets which were found to be optimal by the algorithm were presented. Our TCS chosen was found to be adequate.

We found that the polygon line connecting the primaries in the chromaticity diagram is not necessarily convex and therefore, those optimizations that are carried out in the chromaticity diagram may be misleading. We found that four primary systems yielded the highest coverage, and, that by sacrificing a few percents of coverage, the criterion for the minimum acceptable P/W ratio of the color primaries can also be satisfied.

REFERENCES

[1] Zhang, X., Wandell, B. A., “A Spatial Extension of CIELAB for Digital Color Reproduction”, SID 96 Digest, 731-735, (1996).

[2] Fairchild, M. D., Johnson G. M., Kuang, J., Yamagutchi, H., “Image Appearance Modeling and High-Dynamic-Range Image Rendering”, Proc. of the ACM-SIGGRAPH First Symposium on Applied Perception in Graphics and Visualization, (2004).

[3] Green, Ph., MacDonald, L., Colour Engineering, (Wiley and Sons, 2002), 297-314.

[4] International Commission on Illumination, Colorimetry, 3rd Edition, Publication CIE 2004:15, (2004)

[5] Roth, S., Ben-David, I., Ben-Chorin, M., Eliav, D., Ben-David, O., “Wide gamut, high brightness multiple primaries single panel projection displays”, SID 03 Digest, 10.2, (2003)

[6] International Commission on Illumination, “Criteria for the Evaluation of Extended-gamut Color Encodings”, CIE Publication No. 16. (Draft), (2005)

[7] Moroney, N., Fairchild, M. D, Hunt, R. W. G., Li, Ch., Luo, R. M., Newmann, T.: ”The CIECAM02 Color Appearance Model”, Proc. of the IS&T/SID Tenth Color Imaging Conference, 23-27, (2002)

[8] Wiszecki, G., Stiles, W., S., Color Science: Concepts and Methods, Quantitative Data and Formulae, (John Wiley & Sons, New York, 1982)

[9] Pointer, M. R., “The Gamut of Real Surface Colours”, Color Research and Application, Vol. 5, No. 3, 145-155, (1980)

[10] International Organization for Standardization: “Graphic technology - Standard object colour spectra database for colour reproduction evaluation (SOCS)”, ISO/TR 16066:2003, (2003)

[11] O'Rourke, J., Computational Geometry in C, (Cambridge University Press, 1998)

[12] Li, C., Luo, M. R., Cui, G. H., “Colour-Differences Evaluation Using Colour Appearance Models”, Proc. of the IS&T/SID Eleventh Color Imaging Conference, (2003)

[13] Ohsawa, K., König, F., Yamaguchi, M., Ohyama, N., “Multi-primary display optimized for CIE1931 and CIE1964 color matching functions”, Proc. of the SPIE, Volume 4421, 939-942, (2002)

[14] Vogels, I. M. L. C., Heynderickx, I. E. J., “Optimal and Acceptable White-Point Settings of a Display”, Proc. of the IS&T/SID Twelfth Color Imaging Conference, 233-238, (2004)

[15] M. D. Fairchild., “A Victory for Equivalent Background - On Average”, IS&T/SID 7th Color Imaging Conference, 87-92 (1999)

[16] Press, W.H., Teukolsky, S.A., Vetterling W.T., Flannery, B.P., Numerical Recipies in C, (Cambridge University Press, 408-412, 1988)

Avtorjev naslov / Authors’ address

László BEKE, MSc.
Virtual Environments and Imaging Technologies Laboratory,
Department of Image Processing and Neurocomputing,
Faculty of Information Technology,
University of Pannonia
H-8200 Veszprém, Egyetem u. 10.
Hungary
Tel.: +36 88 624 609
Fax.: +36 88 624 606

E-mail: beke@vision.vein.hu

Richard Kittler

TYPICAL SKY LUMINANCE PATTERNS AND THEIR NEW STANDARDISATION AS BASIS FOR DAYLIGHT CALCULATIONS

Summary

History of sky types used for daylight calculations and the new set of sky types standardised in the ISO and CIE General Sky. Definition of the luminance distribution on the sky vault by gradation and indicatrix functions with their influences on the parametrisation system. Links between sunlight and skylight conditions and possibilities to identify sky types when regular measurement data stored at IDMP stations are available. New possibilities to predict sky luminance glare, absolute interior illuminance levels instead of Daylight Factor criteria, as well as to model annual daylight profiles or year-round daylight changes.

Povzetek

Značilne porazdelitve svetlosti neba in njihova standardizacija kot osnova za izračune osvetljenosti z dnevno svetlobo*; Na začetku članka je predstavljena zgodovina tipov porazdelitve svetlosti neba ter nov nabor tipov neba, uporabljen v ISO in CIE standardih. Sledi definicija porazdelitve svetlosti neba s pomočjo funkcije stopnjevanja svetlosti ter funkcije razpršenosti ter njun vpliv na določanje parametrov modela neba. Podana je tudi povezava med direktno sončno svetlobo in svetlobo neba ter možnosti za določitev ustreznega tipa neba na podlagi meritev svetlosti neba z IDMP postajami. Na koncu so podane nove možnosti za določevanje svetlosti neba, za izračun absolutne vrednosti osvetljenosti prostora namesto faktorja dnevne svetlobe ter za modeliranje sprememb dnevne svetlobe tekom celega leta.*

1 Introduction

During your meetings in 2002 an interesting paper by Kobav and Bizjak, 2002 and last year by Kobav, 2005 were presented introducing the ISO, 2004 and CIE, 2003 Standard General Sky as well as the analysis of measurement results taken by the EKO sky scanner in Lyon. In addition to these some interesting historical basis and developments have to be explained with also recent alternative models of defining relative sky patterns and normal zenith luminance.

2 The history of measurements and studies of sky luminance distributions

The first possibilities for measuring sky luminance arose in the 18th century when Francoise Marie, 1700 invented a subjective luminance meter called „lucimeter“. It consisted of two internally black tubes covered on the downward side with a diffuse thin paper or glass (Figure 1). One was directed on the unknown bright target or light source, while the other usually horizontal tube faced the movable candle stand. The measurement of brightness or luminance followed the idea that an eye is very sensitive to instantly discern differences or equalities of close placed surfaces but due to adaptation no absolute luminance levels. The visual equality of both diffuse glasses had to be adjusted by the distance of the candle stand. However, the available candle sources were too week to rival very bright natural sources, e.g. as the sun, therefore several glasses, i.e. neutral filters had to be applied. Another trick was used by Bouguer, 1729 to measure the optical air mass of the ideally clear atmosphere substituting the sun by moon at the angular elevation 66°11“ and 19°16“ during the night 23/24th November 1725. These elevations represented at the site in Le Croisic, near St. Nazaire, France the noon maximal summer and minimal winter solar solstice, which interested Bouguer, 1760 to define his law of light reduction after transmission through the atmosphere. Now, in modern terms it can be written for an absolutely dry and clear atmosphere either as the sunbeam extraterrestrial flux or illuminance on a fictitious plane placed normal to sunbeams:

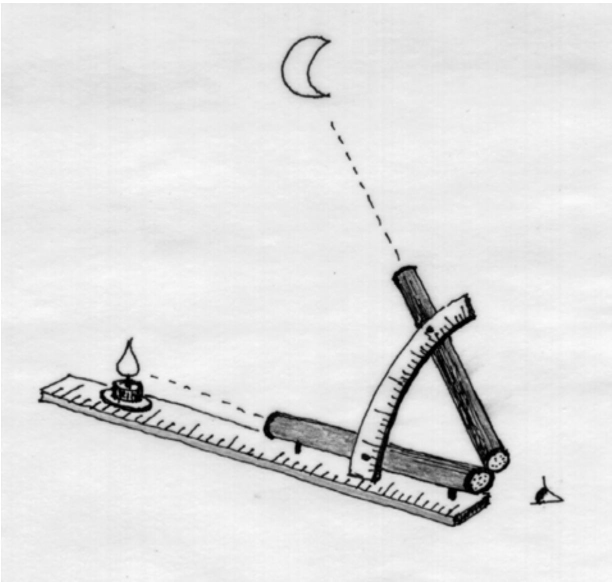


Figure 1: Schematic reproduction of Marie´s subjective lucimeter

$$F = Fo \exp(- av\ m) \qquad (1)$$

where is:

Fo the light flux above the atmosphere equal to the extraterrestrial light solar constant LSC = 133.334 klx or klm/m^2 (Darula et al., 2005),

av luminous extinction coefficient of the Rayleigh (dry and clear) atmosphere, now taken after Clear, 1982 as

$$av = \frac{1}{10.1 + 0.045m} \qquad (2)$$

m relative optical air mass m was originally given in tables by Bouguer, 1729 later by Bemporad, 1904 for different solar altitudes γs, while now it is often taken after Kasten and Young, 1989 in the form of a general equation

$$m = \frac{1}{\sin\gamma s + 0.50572(\gamma s + 6.07995°)^{1.6364}} \qquad (3)$$

Table 1: Comparison of m values

ALT	Bouguer (1729)	Bemporad (1904)	Kasten-Young (1989)
deg	m	m	m
0	35,50	35,40	37,92
1	25,80	27,00	26,31
2	19,00	19,80	19,43
3	14,90	15,40	15,15
5	10,20	10,40	10,31
10	5,56	5,60	5,59
15	3,81	3,82	3,81
20	2,90	2,90	2,90
30	1,99	1,99	1,99
50	1,30	1,30	1,30
70	1,06	1,06	1,06
90	1,00	1,00	1,00

In Table 1 are compared m values after all above authors and note that the old Bouguer´s data are remarkably precise.

Nowadays parallel direct solar beam illuminance penetrating through the actual atmosphere and illuminating a horizontal surface Pv is related to the extraterrestrial horizontal Ev level

$$Ev = LSC \sin \gamma s \qquad (4)$$

$$Pv = Ev \exp(-av\ m\ Tv) \qquad (5)$$

where is«

Tv the luminous turbidity of the real atmosphere expressed as a multiple of the dry and clear case.

If global illuminance Gv and diffuse horizontal illuminance Dv are measured, then Pv/Ev = Gv/Ev - Dv/Ev and the luminous turbidity Tv in the direction of the sun beams can be calculated as

$$Tv = \frac{\ln(Pv / Ev)}{av\ m} \qquad (6)$$

Using Marie´s lucimeter Bouguer has measured also the luminance distribution on a clear sky several times, but he did not insert any measured data into his manuscript published unfortunately in 1760 after his death in 1758. However, in the text he mentioned that measuring sky luminance along the solar almucantar 15 or 20° above horizon he found minimal luminance placed about 110 to 120° on the other side of the sun position, where the luminance is very high.

At the same time Lambert, 1760 introduced under the impression of a fully overcast sky a mathematically simple assumption of a uniform unity luminance on the whole sky vault. This assumption was adopted in the criterion of the Daylight Factor (DF) which served for the assessment of interior daylighting until recently. Nevertheless Kähler, 1908 after luminance measurements on overcast skies in Kiel, Germany suggested to respect the gradual horizon-zenith changes expressed in his formula

$$L\gamma/Lh = 1 + 2 \sin \gamma \quad (7)$$

where is:

Lγ the sky luminance in an arbitrary sky element having the angular elevation γ,

Lh luminance on the horizon.

After similar measurements by Kimball and Hand (1921) in Washington the same formula was recommended by Moon and Spencer (1942) for standardisation in the form normalised to zenith luminance, later adopted by CIE (1955)

$$L\gamma/Lz = (1 + 2 \sin \gamma)/3 \quad (8)$$

After Ralph Hopkinson proposal at the CIE TC/E 3.2 for Daylight meeting the present author was asked in 1964 to prepare the standardisation of relative luminance distribution on a clear sky. Studies by Pokrowski (1929) and by Boldyrev (1935) have shown the combination of the gradation and indicatrix functions, the latter having a better approximation proposed by Krat (1943) with parameters defined by turbidity (Kittler, 1985). After a proposal by Kittler (1967), further discussions and amendments this system of standardisation was adopted by CIE (1973).

Figure 2: EKO sky luminance scanner

More sophisticated daylight measurements initiated by CIE in 1991 for the International Daylight Measurement Programme (IDMP) with regular 1-minute data of global and diffuse data as well as zenith luminance and additional luminance scans of the sky have brought many new information and possibilities of analysis, e.g. on the indicatrix (Kittler, 1969, 1993) and gradation characteristics (Kittler et al., 1998), as well as other data (Kittler et al., 1992) etc.

Nowadays several quite sophisticated luminance scanners can be used to measure the sky luminance distribution, e.g. the German Krochmann or the Japanese EKO (Figure 2) scanners are the more frequent scanners applied in the IDMP network, (Ineichen and Molineaux, 1994).

3 Current sky luminance models and further progress

The current ISO,2004/CIE,2003 standardise the relative luminance distribution of 15 sky types normalised to zenith luminance with specified gradation $\varphi(Z)/\varphi(0°)$ and indicatrix functions $f(\chi)/f(Zs)$, which define the ratio of luminance L in any sky element to the zenith luminance Lz, i.e.

$$\frac{L}{Lz}=\frac{f(\chi)\varphi(Z)}{f(Zs)\varphi(0°)} \qquad (9)$$

Several authors have many some trial to apply these functions to develop different sky models in terms of absolute sky luminance patterns either derived from direct and global measured irradiance (e.g. Perez et al.., 1991 in the so called „All weather model“) or from illuminance levels (e.g. Igawa et al., 1997 with 20 sky models). However, besides the relative relation (9) also further parametrisation was found defining the relation between zenith luminance Lz and horizontal sky illuminance Dv and if these are regularly measured, Lz/Dv is a parameter for selecting the sky type as

$$\frac{Lz}{Dv}=\frac{\varphi(0°)\, f(Zs)}{\int_{Z=0}^{\pi/2}\int_{\alpha=0}^{2\pi}\left[\varphi(Z)f(\chi)\sin Z\cos Z\right]dZ\, d\alpha} \qquad (10)$$

where all angles and parameters to calculate both functions including coefficients a, b, c, d and e are given in ISO,2004/CIE,2003. However, the Lz/Dv ratio after eq. (10) has a special meaning as a selection or identifying parameter valid for any solar altitude after Figure 3, which is very useful also for the determination of zenith luminance in absolute units. In the original study by Kittler et al., (1997) also an approximation of eq.(10) was proposed for solar altitudes under 75 degrees a special attention should be given to very high solar altitudes in tropics (Darula et al, 2006) when the original eq. (10) with the integration has to be adopted.

While this standard is introducing 15 sky types with specific and defined quasi-homogeneous luminance gradations and scattering indicatrices, Perez et al (1993) and Igawa et al. (2004) have chosen a different approach. Under the assumption that irradiance data are more often and world-

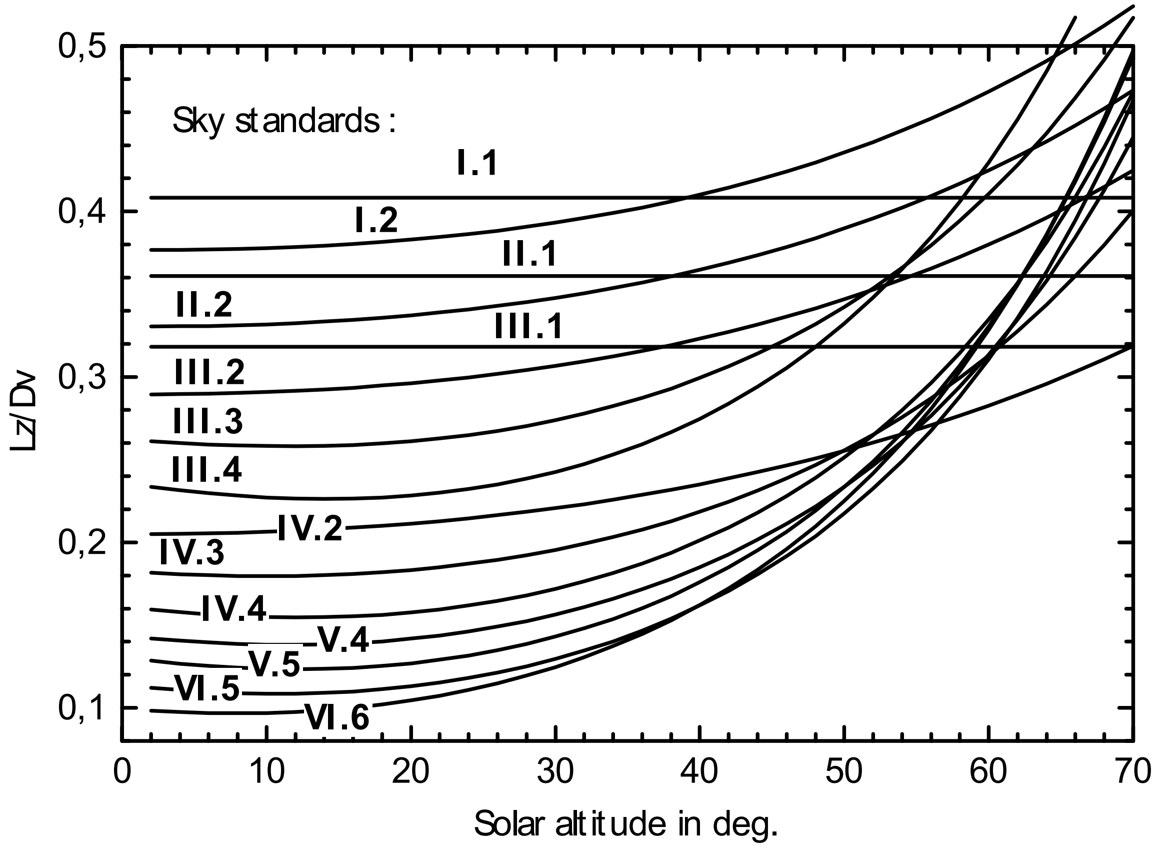


Figure 3: Lz/Dv ratios for different sky types calculated using eq. (10) and an approximation formula after Kittler et al., 1998.

wide available from the meteorological network both latter models apply such data transformed by disputable luminous efficacies to get either absolute illuminance or even luminance quantities. So using eq.(9) to derive gradation and indicatrix coefficients applying different rather complex procedures and normalisation via:

- Perez´s sky clearness ε and sky brightness Δ,
- Igawa´s clear sky index Kc and cloudless index Cle.

Thus specific varying values of coefficients a, b, c, d, and e after measured or expected global and diffuse irradiance under certain solar altitudes are determined and can have arbitrary values differing from those in the ISO/CIE Standard.

4 Absolute zenith luminance models

As the ISO/CIE Standard defines the distribution of luminance on the sky vault only on relative terms, i.e. normalised by zenith luminance it is sometimes needed to determine its value in absolute cd/m² units.

In computer programs for each sky type can be inserted also the calculation of the absolute zenith luminance in cd/m² using eq. (10) as:

$$Lz = \frac{\varphi(0^\circ)\, f(Zs)}{\int_{Z=0}^{\pi/2} \int_{\alpha=0}^{2\pi} \left[\varphi(Z) f(\chi) \sin Z \cos Z\right] dZ\, d\alpha} (Dv/Ev)\ LSC \sin \gamma s \qquad (11)$$

which might be written in a shorter version also as:

$$Lz = (Lz/Dv)(Dv/Ev)\ LSC \sin \gamma s \qquad (11a)$$

where Dv/Ev is in fact expressing the overall transmittance of diffuse skylight through the atmosphere and under certain conditions and sky types can be assumed or predetermined. Also the current state of art enables to identify sky patterns either directly by sky-scan measurements or with regard to measured Lz/Dv ratios, thus absolute sky luminance or resulting global and diffuse horizontal illuminance can be determined in real cases.

Although Igawa et al. (2004) paper is aware of the importance of the Lz/Dv ratio in an earlier paper (Igawa et al. (1999) a simplifying approximation formula is proposed to calculate absolute zenith luminance in cd/m² in dependence on the normalised global illuminance Nevg:

$$Lz = \exp(Ai\ Nevg^5 + Bi\ Nevg^4 + Ci\ Nevg^3 + Di\ Nevg^2 + Ei\ Nevg + Fi) \qquad (12)$$

where Nevg is normalised global illuminance defined as:

$$Nevg = (m\ Gv)/(\ LSC\ Evgms) \qquad (13)$$

Evgms is a standard relative global illuminance under a CIE Clear sky with a luminous transmittance 0.75 approximated by a regression equation:

$$Evgms = -0.323\ \gamma s^4 + 1.486\ \gamma s^3 - 2.581\ \gamma s^2 + 2.09\ \gamma s + 0.19 \qquad (14)$$

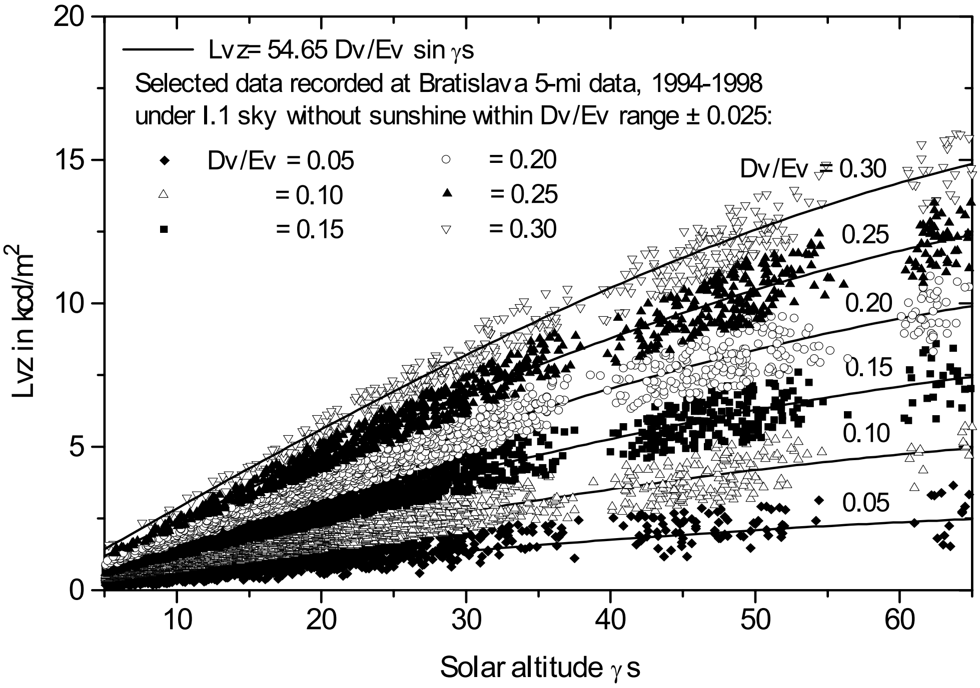


Figure 4: Total number of 9716 cases were identified in the range of SSLD I.1 which validate the Lz, Dv/Ev and γs interdependence.

$$Ai = 18.373\ \gamma s + 9.955 \quad (15)$$
$$Bi = -52.013\ \gamma s - 37.766 \quad (16)$$
$$Ci = 46.572\ \gamma s + 59.352 \quad (17)$$
$$Di = 1.691\ \gamma s^2 - 16.498\ \gamma s - 48.67 \quad (18)$$
$$Ei = 1.124\ \gamma s + 19.738 \quad (19)$$
$$Fi = 1.17\ \ln(\gamma s) + 6.369 \quad (20)$$

The easiest way to validate formula (12) is to test it under the three overcast standard skies:

- SSLD I.1 or sky type 1 which has a constant ratio Lz/Dv = 0.4083,

- SSLD II.1 or sky type 3 which has a constant ratio Lz/Dv = 0.361,

- SSLD III.1 or sky type 5 which has a constant ratio Lz/Dv = $1/\pi$ = 0.31831.

Two logic questions can be posed:

- How come that a darker overcast sky, i.e. I.1 has a brighter zenith luminance that a uniform overcast sky (III.1) ?

- Is it possible that three sky types that have different gradations have after Igawa et al., the same zenith luminance when producing the same diffuse illuminance ?

It is evident that due to the luminance pattern of the sky I.1 its zenith luminance has to be higher than on the sky III.1 where the constant luminance of the whole sky is the same, when both these skies have to yield the same resulting skylight illuminance on an unobstructed exterior horizontal surface. This fact does not take into account Igawa´s approximation eq. (12), which assumes to be valid for all sky types. However, if different sky types are based on gradation and indicatrix differences, then their zenith luminance has to differ especially due to angular distance between the sun position and zenith as expressed by the Lz/Dv ratio under different sky types depending on sunheight (see Figure 3).

In reality under each sky type a range of Dv/Ev ratios can occur but for simplicity sake can be taken rounded relevant values 0.1, 0.2, 0.3 and 0.4 for comparison in Table 2.

Table 2: Comparison of zenith luminance in cd/m² after Igawa 1999 and Kittler et al.1998

γs	Igawa				SSLD I.1			
	Dv/Ev				Dv/Ev			
	0,1	0,2	0,3	0,4	0,05	0,1	0,2	0,3
5	415	700	628	461	237	474	949	1423
10	733	1439	1511	1242	473	945	1891	2836
15	974	2067	2430	2216	705	1409	2818	4227
20	1196	2624	3309	3242	931	1862	3724	5586
25	1420	3155	4155	4278	1150	2301	4601	6902
30	1655	3689	4992	5327	1361	2722	5444	8166
35	1902	4240	5842	6405	1561	3123	6245	9368
40	2164	4813	6718	7532	1750	3499	6999	10498
45	2439	5411	7629	8729	1925	3850	7699	11549
50	2725	6031	8583	10014	2085	4170	8341	12511
55	3019	6669	9580	11406	2230	4459	8919	13378
60	3319	7323	10625	12922	2357	4715	9429	14144
65	3622	7990	11718	14577	2467	4934	9868	14802
γs	SSLD II.1				SSLD III.1			
	Dv/Ev				Dv/Ev			
	0,1	0,2	0,3	0,4	0,1	0,2	0,3	0,4
5	420	839	1259	1678	370	740	1110	1480
10	836	1672	2507	3343	737	1474	2211	2948
15	1246	2492	3737	4983	1098	2197	3295	4394
20	1646	3292	4939	6585	1452	2903	4355	5806
25	2034	4068	6102	8137	1794	3587	5381	7174
30	2407	4813	7220	9626	2122	4244	6366	8488
35	2761	5522	8282	11043	2434	4869	7303	9737
40	3094	6188	9282	12376	2728	5456	8184	10912
45	3403	6807	10210	13614	3001	6002	9003	12004
50	3687	7374	11061	14749	3251	6502	9753	13004
55	3943	7886	11828	15771	3476	6953	10429	13906
60	4168	8337	12505	16673	3675	7351	11026	14702
65	4362	8725	13087	17449	3846	7693	11539	15386

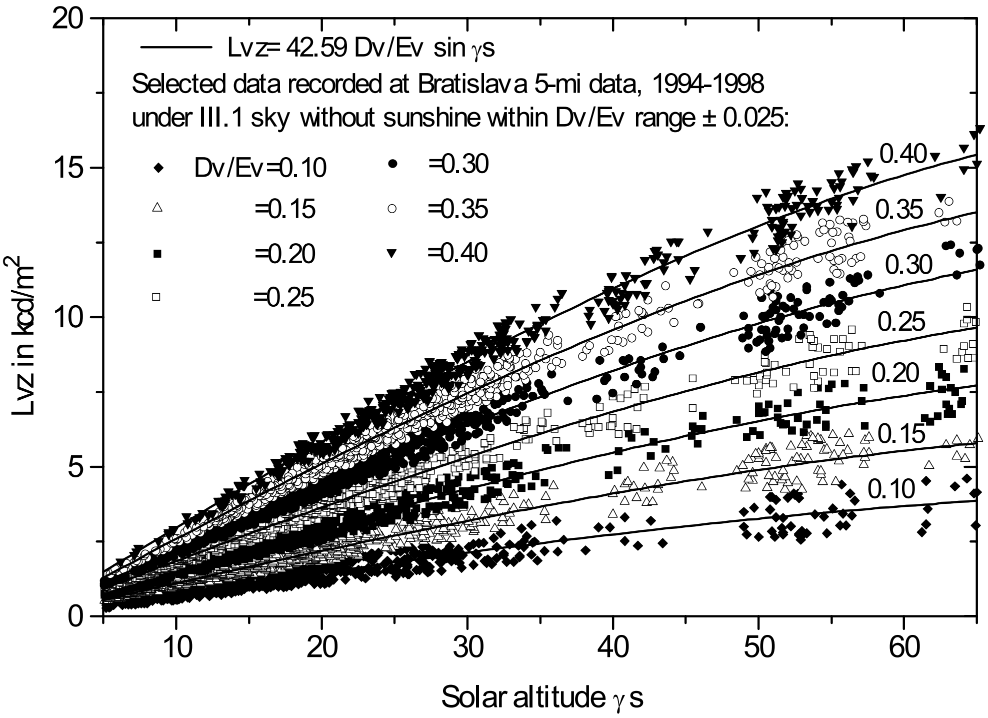


Figure 5: Total number of 5777 cases were identified in the range of SSLD III.1 which validate the Lz, Dv/Ev and γs interdependence.

Of course as under all these selected sky types no sunlight is expected:

$$Gv = Dv = LSC\ (Dv/Ev)\ \sin \gamma s,$$

thus e.g. for I.1 or sky type 1: $Lz = 0.4083 \times 133\,334\ Dv/Ev \sin \gamma s$ (21)

or for III.1 or sky type 5 $Lz = 0.3183 \times 133\,334\ Dv/Ev \sin \gamma s$ (22)

To test these interrelations also measured data based on Bratislava 5-minute records during 5 year 1994-98 were used earlier (Darula and Kittler, 2004). Separately but simultaneously measured Lz and Dv values were selected and groups in bins Dv/Ev as shown in Figure 4 under sky I.1 and in Figure 5 under sky III.1 compared to calculated Lz after eq. (21) and (22).

Similarly it is possible to test Lz values for any standard sky without or with direct sunlight (when Gv = Dv + Pv) under different turbidity Tv and Dv/Ev ratios respecting the interrelation of Dv/Ev and Tv after Darula and Kittler, (2005):

$$Dv/Ev = [(A1\ Tv + A2) \sin \gamma s + 0.7(Tv + 1)X + 0.04\ Tv]/[B\ X + E \sin \gamma s] \quad (23)$$

where is:

$$X = (\sin \gamma s)^C/(\cos \gamma s)^D$$

all parameters A1, A2, B, C, D and E for each sky type with sunlight are in Table 2 in Kittler et al.(1998) or Darula and Kittler, (2005), Table 1.

It has to be noted that absolute zenith luminance cannot be determined without either measured diffuse/global illuminance or presumed Dv/Ev ratios under overcast and cloudy skies or luminous turbidity levels Tv allowing to calculate interrelation of Pv and Dv illuminances under sunny conditions.

Although the Tv and Dv/Ev interdependence results in some complexity also the measured 5 year Bratislava data (Darula and Kittler, 2005) have shown that absolute Lz values can be predetermined after the general formula (11a).

If luminance scan data are also available there is a possibility to analyse these using the method recommended by Tregenza, 2004.

5 Conclusions

A set of standard sky types covering the whole practical range of occurrence enables:

- to calculate zenith luminance and exterior illuminances under various sky types,
- to model daylight climate in any place world-wide,
- to simulate annual profiles or daily changes of sky patterns,
- to specify sky luminance distribution in solid angles of windows in any time and orientation,
- to assess possible ranges of window luminance for glare studies,
- to apply sky types in various computer programs, e.g. as ModelSky., SkyModeller, Virtual Sky Domes etc.

The current computer possibilities enable to work out sophisticated user-friendly programs respecting local situations world-wide as well as arbitrary window and interior dimensions to calculate the skylight illuminance quite easy and quickly.

The next paper by my colleague Dr. Darula will explain and show one of the possible methods and a simple user-friendly computer tool to predetermine interior illuminance from windows.

Acknowledgement

This study is summarising partial results elaborated under the support of the Slovak grant VEGA 2/5093/5 and with thanks for the cooperation under the bilateral Slovak-Czech project SK- CZ-11006.

REFERENCES

Bemporad, A. (1904), Mitteilung der Grossh. Sternwarte Heidelberg, B.4.

Boldyrev, N.G. (1935), O raspredelenii jarkosti po nebu. Svetotekhnika, 6, 16-18.

Bouguer, P. (1729), *Essai d´Optique sur la gradation de la lumiére*.Claude Jombert, Paris.

Bouguer, P. (1760), *Traité d´Optique sur la gradation de la lumiére*. Paris. Rusian translation by N.A. Tolstogo a P.P.Feofilova: Optièeskij traktat o gradacii sveta. Izd. AN SSSR, Moskva 1950.

Clear, R.(1982), Calculation of turbidity and direct sun illuminance. Memo to Daylight Group, LBL Berkeley, Cal.,.

Commission Internationale de l´Éclairage (1955), Natural Daylight. Official Recommendation. Compte Rendu CIE 13. Session, 2, part 3.2, pp.2-4, Central Bureau CIE, Paris.

Commission Internationale de l´Éclairage (1973), Standardisation of luminance distribution on clear skies. CIE Publ. No. 22, Central Bureau CIE, Paris.

Commission Internationale de l´Éclairage, CIE (2003), *Spatial distribution of daylight - CIE Standard General Sky.* CIE Standard S 011/E:2003, CIE Central Bureau, Vienna.

Darula, S. - Kittler, R. (2004), New trends in daylight theory based on the ISO/CIE sky standard. 1. Zenith luminance on overcast skies. Build.Res. Journ., 52, 3, 181-197.

Darula, S. - Kittler, R. - Gueymard, Ch.A.(2005), Reference luminous solar constant and solar luminance for illuminance calculations. Solar Energy, 79, 559-565.

Darula, S. - Kittler, R. (2005), New trends in daylight theory based on the ISO/CIE sky standard. 3. Zenith luminance formula verified by measurement data under cloudless skies. Build.Res. Journ., 53, 1, 9-31.

Darula S. - Kittler, R. - Wittkopf, S.(2006), Outdoor illuminance levels in the tropics and their representation in the Virtual Sky Dome. Archit. Science Review, in print.

Igawa, N. - Nakamura, H. - Matsuzawa, T. - Koga, Y. - Goto, K. - Kojo S. (1997), Sky luminance distribution between two CIE standard skies. Proc. Lux Pacifica, pp. E7 - E18.

Igawa, N. - Nakamura, H. - Matsuura, K. (1999), Sky luminance distribution model for simulation of daylight environment. Proc. Build. Simulation ´99, Vol. 2, 977 - 982.

Igawa, N. - Koga, Y. - Matsuzawa, T. - Nakamura, H. (2004), Models of sky radiance distribution and sky luminance distribution. Solar Energy, 77, 137 - 157.

Ineichen, P. - Molineaux, B. (1994), Characterisation and comparison of two sky scanners: PRC Krochmann and EKO instruments. Broad-band visible and radiation data acquisition and analysis. IEA Techn.Rep. of task 17, p.5-1-8, ASRC, Albany, N.Y.

International Standard Organisation ISO (2004), *Spatial distribution of daylight - CIE Standard General Sky.* ISO Standard 15469:2004.

Kasten, F., Young, A.T.(1989), Revised optical air mass tables and approximation formula. Appl. Optics, 28, 22, pp. 4735-4738.

Kähler K.(1908), Flächenhelligkeit des Himmels and Beleuchtungsstärke in Räumen. Meteor. Zeitschrift, 25, 2, 52-57.

Kimball, H.H. - Hand I.F.(1921), Sky brightness and daylight illumination measurements. Monthly Weather Review, 49, 9, 481- 488.

Kittler, R. (1967), Standardisation of the outdoor conditions for calculation of the Daylight Factor with clear skies. *Sunlight in Buildings*, Bouwcentrum, Rotterdam, 273-286.

Kittler, R. (1969), A simple method of measuring and evaluating the atmospheric diffusion of sunlight when seeking the typical luminance patterns of the clear sky. *Symposium on environmental physics as applied to buildings in the tropics.* vol. II, D1-14. Roorkee, U. P., India.

Kittler, R. (1985), Luminance distribution characteristics of homogeneous skies: a measurement and prediction strategy. Light. Res. and Technol.,17, 4, 183-188.

Kittler, R. Mikler J.(1986), *Základy využívania slnečného žiarenia*. (Basis of the utilisation of solar radiation, in Slovak), VEDA, Bratislava.

Kittler, R., Hayman, S., Ruck, N., Julian, W.(1992), Daylight measurement data: Methods of evaluation and representation. Light. Res. and Technol., 24, 4, 173-187.

Kittler, R.(1993), Relative scattering indicatrix: Derivation from regular radiance/luminance sky scans. Light. Res. and Technol., 25, 125-127.

Kittler, R. - Perez, R. - Darula S.(1998), A set of standard skies characterising daylight conditions for computer and energy conscious design. Final Rep.US-SK grant 92 052, 240 pp., also partly published as A set of standard skies. Polygrafia SAV Bratislava.

Krat, V.A. (1943), Indikatrisa rasseyaniya sveta v zemnoy atmosfere. Astron. zhurnal, 20, 5-6.

Kobav, M. – Bizjak, G. (2002), Predlog CIE standarda za prostorsko porazdelitev dnevne svetlobe – CIE standardno nebo. Proc. Razsvetljava 2002, Laško.

Kobav, M. (2005), Določanje CIE tipa neba na podlagi meritev poprazdelitve svetlosti. Proc. Razsvetljava 2005, Postojna.

Lambert J. H. (1760), Photometria sive de mensura et gradibus luminis, colorum et umbrae. Klett Verlag, Augsburg. German translation by E. Audinga: Lambert´s Photometrie. Verlag Engelmann, Leipzig 1892.

Marie, F. (1700), *Nouvelle découverte sur la lumiére.* Pour la mesurer & en compter les degrés. Luis Sevestre, Paris.

Moon P. - Spencer D.E.(1942), Illumination from a non-uniform sky. Illum.Eng., 37, 10, 707-726.

Perez, R. - Seals, R. - Michalsky, J. (1991), An all weather model for sky luminance distribution. Solar Energy, 50, 3, 235 - 245.

Pokrowski, G.I. (1929), Über die Helligkeitsverteilung am Himmel. Phys. Zeitschr., 390, 20, 697-700.

Tregenza, P.R. (2004), Analysing sky luminance scans to obtain frequency distributions of CIE Standard General Skies. Light. Res. and Technol.,36, 4, 271-281.

Avtorjev naslov / Author’s address:

Richard Kittler, DrSc.
Institute of Construction and Architecture, Slovak Academy of Sciences
SK –845 03 Bratislava, Dubravska cesta 9
Slovakia
Tel.: +421 2 5930 9267
Fax: +421 2 5477 3548
Email: usarkit@savba.sk

Stanislav Darula

CALCULATION OF WINDOW LUMINANCES AND SKY ILLUMINANCE IN SIDE-LIT WORKING PLACES

Summary

The typical sky luminance distribution patterns for practical illuminance and luminance calculations were derived and adopted by ISO in the ISO/CIE 15469:2004 General Sky Standard. All the 15 sky types result different luminances in the window solid angle depend on the sun position, sunshine presence or absence when it is cover by clouds as well as on the optical properties of the atmosphere. The algorithm for calculation of sky luminances in cd/m2 and sky illuminance on the working plane is presented together with the user friendly program called MAMmodeller, which allows calculation of window luminance map on-line on the address http://www.cadplan.com.au. The use of this program will be presented with examples of side-lit working places in different situations.

Povzetek

Izračun svetlosti neba in osvetljenosti na delovnih mestih ob oknu*; Pri praktičnih izračunih osvetljenosti in svetlosti v prostorih, osvetljenih z okni si lahko pomagamo z porazdelitvijo svetlosti neba, ki je definirana v standardu ISO/CIE 15469:2004 in ki navaja 15 različnih tipov neba. Pri izračunu svetlosti dela neba, ki ga vidimo skozi okno moramo upoštevati ustrezen tip neba po standardu, položaj sonca, prisotnost ali odsotnost direktne sončne svetlobe, ki je odvisna od oblačnosti neba ter optične lastnosti atmosfere. V članku je predstavljen algoritem za izračun svetlosti neba v cd/m^2,ki ga vidimo skozi okno ter za izračun osvetljenosti delovne površine, ki jo to okno osvetljuje. Predstavljen je tudi program MAMmodeller, ki omogoča izračun svetlosti dela neba, vidnega skozi okno in ki je dostopen na spletni strani http://www.cadplan.com.au. Uporaba programa je prikazana s primerom osvetljenosti delovnega mesta z oknom pri različnih pogojih.*

1 Introduction

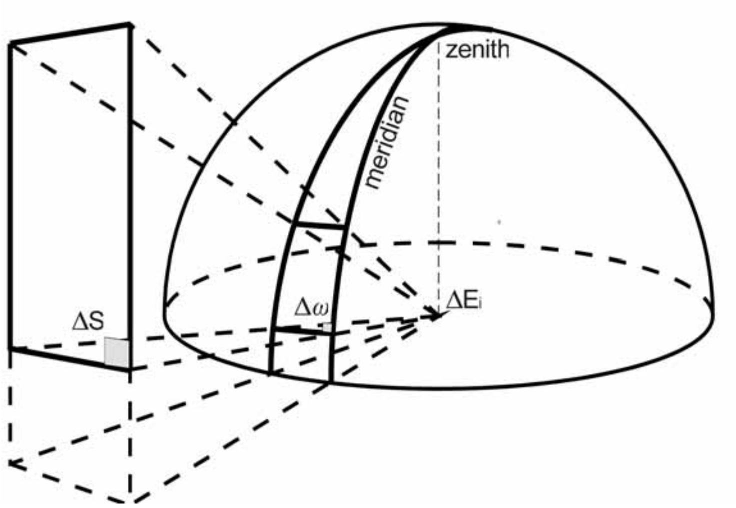


Figure 1: Scheme of meridians at the window edges

Recently Kobav and Bizjak, 2005 introduced a new substitute method to calculate indoor daylight illluminance under new standard sky types. In this paper the standard approach of calculation is shown using the already published MAM method (Kittler and Darula, 2006). Using this approach Prof. Roy et al., 2006 developed a user friendly computer program for WWW side MAMmodeller. In spite of the fact that description of the MAMmodeller is still in print this paper would like to introduce internet on line possibility of calculation.

2 Principle MAM relations

The Method of Aperture Meridians defines a sequential set of meridians within the window solid angle and allows to calculate elementary luminances in angular steps along each meridian for a chosen sky type (Figure 1). To estimate the sunlight and skylight interdependence in any location with regard to the orientation of the assessed interior, the building site and window parameters have to be stated in input of the CADPLAN system, see Figure 2.

The geometry of space is defined in Cartesian coordinates using window plane as a reference. The sun position as well as normal of the window plane are orientated to North direction. On the sky dome with a chosen sky pattern are projected the window edges and a luminance map seen through the window opening.

Using a relevant point on the working plane either the sky luminance map seen from this point can be read or interior sky illuminance in lux can be found .

3 The MAMmodeller package and its use

The user friendly package is containing several possibilities to calculate either window luminances or interior absolute luminance under all CIE standard skies when the user´s control panel is filled in as follows:

- ***Time and location setting***

Actual location of the side has to be defined by geographical latitude φ and longitude λ, e.g. for Ljubljana φ = 46˚13´ N, λ = 14˚29´ E. When choosing date/time (e.g. 12th October at 10:15) for the required assessment these will be inserted automatically and solar altitude γs = 35.91˚ and azimuth As = 168.48˚ will be shown on Figure 3.

- ***Sky information***

The selected sky from the fifteen CIE standards is chosen by its SSLD number with a possibility to define either Dv/Ev ratio for situations without sun (sky type numbers 1 - 6) or Luminous turbidity

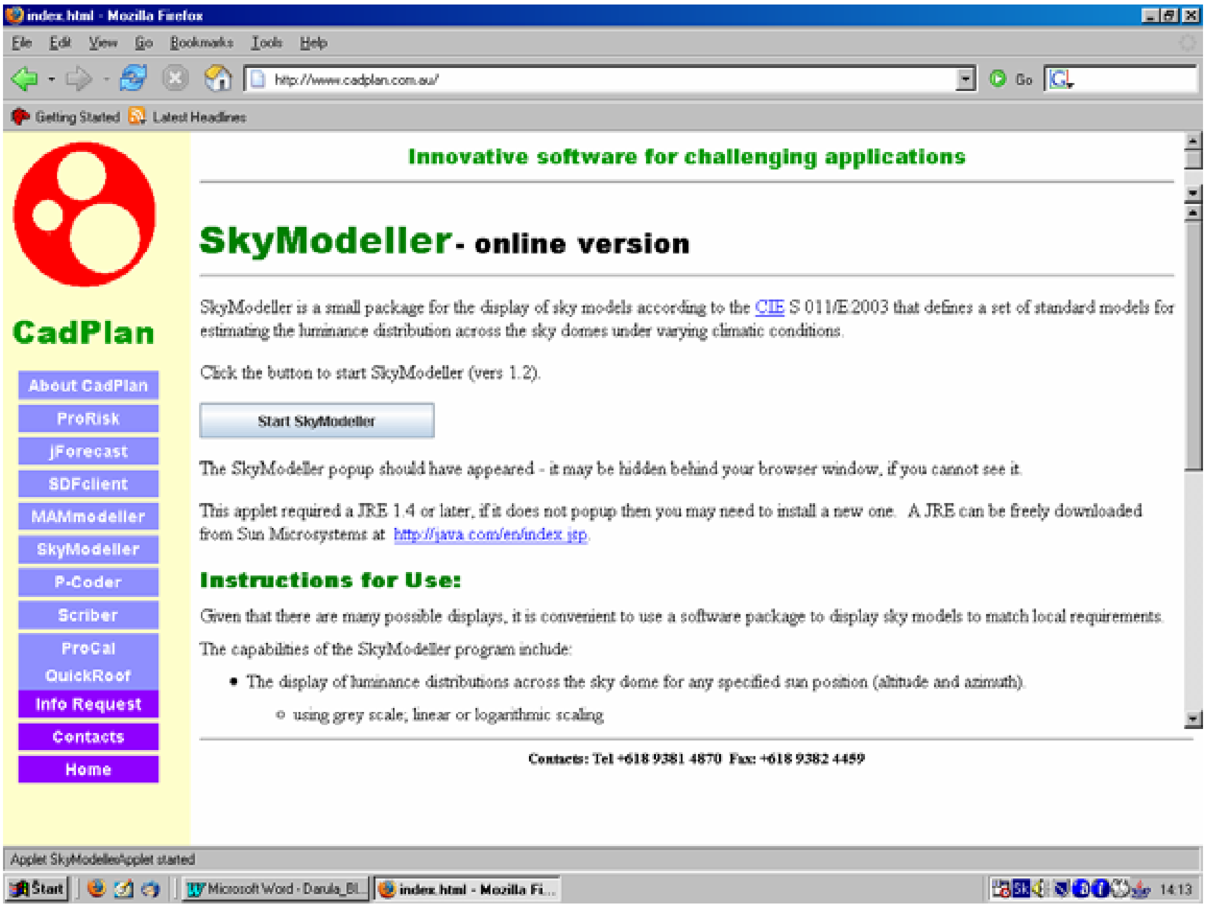


Figure 2: MAMmodeller home page

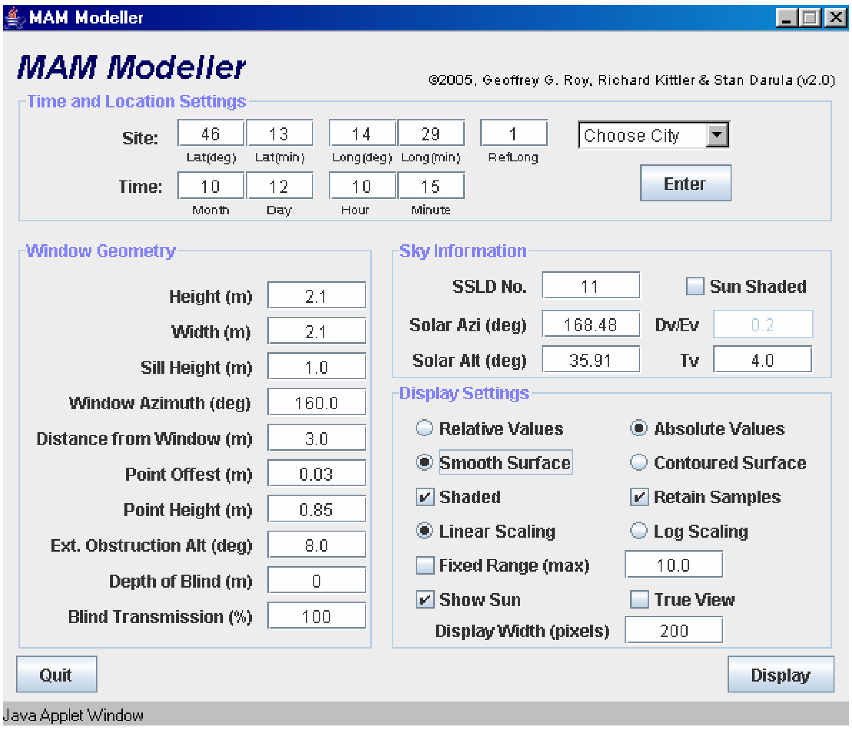


Figure 3: The input data form

factor Tv for sunny situations (sky type numbers 7 - 12). When onla luminance distribution in relative terms are required then these parameters are not valid.

- ***Window geometry***

Window dimensions have to be inserted in appropriate boxes with window orientation and exterior obstruction elevation as well as the placement of the point on the working plane. Simultaneously the transmission of the window glazing or the blind can be put in. In the example on Figure 3 are displayed the inserted window (2.1m x 2.1m on a 1m sill) and obstruction dimensions 8˚ etc.

- ***Display settings***

These can allow the user to choose:

- luminance values within the window to be in relative or absolute terms in cd/m^2,
- various images of luminance maps, e.g. shaded or contoured with either linear or logarithmic scales,
- if the window orientation is toward the sun this can be displayed also by a yellow spot.

An example of input form for chosen working place in Ljubljana is presented in Figure 3.

Luminance map for the Example in two alternatives is in Figure 4 and 5 with statistics report in Table 1.

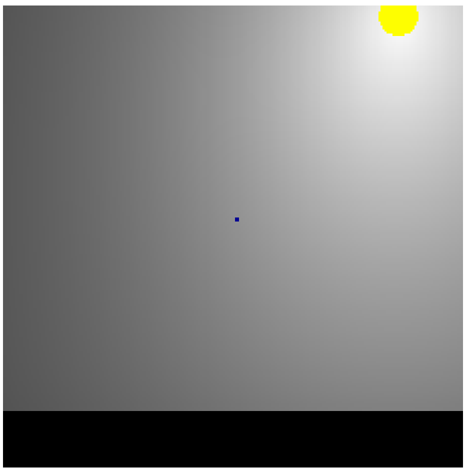


Figure 4: Smooth luminance map for the example

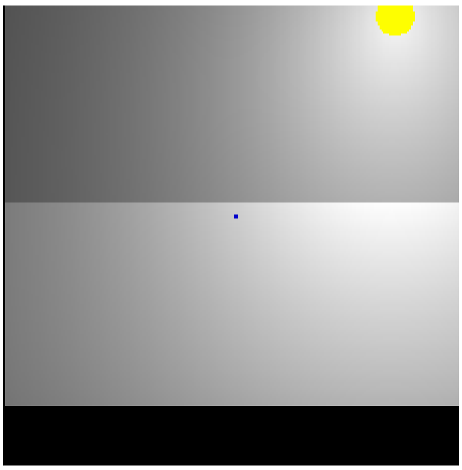


Figure 5: The same with a blind to reduce sun glare but transmitting 70 %

Exterior Conditions: SSLD No = 11 Sun Altitude = 35.91 Sun Azimuth = 168.48 Tv = 4.0 Zenith Luminance (Lz) = 3 462 [cd/m2] Dv = 18 514 [lux] Pv = 39 657 [lux] Gv = 58 170 [lux] Lz/Dv ratio = 0,187 Interior conditions: Window: width = 2.1 height = 2.1 sill level = 1.0 azimuth = 160.0 Interior Point: from window = 3.0 centre offset = 0.3 level = 0.85 External obstruction: altitude angle = 8.0	
Sky Illuminance at Point in room = 2 188 [lux]	Sky Illuminance at Point in room =1 790 [lux]

Table 1: Example of the statistics report

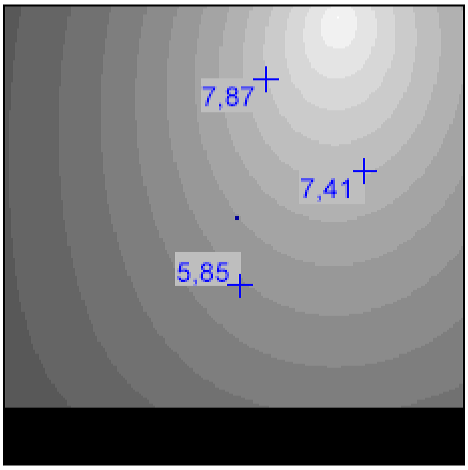


Figure 6: Same as Figure 4 but with stepped luminance map and sampling points with absolute luminances

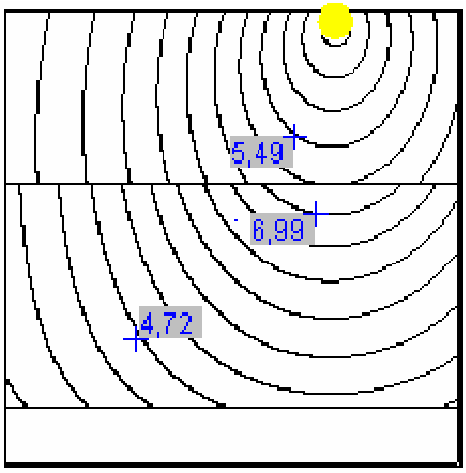


Figure 7: Same as Figure 5 but with contoured luminance map and sampling points with absolute luminances

If a user wishes he can select also the stepped or contoured luminance map images as shown on Figure 6 and 7. There are also possibilities to retain the chosen luminances in sampling point, e.g. at window corners or on its centerline, the luminance contours can be either in linear or logarithmic scaling etc.

A summary of calculation results are collected in the so called Statistics Report (e.g. in Table 1) where in the last line is the interior sky illuminance at the chosen point of the working plane in lux.

4 Total illuminance in a specific point of the working plane

Having the illuminance produced by the sky luminance seen through the window it is necessary to determine also the illuminance contribution caused by reflected light from exterior or interior surfaces. The interreflection conditions are usually very complex but for rough linear approximation a quite simple relation can be recommended:

$$Ei = Es\ (1 + 1.368\ \rho_a) \qquad (1)$$

where is:

Ei the total interior illuminance in lx,

Es sky illuminance,

ρ_a average reflection factor for all interior surfaces.

This formula is restricted for side-lit interiors regular in plan with only one window and without exterior obstructions.

5 Conclusions

After the recent international standardisation of sky types the new Method of Aperture Meridians was developed as well as its implementation in new computer package MAMmodeller. Thus it provides designers with a simple and easy tool accessible on the WWW page (http://www.cadplan.com.au) for a quick assessment of daylight conditions under various sky standards. Also specific localities with their characteristic weather conditions can be simulated close to reality and different cloudiness and atmospheric properties can be considered.

Acknowledgement

This paper was elaborated under the support of the Slovak grant VEGA 2/5093/5 and with thanks for the cooperation under the bilateral Slovak-Czech project SK- CZ-11006.

REFERENCES

Kittler, R. - Darula, S., The method of aperture meridians: a simple calculation tool for applying the ISO/CIE Standard General Sky. Light Res. Technol., 38, (2), p.109 – 122, 2006.

Kobav M.B. - Bizjak G., Developing substitutive light source for indoor daylight calculations. Proc. Lux Europa 2005, 238 – 241, Berlin 2005.

Roy, G. G. - Kittler, R. - Darula, S., An implementation of the Method of Aperture Meridians for the ISO/CIE Standard General Sky. Light Res. Technol., in print.

Roy, G. G. - Kittler, R. - Darula, S., MAMmodeller, http://www.cadplan.com.au, (cited 2005).

Avtorjev naslov / Author´s address:

Stanislav Darula

Institute of Construction and Architecture, Slovak Academy of Sciences

SK 845 03 Bratislava, Dubravska cesta 9

Slovakia

Tel.: +421 5930 9267

Fax: +421 5447 73548

Email: usarsdar@savba.sk

Axel Stockmar

OUTDOOR WORK PLACE LIGHTING ACCORDING TO EN 12464-2 / CIE S 015

Summary

The draft European Standard prEN 12464-2 "Lighting of Outdoor Work Places" specifies the lighting requirements for the lighting of tasks in most outdoor work places and their associated areas in terms of quantity and quality. Furthermore the standard sets limits of obtrusive light for exterior lighting installations which are based on publication CIE 150:2003. Lighting levels are given in terms of average maintained illuminances of task and surrounding areas. For the calculation of illuminances and uniformities the maximum grid cell sizes can be evaluated using a formula which takes into account the actual dimensions of the area under consideration. The glare directly from the luminaires of an outdoor lighting installation is determined using the CIE Glare Rating (GR) method according to publication CIE 112:1994.

Povzetek

Razsvetljava delovnih mest na prostem v skladu s standardom EN 12464-2 / CIE S 015*; Predlog evropskega standarda prEN 12464-2 »Razsvetljava delovnih mest na prostem« specificira svetlobne zahteve za razsvetljavo delovne naloge na večini delovnih mest oziroma delovnih področij na prostem tako kvantitativno kot kvalitativno. Poleg tega standard postavlja tudi meje za vsiljeno svetlobo, ki jo povzroča zunanja razsvetljava in ki temeljijo na CIE 150:2003 dokumentu. Svetlobne zahteve so podane v obliki srednje vzdrževane osvetljenosti področja delovne naloge in njene okolice. Standard podaja tudi izraz, s pomočjo katerega je možno določiti največjo še ustrezno velikost mreže za izračun srednje osvetljenosti ter njene enakomernosti in ki upošteva dejanske dimenzije obravnavanega področja. Neposredno bleščanje svetlobnih virov pa se po standardu določi s pomočjo metode CIE indeksa bleščanja po publikaciji CIE 112:1994.*

1 Introduction

The draft European Standard prEN 12464-2 “Lighting of Outdoor Work Places” [1] specifies the lighting requirements for the lighting of tasks in most outdoor work places and their associated areas in terms of quantity and quality. Despite of different normative references this standard is identical with the CIE Standard S 015 “Lighting of Outdoor Work Places” [2].

These standards specify lighting requirements for outdoor work places which meet the needs for visual comfort and performance; they do not specify lighting requirements with respect to safety and health of workers at work, although the lighting requirements as specified usually fulfil safety needs.

2 Lighting Design Criteria

The main parameters determining the luminous environment are the luminance distribution, the illuminance level and uniformity, the limitation of glare, the directionality of light (modelling), the colour appearance and colour rendering, and the degree of flicker [1][2].

The luminance distribution in the filed of view controls the adaptation level of the eyes. A well balanced luminance distribution (sudden changes should be avoided) is needed to increase the visual acuity, the contrast sensitivity, and the efficiency of the ocular functions.

The illuminance and its distribution (on task and surrounding area) have a great impact on how quickly, safely, and comfortably a person perceives and carries out a visual task. The illuminance values specified in the standards [1][2] are maintained illuminances over the task area on the reference surface, which may be horizontal, vertical or inclined. The task area is defined as the partial area in the work place in which the visual task is carried out. For places where the size and/or the location of the task area are unknown, the area where the task may occur is the task area. The maintained illuminance of the surrounding area shall be related to the maintained illuminance of the task area and should provide a well-balanced luminance distribution in the field of view. For task area illuminances of 100 lx or above the illuminances of the surrounding area are specified as four steps down on the recommended scale of illuminances which was taken from the European standard EN 12665 “Basic terms and criteria for specifying lighting requirements” [3]. The surrounding area is regarded as a strip surrounding the task area in the field of view; the width of this strip should be at least 2 m.

Alongside the average maintained illuminances specified for a large number of areas, tasks and activities there are also requirements given concerning uniformities (minimum/average) and diversities (minimum/maximum) [1][2] for task and surrounding areas. For the calculation and verification of illuminance values (minimum, average, maximum) a grid system has to be used which is based on a formula giving the maximum grid cell size dependent on the area dimensions. This formula is equivalent to the equation given in the European standard EN 12193 “Sports lighting” [4].

The colour qualities of near-white lamps are characterised by the colour appearance of the lamp (warm, intermediate, cool) and the colour rendering capabilities expressed in terms of the general colour rendering index R_a. This methodology is the same as used for the lighting of indoor work places [5]. For the recognition of safety colours the light sources shall have a minimum colour rendering index of 20; for specific tasks, areas or activities requirements are given in the schedule of lighting requirements [1][2].

To highlight objects, to reveal textures or to improve the appearance of people (“modelling”) directional lighting may be suitable. Modelling is the balance between diffuse and directional light; too directional lighting will produce harsh shadows. Lighting from specific directions may reveal details within a visual tasks, increase their visibility and making the task easier to perform. Unfortunately there are no measures given in the standards [1][2], only verbal descriptions.

3 Evaluation of Glare

Glare is the sensation produced by bright areas within the field of view and my be experienced either as discomfort or disability glare [1][2]. The glare directly from the luminaires of an outdoor lighting installation shall be determined using the CIE Glare Rating (GR) method according to CIE publication 112:1994 [6]. For a given observer position and a given viewing direction (2º below the horizontal) the degree of glare is dependent on the equivalent veiling luminance produced by the luminaires and the equivalent veiling luminance produced by the environment in front of the observer. The veiling luminance caused by the lighting installation is calculated according to the Holloday formula. The veiling luminance of the environment is approximated; i.e. it is assumed to be 3.5 % of the average luminance of the area under considerations [6]. If no particular observer positions and viewing directions are specified, the glare rating should be computed at the illuminance grid positions at 45º intervals radially about the grid points with the 0º direction parallel to the long axis of the task area [1][2].

4 Obtrusive light

Obtrusive light is defined as light, outside the area to be lit, which, because of quantitative, directional, or spectral attributes in a given context, gives rise to annoyance, discomfort, distraction or a reduction in the ability to see essential information. The time after which stricter requirements (for the control of obtrusive light) will apply, often a condition of use of lighting applied by a government controlling authority, e.g. the local government, is called curfew [1][2][7]. To safeguard and enhance the night time environment it is necessary to control obtrusive light which can present physiological and ecological problems to surroundings and people. To evaluate the effects of obtrusive light from outdoor lighting installations the methods described in CIE Publication 150:2003 [7] have been included in the standards [1][2] for the lighting of outdoor work places. For the different environmental zones E1 to E4, i.e. natural, rural, suburban, and urban, limits are specified for pre- and post-curfew hours in terms of maximum vertical illuminances on properties, of maximum luminous intensities of individual light sources into potentially obtrusive directions, of maximum average luminances of facades and signs, and of maximum upward light ratios. Furthermore the maximum values of threshold increments for users of nearby roads are considered.

5 Lighting requirements for areas, tasks, and activities

In the schedule of the lighting requirements a large number of areas, tasks, and activities are listed including airports, building and industrial sites, harbours, parking areas, petrochemical industries, power and water plants, railways, saw mills, and shipyards [1][2]. For the specific areas, tasks, and activities requirements are given in terms of average maintained illuminances, uniformities, glare rating limits, and colour rendering indices. An additional column contains advice and footnotes for exceptions and special applications for situations listed, e.g. diversity requirements for railway and tramway lighting [1][2]. As the recommended illuminances for the tasks are given as maintained illuminances the design should take into account an appropriate maintenance factor. The maintenance factor to be applied depends on the characteristics of the lamp and control gear, the luminaire, the environment, and on the maintenance programme. For the elaboration of a maintenance schedule it is recommended to follow the methods described in the CIE guide on the maintenance of outdoor lighting systems [8].

REFERENCES

[1] prEN 12464-2: "Light and lighting, lighting of work places – Part 2: Outdoor work places", 2003

[2] CIE Standard S 015 "Lighting of Outdoor Work Places", Vienna, 2005

[3] EN 12665 "Light and lighting – Basic terms and criteria for specifying lighting requirements", 2002

[4] EN 12193 "Light and lighting – Sports lighting", 1999

[5] EN 12464-1: "Light and lighting, lighting of work places – Part 1: Indoor work places", 2003

[6] "Glare evaluation system for use within outdoor sports and area lighting", CIE Publication 112, Vienna, 1994

[7] "Guide on the limitation of the effects of obtrusive light from outdoor lighting installations", CIE Publication 150, Vienna, 2003

[8] "The maintenance of outdoor lighting systems", CIE publication154, Vienna, 2003

Avtorjev naslov / Authors' address:

Axel Stockmar, Dipl.-Ing..
LCI Light Consult International
Lindenallee 21A
D-29227 Celle
Tel.: +49 (0) 5141 83069
Email: a.stockmar.lci@t-online.de

Peter Raynham

PUBLIC LIGHTING, HOW AND WHY

Summary

Lighting for pedestrians and motorists has developed in different ways producing different lighting solutions for each type of road user. This paper reviews the current basis for road lighting and looks at the ways that the limitations in the current design guidance can be overcome.

Povzetek

Javna razsvetljava, kako in zakaj*; Razsvetljava za pešce in voznike motornih vozil se je razvijala po različnih poteh in pripeljala do različnih rešitev za razsvetljavo enih in drugih uporabnikov cest. Članek podaja trenutno veljavne osnove za načrtovanje cestne razsvetljave ter nakazuje možne načine, kako preseči omejitve v trenutno veljavnih priporočilih.*

1. Introduction

Public lighting in town centres and along roads is now taken for granted. However, there is a dichotomy in the way public lighting has evolved and is specified: lighting for drivers is specified in terms of luminance whilst lighting for pedestrians is specified in terms of illuminance. The object of this paper is to review the research that underpins current road lighting practice for pedestrians and motorists and to examine the validity of the current road lighting standard[1].

2. Lighting for Motorists

The starting point for lighting for motorists was the work carried out by Blackwell[2] and Weston[3]. They studied various visual tasks and came up with the basic rules of task performance. They discovered that the ability to do a task was based on task size, task luminance and the luminous contrast of the task against its background.

The ideas of task performance were carried over into road lighting research. Early experiments in road lighting research reported in de Boer's book[4] were about putting visual tasks on a road surface and using the ability of observers to do the tasks as a metric of the quality of the lighting. After a certain amount of research a standard task was used. It was a 200mm square having a contrast with respect to the road surface of 0.33 and placed on the road 100m away from the observer. This task was used to develop the current road lighting recommendations.

Road lighting is currently specified using the following parameters:

- Average Luminance (L_{Av})
- Overall Uniformity of luminance (minimum / average) (U_O)
- Longitudinal Uniformity of luminance (minimum / maximum)(U_L)
- Threshold Increment (TI%)
- Surround Ratio (SR)

The parameters all have a role in ensuring the lighting quality for the driver. Visual performance is governed by L_{Av} and U_O. The ability to see an object on the road is a function of luminance on the darkest part of the road. The performance is also reduced by the disability glare – TI.

The combination of these parameters used on a road is taken from one of the ME classes specified in the European standard for road lighting.

Class	Luminance of the road surface of the carriageway for the dry road surface condition			Disability glare	Lighting of sroundings
	L in cd/m² [minimum maintained]	U_o [minimum]	U_l [minimum]	TI in %1) [maximum]	SR2) [minimum]
ME1	2,0	0,4	0,7	10	0,5
ME2	1,5	0,4	0,7	10	0,5
ME3a	1,0	0,4	0,7	15	0,5
ME3b	1,0	0,4	0,6	15	0,5
ME3c	1,0	0,4	0,5	15	0,5
ME4a	0,75	0,4	0,6	15	0,5
ME4a	0,75	0,4	0,5	15	0,5
ME5	0,5	0,35	0,4	15	0,5
ME6	0,3	0,35	0,4	15	no requirement

1) An increase of 5 percentage points in *TI* can be permitted where low luminance light sources are used.

2) This criterion may be applied only where there are no traffic areas with their own requirements adjacent to the carriageway.

Table 1 The Luminance Requirements Table (Table 1a) from EN 13021-2

Table 1 gives all the necessary information to design road lighting for motorised traffic in a wide variey of conditions. The hardest task for the lighting designer is to select the appropriate class from the table.

There are however a number of potential problems with this principle of road lighting which may mean this method of lighting is sub-optimal. The problems are:

- Road lighting is based on 200 mm square task, on the road surface, 100 m away from the observer. Is this the most relevant task for typical driving conditions?
- Road lighting is based only on detecting objects by luminous contrast; what might be the impact of colour contrast?
- What is the effect of vehicle headlights on the lighting?
- Is longitudinal uniformity the best parameter to use if it is wished to improve driver comfort?

An exploration of the problems associated with the above bullet points has been previously published in a paper in 2004[5]. There is also one further problem with the current way that road lighting is defined. As the task for which the lighting is designed is a small task directly ahead of the driver then it is only the centre of the visual field that is used to carry out the task. The central region of the eye, the fovea, is different from the rest of the retina in that it only contains cones and not a mix of rods and cones.

The cones in the eye are responsible for vision at high light levels (above 3cdm^{-2}). There are 3 types of cone, each sensitive to a different set of wavelengths of light and in combination they give rise to colour vision. The combined sensitivity of the cones gives rise to the photopic function which is the basis of the lumen. In low light conditions (below 0.003 cdm^{-2}) it is the rods that are responsible for vision. There is only one type of rod cell so colour vision is not possible at low light levels. The sensitivity of the rods gives rise to the scotopic function, this function shows a greater response at the blue end of the visible spectrum as compared with the photopic function. Road lighting provides a visual environment that is between the photopic and scotopic levels, the so called mesopic region. In the region the eye is in an intermediate state and it is normal to model the response of the eye as a combination of photopic and scotopic response functions. So typically one would expect a slight shift to the blue end of the spectrum in the sensitivity.

There have been a large number of experiments to determine if this shift happens, and it has been established for a series of off axis tasks. This finding has potential importance for road lighting. If it is important for drivers to use peripheral vision then it will be necessary to consider the use of blue rich light sources. The problem is that because road lighting is based on the assumption that the critical task for drivers is the ability to see small sections of the road a long way ahead of them rather that a true analysis of the visual tasks involved in driving there is no way of knowing the importance of the colour of the light source.

3. Lighting for Pedestrians

The development of lighting for pedestrians has been based on a series of studies that have been carried out into the needs of road users. It is much easier to do experiments with people walking than it is to experiment with cars. Moreover, the visual needs of pedestrians are in many ways easier to meet that those of motorists. Just walking along a footpath is easy in visual terms you need less than 1 lux on the path to see where you are putting your feet, however, there are a whole series of issues that are important to pedestrians. These tasks may be broken down in a number of ways but perhaps the best is that discussed by Jones[6]. Jones divided the requirements of the pedestrian as follows:

- Safe movement
- Visual orientation
- Visual comfort
- Facial recognition
- A general feeling of safety

Clearly these factors interact, for example if facial recognition is easy then according to van Bommel and Caminada[7] a feeling of security may be induced. Moreover, a lighting system that helps meet one of the above requirements of pedestrians is also likely to help with the others. However, it is worth looking at how lighting can help meet each of these requirements separately in order to understand the total set of requirements placed upon a lighting installation.

3.1 Safe Movement

The amount of light needed for safe movement is relatively low as the visual tasks in walking along a road are limited to checking for obstacles on the footpath and getting information about orientation and position. In order to judge the illuminance necessary to walk and avoid obstacles a number of authors refer to emergency lighting documents such as the current European Standard on Emergency Lighting[8] as a source of guidance on how much light is needed for safe movement. The current European Standard requires 1 lx minimum on the centre of an escape route. This value is perhaps somewhat on the high side for street lighting as it was designed for use at a time when a building is being evacuated and there may be some level of panic.

3.2 Visual Orientation

Orientation is achieved if pedestrians can identify features of the environment and from them deduce their location and thus plan their route. In residential areas orientation is relatively easy as the majority of the pedestrians will be familiar with the area and so large objects such as houses and trees can serve as land marks and provide pedestrians with all the information that they need to work out where they are. In town centres it should be assumed that people are less familiar with their surroundings and thus it is important to provide signage giving directions and street names and directions. Illuminance on vertical surfaces, particularly signs, is important in revealing the forms of features and thus helps the process of orientation.

3.3 Visual Comfort

Visual comfort is generally related to the absence of glare. However there are many ways that glare may manifest itself and glare may also be important in reducing the visibility of objects. The current European Standard on Road Lighting[9] uses 3 metrics of glare:

- Threshold Increment (TI) Ti is the measure of glare usually used for roads designed for motorised traffic. However, as it is a measure of how much visibility has been lost due to glare it may be used by lighting researchers as a metric for glare. For example Rombauts et al[10] used typical values of TI on streets to correct their findings.

- Luminous intensity classes are a means used to restrict glare and spill light from road lighting installations. They are a simple set of restrictions on the relative output of luminaires at high angles. As such they provide a means of controlling luminaire output and reducing the glare that may be caused. However, there is very little research that links these limits to any measurable glare phenomenon. Table 2 listing the classes is taken from the current European Standard on Road Lighting[9]

Class	Maximum luminous intensity in cd / klm			Other requirements
	at 70° [a]	at 80° [a]	at 90° [a]	
G1		200	50	None
G2		150	30	None
G3		100	20	None
G4	500	100	10	Luminous intensities above 95° [a] to be zero
G5	350	100	10	Luminous intensities above 95° [a] to be zero
G6	350	100	0	Luminous intensities above 90° [a] to be zero
[a] Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.				

- Glare Index Classes – various formulae have been derived by researchers for the evaluation of discomfort glare. The formulae all involve the luminance and the area of the light source. The area of the source is important because larger sources of low luminance cause less glare the smaller sources of higher luminance. The formula now adopted in the European Standard is:

$$GI = \frac{I}{\sqrt{A}}$$

Where GI is the glare index, I the intensity of the maximum source between elevation angles of 85 and 90 degrees and A is the luminous area of the source in the direction of the Intensity.

Glare is a highly complex phenomena, that is generally split into 2 categories namely disability and discomfort glare. Disability glare happens when the glare makes it harder to see things and thus visibility is reduced. It therefore easy to research the impact of disability glare using vision tests. TI is the metric used to control disability glare and it well researched and the meaning and impact is well understood. Discomfort glare is a subjective impression that is formed of the lit environment and so it is far harder to characterise the exact circumstances that give rise to discomfort. For this reason the formula behind glare index classes is not well tested.

Some authors[11,12], have extended the concept of visual comfort to include a large number of other features of the visual environment raging from the modelling of peoples faces to nature of the light source and the extent to which light penetrates into private houses. Hargroves[11] developed some of these ideas into the concept of "pleasantness" and then derived recommendations for lighting systems for shopping centres to achieve pleasantness.

3.4 Facial Recognition

It has long been established people like to maintain a personal space around themselves. The basic ideas of personal spaces were developed by Edward Hall[13] and he categorised the personal spaces around a person into intimate (up to 0.5 m), personal (up to 1.2m) and social consultative (up to 3m). Space outside this area was termed public space. Hall discussed the importance of these zones to people and why people felt uncomfortable with letting strangers entering their personal spaces. Van Bommel and Caminada used the basic ideas of Hall to explain why pedestrians at night did not like coming too close to people they did not recognise and thus realised the importance of facial recognition. van Bommel and Caminada[7] came up with the criterion that the lighting should be such as to permit the recognition of a face at a distance of 4m. They then went on to establish that semi-cylindrical illuminance on a persons face was the best measure of lighting in order to determine how easy it was to recognise their face. The link between facial recognition and semi-cylindrical illuminance has also been tested by a number of other researchers. In a review of a number of studies van Bommel[14] found that the relationship between facial recognition distance and semi-cylindrical illuminance was basically sound, however, it was found to be the case that when light incident from behind formed a significant part of the semi-cylindrical illuminance the facial recognition distance was shorter than expected. van Bommel suggested the solution would be to adopt a truncated form of semi-cylindrical illuminance.

Many researchers[10,15], looking at recognition distance found that older people need more light to be able to recognise a face at a given distance. Also Raynham and Saksvikrønning[15] found that the colour rendering of the light is important, a source of low colour rendering (Ra20) giving the same recognition distance as source of high colour rendering (Ra80) but with only half the illuminance.

3.5 A General Feeling of Safety

Van Bommel and other researchers[6,7], argue that facial recognition is one of the key ways to promote a feeling of safety, however, feelings of safety and fear are dependant on factors other than the lighting and a study by Boyce et al[16] in areas of New York City and Albany showed that in general the greater the amount of light provided by the greater the feeling of safety. Analysis of the experimental findings also revealed that in general men felt safer than women. The difference in sense of safety was also found by Mansfield and Raynham[17] who also found that older people felt less safe than young people.

Boyce's study also looked at a series of car parks in Albany and compared the feeling of safety during the day and at night. In all cases he found that people felt safer during the day. Moreover, he was able to relate the change in the feeling of safety between day and night to illuminance at night, the higher the illuminance the less the change in feeling of safety.

Boyce's study assessed feelings of safety and compared them to the horizontal illuminance at the site. However, at all of the sites he used he also measured the vertical illuminance in 4 different directions. He found that as most of the sites he visited had similar lighting installations in terms of the mounting height and spacing of the luminaires and thus the ratios between the horizontal and vertical illuminance values were fairly constant. This is perhaps a weakness of the study as while it tells us that more light will improve a sense of security we do not know which metric of the lighting that is the most important.

The main factor working against a feeling of safety is a fear of crime. Fear of crime is a very complex phenomenon that is only loosely related the risk of being a victim of crime. For example Raynham and Gardner[18] found that young men were many times more likely to be victims of crime than old ladies, however, their fear of crime was much less.

In some instances fear of crime and crime are related. Painter and Farrington[19] found that good street lighting reduced the amount of crime; in fact they were able to establish that the cost saved by the community in one year from reduced crime was greater than the cost of installing the new lighting system. Whilst they did not come to a conclusion as how this effect was created, one of the plausible explanations was that good lighting reduced the fear of crime and thus more people used the streets at night, thus making it harder to commit a crime unobserved.

In general lighting can help reduce the fear of crime, however there are some cases where lighting alone may not have any effect on the felling of safety. Painter and Farrington reported that lighting has little effect in areas of low crime and Raynham and Gardner[19] found that in an area where there was a perceived threat from you people hanging around, extra lighting did nothing to reduce the perceived fear of crime.

3.6 Lighting for Pedestrians Standards and Practice

It is common practice to design lighting for pedestrians in terms of horizontal illuminance, with the S classes of EN 13201-2 being the most common set of criteria used for the designs. However, reviewing the research it is often vertical or semi-cylindrical illuminance that seems to be the important factor in satisfying the needs of the pedestrian. This fact has often been looked at by researchers such as Jones[6] and Hargroves[11]. Their findings have been that they found that horizontal illuminance whilst not a perfect metric for the lighting in most cases functioned well and provided a means to easily describe the impact of the lighting. This finding is not surprising as most lighting schemes have similar geometries in terms of the mounting height and spacing of the lanterns and so one would expect a series of fixed ratios between the horizontal and vertical components of illuminance.

4. Conclusion

The development of road lighting for pedestrians has followed a different path to lighting for motorists. For motorists some fundamental assumptions were made about the visual tasks involved in driving and following on from this it was possible to develop some precise metrics to control the lighting.

Lighting for pedestrians has been developed by trying to understand the needs of pedestrians and developing metrics of lighting that correspond to these needs. This has lead to a series of different requirements for pedestrian lighting. Current lighting practice does not exactly meet these needs, rather an approximate method of design is used, whilst this is not ideal it provides reasonable results in most cases.

Now that it is becoming more important to restrict the amount of energy used in street lighting it is important to optimise the way street lighting is designed. For highway lighting this means finding out what are the safety critical visual tasks that drivers have to do and for pedestrian lighting changing the way lighting is designed so that the visual needs of pedestrians can be met exactly.

[1] EN 13201 Road Lighting parts 2 - 4 and CEN/TR 13201-1 Road Lighting Selection of lighting classes

[2] Blackwell, H. R., Specification of interior illumination levels, Illum Engng, **54**, 317, 1959

[3] Weston, H. C., Industrial Health Research Report 87, London HMSO 1945

[4] de Boer J. B. ed Public Lighting, Philips Technical Library, Eindhoven, 1967

[5] Raynham P., An examination of the fundamentals of road lighting for pedestrians and drivers, Lighting Research and Technology, **36(4)** 2004, pp 307 - 316

[6] Jones G. A subjective assessment of residential road lighting, CIBSE National Lighting conference 1996

[7] Van Bommel W. J. M., Caminada E., Considerations of the lighting of residential areas for non-motorised traffic, CIBSE National Lighting Conference 1982

[8] EN 1838:1999, Lighting applications. Emergency lighting

[9] EN 13201-2 2003 Road lighting – Part 2: Performance requirements

[10] Rombatus P., Vandewyngaerde H., & Maggetto G. Minimum semi-cylindrical illuminance and modelling in residential area lighting, Lighting Research & Technology 21(2) 49-55 (1989)

[11] Hargroves R., Lighting for Pleasentness Outdoors, CIBSE National Lighting Conference 2001

[12] Rombatus P., Vandewyngaerde H., & Maggetto G. Minimum semi-cylindrical illuminance and modelling in residential area lighting, Lighting Research & Technology 21(2) 49-55 (1989)

[13] Hall E.T., The hidden dimension, Anchor Books, New York (1996): Reprinted by Anchor Books (a division of Random House Inc) 1990

[14] Van Bommel W. J. M., Public lighting and residential function, CIE proceedings 22nd session Melbourne

[15] Raynham, P. & Saksvikrønning, T. White Light and Facial Recognition, The Lighting Journal 68, 1 January/February 2003, pp 29-33

[16] Boyce P. R., Eklund N. H., Hamilton B. J., & Bruno L. D., Perceptions of safety at night in different lighting conditions, Lighting Research & Technology 32(2) 79-91 (2000)

[17] Mansfield K. & Raynham P., Urban Lights: Sustainable Urban Lighting for Town Centre Regeneration, Lux Europa 2005, Berlin pp 491-493

[18] Raynham P. & Gardner C. Urban Lights: Sustainable Urban Lighting for Town Centre Regeneration, Lux Europa 2001, Reykjavik pp 81-84

[19] Painter K. A. & Farrington D. P., The financial benefits of improved street lighting based on crime reduction, Lighting Research and Technology 33,1 (2001) pp 3-12

Avtorjev naslov / Author’s address

Peter Raynham
Lighting Education Trust Lecturer
The Bartlett School of Graduate Studies
University College London
Gower Street
London WC1E 6BT
England

Torsten Onasch

LIGHT IN ARENAS – ARENAS IN LIGHT

Summary

Where in former times the sport events themselves stood in the center of attention, so today the buildings, arenas and sports stadiums themselves contribute to the attractiveness of the meeting. Stadias and arenas are no longer only places for sport, but proper magnets, which need to be well produced. In addition they are universal used and open to numerous organizers for various activities and for events of all types. Their attractiveness contributes in additionto making the towns and cities, where they are built to a more interesting place alltogether. The sporting temples of the 21. Century are important architectural monuments and as such must be presented in the right light – both for players and spectators as well as for passers - by.

To a stadium belongs the perfect lighting solution for the interior and external areas.

For instance:
- exterior lighting: approach road ways, park areas
- architecture lighting: facade lighting, customised solutions, light effects
- sports area lighting: floodlights, grandstand illumination
- interior lighting: lounges, catering, transfer areas, changing rooms, sanitary areas, first assistance area, office/conference rooms, control rooms
- safety and emergency lighting: Escape routes, emergency exits, emergency lighting

Povzetek

***Svetloba v areni, arena v svetlobi**; Medtem ko je v včasih bil v centru pozornosti predvsem športni dogodek, pa danes tudi zgradbe, arene in športni štadioni prispevajo k atraktivnosti dogodka. Štadioni in arene tako niso več samo prostori, kjer se odvijajo športni dogodki, pač pa tudi magnet za obiskovalce, ki pa mora biti dobro izdelan. Poleg tega niso več namenjeni samo športu pač pa različnim prireditvam in dogodkom vseh vrst. Njihova atraktivnost pa prispeva tudi k večji zanimivosti krajev in mest, kjer se nahajajo. Športni templji 21. stoletja so pomembni arhitekturni spomeniki in kot take jih je treba predstaviti v pravi luči torej z ustrezno razsvetljavo. Ta mora ustrezati tako tekmovalcem in gledalcem pa tudi mimoidočim. Stadion tako potrebuje odlično razsvetljavo za notranje in zunanje površine. Na primer: zunanjo razsvetljavo za dovozne poti in parkovne površine, arhitekturno razsvetljavo za fasado in svetlobne efekte, reflektorsko razsvetljavo za športne površine, notranjo razsvetljavo za lože, lokale, hodnike, garderobe, sanitarije, ambulante, pisarne, konferenčne dvorane in kontrolne sobe ter varnostno razsvetljavo.*

Stadia lighting must also present the stadium by himself and to make a contribution for guidance. Perfect lighting must therefore fulfill many requirements: The spectators expect an optimally illuminated event and/or expect an event that comes to life through light. The stadia operators need an efficient and easy to run system including energy-efficient lighting solutions. For the TV broadcasting of the meetings aspects such as non-glaring and shade reduction are of importance. The shadows on the playing field should not be to hard. For good seeing therefore the even distribution of the light is necessary as well as the necessary lighting level: A too strong interrelation of light and shadows makes excessive demands of the eyes, because they must constantly adapt again. The sportsmen and participants of sports meetings need the correct lighting for the special tasks of viewing for the respective kind of sport. In addition a sufficient general lighting must be provided. Light makes a stadium not only bright, but also provides for a pleasant atmosphere.

1.Requirements

Quality Sports Lighting

Recommendations and regulation for quality sports lighting are defined in the European standard for sports lighting **EN 12193**. This standard includes the most important requirements for lighting of different kinds of sports as well as further quality requirement such as colour rendering of the lamps, glare limitation and relevant areas for which these demands are valid.

Guideline for Artificial Lighting of Football Grounds

This guideline combines hints and regulations, which are from FIFA's and modern broadcasting companies point of view at least necessary to garantee an optimum TV coverage. Here also special geometric minimum standards (height of the stadium, position of the cameras, etc.) are pointed out. The criteria defined in this publication can be exceeded by locally agreed lighting values.

Emergency Lighting

Operation and maintenance of emergeny lighting are also defined in standard **EN 1838** for lighting requirements and standard **VDE 0108** for electro-technical requirements. For large arenas standard EN 1838 for an anti-panic lighting is compulsory to reach the emergency exits without panic.

These security and electro-technical requirements of luminaires for emergency lighting are defined in standard **DIN EN 60598-2-22.**

Television Broadcast

The high definition television standard **HDTV** initiates a change in the broadcasting of sports events. Sharper images, more contrast and details, nearly stereoscopic.

This obviously better quality is reached by the higher number of pixels. Whereas the former German PAL signal reproduces 720 x 576 pixels, HDTV reproduces 1920 x 720 or 1080 pixels. The whole amount of pixels increases from about 400 000 to two million. For an optimum reproduction of the images there are special kinds of cameras and a particularly high-quality illumination necessary.

Light Emission

Besides it is also necessary to limit the light emission. The international lighting comissio – **CIE** – made a number of recommendations to disturbing diffuses light and in some parts of Europe and the United States there are specifications for limitation of such diffused light.

Indoors

The European standard "Illumination of indoor working places" defines criteria for suitabel and adequate lighting for a better and more effective vision. This standard defines the regulations concerning quantity and quality of the illumination of most working places and the related desktops.

Energy pass for Buildings

With the new European legislation the illumination of new buildings is regulated already in the pre-planning when submitting the building application form. Also for renovations and old buildings the Energy pass for Buildings is relevant. The **EG-guideline 2002/91/EG** for the total energy efficiency of buildings demands energy passes for new and old buildings. The members of the EU put this regulation gradually into national law.

2 Concept Description

2.1 Outdoors

Millions of people are fascinated by important sports events. The illumation of the access roads is important, also because it is an additional help for orientation, here you have bollard luminaires and the car-park lighting. High illumination in parking garages increases the subjective feeling for security. Illuminating the environment of the arena has not only functional aspects, it also creates a special atmosphere.

Within the area the regulation for official buildings applies, that means that roads especially entries and exits have to be cleary marked and well illuminated to prevent accidents. Illumination of roads and outdoor lighting in general has to be energy-efficient and has to have minimum light emission. The luminaires have to function also under extreme weather conditions and have to be easy to maintain. Roundabouts, crossings, etc. as well as subways and tunnels demand high impact of light, security and maintenance possibilities of the lighting system.

New initiatives of the EU demand a high level of energy efficiency for outdoor lighting systems. The reduction of light emission involves an increas in light efficiency.

Outdoor Lighting SAP Arena Mannheim Germany

2.2 Architectural Lighting

Sports grounds are not only areas for competitions but also represent brands, companies and sports clubs through the design of walls and facades. You can decide between integrated lighting solutions, flood and spot lighting. In the first solution lamps and luminaires are integrated in the facade. Heat development and compability between material and the luminaire have to be observed. Colour effects and colour changes, controlled by PC systems create diversifications and thus emphasise brands and their identities. The LED technology opens new options which have not be possible yet.

Important criteria are the necessary lighting level, light colour and colour rendering. The lighting level is orientated on the surrounding of the sports ground. Inside cities higher levels of illuminances are required than outside cities.

The lighting colours depends on the surface colour of the facade. For intensification of warm colours also warm-white lamp colours are used. Cold colours are intensified by neutral-white and daylight-white colours which could create an exciting atmosphere.

The positioning of the floodlights for illuminating a facade is orientated primarily on visible structures and architecture or on the surroundings. Under all circumstances it has to be excluded to glare passengers and visitors. Architectural lighting and traffic lighting have to be coordinated.

Environmental aspects require an limited light emission.

Arena Porto Portugal

2.3 Floodlighting

The illumation of sports grounds is important for the sportsmen and the spectators as well. TV broadcasting demand additonal requirements. For good viewing conditions vertical illuminances and good local uniformity of the horizontal illuminances are important requirements as well as a low glare effect of the spot and the flood lights. This is the reason for using rotation-symetric beaming floodlights. In some cases a mixture of symetric and asymetric flood lights could be necessary if the height is not sufficient.

In the traditional site the floodlights are mounted on four poles; here you get the typical four shadows on the grass. All quality requirements are fulfilled. Modern stadiums gradually develpe to arenas.

To some extend completely closed roofs, or at least a roof over the grandstand opens new possibilities for illumination. The floodlights are installed in one or two rows in different rotation and inclination angles under the roof. Because of the low distance of the floodlights to the field they could be mounted in lower heights in comparision to a four-pole installation. This kind of illumination is the most popular solution today.

The grandstands are illuminated from out of the roofs, this is not only for the security of the visitors but also for the broadcasting companies who want to reproduce the atmoshpere of the stadium.

Stadium Lokomotive Moskau, Russia

EM Stadium Salzburg, Austria

2.4 Indoor Lighting

Indoor lighting demand a number of requirements, integrated in the standard EN 12464-1.

Beyond standardised requirements on illumination there are solution concepts which influence the well-being of the people and the productivity of their work in a positive way.

The demand to realize flexibility, aesthetics, well-being and energy in buildings combines an overall view of lighting quality.

Light for Well-Being

Separated switching and dimming of the components provide changeable environments in the building, the electronic control units increase the comfort through flicker-free light.

The first component of the lighting is the reflected part from the ceiling and the wall, the second component is the direct part for the funtional and task areas.

Switching and dimming means a change in the lighting level and the lighting colours.

VIP-Area Allianz Arena Munich, Germany

2.5 Emergency and Safety Lighting

Good illumination gives you a feeling of safety and guarantees that in case of an emergency enough light for all areas is available. The decentralised implementation of emergency systems secures an individual supply of emergency light for all areas. Lighting is part of every safety concept. A good protection effect is suddenly flashing bright light. In floors and stairs as well as in parking areas and parking garages the feeling for safety could be increased by aimed wall and ceiling illumination and a good illumination of the emergency exits. Dependent on the building the power supply could be done via central batteries, single batteries or emergency generators.

3 Functional Description

3.1 Outdoor Lighting

3.1.1 Access Roads

Access roads have to fulfill the requirements of the international or country-specific standards for street lighting, i.e. **DIN EN 13201.** The basic principal is "view and to be viewed". Different lighting systems are suitable to ensure various demands on lighting level, uniformity and minimum glare.

Mast-mounted luminaires with high-optimized reflectors and secondary systems are most popular. On main roads HST lamps are used because of their high energy efficiency mostly the four-years-version is used. Close to buildings HQI and fluorescent lamps are used due to the better colour rendering.

Access Roads SAP Arena Mannheim, Germany

3.1.2 Parking Garages

Parking garages have to be illuminated very brightly to ensure the safety of persons and vehicles. Especially narrowness in a building and engineered barriers caused by the architecture such as concrete beams should be specially illuminated by T5 or T8 fluorescent lamps to increase the attentiveness of the visitors.

Clearly marked and separated ways for vehicles and pedestrians reduces the risk of accidents. For a better orientation access and exit roads are well illuminated.

3.1.3 Stadium Access and Exit

The entrance has a reprensentative function especially for the visistors. Friendly bright entrances have orientation funcion: Light divides floor plans, shows the way to the cash counters, stand, catering areas and toilets. They are meeting points to see others and receive first aid.

Formula 1 Track, Shanghai, China

3.2 Architectural Lighting

3.2.1 Facade Illumination

Various lighting concepts are necessary to design a facade with light. Normally a facade is a central element to present brands. Here you can "feel" the brand - here lighting, architecture and lighting scenarios show the uniqueness of the stadium. The facade is some kind of packaging. It wraps the stadium, makes curious and transforms the stadium to a real landmark.

No matter if the facade illumination is an integrated system or a lighting concept or a mixture of both, it is important to keep the light emission as low as possible according to the surroundings.

The angle of the reflected beam or the optical systems have to be adapted to the respective situation. LED as innovative source of light open new possibilities, i.e. Logos or special writings or displays with changing colours.

Allianz-Arena Munich, Germany

3.3 Sports Lighting

3.3.1 Floodlights

Floodlights with a HQI 2000W should work without failure under every surrounding temperature. Therefore many available products do not have an extra housing in the reflector. The reflector, which is necessary for the different light distributions is at the same time the housing and cares for an optimum cooling. For a mast implementation of the floodlights an optimum hail protection should be available, which could easily be fixed at the floodlight. For TV broadcasting a high colour rendering is absolutely necessary – here metal halid lamps should be used. The relationship between lifetime of the lamp and its colour rendering is very well tuned, it is nearly constant during the whole lifetime of the lamp. On training grounds also lamps with a higher luminous flux can be used. Therefore you can save energy and at the same time you can guarantee a good illumination level. Every floodlight has to have the possibility to implement a telescopic sight for an excat aiming according to coordinates on the field. At least five different light distributions are necessary to transport the light with the required illuminance and uniformity. Shutters integrated in the floodlights care for a reduced light emission in the upper area. Safety glass with a high level of transmission is the condition for a high efficiency of the system. The floodlight has a mechanical connector to gurantee a voltage free opening of the housing (tool free)

Helsinki Olympic Stadium

3.3.2 Grandstands

There a different ways to illuminate the tribunes, whereas floodlights beaming from the inner edge of the roof are most popular. The asymetric light is very important for TV cameras to show emotions and faces. Security cameras are installed on various places to aim at special persons or tumults. For illumination of events or emergencies you have to choose lamps with an immediate ignition (i.e. fluorescent lamps or halogen lamps).

indirect illumination of the tribunes Commerzbank Arena, Frankfurt/M., Germany

3.4. Indoor Lighting

3.4.1 Lounges

Lounges are reception, waiting and resting areas – they sould be illuminated in a way to give them a special atmosphere through light control and selection of luminaires.

Light should emphasise the architectural structures. Illumination of vertical areas through

uplights and wallwashers are important planning details. Light colours should harmonise with the other colours used. Glare-free light at working places is required.

Lounge, Stockholm, Sweden

3.4.2 Catering

These areas could also be used as party or meeting areas. Illumination of walls by using uplights contribute to a communicative atmosphere. Counters and bars can be also emphasised. Accent lighting in combination with indirect light do this. Recommended light colour for catering areas is warmwhite. Lamps with a good colour rendering is important to show food and beverages in an appetising way. Should you wish to use these areas in a different way you should plan further lighting concepts in combination with lighting management system. Daylight systems and micro-sunshield louvers could also be used.

Catering Area Allianz Arena Munich, Germany

Cafeteria, Milton Keynes, United Kingdom

3.4.3 Transfer Areas

It is possible that transfer areas have daylight or have to be illuminated completely with artificial light. In such a case question of maintenance and energy consumption are of central importance for the lighting concept. With light management systems, i.e. DALI and EIB the lighting level can be regulated to save energy and operating costs.

Floor, entrances and exits can be illuminated with wall or ceiling lighting as well as accentuating architectural structures.

Closed luminaires have a low maintenance effort because of their low pollution degree.

Using T5 lamps in combination with HVG's bring more energy efficiency. Here a good uniformity of the light is important.

Allianz Arena Munich, Germany

3.4.4 Changing Rooms, Sanitary Areas, First Aid Areas

In changing rooms, sanitary areas, first aid areas sufficient illuminance should be guaranteed. Warm colours dominate. Damp proof luminaires are to be favoured because of their high quality material and their high protection class. Prismatic technology cause a good and uniform illumination.

Sanitary Areas, First Aid Areas

A minimum luminous flux of 100 lux is standard; due to sanitary reasons a luminous flux of 300 lux is recommended. That make the work of the cleaning personnel much easier

In showers and toilets luminaires with IP X4 or IP X5 should be used.

In rooms without any daylight it is important, to have an efficient handling, thats why are often used luminaires with electronic ballasts.

Changing rooms

The general requirement is to have 100 lux, but is more comfortable to have in this rooms 300 lux. You will have an better feeling. Also you will get the impression of hygiene and cleanness.

3.4.5 Offices and conferenz rooms

Single offices and meeting rooms

Often this rooms have an direct contact with daylight. Standing luminaires with glare free pism structures offer a very large flexibility in combination with the furnitures. In addition you can use a general room lighting with direct or direct-indirect luminaires.

Open-plan offices

Open-plan offices gives you the possibility of working groups and teams with a completely flexible area use and room layout. For this a general room lighting proves as a very suitable conceptional beginning. It is implemented with a lower room hight preferentially as direct lighting, with sufficient hight as direct indirect lighting. A direct indirect lighting contributes to a high room comfort by an increase of the vertical density of light and produces thereby a daylight-similar lighting environment. In connection with a light management system can be reduced the energy costs by a daylight and presence-dependent lighting control. Daylight systems improve the viewing comfort and increase the daylight portion in window-far room zones. With daylight skylight solutions a micro raster offers itself as sun protection, which is integrated into the glazing. This fades out the direct sun exposure effectively, without impairing the view substantially.

Conference rooms

The use of conference rooms makes several demands for the lighting: A balanced relationship of horizontal and vertical lighting is priority. With the horizontal component a sufficiently high lighting level is to be obtained, in order to be able to read conference documents problem-free on the conference tables. A sufficient vertical lighting component produces a friendly, bright space atmosphere and promotes communication.

Within the range of the medium wall an additional lighting should provide good viewing cdonditions on diagrams. On the other hand the medium wall must be able to be darkened perfectly for a projection, while at the same time in the room a basic lighting or a writing lighting remains.

For this is a lighting management system proves as meaningful, where you can call pre-programmed light scenes.

3.4.6 Controll rooms

In control rooms and/or switching centers is usually little quantity of daylight. Densities of light of 200 lux are recommended. In order to produce however positive light attractions and a natural time rhythm, densities of light of approx.. 300 lux should be considered. Lighting solutions should stimulate the natural bio rhythm. This can be made by different kinds: the "brilliant" and the "dynamic" light. Brilliant light promotes here the physiological and the mental awake condition and leads to an increased activity, to a higher sensitivity and to a larger attention. Dynamic light with changing densities of light and changing colors of light increases however the perception ability in a room. Self-regulating and variable light management systems produce a biodynamic light with high lighting values as well as changeable colors of light and light intensities.

It is not allowed to have any glare. If a glare arises, then the perception is impaired. This can lead to dangerous situations. In addition the brightness differences in the room should be determined and also the illuminance densities by objects in the field of view. The luminance differences in the surrounding field of the direct viewing task should not exceed the factor 3 thereby glare are avoided. The space light must be supplemented depending upon task of work by arranged point light

Police control room, Nürnberg, Germany

3.5 Safety and emergency lighting

3.5.1 Escape routes + emergency exits

If the emergency lighting for emergency routes fulfills their tasks, then it must create sufficient viewing conditions for orientation on emergency routes and building surfaces. At the same time fire fighting and safety devices must be easy to find.

For the marking and lighting of escape/emergency routes and emergency exits are always necessary:

- luminaries with a rescue sign
- luminaries for the illumination of the escape routes
- in addition escape and emergency route plans must be visibly attached for everyone

According to DIN EN 1838 the emergency lighting for escapey routes is the "part of the emergency lighting, for which it makes possible to recognize and use rescue mechanisms clearly, if persons are present".

On the axis of the escape route with a width up to 2 meters must have the horizontal illuminance a value not lower than 1lx, and the relationship of the largest to the smallest illuminance may not exceed 40:1 along the center line. The luminaires must be mounted in a hight of minimum 2 m.

If an emergency exit is not to be seen direct, than it is necessary to attach one or more lit and/or behind-shone rescue signs with indication of direction.

Safety lights for emergency routes or rescue indication lights create an appropriate density of light level according to DIN EN 1838, if they are attached on the following places:

- at everyone door, which can be used in a emergency case
- close at stairs, in order to light up each stage or every other changed level
- at prescribed emergency exits
- at each change of direction
- on each crossing of corridors or courses
- neat to every last exit
- close to each first aid place, fire fighting devices and reporting direction

According to **DIN EN 1838** rescue characters and safety lights must fulfill the following quality criteria: The colors must correspond to ISO 3864. The luminance of the safety color must amount at least 2 cd/m². Fortheu sing with general lighting higher requirements are applied: 200cd/m² middle luminance on the entire area. The relationship of the largest to the smallest luminance may be larger neither in the white surface nor in the safety color than 10:1. The relationship of the luminance L white to the luminance L color must have at least 5:1 and may not larger than 15:1.

LED-safety light

3.5.2 Emergency/ spare lighting

Emergency lighting is the superordinate term if the general artificial lighting malfunctioned. Emergency lighting needs therefore its own power supply: Single battery, group battery, common battery, aggregates or a particularly secured net. If a spare lighting has to take over tasks of the emergency lighting, than it has to fulfill all requirements of DIN EN 1838. Possibly necessary activities can be continued then. If its lighting level is however under the minimum of the general lighting, the spare lighting may be only used, in order to drive or terminate a working process down. The time interval between the loss of the general artificial lighting on disturbance of the current supply and reaching the necessary density of light should be as short as possible. The rated service time for working places must be ensured for one hour at least. The color reproduction index RA of the lamps must amount to at least 40, so that safety colors are to be recognized clearly.

4.Interfaces

The rising requirements at comfort and efficiency in the using of buildings lead in the building services to the use of modern digital control systems, which cover comprehensive building functions generally and the front lighting in the special. In stages extensive Facility management systems are used. Light control systems are to be seen here as important part and offering light solutions to the following central main topics:

- central administration
- application-spreading energy management
- daylight dependent controls
- integration of light, glare shield, heating and ventilation
- automation of routine tasks
- failure reports
- cost transparancy

By DALI (digital Addressable Lighting interface) it is possible to address dimmable ECG individually and digitally with the help of a controller and assign groups to stop scenes and for feedbacks. Depending upon design of the controller - from simple to complex - all requirements for the subsystem "light" can be covered with DALI.

In simplest case is only the dimming and the switching, in the complex case is a scene management with feedback of lamp errors possible. For these applications a multiplicity of different controllers are available, from the simple control module up to the gateway between DALI and the building bus system.

Building-comprehensive light solutions are based on field bus systems such as EIB or the pofibus DP. These systems steer and supervise all technical building functions and functions of the light management. The integration of the operating devices is made here by gateways to the superordinate systems. The RGB light control for tendencyful light accents and/or light productions.

REFERENCES (extract)

Allianz Arena Munic 2005
Ernst Happel Stadium Vienna 2006
San Siro Milano 2005
Stadio Communale Di Torino 2005
Olympic Horse Track Athens 2004 (2133 floodlights)
Stadium Tijanjin 2005
6 of 9 stages in Portugal for the European football championship 2004

Avtorjev naslov / Authors' address:

Dipl. Ing. Torsten Onasch.
Project Manager Sports Lighting
Siteco Beleuchtungstechnik GmbH
Ohmstrasse 50
83301 Traunreut
Germany
Tel.: +49 8669 33 386
Fax: +49 8669 33 443
Email: t.onasch@siteco.de

Primož Gspan

OBVEZNA ALI PROSTOVOLJNA UPORABA STANDARDOV ZA RAZSVETLJAVO PRI DELU

Povzetek

Iz prvotnega enotnega slovenskega standarda OSIST prEN 12464 sta od leta 2004 nastala in ostala še vedno z isto oznako dva dela. Prvi del, ki je že dobro opisan v 2. izdaji Priporočil SRD Pr4/1,Pr4/2, 2004, se nanaša na delovna mesta v delovnih prostorih, drugi na delovna mesta na prostem. V prispevku so opisane nekatere značilnosti standarda, ki so pomembne za uporabo, zlasti 2. dela. Opozorjeno je, da je po zakonodaji s področja varnosti in zdravja pri delu uporaba tega standarda obvezna. V prispevku je omenjena publikacija ZVD št. 137, kjer je med drugim navedena poslovenjena nomenklatura delovnih mest in del na prostem, priložena ji je zgoščenka za priročnejšo uporabo pri presoji skladnosti z zahtevami standarda na temelju terenskih meritev, predlagan je postopek za poenostavljen ter ekonomsko in strokovno sprejemljiv predpisan periodični nadzor primernosti umetne razsvetljave na delovnih mestih. Predlagana je tudi »stopnja obremenitve« SO na temelju skladnosti s predpisom kot kriterij za določanje stopnje tveganja R, kot jo zahteva slovenski predpis o izjavi o varnosti.

Obveznost uporabe standarda SIST EN 12464

Standard je po definiciji za uporabo *neobvezen dokument*, ki ga s konsenzom sprejme priznani organ, in ki določa pravila, smernice in značilnosti za dejavnosti in za njihove rezultate in ki s tem zagotavlja enotnost, kakovost in skladnost zahtev, proizvodov in dejavnosti ter je usmerjen na doseganje optimalne stopnje urejenosti na določenem področju. Na *splošno* je zato uporaba slovenskih nacionalnih in drugih standardov *prostovoljna*.

V naši državi slovenski nacionalni organ za standarde sprejema slovenske standarde z oznako SIST, ki so lahko pripravljeni kot izvirni nacionalni standardi ali privzeti mednarodni, evropski ali tuji nacionalni standardi.

V posebnih primerih postane uporaba standarda *obvezna*, če se na standard sklicuje *predpis*. Ob tem pa se mora po zakonu o standardizaciji[1] predpis sklicevati na slovenski nacionalni standard SIST.

Sklicevanje predpisa na standard je možno na tri načine: *datirano sklicevanje* na določeno izdajo standarda, *nedatirano sklicevanje*, pri čemer velja zadnja verzija (izdaja) standarda in *splošno sklicevanje* na vse standarde določenega organa ali na določenem področju, ne da bi standarde po oznakah posebno navedli. V zadnjem primeru pravimo, da se sklicujemo na splošne klavzule, kot je »stanje tehnike« in ki imajo vlogo pravnega vira v hierarhiji predpisov. To velja tudi za standarde, ki urejajo razsvetljavo na delovnih mestih.

Pravilnik o spremembah in dopolnitvah Pravilnika o zahtevah za zagotavljanje varnosti in zdravja delavcev na delovnih mestih[2] določa v 3. členu: 'V 31. členu se drugi odstavek spremeni tako, da se glasi: »Za izpolnjevanje zahtev iz prejšnjega odstavka *mora delodajalec upoštevati določila slovenskih standardov za razsvetljavo na delovnih mestih*.«' S takšnim splošnim sklicevanjem so postala »*določila slovenskih standardov za razsvetljavo na delovnih mestih*« *obvezna* za uporabo. Izdajatelj pravilnika se je torej smiselno odločil za obvezno upoštevanje *vseh slovenskih standardov*, ki se nanašajo na razsvetljavo na delovnih mestih. Dva od teh sta privzeta standarda EU in sicer SIST EN 12464-1[3] in OSIST prEN 12464-2[4]. Prvi se nanaša na delovna mesta v prostorih, drugi pa na delovna mesta na prostem. Prvotno je bil to samo en standard[5], ki je vseboval delovna mesta na splošno, leta 2004 pa se je razdelil na sedanja dva dela. Dopolnim naj, da ima v Nemčiji oznako DIN EN 12464-2, pri tem pa je v EU od lani standard z oznako EN ISO/FDIS 8995-2[10], prejšnji prEN 12464-2 pa je umaknjen.

Kakor koli, zametek o *obvezni uporabi* je vgrajen že v vsebino samega standarda z definicijo »vzdrževane osvetljenost« s tem, da eksplicitno določa, da pod določeno mejo povprečna osvetljenost na določeni površini *ne sme* nikdar pasti.

Ne glede na obliko oznake in dodatne bolj ali manj umetno ustvarjene dileme, pripombe, tolmačenja ali izgovore, ugotovimo, da je uporaba standarda SIST EN 12464-1 in OSIST prEN 12464 *obvezna*, ker se na standarda implicitno sklicuje v uradnem listu objavljeni predpis[2], ki ureja zahteve varnosti in zdravja pri delu.

Nekatere značilnosti standarda serije 12464

Posebej moramo poudariti, da se moramo pri razsvetljavi na delovnih mesti zavedati, da standard, ki se sicer omejuje samo na zahteve za *umetno* razsvetljavo, šteje *naravno* razsvetljavo kot *temeljno* in ji je umetna samo dopolnilo, kjer in kadar naravna ne zadošča. To izhodišče je posebno pomembno pri arhitekturni zasnovi objektov pa tudi razporeditvi delovnih mest in ki je včasih premalo upoštevano, ker niso redki primere, kjer si je arhitekt zamislil prostore s pomanjkljivo ali celo brez naravne osvetljenosti. Podobno velja za vedno priporočen zadostni optični stik z okolico za boljše počutje (čitaj: proizvodnost) zaposlenih.

Posebnosti prvotnega standarda, še preden je bil razdeljen na dva dela, so bile dovolj podrobno opisane v publikaciji Priporočila SRD Pr4/1,Pr4/2, 2004[6], namenjeni predvsem projektantom. Zato vseh posebnosti podrobno ne navajajmo.

Pričujoči sestavek pa je namenjen v prvi vrsti strokovnim delavcem s področja varnosti in zdravja pri delu, ki se s projektiranjem neposredno na ukvarjajo, pač pa imajo pomembno vlogo pri izbiri zahtev za razsvetljavo za določeno delo, pri predpisanem periodičnem nadzoru (meritvah) na delovnem mestu in inšpekcijskemu organu pri preverjanju izvajanja predpisov. Zato naj kljub temu, da projektanti področje dobro poznajo, ponovno spomnimo na nekatere značilnosti standarda, ki se jih včasih premalo zavedamo in ki so pomembne zlasti za strokovnega delavca za varnost in zdravje pri delu, pooblaščenega zdravnika in za nadzorni organ.

Redni periodični nadzor nad delovnim okoljem, kamor spada tudi razsvetljava na delovnih mestih, določa Pravilnik o preiskavah delovnega okolja, pregledih in preizkusih sredstev za delo [9], čeprav so nekateri mnenja, da so roki za periodične preglede določeni v izjavi o varnosti. Verjetno menijo, da to velja za krajše roke od 3 leta, kot jih na splošno zahteva pravilnik[9].

Pri uporabi standarda moramo vedeti, da vsebuje *minimalne* zahteve za razsvetljavo (zato res ne smejo biti vrednosti v praksi manjše), glede ekonomike pa moramo zahteve šteti kot *maksimalne*, da z izpolnitvijo zahtev standarda po nepotrebnem ne tratimo in zapravljamo energije več, kot je neobhodno potrebno.

Zato ne smemo pozabiti, da standard usklajuje minimalne pogoje za vidne zahteve dela in zahteve po ekonomiki – varčevanju z energijo -, pri čemer pa posebej poudarja, da *ni dovoljeno varčevanje pri energiji na račun premajhne osvetljenost oz. nezadostne kakovosti razsvetljave*. V tem smislu tudi ne omejuje uporabe tudi novih in inovativnih rešitev.

Pri nas je še manj znan pojem »*vzdrževane osvetljenosti*«, ki ga uvaja standard namesto prejšnje »imenske (nazivne) osvetljenosti« in sicer iz praktičnega razloga, ker je bila imenska osvetljenost projektantski pripomoček in jo v praksi ni bilo mogoče mersko preverjati. »Vzdrževana osvetljenost« pa je definirana kot tista meja osvetljenosti, pod katero na delovnem mestu povprečna (krajevno) osvetljenost ne sme pasti tekom staranja razsvetljevalne naprave in pomeni točko, pri kateri je potrebno servisirati razsvetljavo. Iz tega jasno izhaja naloga merilca, ki meri zadostnost osvetljenosti: ugotoviti mora *povprečno osvetljenost področja opravljanja vidne naloge*, in če je ta pod vzdrževano osvetljenostjo, mora ugotoviti, da osvetljenost ni zadostna. V tem primeru je mišljeno povprečje osvetljenosti preko površine, kjer se opravlja vidna naloga.

Razen *osvetljenosti*, ki jo za posamezna dela predpisuje standard, predpisuje tudi vrsto drugih bistvenih zahtev za razsvetljavo, ki morajo biti izpolnjene za udobno, dobro in neškodljivo opravljanje vidne naloge delavca: največjo dopustno mero bleščanja, zahtevano stopnjo barvne reprodukcije, enakomernost osvetljenosti, barvno temperaturo in ponekod dodatne zahteve v obliki opomb. Zahteve so navedene podrobno za posamezna dela znotraj širše razdelitve na različne tipične vrste dejavnosti (promet, industrija, uradi, zdravstvo itd.).

Posebej opozorimo v tem sestavku na del standarda (OSIST prEN 12464-2), ki se nanaša na *delovna mesta na prostem* in ki jih priporočila[6] podrobno ne navajajo.

Za nas so novost kriteriji za preprečevanje *moteče svetlobe* v smislu varstva naravnega in bivalnega okolja, za kar si s posebnim predpisom že več let prizadeva MOP. Predpisane omejitve so podane v obliki dopustnih mej za svetlobo v okolici zunanje razsvetljave. V odvisnosti od štirih stopenj varovanja okolja predpisuje standard največji dopustni delež navzgor usmerjene svetlobe svetil v %, največjo navpično osvetljenost oken bivalnih prostorov, največjo svetilnost virov svetlobe in svetlost zgradb.

2. del standarda podaja v obliki preglednice tudi mejne vrednosti za: vzdrževano osvetljenost, razred bleščanja, razred barvne reprodukcije, barvno temperaturo in nekatere posebne zahteve v obliki opomb (nova verzija EN ISO 8995-2 še enakomernost razsvetljave U_0).

Med 1. in 2. delom so tudi nekatere razlike. Za delovna mesta v objektih je npr. nekoliko drugače definirano območje vidne naloge in neposredne okolice, ki je v 1. delu bolj točno določeno. Tudi koeficient bleščanja UGR_L je za delo v objektih drugače definiran, kot je definiran za dela na prostem GR_L. Pri določanju povprečne osvetljenosti s pomočjo merske mreže je treba pri obeh nekaj iznajdljivosti in trezne presoje.

Opozoriti je treba, da so bila dela in opravila doslej v celoti *poslovenjena* za delovna mesta v prostorih (1. del)[6], za dela na prostem (2. del) pa so bila poslovenjena v posebni publikaciji[7]. Poleg poslovenjenih tabel so poslovenjena tudi po abecednem redu urejena gesla, ki omogočajo lažjo uporabo tabel.

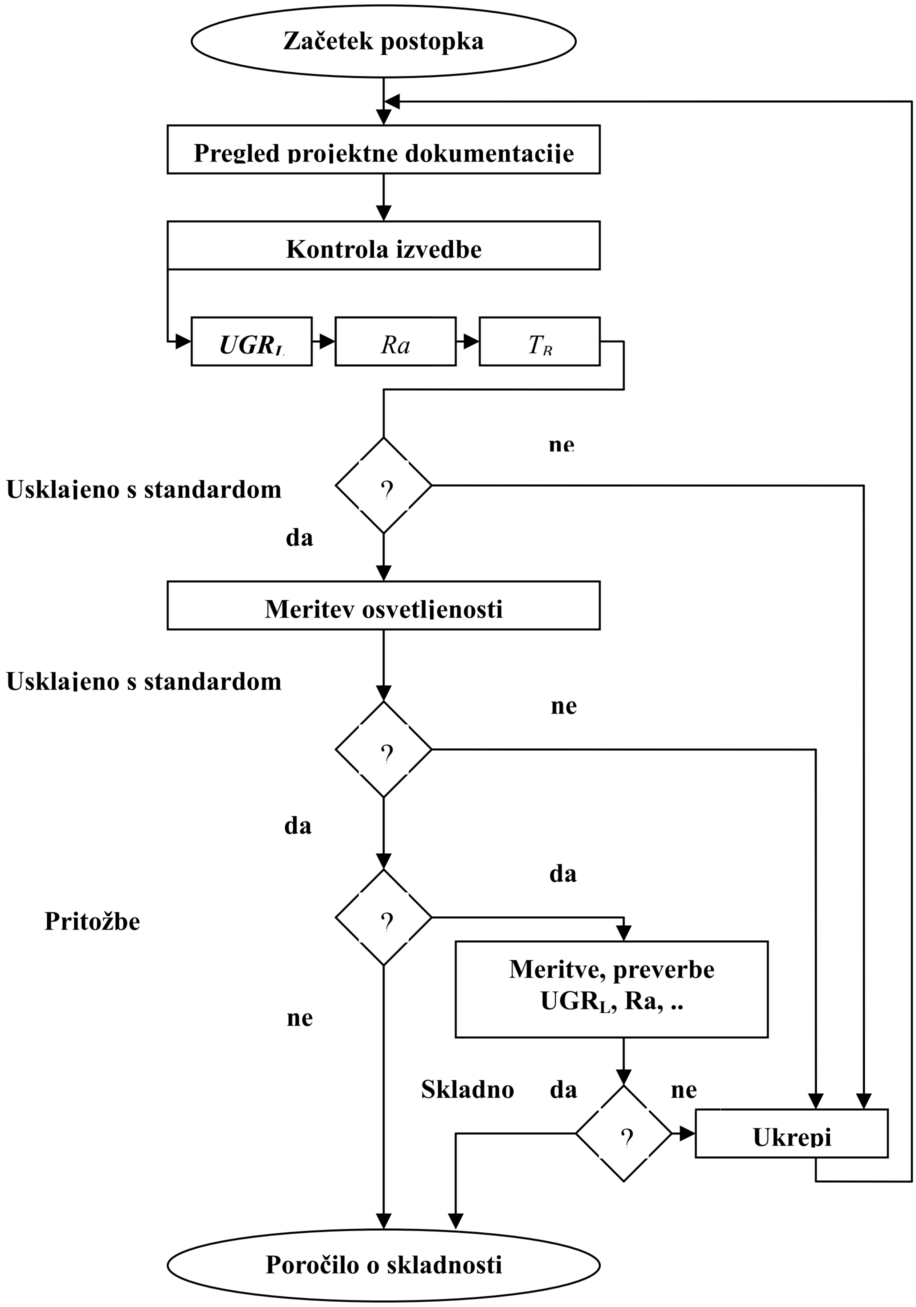
Preverjanje skladnosti z zahtevami standarda

Skladnost z zahtevami se načeloma preverja trikrat: za zahtevne objekte pri obvezni reviziji projektov, pri novi razsvetljavi v postopku prevzema investicije oz. pridobitev obratovalnega dovoljenja, ter pri obveznih periodičnih preiskavah in pregledih delovnega okolja. Za strokovne delavce in inšpekcijski organ, ki jim je v prvi vrsti namenjen ta sestavek, je zlasti pogosto zadnje opravilo: periodične »meritve«.

Že v standardu je vgrajen duh ekonomike, kot je bilo omenjeno. Tudi periodične preiskave, v našem primeru preverjanje primernosti razsvetljave, morajo biti gospodarno opravilo. Zaradi »stroškov« so se doslej periodične meritve omejevale praktično izključno na merjenje osvetljenosti na delovnih mestih. Vendar standard poleg osvetljenosti, ki je najlažje in najpreprosteje merljiva, zahteva izpolnitev še drugih zahtev, kot so: bleščanje, barvna reprodukcija in barvna temperatura. Razen tega morajo biti v smislu predpisov s področja varnosti in zdravja pri delu rezultati preiskav integrirani v *izjavo o varnosti z oceno tveganja*.

Gospodarnost nadzora nad razsvetljavo na delovnih mestih zahteva takšen postopek, ki da z najmanjšim vlaganjem največji učinek. Zato je smiselno največjo pozornost nameniti običajno najpomembnejšemu parametru, ki določa vidnost: osvetljenosti. Bleščanje, kakovost podajanja barv in barvna temperatura so parametri, ki zahtevajo dražjo opremo, več znanja, meritve so zahtevnejše, ali so parametri merljivi samo laboratorijsko.

Zato gospodarno presojo v smislu standarda je primeren naslednji postopek:



Kot prvi korak najprej *preverimo po projektni dokumentaciji*, ali so izhodišča projekta skladna z zahtevami veljavnega standarda. Koristna je še *praktična kontrola izvedbe*, ali so npr. mesta namestitve in je izbira svetilk in sijalk skladna z zahtevami projekta. Če ugotovimo bistvene napake ali odstopanja, je naslednji korak ugotovitev, da so potrebni *ukrepi*. Po korekcijah in izvedbi ukrepov se preverjanje vrne na stopnjo prvega koraka.

Če so glavni *podatki v projektu* o stopnji bleščanja, kakovosti podajanja barv, barvni temperaturi ipd. pravilno izbrani in če namestitev, izbira svetilk, senčnikov ipd. ustreza zahtevam projekta, naredimo naslednji korak: mersko in računsko kontrolo osvetljenosti ter enakomernosti osvetljenosti na območju vidne naloge in neposredne okolice. Če so rezultati skladni z zahtevami standarda, preverimo v naslednjem koraku, ali morda zaposleni oz. uporabniki delovnega prostora nimajo *pripomb* na razsvetljavo. Če pripomb ni, zaključimo preiskavo z ugotovitvijo skladnosti z zahtevami.

Če ugotovimo pritožbe zaposlenih, so potrebne dodatne zahtevnejše preiskave, ki naj ne vključujejo samo tehničnih parametrov, ampak preko pooblaščenega zdravnika tudi vid zaposlenih. S temi preiskavami se ugotovi morebitne vzroke problemov in se predlaga primerne rešitve in ukrepe. Preiskava pa se nadaljuje spet v eni od prejšnjih stopenj v odvisnosti od vrste pomanjkljivosti.

Pri tem je treba opozoriti tudi na navedbo standarda, da zahteve veljajo za *običajne razmere*. Če razmere niso običajne, če imamo npr.opravka s slabo vidnimi predmeti dela, slabovidnimi ali starejšimi delavci, posebno hudimi posledicami v primeri napačne vidne zaznave predmetov dela ipd., je treba v smislu standarda osnovne zahteve standarda temu ustrezno in utemeljeno prilagoditi.

Razsvetljava v izjavi o varnosti z oceno tveganja

Izjava o varnosti z oceno tveganja je temeljni dokument, ki dokazuje staje varnosti pri delu, opozarja na posebne nevarnosti in škodljivosti in navaja potrebne korektivne ukrepe. Ena od možnih nevarnosti je tudi razsvetljava. Strnjeni povzetki rezultatov preiskav razsvetljave morajo biti zato primerno razvidni tudi v izjavi o varnosti z oceno tveganja v takšni obliki, ki je skladna z oceno drugih nevarnosti in škodljivosti pri delu.

Navada je, da se v izjavi o varnosti z oceno tveganja ugotovljena »stopnja tveganja« po pomembnosti označuje z 1 do 5, pri čemer pomeni 1 nevtralno, nenevarno, neškodljivo stanje, kot si ga želimo, stopnja nad 4 pomeni odstopanje od predpisov, torej stanje, kjer so *obvezni* ukrepi, 5 pa pomeni kritično stanje, kjer so posledice neupoštevanja ukrepov lahko težke ali usodne. Stopnja 3 pomeni, da je nevarnost ali škodljivost sicer še sprejemljiva, vendar je na meji sprejemljivega in zato zahteva pozornejši nadzor, stopnja 2, ki pri razsvetljavi ni smiselna, pa opozarja na nevarnost ali škodljivost, čeprav je stanje brez dvoma v sprejemljivih mejah.

Zaradi skladnosti z drugimi škodljivostmi po omenjenem principu lahko priredimo tudi rezultatom preiskav razsvetljave tako imenovano »*stopnjo obremenitve*« *SO*, ki po vrednostih ustreza razredom tveganja po zahtevah izjave o varnosti. Pri preiskavah in ugotovitvah o ustreznosti razsvetljave v delovnem okolju lahko ugotovitvam priredimo vrednost *SO* po naslednji shemi:

SO:	**1**	**3**	**4**	**5**
ustreza kriterijem:	ustreza vsem zahtevam pravilnika in standarda	ustreza $E_{\mathrm{DM,u}}$; druge zahteve niso izpolnjene ali niso znane	ne ustreza $E_{\mathrm{DM,u}}$; ne ustrezajo drugi parametri; pritožbe zaposlenih	nevarno; hude pritožbe zaposlenih

Opozoriti je treba, da, čeprav standard navaja naravno osvetljenost kot temeljno, od prenehanja veljavnosti JUS U.C9.100[8] nimamo določil o zahtevah za naravno razsvetljavo delovnih mest. Torej določil, do kdaj naravna osvetljenost na delovnem mestu zadošča in kdaj jo je treba dopolniti ali nadomestiti z umetno. Za minimalno naravno osvetljenost na delovnih mestih se morebiti lahko začasno, dokler ni boljšega pravila, sklicujemo na določilo prejšnjega standarda[8], ki je vseboval pravilo, da mora *koeficient dnevne osvetljebnosti*, ki ga na terenu določamo z meritvijo, zagotavljati pri 5000 lx horizontalne zunanje osvetljenosti vsaj polovico zahtevane umetne osvetljenosti s sijalkami. Minimalno to umetno osvetljenost pa določa standard.

Sklep

Dejstvo je, da je trenutno področje predpisov o zahtevah za umetno razsvetljavo na delovnih mestih očitno precej dinamično. Nastane vprašanje, ali naj pustimo zato, ker so na voljo včasih šele osnutki standardov, npr. z oznako pr, FDIS, OSIST ipd., določeno področje neregulirano, ali pa naj vire, kakršne pač imamo, kljub temu upoštevamo, čeprav še niso dokončno dodelani. Brez dvoma je škoda, če je področje popolnoma neurejeno, lahko večja, kot če se ravnamo po predlogih, ki se navadno z manjšimi dopolnitvami dopolnijo v končno obliko. To je bila tudi dilema pri slovenskih standardih za umetno razsvetljavo na delovnih mestih. Odločili smo se za prvo možnost in smo opozorili strokovnjake, ki načrtujejo ali nadzorujejo razsvetljavo, na trenutno veljavne predloge oz. osnutke. Da tega nismo naredili močno napačno, dokazuje, da npr. pri razsvetljavi, ki jo določa novi samostojni standard EN ISO/FDIS 8995-2:2005[10], ni vsaj za razsvetljavo na prostem veliko ali pomembnih razlik od prvotnega prEN 12464-2. Zadnja izdaja standarda[10] definira nekatere nove veličine, kot je različnost (diversity E_{min}/E_{max}), določa pas neposredne okolice okrog mesta dela na širino 2 m, dodaja nekaj pojasnil (za bleščanje), nekatere pogoje za ne-cestno razsvetljavo ipd. Večinoma pa so zahteve za razsvetljavo, kot je vzdrževana osvetljenost in drugi parametri ostale pretežno enake z manjšimi popravki. Dodana pa je pri standardu za zunanjo razsvetljavo še minimalna dopustna enakomernost osvetljenosti ($U_0 = E_{min}/E_{ev}$).

Stvar tehničnih komisij pri SIST-u je proučiti in umakniti dosedanje verzije standardov vrste 12464 in jih nadomesti z novimi, veljavnimi v EU. S opisano sprejeto formulacijo v pravilniku o zahtevah za delovna mesta pa bojo kot obvezni obveljali novo sprejeti ustrezni SIST-i, ne da bi bila potrebna sprememba pravilnika. Dotlej veljata formalno trenutni verziji. Kljub vsemu bo delo pri uporabi novih standardov lažje, ker smo preko prejšnjih že dobro seznanili z načeli, pa tudi, kar ni za zanemariti, imamo poslovenjeno nomenklaturo delovnih mest oz. opravil. Čeprav smo formalno sicer dolžni do spremembe uporabljati sedaj veljavne standarde, je smiselna tam, kjer so razlike v primerjavi z novostjo, tudi vsaj v obliki komentarja ustrezna pripomba in navedba nove zahteve.

Viri

1. Zakon o standardizaciji, Ur.l. RS 59/99
2. Pravilnik o spremembah in dopolnitvah Pravilnika o zahtevah za zagotavljanje varnosti in zdravja delavcev na delovnih mestih, Ur.l. RS 39/2005
3. SIST EN 12464-1, Lighting applications – Lighting on Workplaces – Part 1: Indoor workplaces
4. OSIST prEN 12464-2, Lighting applications – Lighting on Workplaces – Part 1: Outdoor workplaces
5. OSIST prEN 12464:2003, Lighting applications – Lighting on Workplaces
6. Neumüller S., Planinšek V. idr., Notranja razsvetljava in vzdrževanje sistemov notranje razsvetljave, 2. izdaja, Priporočila SRD, Pr4/1,Pr4/2, Maribor, 2004
7. Gspan P., Žebovec S., Zahteve za razsvetljavo pri delu in standard 12464, ZVD, zv. 137, Ljubljana, 2006

8. JUS U.C9.100, Ur.SFRJ, 48/62
9. Pravilnik o preiskavah delovnega okolja, pregledih in preizkusih sredstev za delo, Ur.l. RS 35/1988
10. EN ISO/FDIS 8995-2:2005, Lighting in workplaces – Part 2: Outdoor

Avtorjev naslov:

Primož Gspan
Na Jami 11
Ljubljana

Gorazd Golob, Marta Klanjšek Gunde, Marko Jankovec, Jure Ahtik, Matej Vaupotič

PROBLEM UPORABE LED SVETIL V TISKARNI

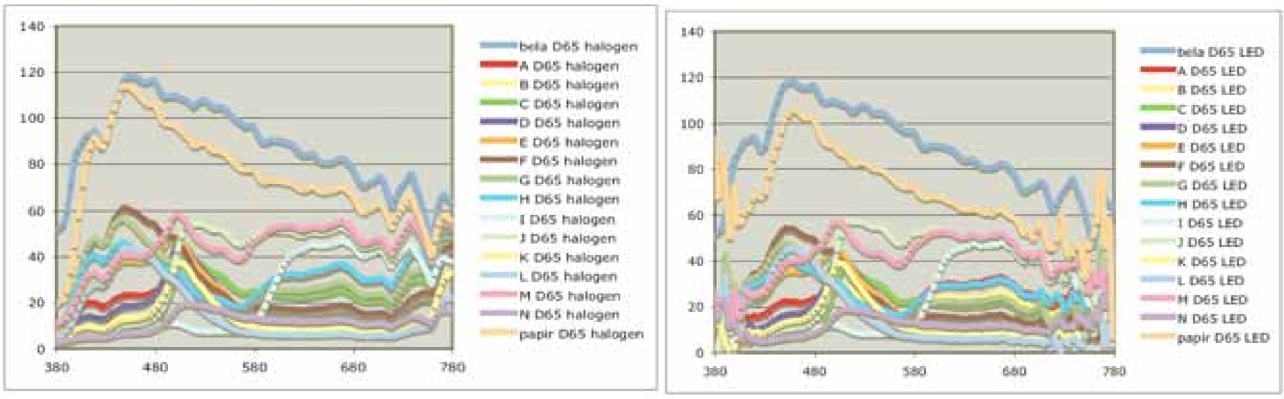
Povzetek

V tem delu objavljamo prve rezultate raziskave problemov uporabe alternativnih svetil za razsvetljavo svetlobnih kabin oz. pultov za kontrolo barv v tiskarni. Na osnovi 14 vzorcev barv, odtisnjenih na različne tiskovne materiale smo določali posebni indeks metamerije in ugotovili kritične materiale in barve za reproduciranje.

Meritve s spektroradiometrom smo opravili pri osvetlitvi vzorcev z LED in halogensko svetilko, v teku pa so še meritve pri osvetlitvi z navadno voframovo žarnico, "varčno žarnico" in fluorescentnimi svetilkami. Rezultati prvih meritev potrjujejo navedbe v literaturnih virih glede spektralnih značilnosti svetlobe, prisotnost metamerije in neznačilne anomalije predvsem v modrem in rdečem delu spektra (slika1). Posebni indeks metamerije (na osnovi 14 vzorcev) pri svetlobi halogenskega in belega LED svetila tako znaša 3,1, barvna razlika ΔEab barv v modrem in rdečem področju in papirja pa je od 4,2 do 5.*

Zaradi precejšnje razlike v lastnostih obeh svetlob, predvsem CCT, indeksa barvnega videza (CRI) in osvetljenosti vzorcev, bodo končni rezultati objavljeni šele po dodatnih meritvah z medsebojno bolj primerljivimi viri, ki bodo opravljene v avgustu 2006.

***Ključne besede**: halogenska svetilka, LED, indeks barvnega videza (CRI), spekter, anomalije.*



Slika1: Spektri 14 barvnih vzorcev, belega papirja in referenčnega standarda pri osvetlitvi s halogensko svetilko (levo) in belo LED svetilko (desno).

Naslovi avtorjev:

Gorazd Golob[1], Marta Klanjšek Gunde[2], Marko Jankovec[3], Jure Ahtik[1], Matej Vaupotič[1]

[1] Univerza v Ljubljani, Naravoslovnotehniška fakulteta

[2] Kemijski inštitut, Ljubljana

[3] Univerza v Ljubljani, Fakulteta za elektrotehniko

Andrej Orgulan, Tomaž Slatinek

VPLIV OSVETLJENIH POVRŠIN NA SVETLOBNO ONESNAŽENJE

Povzetek

Svetlobno onesnaženje zajema širok spekter vplivov razsvetljave na okolico. Zatem, ko je dozorelo spoznanje, da je te vplive potrebno nadzirati in omejevati, se je pojavila nova težava – kakšni kriteriji in metode za njihovo vrednotenje bi bili najbolj smiselni in učinkoviti v praksi. Za vrednotenje vplivov cestne razsvetljave, katere delež pri skupnih svetlobnih emisijah je znaten, je predlagana metoda t.i. škatle, ki bi omogočala izračun vplivov z obstoječimi programskimi orodji. Pomanjkljivost takšnega pristopa je v tem, da izgubimo podatek o smeri izsevane svetlobe, kar je eden od bistvenih podatkov za objektivno vrednotenje. Druga pomanjkljivost obstoječih orodij je približno računanje z reflektiranimi deleži svetlobe, saj so npr. podatki za cestne površine standardizirani za popolnoma drugačne razmere izračuna. V tem prispevku je prikazana metoda, ki upošteva te pomanjkljivosti ter rezultati izračunov za nekatere tip cestne razsvetljave.

Abstract

Light pollution consist of various influences of light emissions. Awareness, that this impact should be monitored and reduced has matured in recent years. But new problem turned up: what are the criteria and suitable estimation methods for evaluation of impact. For influence of the road lighting on light pollution “shoe box method” has been proposed, because it can be used with existent computer tools, without modifications. This approach has obvious deficiency – the results doesn’t show the angle of emitted light, which is crucial data for light pollution evaluation. Another limitation of existent computer programs is calculation with reflected portion of light. Road surfaces are standardized in various reflection classes, but for different calculation approach. In this paper, method for taking these aspects into account is discussed, and some results, showing influence of various street luminaires are presented.

1. Uvod

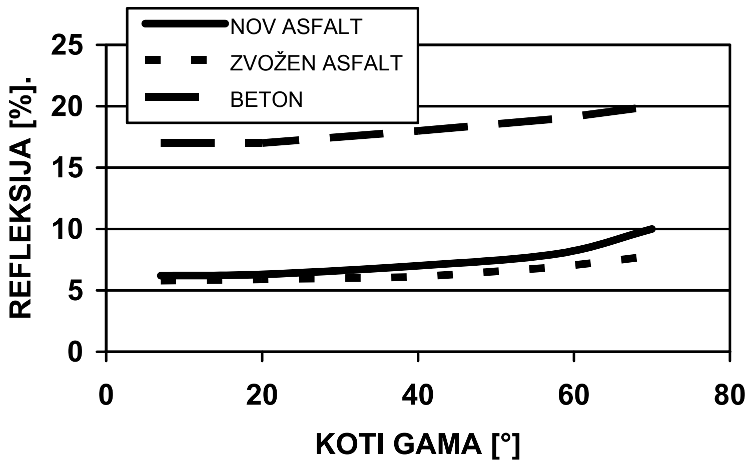
Vsa zunanja razsvetljava lahko povzroča svetlobno onesnaženje, vendar bo povprečen opazovalec najprej opazil cestno in ulično razsvetljavo. Razlog za to je, da je cestna razsvetljava v zemljepisnem smislu povsod daleč najbolj razširjena in je prisotna tako v mestnem kot tudi v ruralnem področju. Za razliko od npr. razsvetljave reklamnih panojev, ki je omejena predvsem na gosto poseljena mestna področja.

Drug odmeven primer neprimerne razsvetljave je mnogokrat razsvetljava kulturnih znamenitosti, ki je mnogokrat neprofesionalno izvedena in pri kateri gre dobršni del svetlobe mimo objekta razsvetljave naravnost v nebo

Te vplive razsvetljave na svetlobno onesnaženje lahko bistveno zmanjšamo z dobrim načrtovanjem razsvetljave. Ne moremo pa bistveno zmanjšati deleža reflektirane svetlobe, ki se odbije v prostor od teh osvetljenih površin. V tem prispevku bo prikazan delež vpliva zaradi takšnih osvetljenih površin, nekatere omejitve in težave, s katerimi se srečujemo pri takšnih izračunih in predlogi nekaterih rešitev.

2. Refleksijske lastnosti vozišč

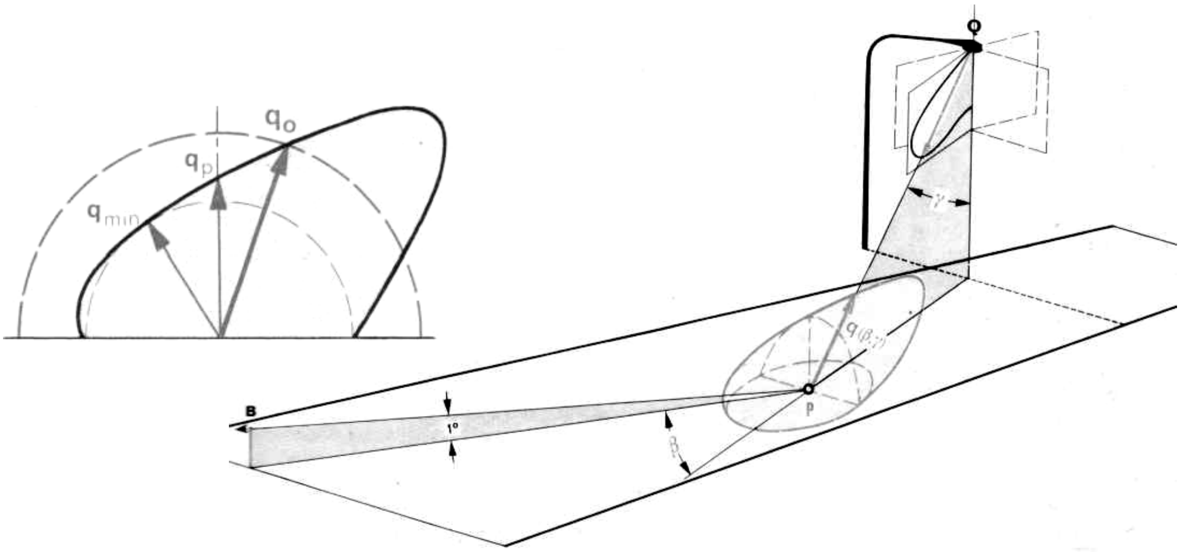
Na osnovi dosegljivih podatkov sl. 1 [1] se manj kot 10 % svetlobe odbije nazaj v prostor, kar pomeni, da tudi cesta z zastrtimi svetilkami, ki same po sebi ne sevajo v prostor nad horizontalo, povzroča svetlobno onesnaževanje v velikosti do 10 % inštaliranega svetlobnega toka. Pri svetlejših (betonskih) voznih površinah je odbite svetlobe več (do 20 %), pri temnejših pa manj.



Slika 1: Refleksije svetlobe na asfaltu in betonu v odvisnosti od vpadnega kota

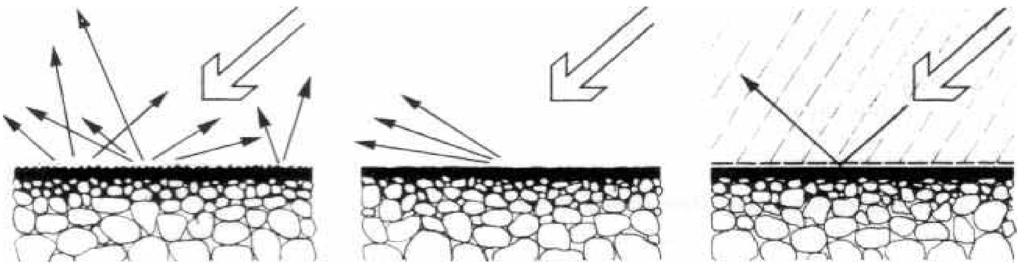
Pri projektiranju cestne razsvetljave se moramo držati predpisanih vrednosti svetlosti cestišča, zato temna cestišča potrebujejo večjo osvetljenost, da dosežemo želeno svetlost.

Postopek izračuna odbite svetlobe s pomočjo q-telesa in tudi r-tabel ima to pomanjkljivost, da je možno po tej metodi izračunati samo odboj v smeri opazovalca ($\alpha = 1°$) (sl. 2.). Ta kot ene stopinje je vezan na udeležence v prometu, katerim je ta razsvetljava namenjena in ti pod tem kotom opazujejo cesto pred seboj [3]. Oblika q-telesa označuje refleksijske lastnosti površinskega sloja nekega cestišča. Telesa podolgovate oblike so značilna za gladke površine vozišč; telesa bolj polkrogelne oblike pa definirajo bolj grobe (difuzno refleksiraloče) površine vozišč. q-telo lahko prikažemo tudi kot polkroglo s premerom q_0, ki ima enak volumen kot q-telo. Polmer te polkrogle določa srednjo vrednost svetlosti q-telesa in ga zato imenujemo srednji koeficient svetlosti (q_0). Popolnoma difuzno refleksirajoči del q-telesa pa ustreza polmeru q_{min}. Koeficient svetlosti ki v q-telesu ponazarja vertikalni vpad svetlobe, označujemo s q_p in ga uporabljamo pri določitvi zrcalnih lastnosti vozišč.



Slika 2: Oblika q telesa in odboj svetlobe na cestišču

Odboj svetlobe na različnih podlagah je prikazan na sliki 3. Vidimo, da gre na suhi novi vozni površini (z grobo teksturo) za bolj difuzni odboj (R1 refleksijski razred), pri zvoženi cesti za kombinacijo difuznega in zrcalnega odbija (R3 refleksijski razred), pri mokri cesti pa za zrcalni odboj (W1 refleksijski razred).

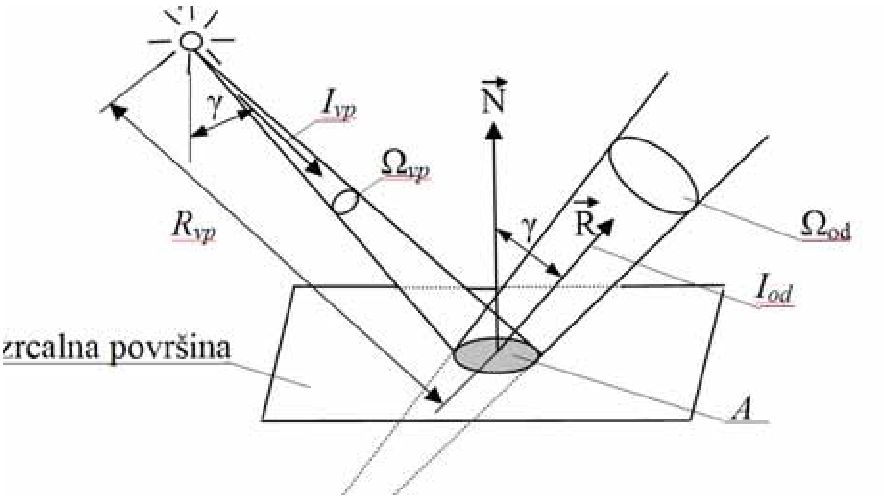


nova vozna površina zvožena vozna površina mokra vozna površina

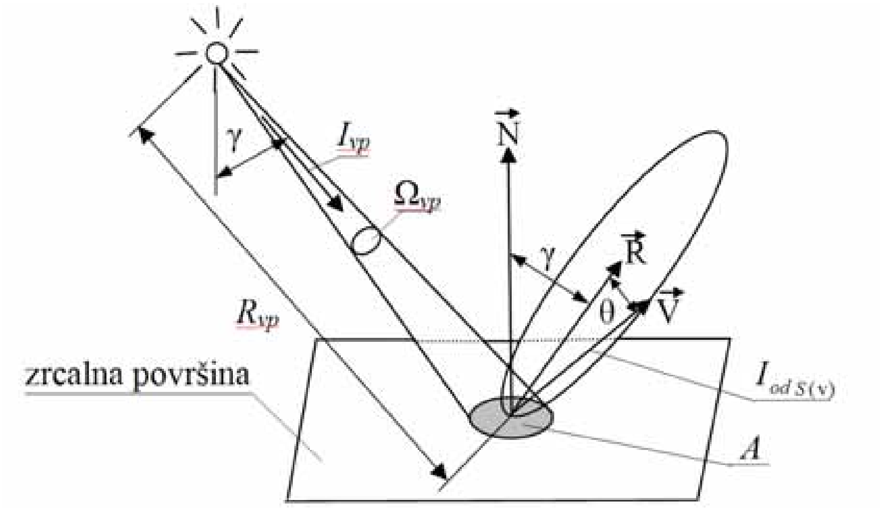
Slika 3: Odboj svetlobe na različnih podlagah

2. Matematični model odboja svetlobe

Svetlobni tok, ki vpada na gladko površino, se deloma absorbira, deloma pa se odbije, pri čistem zrcalnem odboju (sl. 4) pod odbojnim kotom, ki je enak vpadnemu, le zrcaljen preko normale na ravnino ($\Omega_{vp} = \Omega_{od}$).



Slika 4: Čisti zrcalni odboj



Slika 5: Zrcalni odboj

Ker pa vsaka realna površina odboj nekoliko razprši okoli odbojnega kota, vzamemo za razpršitev empirično določen parameter, ki je kosinus na potenco *ns* kota Θ med zrcalno odbojnim vektorjem R in vektorjem opazovanja V (sl. 5).

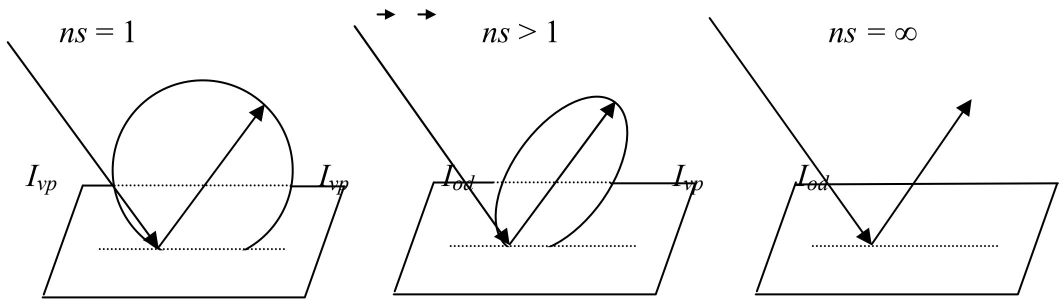
$$I_{od} \cdot \Omega_{do} = I_{vp} \cdot \Omega_{vp} \cdot ks \cdot \cos^{ns}(\Theta) \cong I_{vp} \cdot \frac{A \cdot \cos(\gamma)}{R_{vp}^{\ 2}} \cdot ks \cdot \cos^{ns}(\Theta) \qquad (1)$$

Želimo izračunati odbiti svetlobni tok $\left(\phi_{od \xrightarrow{} s(v)}\right)$ v točno določen del kupole, uporabimo enačbo :

$$\phi_{od\,S(\mathrm{v})} = I_{od\,S(\mathrm{v})} \cdot \Omega_{od\,S(\mathrm{v})} \cong I_{vp} \cdot \frac{A_p \cdot \cos(\gamma)}{R_{vp}^{\ 2} \cdot 2\pi} \cdot ks \cdot (\cos(\Theta))^{ns} \cdot \frac{S(\mathrm{v})}{R_{od}^{\ 2}} \qquad (2)$$

Ostane nam še edino določitev parametra (potence) *ns*. Parameter *ns* vpliva na porazdelitev zrcalnega dela odboja. Možne nastavitve parametra n so od 1 do ∞. Pri $n = 1$ je porazdelitev v obliki krogle, pri $n > 1$ je porazdelitev v obliki rotosimetrične elipse, ki rotira okoli premice skozi gorišči, ki ležita na premici na kateri leži vektor odboja R. Z večanjem potence n se veča razdalja med goriščema elipse ali z drugimi besedami elipsa se oža vse do $ns = \infty$ pri katerem pridemo do čistega zrcalnega odboja (sl. 4.6). Pri čistem zrcalnem odboju iz enačbe (2) odpade $\frac{1}{2\pi}$ in odbojni kot je enak vpadnemu, zato je potrebno z večanjem *ns* večati tudi refleksijski parameter za zrcalni odboj *ks*, da odbiti svetlobni tok z večanjem *ns* ostane enak.

Kosinus na *ns* kota med zrcalno odbojnim vektorjem in vektorjem opazovanja $(\cos(\Theta))^{ns}$ lahko zaradi hitrejšega delovanja programa zamenjamo z skalarnim produktom med enotskim vektorjem zrcalno odbojnega vektorja in enotskim vektorjem v smeri opazovalca na enako potenco $(R*V')^{ns}$.



Slika 6: Vpliv parametra *n* na porazdelitev odboja

3.Izračuni in komentar rezultatov

Za primer izračuna vzamemo 100 metrov dolgo in 15 metrov široko cesto, kamor postavimo tri svetilke na 15, 50 in 85 metrov po širini pa na 5 metrov. Za svetilke izbermo svetilko »SITECO 5NA 393 E-1PT03GB ST 100 (*33338_1.ldt*)« s svetlobnim tokom 16500 lm, ki spada v razred bleščanja G2 (polzastrta svetilka). Refleksijske parametre sem določil kot:

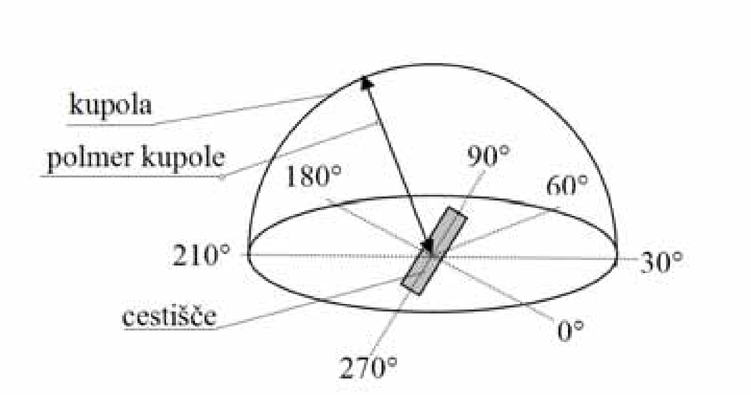
kd = 0.01 ; kd je refleksijski faktor za difuzni del odboja

ks = 0.15 ; ks je refleksijski faktor za zrcalni del odboja

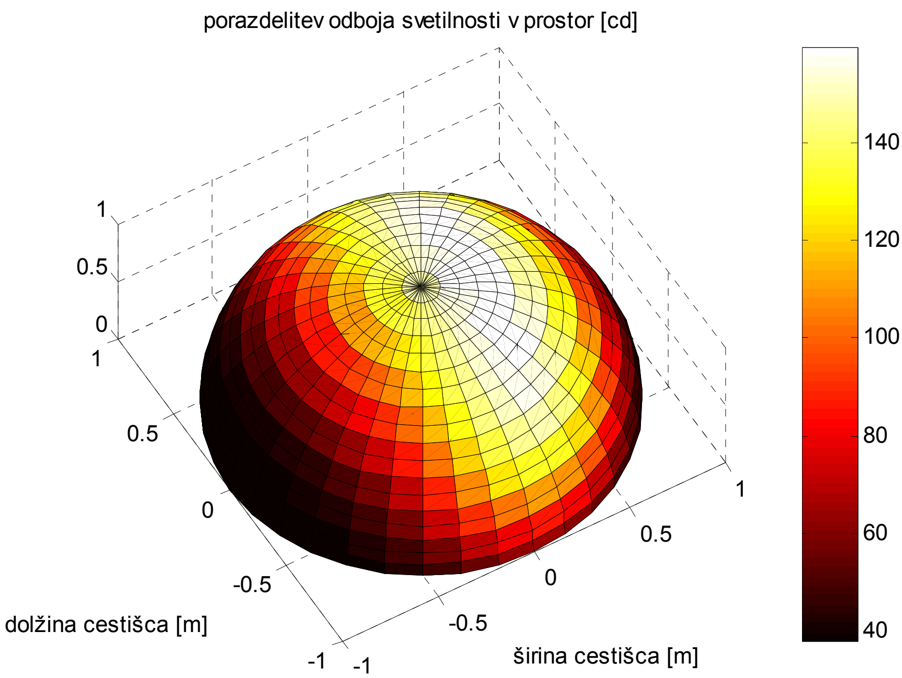
ns = 10 ;   večji kot je ns ožje je polje zrcalnega odboja

Povprečna horizontalna osvetljenost je bila v tem primeru 16 lx, minimalna horizontalna osvetljenost 6,96 lx in razmerje enakomernosti 0,43, kar je skladno z zahtevami. Odbiti svetlobni tok je bil v tem primeru 552 lm, svetlobni tok direktno proti kupoli 312 lm, kar je skupaj 864 lm in to je 1.75 % oddanega svetlobnega toka treh svetilk.

Porazdelitev svetilnosti odboja v prostor (kupolo), ki je postavljena nad cesto je prikazana na sliki 7. Svetilnost v [cd] je predstavljena tudi v barvni lestvici zraven grafa. na sliki 8 je prikazana kupola nad cesto. Svetlejši deli grafa predstavljajo večji svetlobni tok v tej tisti smeri. Svetilnost v [cd] je predstavljena tudi v barvni lestvici zraven kupole.



Slika 7: Postavitev in orientacija kupole nad cestiščem



Slika 8: Porazdelitev odboja svetlobe v kupolo

Iz tabele 1 je razvidno, da je razlika med zastrto svetilko »SITECO 5NA 393 E-1PT02GB ST 100 (*33344_1.ldt*)« in polzastrto svetilko »SITECO 5NA 393 E-1PT01GB ST 100 (*33338_1.ldt*)« v svetlobnem onesnaževanju največ en odstotek, kar je zelo malo, saj smo pričakovali večjo razliko. Preseneti nas tudi direktni vpad svetlobe v kupolo pri polzastrti svetilki »SITECO 5NA 393 E-1PT01GB ST 100 (*33338_1.ldt*)«, saj bi pričakovali, da bo večji vsaj 5 %, kot je navedeno v [5]. To seveda velja le, če svetilka ni rotirana v x ali y smeri, ker je v tem primeru direktni svetlobni tok proti kupoli znatno večji

Tabela 1: Primerjava odboja svetlobe pri dveh različnih svetilkah

svetilka	*kd*	*ks*	*ns*	Φ_{od} [%]	Φ_d [%]	$\Phi_{od} + \Phi_d$ [%]
33338_1.ldt (polzastrta)	0,1	0	10	5,028 %	0,63 %	5,658 %
33344_1.ldt (zastrta)	0,1	0	10	4,817 %	0 %	4,817 %
33338_1.ldt (polzastrta)	0	0,5	10	3,564 %	0,63 %	4,194 %
33344_1.ldt (zastrta)	0	0,5	10	3,983 %	0 %	3,983 %
33338_1.ldt (polzastrta)	0,02	0,2	10	3,066 %	0,63 %	3,696 %
33344_1.ldt (zastrta)	0,02	0,2	10	2,772 %	0 %	2,772 %
33338_1.ldt (polzastrta)	0,018	0,22	10	3,043 %	0,63	3,673 %
33344_1.ldt (zastrta)	0,018	0,22	10	2,754 %	0 %	2,754 %
33338_1.ldt (polzastrta)	0,05	0,2	10	5.539 %	0,63 %	6,169 %
33344_1.ldt (zastrta)	0,05	0,2	10	4,99 %	0 %	4,99 %
33338_1.ldt (polzastrta)	0,05	0,5	10	7,667 %	0,63 %	8,296 %
33344_1.ldt (zastrta)	0,05	0,5	10	6,931 %	0 %	6,931 %

4. SKLEP

Namen tega dela je bil ugotoviti kolik del svetlobe se odbije od voznih površin in v katero smer, ter ali na to vpliva izbira svetilke.

Da bi lahko ocenili svetlobno onesnaževanje smo naredil program za izračun odboja svetlobe na cestnih površinah, ki omogoča poljubno izbiro svetilk cestne razsvetljave, njihovo poljubno namestitev in orientacijo v prostoru, ter izračuna porazdelitev odbite svetlobe v prostor. Ugotovimo, da dajo najboljše rezultate svetilke z ravnim steklom, se pravi popolnoma zastrte svetilke. Te svetilke torej manj bleščijo in ne povzročajo velikega svetlobnega onesnaževanja. Prav tako lahko ocenimo, da te svetilke ne dajejo slabše enakomerne osvetljenosti cestišča, kar lahko preverimo v komercialnih programih.

Za popolni nadzor nad svetlobnim onesnaženjem potrebujemo vse možne podatke, ki jih lahko pridobimo in ustrezno programsko opremo, ki nam bo dala vse potrebne rezultate. Škatelna metoda nam teh rezultatov ne daje, zato moramo pritisniti na razvijalce komercialnih programskih paketov, da bodo v izračune vključili tudi porazdelitev odbite svetlobe v prostor, kar je enostavno z minimalnimi modofikacijami obstoječih programov.

Večja težava je pridobitev in standardizacija refleksijskih parametrov asfaltnih (in drugih) površin, saj so ti podatki nujno potrebni za natančnejše izračune. Težave tukaj niso omejene samo na meritve, ampak tudi na interpretacijo teh meritev, saj je govora o izredni količini podatkov, ki jih je treba pripraviti na čimbolj učinkovit način.

5.Viri

1. Leon Kos, *Distribuirani sistem za upodabljanje tridimenzionalnih objektov,* Pridobljeno 7. 6. 2005 iz http://www.lecad.uni-lj.si/~leon/distray/node2.html
2. P. Podlipnik: *Svetlobno tehnični priročnik*, ČGP Delo, Ljubljana, 1978
3. H. j. Hentschel: *Licht und Beleuchtung*, CIP-Kurtztitelaufnahme der Deutschen Bibliothek, 1987
4. Laurence T. Maloney *Physics-Based Approaches to madeling Surface Color Perception,* Pridobljeno 15. 10. 2005 iz http://www.psych.nyu.edu/maloney/MaloneyColorCambridgeUP1999.pdf
5. P. Ronbouts: *Precise Evaluation of Upward Flux from Outdoor Lighting Installations (applied in the case of roadway lighting),* La Serena (Chile) Light Pollution Symposium, March 2002
6. Priporočila SDR cestna razsvetljava, Slovensko društvo za razsvetljavo / SDR, Maribor, 2000
7. M. Bizjak, Cestna razsvetljava – pregled nekaterih pomembnejših raziskav in spoznanj ter izzivi za prihodnost, Razsvetljava 2005 – zbornik, Maribor 2005, Slovensko društvo za razsvetljavo / SDR, Maribor 2005

Naslov avtorja:

mag. Andrej Orgulan, Tomaž Slatinek

Fakulteta za elektrotehniko, računalništvo in informatiko,

Univerza v Mariboru

andrej.orgulan@uni-mb.si

Primož Puhar, Grega Bizjak

MERITEV ODSEVNOSTI CESTNIH POVRŠIN

Povzetek:

V članku je predstavljena naprava za merjenje odsevnosti cestnih površin in ustrezen postopek meritve. Rezultati meritev podajajo kotno porazdelitev odsevnosti obravnavane cestne površine za različne vpadne kote svetlobe in so podani tako tabelarično kot grafično. Z njihovo pomočjo je možno izdelati matematični model odsevnosti, ki ga lahko uporabimo v izračunih odsevanega svetlobnega toka in tako ocenimo primernost materiala cestne površine v kombinaciji s cestno svetilko s stališča svetlobnega onesnaževanja nočnega neba. Napravo lahko uporabimo tudi za meritve odsevnosti drugih površin. Poleg same konstrukcije in delovanja naprave so v članku predstavljene tudi njene omejitve ter napotki za ustrezno izvedbo meritev.

Ključne besede: odsevnost cestnih površin, meritve odsevnosti, svetlobno onesnaženje,

Abstract:

In the paper the device for measuring the road surface reflectance is presented together with the measuring procedure. The results give angular distribution of reflectance of road surface under investigation for different light incident angles and are presented in tables and graphs. With the help of obtained results it is possible to produce mathematical model of reflectance, which can be used for calculation of reflected luminous flux and so for the evaluation of road surface in combination with street luminaire from the ‘night sky light pollution’ point of view. The device can also be used for measurement of reflectance of other surfaces. Beside the construction and the operation of the device also its limits are present together with some directives for its successful use.

Keywords: road surface reflectance, measurement of reflectance, light pollution

1. Uvod

Zadnja leta je aktualna tema svetlobno onesnaženje, ki je posledica uhajanja svetlobnega toka v nebo. Glavne posledice svetlobnega onesnaženja so astronomske, biološke, ekonomske ter varnostne. Znane so rešitve z zmanjšanjem svetilnosti svetil ter njihovim zastiranjem. Čeprav je direkten svetlobni tok prevladujoč, svetlobno onesnaženje povzroča tudi svetlobni tok odbit od osvetljene površine.

Da bi zmanjšali svetlobno onesnaženje kot posledico odseva, potrebujemo kvantitativno oceno odseva svetlobe od osvetljene površine. To oceno lahko dobimo iz kotne porazdelitve odsevnosti površine. Omenjeno karakteristiko je možno izmeriti z merilno napravo, opisano v nadaljevanju članka.

Iz poznane kotne porazdelitve odsevnosti je možno izdelati matematični model odsevnosti površine, ki ga lahko skupaj z modelom svetila uporabimo v računalniških simulacijah. Rezultati simulacij nam tako omogočajo tudi pridobitev informacij o odsevani svetlobi, ki jih skupaj z informacijami o svetlosti oziroma osvetljenosti cestišča potrebujemo za pravilno izbiro rešitve cestne razsvetljave.

2 Kotna porazdelitev odsevnosti površine

Odsevnost površine podaja delež svetlobnega toka, ki se odbije od opazovane površine, kotna porazdelitev odsevnosti površine pa delež svetlobnega, ki se od osvetljene površine odbije v določeni smeri. Za začetek predpostavimo, da svetlobni vir osvetljuje površino pod vpadnim kotom α. Zaradi odsevnosti površine se vpadni svetlobni tok odbije, zaradi njenih odsevnih lastnosti (hrapavosti) pa tudi neenakomerno razprši v prostor. To lahko opazimo kot razlike v svetlosti površine, če jo opazujemo pod različnimi koti. Ko izmerimo svetlost pri različnih odbojnih kotih β, dobimo kotno porazdelitev odsevnosti pri določenem vpadnem kotu α. Celotno kotno porazdelitev svetlosti pa dobimo, ko meritev ponovimo z različnimi vpadnimi koti svetlobe α.

Po definiciji podaja odsevnost površine ρ [-] razmerje med vpadlim in odsevanim svetlobnim tokom.

$$\rho = \Phi_{odsevani}/\Phi_{vpadli}$$

Pri difuznih površinah pa lahko odsevnost podamo tudi z razmerjem med svetlostjo površine L [cd/m^2] in osvetljenostjo te iste površine E [lux = lm/m^2] in sicer s pomočjo spodnjega izraza, kjer je Ω_0 enota prostorskega kota:

$$\rho = \pi \,.\, \Omega_0 \,.\, (L/E)$$

Omenili smo že, da je osvetljena površina različno svetla pod različnimi vpadnimi in odsevnimi koti. Različne vrednosti svetlosti lahko združimo v funkcijo kotne porazdelitve svetlosti L (α, β), ki ima dva parametra: vpadni (α) in odsevni (β) kot. Kadar se tudi osvetljenost spreminja s spremembo vpadnega kota, pa lahko to opišemo s funkcijo kotne porazdelitve E (α) z vpadnim kotom (α) kot parametrom.

Ker izračunavamo odsevnost kot kvocient dveh funkcij, kjer ima svetlost parametra α in β, osvetljenost pa parameter α, dobimo tudi odsevnost površine kot funkcijo dveh parametrov α in β.

$$\rho\ (\alpha, \beta) = \pi \ . \ \Omega_0 \ . \ (L\ (\alpha, \beta)\ \ /\ E\ (\alpha))$$

Če za izvedbo meritve uporabimo svetilo s konstantno svetilnostjo skozi celotno meritev, lahko funkcijo porazdelitve osvetljenosti E (α) razbijemo na produkt:

$$E\ (\alpha) = E_0 * \cos(\alpha)\ ,$$

kjer je E_0 osvetljenost površine, kadar je nameščena pravokotno na vir svetlobe (α = 0°). Kotna porazdelitev odsevnosti postane torej enaka:

$$\rho\ (\alpha, \beta) = \pi \ . \ \Omega_0 \ . \ \ (L\ (\alpha, \beta)\ /\ E_0 * \cos(\alpha))\ .$$

Meritev kotne porazdelitve odsevnosti v tem primeru torej lahko izvedemo s pomočjo meritve kotne porazdelitve svetlosti.

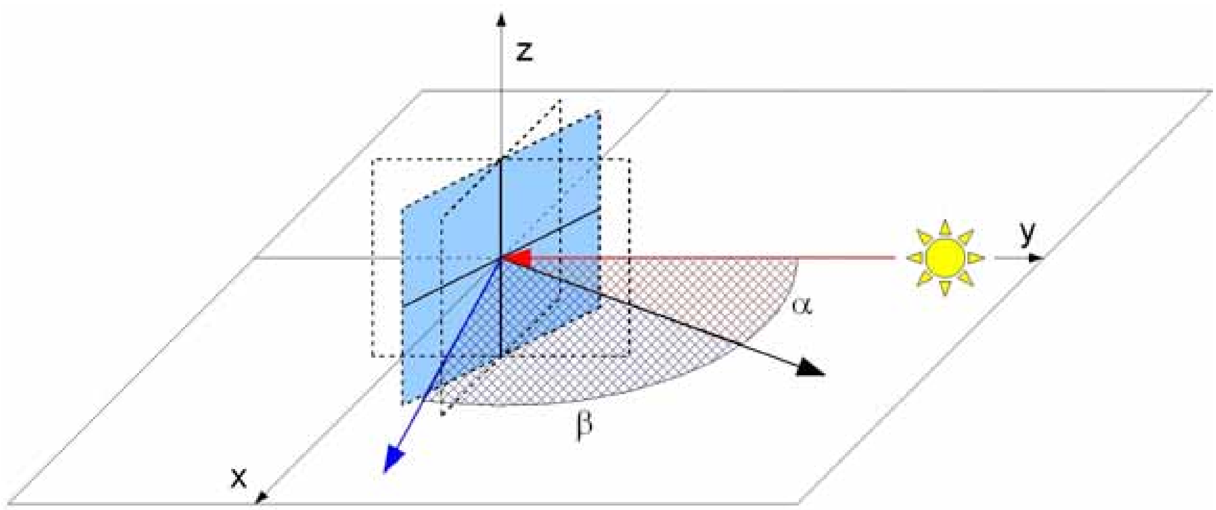
3 Naprava za meritev kotne porazdelitve svetlosti (odsevnosti)

Naprava za merjenje kotne porazdelitve svetlosti je sestavljena iz izvora svetlobe (reflektorja oziroma sončnega simulatorja), fotometrične klopi, merilnika osvetljenosti, merilnika svetlosti ter nosilca za merjenec. Naprava, ki smo jo izdelali, je prilagojena je za valjaste merjence premera 100mm.

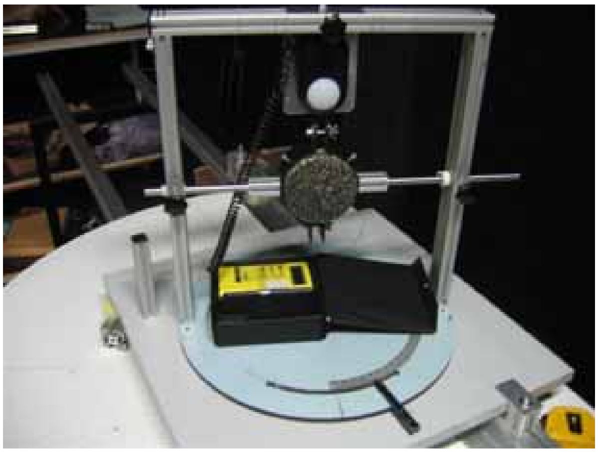
Izvor svetlobe je vpet statično. Razdalja do merjenca se lahko spreminja in znaša od 2 do 3 metre. Vzorec in merilnik osvetljenosti sta vpeta v osi, ki omogoča zasuk od 0° do 90° glede na svetilo. Za izvor svetlobe je uporabljen reflektor, torej vir usmerjene svetlobe, z ozkim svetlobnim snopom, ki pa je dovolj širok, da pokrije tako merjenec kot tudi glavo merilnika osvetljenosti v njegovi neposredni bližini nekaj centimetrov nad njim. Zaradi ozkega snopa svetlobe lahko na omenjeni razdalji smatramo, da je osvetljenost merjenca in glave merilnika osvetljenosti enaka. Merilnik svetlosti je montiran na premični ročici dolžine en meter, ki omogoča zasuk od 0° do 90° glede na trenutni položaj merjenca oziroma od 0° do 180 ° glede na položaj svetlobnega vira.

Kot merjenja na merilniku svetlosti je bil nastavljen na 1,1°, kar pomeni, da je velikost merjene površine, ko je os merilnika svetlosti pravokotna na površino merjenca (α=0°), manjša od 3 cm^2 (površina merjenca je 78 cm^2). Zaradi te razmeroma majhne merjene površine, je potrebno da ima merjenec relativno fino zrnatost površine, če želimo, da je rezultat meritve uporaben. Ker smo za izvedbo meritev uporabili vzorec že rabljene asfaltne cestne obloge, smatramo, da je bil ta pogoj izpolnjen. Z večjim kotom β merjena površina narašča. Z napravo smo omejeni na meritve pri kotih β med 0° in 90°. Vendar pa je pri kotih večjih od 70° rezultate jemati z določeno rezervo, saj je v teh primerih merjena površina večja od površine merjenca, teoretično pa je merjena površina pri kotu 90° celo neskončno velika. Zaradi tega smo sklenili meritve izvajati samo do kota 80°.

Idejna skica naprave je predstavljena na sliki 1. Merjenec, ki stoji v koordinatnem izhodišču, je za kot α premaknjen glede na svetlobni vir, ki leži na osi y. Merilnik svetlosti pa je glede na merjenec premaknjen še za kot β. Naslednje slike pa prikazujejo izvedbo naprave.

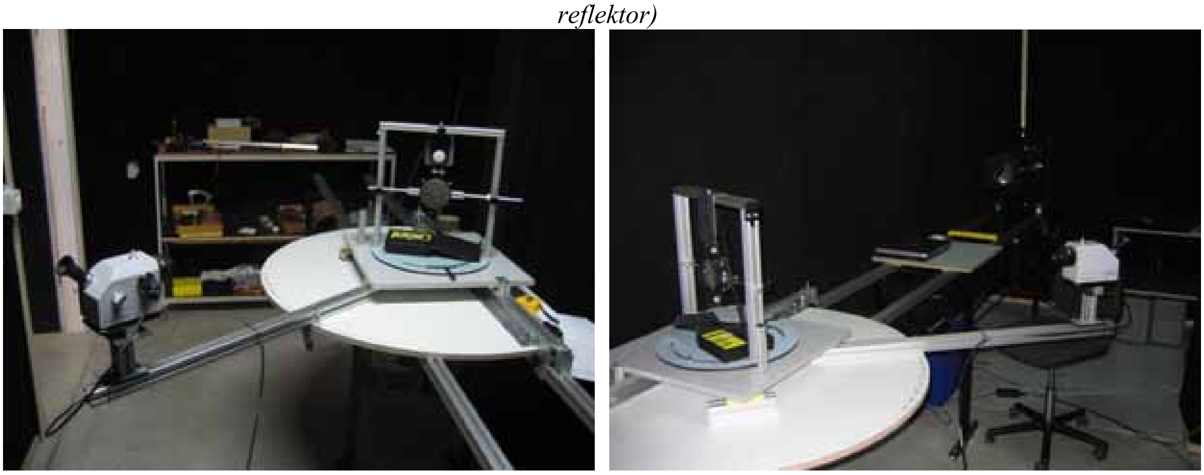


Slika 1: Idejna skica naprave



Slika 2: Vzorec vpet v nosilec v osi svetlobnega vira ter nad njim glava merilnika osvetljenosti

Slika 3: Svetlobni vir z ustreznimi lečami, ki omogočajo ustrezno ozek svetlobni snop (sončni simulator oziroma reflektor)



Slika 4: Namestitev merilnika svetlosti na pomično ročico

Pri izvedbi meritev so bili uporabljeni naslednji inštrumenti: svetlobni vir oziroma sončni simulator Canto 575 msd/msr z žarnico Osram HSR 575/60, merilnik svetlosti MAS40-100 ter merilnik osvetljenosti BEHA 93408.

4. Izvedba meritve

Iz izkušenj lahko sklepamo, da bo kotna porazdelitev svetlosti (odsevnosti) pri difuznih oziroma hrapavih površinah zvezna in relativno gladka. Tako lahko le-to torej interpoliramo iz diskretnih rezultatov meritev. Korak kota med dvema meritvama moramo izbrati tako, da bo interpolirana funkcija dovolj točna in da meritev ne bo trajala predolgo. Če med samo meritvijo iz rezultatov ugotovimo, da smo izbrali prevelik ali premajhen korak, ga popravimo in začnemo znova. Za meritev kotne porazdelitve svetlosti testnega vzorca smo izbrali 5° korak za vpadni in odsevni kot. Vendar pa smo na koncu iz rezultatov ugotovili, da bi lahko izbrali tudi večji korak (10° ali celo nekaj več), pa se rezultati ne bi bistveno spremenili, precej skrajšal pa bi se čas, potreben za izvedbo meritve (vsaj na četrtino). Za boljšo preglednost podajanja rezultatov je primerno, da izberemo linearen korak, ni pa nujno potrebno za samo meritev in analizo.

Meritev začnemo z meritvijo pravokotne osvetljenosti E_0. Če svetilnosti svetlobnega vira ne bomo spreminjali oziroma je sprememba zaradi zunanjih vplivov zanemarljiva, je to edina potrebna tovrstna meritev. Vrednosti osvetljenosti pri ostalih vpadnih kotih lahko izračunamo po zgoraj navedeni formuli.

Meritev svetlosti začnemo pri vpadnem kotu α=0° in odsevnem kotu β=0°. Merjenec je pravokoten na svetilo, merilec svetlosti pa je pravokoten na merjenca. Po prvi meritvi premaknemo merilec svetlosti v smeri urinega kazalca in tako povečamo odsevni kot β, za izbran korak ter opravimo naslednjo meritev. To ponavljamo do kota β=70° (oziroma 80°), kjer dobimo še zadnjo uporabno meritev. S tem zaključimo skupino meritev pri vpadnem α=0°. Za naslednjo skupino meritev zasukamo merjenec za izbran kot prav tako v smeri urinega kazalca. Merilnik svetlosti postavimo pravokotno na merjenec, kar je izhodiščni položaj za vsako skupino meritev, in opravimo prvo meritev v skupini. Ostale meritve v skupini opravimo po prej opisanem postopku. Skupine meritev opravimo do vpadnega kota α = 85°. Meritev pri vpadnem kotu α = 90° z vidika odsevnosti ni smiselna, saj je osvetljenost pri tem kotu enaka nič (E(90°) = 0), odsevnost ρ pa je posledično neskončna.

Po začetku meritve se je izkazalo, da ima naprava še dve, sicer logični, pomanjkljivosti. Prva je ta, da je nemogoče priti do nekaterih rezultatov v bližini α=0° in β=0° (v tabelah so označeni z rdečo barvo). Problem leži v fizični velikosti merilnika svetlosti, ki v tem položaju zastira pot vpadajoči svetlobi in meče senco na merjenec. Zaradi tega nismo uspeli izmeriti rezultatov pri kombinaciji kotov (0°, 0°), (0°, 5°) in (5°, 0°). Omenjene vrednosti smo zato za predstavitev rezultatov interpolirali iz sosednjih rezultatov. Omenjena interpolacija zaradi majhnega koraka in posledično velikega števila uporabnih rezultatov ne vpliva bistveno na točnost rezultatov oziroma kasnejše analize. Druga pomanjkljivost ima podoben vzrok, vendar je opazna pri meritvi pri velikem vpadnem in odsevnem kotu. Pri velikem odsevnem kotu namreč merilno polje merilnika svetlosti, pri dani velikosti merjenca in uporabljenem merilnem kotu merilnika, zajame tudi del okolice merjenca, kjer pa se pri velikem vpadnem kotu nahaja svetlobni vir. Posledično izmerimo zelo visoke vrednosti svetlosti, ki pa so seveda napačne. Zato nismo upoštevali rezultatov, dobljenih pri kotih (75°, 75°), (75°, 80°), (80°, 75°), (80°, 80°), (85°, 75°) in (85°, 80°).

5. Rezultati meritev

Rezultati meritev kotne porazdelitve svetlosti na obravnavanem vzorcu so podani v nadaljevanju. V tabeli 1 smo najprej navedli velikost osvetljenosti vzorca pri različnih vpadnih kotih α, ki so rezultat meritve osvetljenosti pri kotu α = 0°. Vrednosti za ostale kote so izračunane po zgoraj navedeni formuli.

Tabela 1: Funkcija kotne porazdelitve osvetljenosti E za kote α med 0° in 85°

α[°]	E [lux]
0	53000
5	52798
10	52195
15	51194
20	49804
25	48034
30	45899
35	43415
40	40600
45	37477
50	34068
55	30400
60	26500
65	22399
70	18127
75	13717
80	9203
85	4619

Izmerjene vrednosti svetlosti obravnavanega vzorca pa so podane v tabelah 2 in 3. Vrednosti v tabeli 2 se nanašajo na kote odsevanja med 0° in 40°, vrednosti v tabeli 3 pa na kote odsevanja med 45° in 80°. Tabeli sta ločeni zaradi večje preglednosti.

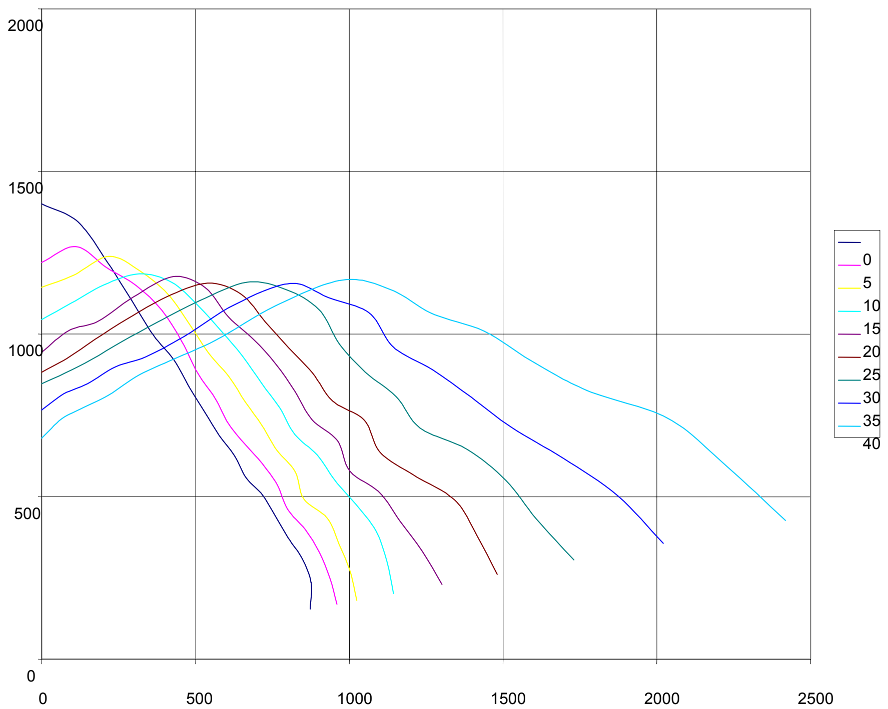
Tabela 2: Izmerjena funkcija porazdelitve svetlosti L(0°–85°, 0°–40°) [cd/m^2]

α[°]/β[°]	0	5	10	15	20	25	30	35	40
0	1400	1350	1238	1139	1061	1016	963	926	898
5	1220	1274	1222	1189	1142	1078	1015	981	945
10	1144	1185	1258	1236	1196	1137	1086	1061	1031
15	1044	1099	1169	1227	1234	1201	1166	1138	1110
20	944	1015	1055	1153	1252	1260	1215	1201	1185
25	883	928	998	1085	1185	1276	1296	1267	1250
30	847	884	935	1011	1103	1217	1339	1387	1403
35	766	819	860	931	990	1095	1260	1410	1451
40	680	742	786	841	931	1018	1133	1326	1522
45	631	663	715	783	839	938	1054	1210	1418
50	551	603	627	679	748	819	948	1093	1305
55	500	549	572	627	704	780	886	1034	1231
60	439	478	507	550	610	686	796	928	1089
65	383	405	439	488	532	602	694	814	1005
70	314	331	355	391	449	507	587	689	872
75	226	245	275	309	351	407	479	572	712
80	161	171	194	216	243	287	347	419	519
85	60	74	78	94	110	137	167	200	260

Tabela 3: Izmerjena funkcija svetlosti L(0°–85°, 45°–80°) [cd/m²]

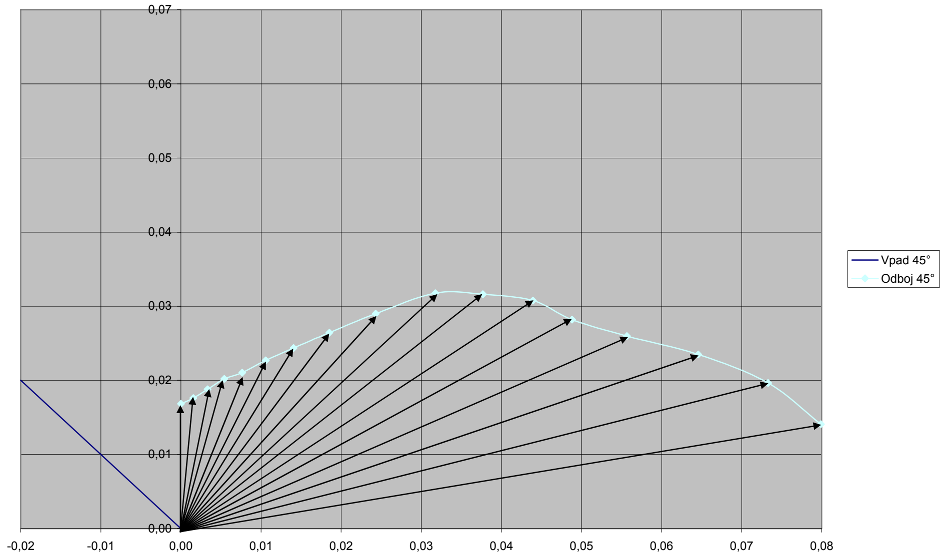
α[°]/β[°]	45	50	55	60	65	70	75	80
0	0,017	0,016	0,017	0,017	0,017	0,017	0,017	0,017
5	0,018	0,018	0,018	0,017	0,018	0,018	0,018	0,018
10	0,019	0,019	0,019	0,019	0,020	0,020	0,020	0,020
15	0,021	0,021	0,021	0,022	0,022	0,023	0,023	0,023
20	0,023	0,023	0,024	0,023	0,024	0,025	0,026	0,027
25	0,026	0,026	0,027	0,026	0,028	0,030	0,031	0,031
30	0,030	0,030	0,031	0,031	0,033	0,035	0,036	0,038
35	0,035	0,034	0,036	0,037	0,039	0,042	0,045	0,047
40	0,040	0,041	0,043	0,045	0,048	0,053	0,057	0,060
45	0,045	0,049	0,054	0,056	0,061	0,069	0,076	0,081
50	0,047	0,057	0,065	0,073	0,081	0,092	0,103	0,111
55	0,049	0,065	0,082	0,096	0,114	0,134	0,153	0,170
60	0,051	0,067	0,090	0,119	0,156	0,195	0,232	0,262
65	0,056	0,074	0,099	0,142	0,209	0,295	0,373	0,443
70	0,061	0,082	0,113	0,161	0,252	0,412	0,574	0,767
75	0,069	0,091	0,129	0,185	0,299	0,514		
80	0,078	0,108	0,150	0,227	0,353	0,648		
85	0,079	0,117	0,161	0,243	0,417	0,759		

Za boljši prikaz rezultatov meritev je v nadaljevanju na sliki 5 podana še kotna porazdelitev svetlosti v (kvazi) polarnem diagramu. Na sliki so podane vrednosti svetlosti vzorca pri vpadnih kotih svetlobe med 0° in 40°. Vpadni koti so navedeni v legendi na desni strani slike.



Slika 5: Graf kotne porazdelitve svetlosti pri vpadnih kotih od 0° do 40°

Na zgornji sliki je na abscisi in na ordinati veličina svetlost enota pa cd/m^2. Graf je dobljen tako, da je vrednost svetlosti pri določenem odsevnem kotu razdeljena na horizontalno in vertikalno komponento, ki nato predstavljata točko v grafu. Posamezne točke za upoštevane odsevne kote so nato med seboj povezane kot to prikazuje slika 6 za primer, ko je vpadni kot enak 45°. Na obeh oseh je v tem primeru navedeno razmerje L/E.



Slika 6: Detajlni graf kotne porazdelitve odsevnosti pri vpadnem kotu 45°

6 Zaključek

Izdelana priprava lahko izmeri funkcijo kotne porazdelitve odsevnosti pri vpadnih kotih od 0° do 85° za odsevne kote od 0° do 70° (ρ[0°-90°, 0°-70°]). Za meritev odsevnosti pri večjih odsevnih kotih bi morali ali vzeti vzorec z večjo površino ali zmanjšati merilno področje merilnika svetlosti za celotno meritev. Slednja rešitev ni najbolj primerna, saj so vzorci zrnati in zato rezultati pri manjših odsevnih kotih ne bi bili pravilni. Dodatna omejitev je še v območju blizu $\alpha = 0°$ in $\beta = 0°$, saj merilnik svetlosti zakriva svetlobni vir.

Pri meritvi testnega vzorca smo se odločili za linearen korak 5° tako pri vpadnem kot tudi pri odsevnem kotu. Za popolnoma neznan vzorec je tak korak zadovoljiv. Če pa že poznamo približno kotno porazdelitev merjenca, se lahko odločimo tudi za nelinearen korak in sicer manjši (1°-5°) v bližini ekstremov in večji (10°-20°) na ostalem območju. S slednjo rešitvijo lahko razpolovimo čas merjenja.

Pri izmerjenih rezultatih na testnem vzorcu lahko opazimo skoraj zrcalni odboj pri višjih vpadnih kotih, kar pa nam je že znano iz vsakodnevnega življenja in uporabe cest.

Naprava pa ni uporabna izključno za merjenje odsevnih karakteristik cestnih površin. Eden izmed primerov uporabe je lahko merjenje odsevne karakteristike svetlobnih celic, saj lahko s pomočjo kotne porazdelitve odsevnosti izračunamo odstotek odbitega svetlobnega toka. V podobnem duhu lahko uporabimo napravo tudi na drugih površinah.

LITERATURA

1. DARK SKY SLOVENIJA, http://www.temnonebo.org/
2. Fördergemeinschaft Gutes Licht, Lighting with Artificial Light, http://www.licht.de
3. CIE Publ. No. 44: Absolute methods for reflection measurements, 1979
4. Chuck Moidel: Bi-Directional Reflectance Distribution Functions,
5. T. Lefebvre, A. Kemeny, D. Arquès, L. Joly, S. Michelin: Rendering of complex materials for driving simulators, DSC, 2005
6. Primož Puhar: Meritev odsevnosti cestnih površin, seminarska naloga pri predmetu Svetlobna tehnika na podiplomskem študiju Elektrotehnike, Fakulteta za elektrotehniko Univerze v Ljubljani, 2006

Avtorjev naslov:

Primož Puhar, univ. dipl. inž. el.

4248 LESCE, Finžgarjeva ulica 6

Slovenija

Tel: 031-378-901

Elektronski naslov: primoz.puhar@gmail.com

Grega Bizjak

Univerza v Ljubljani, Fakulteta za elektrotehniko

Tržaška 25, 1000 Ljubljana, Slovenija

Tel.: 01 - 4768 446

Elektronski naslov: grega.bizjak@fe.uni-lj.si

Matej B. Kobav

UPORABA DIGITALNEGA FOTOAPARATA S ŠIROKOKOTNIM OBJEKTIVOM V FUNKCIJI MERILNIKA PORAZDELITVE SVETLOSTI NEBA

Povzetek

V članku so predstavljeni postopki uporabe digitalnega fotoaparata kot merilnika porazdelitve svetlosti neba ter ugotovitve, ki smo jih zabeležili ob praktični uporabi.

Digitalna fotografija je v zadnjem času doživela velik razcvet in z njo tudi fotografska oprema. V našem primeru smo za meritev porazdelitve svetlosti neba uporabili digitalni fotoaparat Nikon Coolpix 5000 in pripadajoči širokokotni objektiv. Fotografije so bile posnete na meteorološki postaji ENTPE (Ecole Nationale des Travaux publics de l'Etat) v Lyonu, kjer je bil v letu 2005 nameščen tudi merilnik porazdelitve svetlosti. Digitalne fotografije so bile najprej obdelane s programom PHOTOLUX, s katerim smo pretvorili digitalno fotografijo v karto svetlosti. Svetlosti posameznih elementov neba so bile nato obdelane z dvema računalniškima programoma in nato grafično prikazane ter analizirane. Na koncu članka so opisane tudi težave, s katerimi se srečamo pri uporabi digitalnega fotoaparata.

Abstract

In the present article we present the use of digital camera with fish-eye lenses in function of sky scanner and remarks we noticed at practical work.

We are living in an age that digital photography is in a full bloom. Every day there are new digital cameras put to the market and together with cameras also all the needed equipment. In our case we used Nikon Coolpix 5000 digital camera and appurtenant fish-eye lenses. All digital images of the sky vault were taken in year 2005 at the ENTPE IDMP station in Vaulx-en-Velin, France. In the same period (May 2005 - December 2005) on the same IDMP station there was installed also EKO sky luminance scanner. Images were first transformed into luminance maps with Photolux. Luminance values were analyzed and compared to the one derived with sky luminance scanner. At the end we list also problems occurred with use of digital camera.

1.Uvod

Strošek, ki ga lastniki objektov namenijo za vzdrževanje le-teh v njegovi življenjski dobi, je neprimerljivo višji od stroška, ki ga investitor nameni za gradnjo. Želja vseh investitorjev je, da bi bili stroški vzdrževanja objektov čim manjši in da bi to željo uresničili, so pripravljeni že v začetni fazi (pri projektiranju) odšteti nekaj več sredstev za kvalitetne študije in projekte, ki bi zagotavljali maksimalne prihranke oz. zmanjševali stroške rednega vzdrževanja objekta. Med stroški vzdrževanja poslovnih objektov enega od večjih deležev predstavlja tudi strošek za razsvetljavo. Tako mora biti že v začetni fazi ena od prednosti pri projektiranju tudi pravilna postavitev oken, okenskih odprtin, svetlobnikov in svetlobnih cevi. S pravilno postavitvijo oken lahko v dnevnem času zmanjšamo porabo električne energije za razsvetljavo. Z ustrezno projektiranimi senčili pa lahko zagotovimo še dodatne prihranke pri energiji, ki se porabi za ustvarjanje primerne klime v objektu. Nikakor pa ne smemo pozabiti na človekovo ugodje, saj je storilnost v delovnih prostorih, kjer se zaposleni dobro počuti, veliko večja.

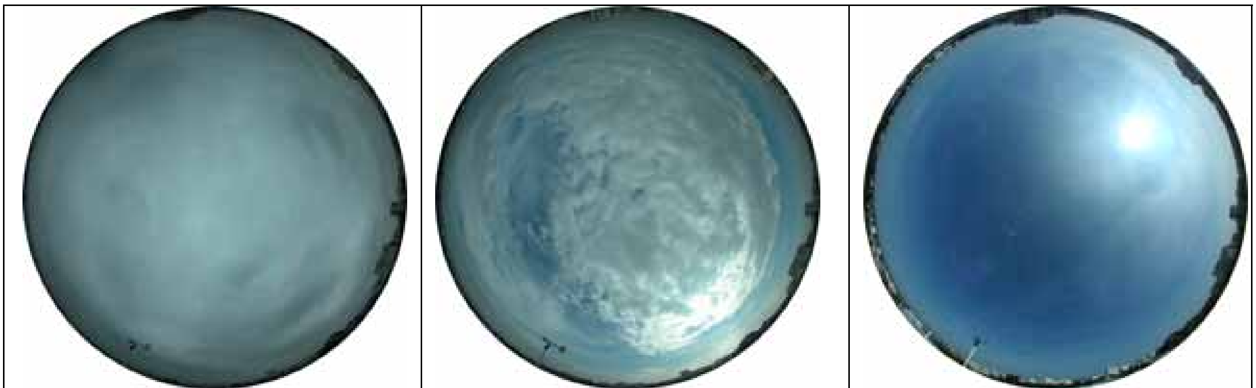
Za dosego vseh teh ciljev pa je potrebno poznati pogoje, ki vplivajo na vnos svetlobe v prostor. Vsekakor je med njimi najbolj pomembno poznavanje dogajanja na nebu in s tem porazdelitev svetlosti neba.

Za meritev svetlosti neba se uporabljajo posebne merilne naprave. Na žalost je cena teh merilnih naprav zelo visoka in tako je na celem svetu nameščenih le dober ducat merilnikov porazdelitve svetlosti neba.

Zato smo v sodelovanju z ENTPE naredili študijo, v kateri primerjamo rezultate, dobljene s pomočjo merilnika porazdelitve svetlosti in rezultate, ki jih dobimo z uporabo digitalnega fotoaparata, širokokotnega objektiva in ustrezne programske opreme.

2. Slikanje z digitalnim fotoaparatom in širokokotnim objektivom

Merilnik porazdelitve svetlosti, ki je bil nameščen na ENTPE meteorološki postaji, je bil izposojen od Kyushe Univerze (Japonska) za dobo enega leta. Ker je eno leto v raziskovalnem smislu zelo kratka doba za opazovanje neba, smo želeli nadaljevati z meritvami in opazovanjem tudi kasneje, ko je bil merilnik porazdelitve svetlosti že vrnjen na Japonsko. Namesto merilnika porazdelitve svetlosti bi uporabljali digitalni fotoaparat s širokokotnim objektivom in ustrezno programsko opremo s katero bi lahko odčitali porazdelitev svetlosti.



6. oktober 2005, 10:42	7. september 2005, 9:32	15 september 2005, 14:02

Slika 1. Primeri fotografij za različne tipe neba

V času, ko je bil merilnik porazdelitve svetlosti še nameščen, smo nekaj dni vzporedno z meritvijo fotografirali tudi nebo z digitalnim fotoaparatom in širokokotnim objektivom (slika 1). Nebo smo fotografirali v istem trenutku, ko je deloval tudi merilnik porazdelitve svetlosti. Tako je bila možna direktna primerjava rezultatov dobljenih iz digitalnih fotografij in merilnika porazdelitve svetlosti.

3. Pretvorba svetlosti iz digitalnih fotografij v datoteko formata .05D

Če smo želeli celovito primerjavo med rezultati digitalnih fotografij narejenih s širokokotnim objektivom in rezultati merilnika porazdelitve svetlosti, smo morali digitalne fotografije pretvoriti v obliko, ki je enaka izhodnim podatkom merilnika porazdelitve svetlosti. Merilni rezultati iz merilnika porazdelitve svetlosti so podani v .05D datoteki, kjer so svetlosti posameznih 145 elementov neba nanizane brez ločila druga za drugo v tekstovni obliki. Svetlosti so podane v formatu X.XXX, vendar niso podane v absolutnih vrednostih, ampak so deljene s faktorjem *k* (slika 2). Faktor *k* se izračuna s pomočjo naslednje enačbe:

$$L = k \cdot L_F$$
$$L = 10^6 / f_C \cdot k_{SS} \cdot L_F \Rightarrow k = 10^6 / f_C \cdot k_{SS} \quad (1)$$

Kjer je:

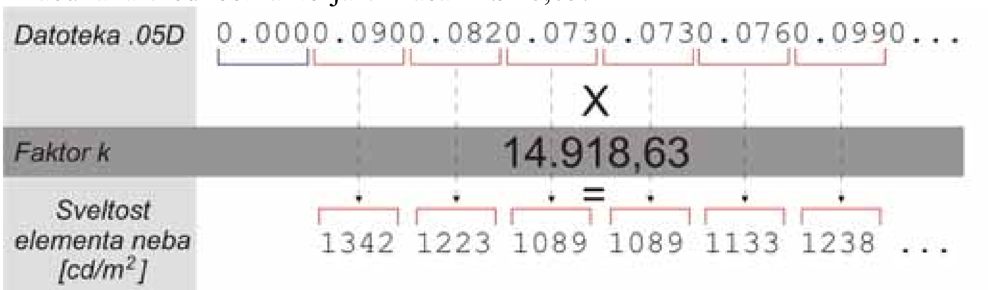
L svetlost elementa neba,

f_C kalibracijski faktor merilnika porazdelitve svetlosti (110.6),

k_{SS} faktor merilnika porazdelitve svetlosti, ki smo ga določili pod umetnim nebom (1.65)

L_F svetlost podana v .05D datoteki.

Izračunana vrednost faktorja *k* znaša 14.918,63.

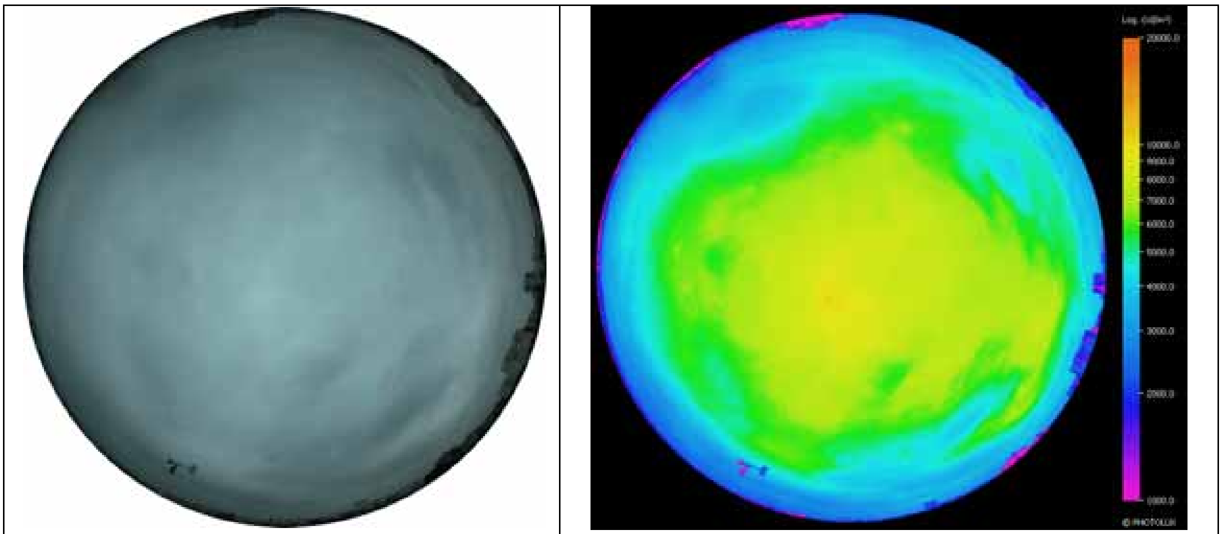


Slika 2. Izračun vrednosti svetlosti iz .05D datoteke

4. Merilni postopek

Fotografije so bile posnete z digitalno kamero Nikon Coolpix 5000 in pripadajočim širokokotnim objektivom.

Prvi korak pri obdelavi fotografij je bil uvoz le-teh v program PHOTOLUX, kjer so se izračunale svetlosti posamezne točke na fotografiji in kreirala se je karta svetlosti (slika 3). Ko so bile svetlosti posameznih točk na fotografiji izračunane, smo jih shranili v pravilnem vrstnem redu, da smo omogočili njihovo uporabo za kasnejše izračune.



a	b

Slika 3. Originalna fotografija (a) in pripadajoča karta svetlosti (b) za 6. oktober 2005, 10:42

Programska oprema Photolux omogoča izvoz vrednosti svetlosti v Genelux formatu. Pri Genelux formatu je nebo razdeljeno na elemente, ki imajo med seboj skoraj popolnoma enak prostorski kot. Gostota mreže, s katero razdelimo nebo, pa je spremenljiva od 1^0 do 30^0 zenitnega kota. Vzporedno s spreminjanjem gostote mreže se spreminja tudi število elementov, na katere razdelimo celotno poloblo neba (Tabela 1).

Table 1. Število elementov neba in prostorski kot v odvisnosti od gostote Genelux mreže

Genelux mreža [^{0}]	1	2	3	5	6	10	15	30
Število elementov	20673	5181	2310	835	583	212	97	26
Prostorski kot [sr]	0.000304	0.001213	0.002720	0.007525	0.010777	0.029638	0.064775	0.241661

Za nadaljnjo analizo smo izbrali najbolj natančne podatke, ki pa so zbrani, če uporabimo Genelux format z gostoto mreže 1^0.

5. Povezava rezultatov iz merilnika porazdelitve svetlosti in digitalnih fotografij

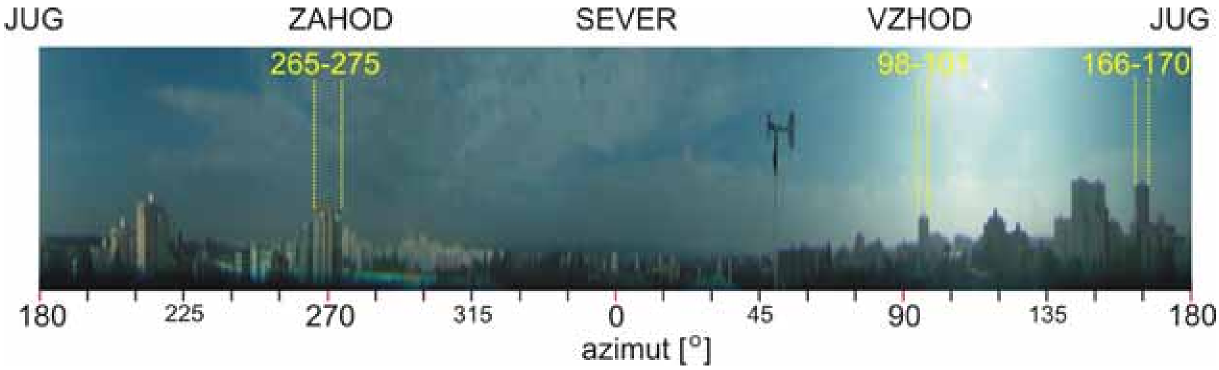
Fotografije, ki jih naredimo z digitalnim fotoaparatom in širokokotnim objektivom so zrcalne. Slika, ki jo dobimo, je enaka podobi, ki jo vidimo z našimi očmi, če se uležemo na tla in se ozremo proti zenitu. Če je naše telo pri tem poravnano v smeri sever-jug in imamo glavo v smeri severa, potem je vzhod na naši levi strani in zahod na naši desni strani. Pri podatkih, ki jih dobimo iz merilnika porazdelitve svetlosti, pa je obratno. Slika iz merilnika porazdelitev svetlosti ima enako orientacijo kot so strani neba (sever na vrhu, jug na dnu, vzhod na desni in zahod na levi).

6. Zrcaljenje in rotacija digitalne fotografije

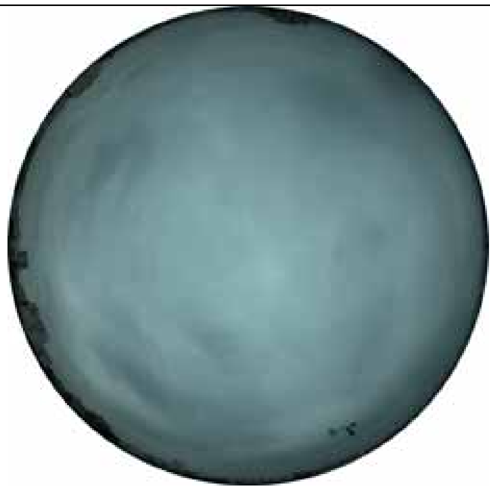
Kot že omenjeno, je potrebno vse fotografije, posnete z digitalno kamero, zrcaliti in tudi rotirati.

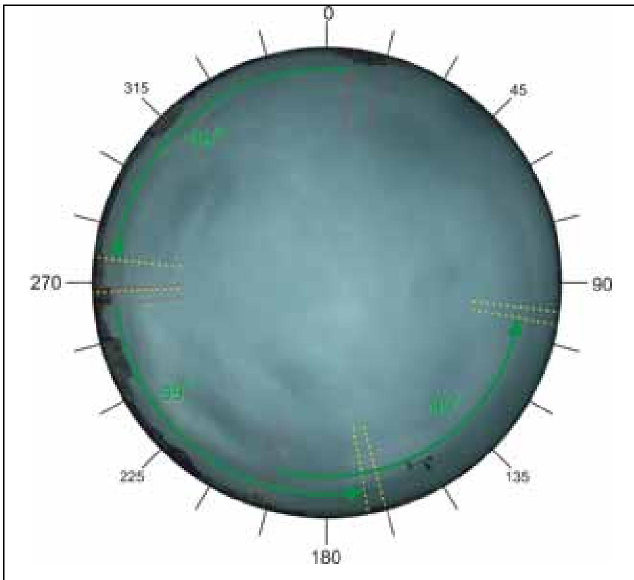
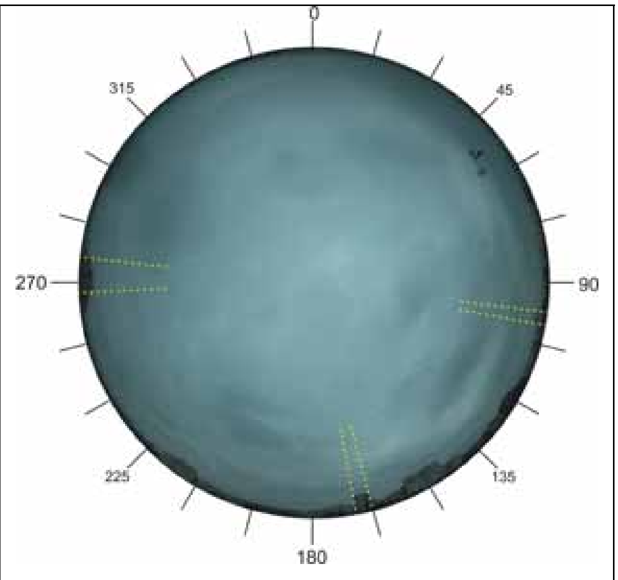
Fotografije so bile posnete namreč tako, da je bil zgornji del fotoaparata obrnjen proti zahodu in poravnan s smerjo sever-jug. Zaradi bližnjih objektov, je bilo namreč pri takšni namestitvi najlažje poravnati fotoaparat v skladu s smermi neba. Če bi hoteli izvesti samo zrcaljenje fotografije, bi moral biti zgornji del fotoaparata (in fotografije) obrnjen proti severu.

Poleg zrcaljenja je torej potrebna tudi rotacija. Da smo lahko določili pravi kot rotacije za vsak posamezen dan, ko smo fotografirali nebo, smo pozicijo sonca na fotografiji primerjali z izračunano pozicijo. Prav tako smo primerjali tudi lokacijo višjih objektov. Pred prvimi meritvami smo namreč izmerili azimute nekaterih višjih in dobro vidnih okoliških objektov (slika 4).

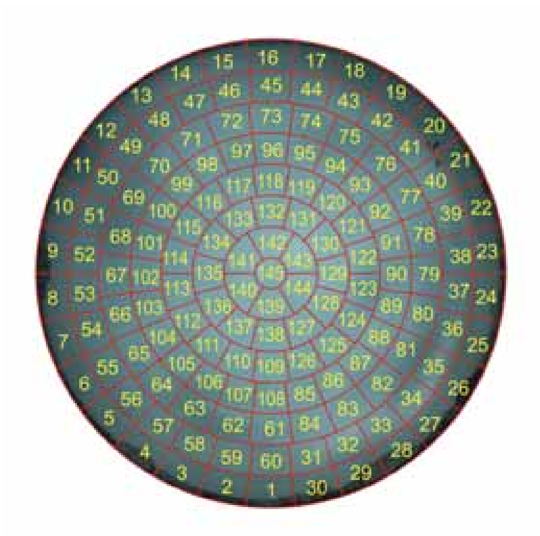


Slika 4. Azimuti nekaterih višjih in izrazitejših objektov

	
Originalna fotografija	Horizontalno zrcaljena fotografija

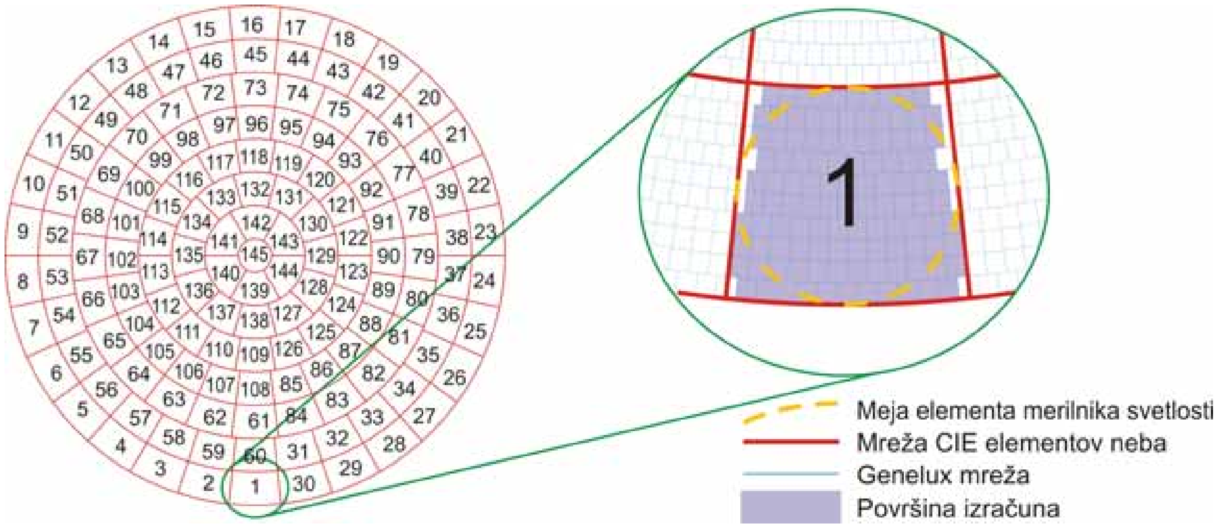
	
Horizontalno zrcaljena fotografija z vrisano masko azimutov	Horizontalno zrcaljena in rotirana fotografija za 99^0 v obratni smeri urinega kazalca

Slika 5. Preoblikovanje fotografije



Slika 6. Zrcaljena in rotirana digitalna fotografija z mrežo 145 CIE elementov neba

Ko je fotografija zrcaljena in pravilno orientirana, lahko nanjo napnemo mrežo 145 CIE elementov neba (slika 6). Elementi neba, ki so definirani s CIE standardom, imajo prostorski kot približno 150 krat večji kot je prostorski kot posameznega elementa v Genelux datoteki. Tako je potrebno za vsakega od 145 elementov neba poiskati pripadajoče elemente iz Genelux datoteke (slika 7).



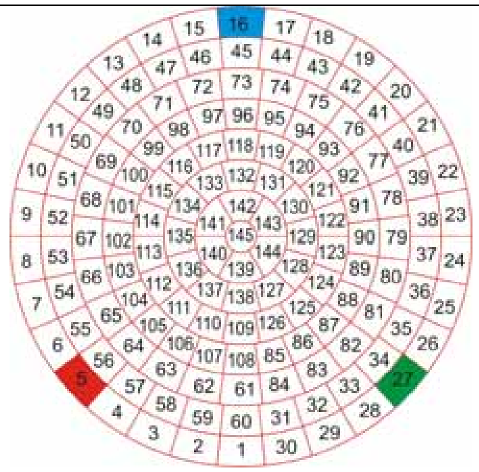
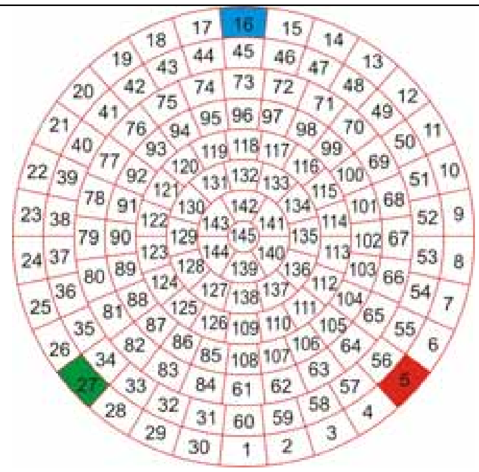
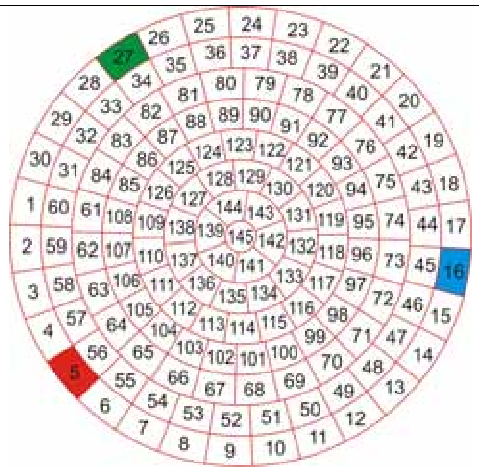
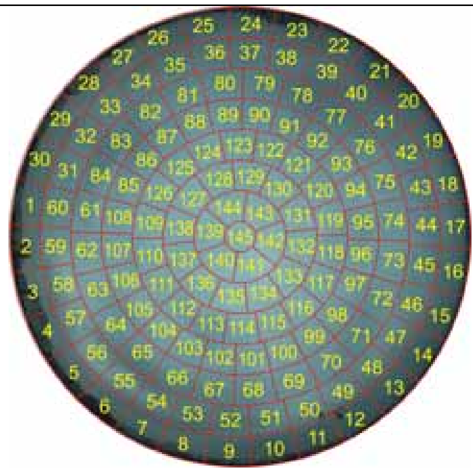
Slika 7. Določitev elementov Genelux mreže, ki ustrezajo CIE elementu neba št. 1.

Za vsakega od 145 CIE elementov neba se nato izračuna povprečna vrednost svetlosti pripadajočih elementov iz Genelux mreže in ta vrednost je shranjena kot vrednost svetlosti CIE elementa, dobljena iz digitalne fotografije.

Izračunane vrednosti svetlosti CIE elementov se nato delijo s faktorjem *k* in kalibracijskim faktorjem digitalnega fotoaparata ter zapišejo v .05D datoteko skupaj v uvodnim delom "0.000" in zaključkom "0.0070.010110.60.00005/10/0610:00:0510:00:28LYON". V zaključku datoteke so shranjeni podatki o kalibracijskem faktorju merilnika porazdelitve svetlosti ter datum, ura in kraj meritve"

7.Zrcaljenje in rotacija mreže CIE elementov neba

Zrcaljenje in/ali rotacija digitalne fotografije v grafičnih programih za urejanje slik (Photoshop, Paint Shop…) ima nepopravljive posledice. Ko je slika grafično obdelana (zrcaljena in rotirana) in ponovno shranjena, se izgubijo vsi podatki o fotoaparatu in o nastavitvah le-tega pri nastanku fotografije. S tem pa fotografija postane neuporabna za nadaljnjo obdelavo v programu Photolux. Zato so fotografije najprej obdelane v programu Photolux, nato pa za grafični prikaz zrcaljene in rotirane. Za nadaljnje izračune bi torej morali zrcaliti in zavrteti podatke v Genelux datoteki. Ker je pravilno zrcaljenje in rotacija več kot 20.000 vrednosti svetlosti skoraj nemogoča, je enostavneje zrcaliti in zavrteti mrežo CIE elementov neba. Zrcaljena in rotirana mreža CIE elementov se nato napne na originalno digitalno fotografijo in iz Genelux mreže se izberejo elementi, ki ustrezajo posameznemu CIE elementu (slika 8).

	
Originalna mreža CIE elementov	Zrcaljena mreža CIE elementov
	
Zrcaljena in rotirana mreža CIE elementov	Originalna digitalna fotografija z zrcaljeno in rotirano mrežo CIE elementov

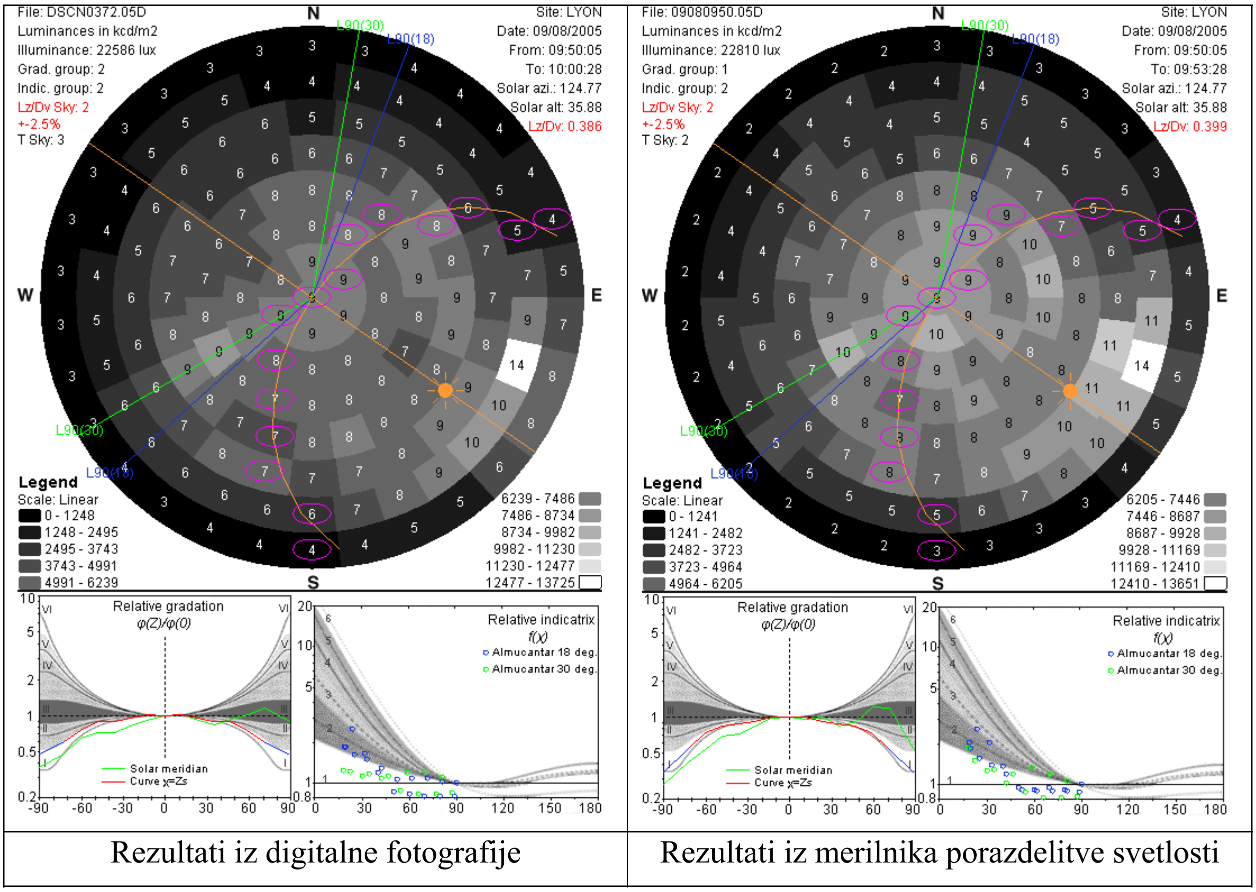
Slika 8. Preoblikovanje mreže CIE elementov neba

Določitev pripadajočih elementov Genelux mreže za posamezen element neba in oblikovanje .05D datoteke je enako kot v prvem primeru.

8. Primerjava rezultatov dobljenih s pomočjo .05D iz merilnika porazdelitve svetlosti in digitalnih fotografij

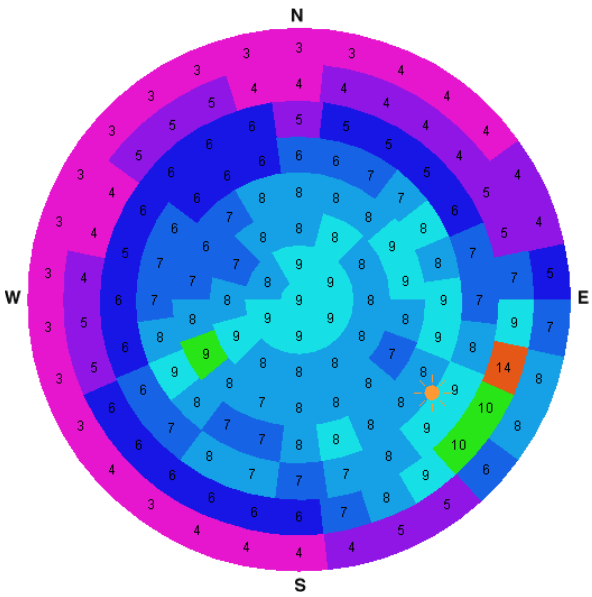
Pri vrednotenju rezultatov iz digitalnih fotografij smo analizirali dva sklopa meritev. V prvem sklopu je 112 digitalnih fotografij, ki so bile posnete z Nikon Coolpix 5000 fotoaparatom (v lasti ENTPE), 7., 8., 13., 15., 16. septembra in 6. oktobra 2005. V drugem sklopu pa je 48 digitalnih fotografij, posnetih z Nikon Coolpix 5000 fotoaparatom (v lasti FE), 30. novembra ter 1., 2. in 7. decembra 2005.

S programsko opremo, ki smo jo razvili za obdelavo in analizo podatkov iz merilnika porazdelitve svetlosti, smo analizirali tudi vseh 160 .05D datotek, ki smo jih dobili z obdelavo digitalnih fotografij. Rezultate analize smo primerjali z rezultati iz merilnika porazdelitev svetlosti (slika 9).



Slika 9. Prikaz rezultatov porazdelitve svetlosti iz digitalne fotografije in merilnika

Za bolj nazoren prikaz rezultatov dobljenih iz digitalne fotografije, smo izbrali tudi predstavitev, ki je podobna zgoraj opisani, le da smo za prikaz uporabili obratne barve (slika 10).



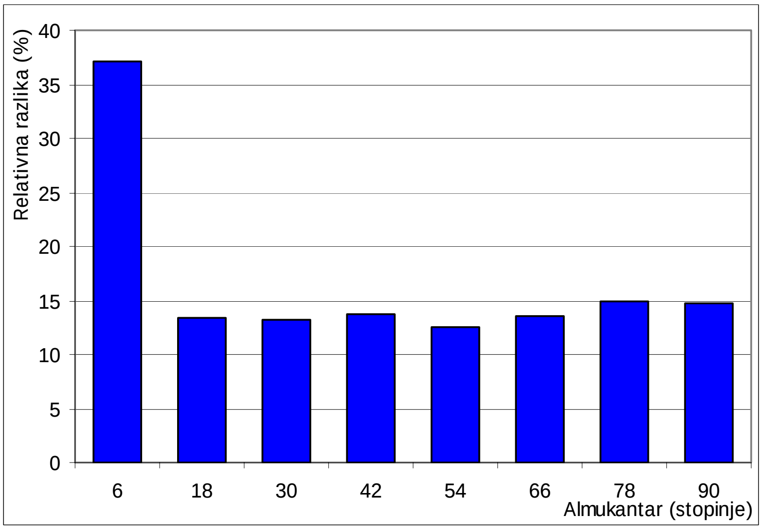
Slika 10. Prikaz porazdelitve svetlosti dobljene iz digitalne fotografije v obratnih barvah.

Za vseh 160 digitalnih fotografij smo naredili primerjavo vseh podatkov dobljenih z analizo (horizontalna osvetljenost, štiri vertikalne osvetljenosti, svetlost zenita, razmerje Lz/Dv in vseh 145 svetlosti elementov neba). Glavne razlike med digitalnimi fotografijami in merilnikom porazdelitve svetlosti so se pokazale pri vrednostih svetlosti na prvem almukantarju (0-12 stopinj višine). Razlike v svetlosti na tej višini so bile skoraj trikrat večje kot razlike na ostalih višinah (slika 11). Najbolj verjeten razlog za velike razlike v svetlosti je širokokotni objektiv, ki ima največje popačenje prav na robu fotografije (pri majhnih višinah elementov neba).

Zaradi velike razlike v svetlosti elementov pri majhnih višinah smo za nadaljnje analize izločili elemente, katerih zenitni kot je večji kot 78 stopinj. Večina teh elementov neba je vsaj delno pokritih z okoliškimi stavbami in ti elementi so bili izvzeti iz analize tudi pri obdelavi podatkov iz merilnika porazdelitve svetlosti.

Pri izdelavi .05D datotek smo za vsakega od fotoaparatov uporabili drugačen koeficient *k*. Nova vrednost, ki smo jo uporabili za Nikon CoolPix 5000 v lasti ENTPE je bila 15945.9, kar je 6.9% več kot pri prvotni nastavitvi. Povprečna horizontalna osvetljenost, ki je bila izračunana iz digitalnih fotografij s prvotnim faktorje *k*, je bila za 6.9% večja kot povprečna horizontalna osvetljenost, ki je bila izračunana iz podatkov dobljenih iz merilnika porazdelitev svetlosti. Zaradi tega smo se odločili, da spremenimo faktor *k*. Zaradi enakega razloga smo spremenili tudi vrednost koeficienta *k* za fotoaparat Nikon CoolPix 5000 v lasti FE na vrednost 18018.9.

Za oba sklopa meritev smo naredili primerjalne tabele z najbolj pomembnimi podatki (tabela 2) in nato povzeli rezultate v tabelah 3 in 4.



Slika 11. Relativne razlike v svetlosti elementov na različnih višinah.

Tabela 2. Vzorčna primerjalna tabela podatkov za 8. september ob 9:50 (GMT+1)

	Digitalna fotografija	Merilnik porazdelitve svetlosti	Razlika
Horizontalna osvetljenost [*lx*]	22586	22810	- 0.98%
Svetlost zenita [cd/m^2]	8712	9100	+ 4.45%
Lz/Dv [$cd/m^2\ lx$]	0.386	0.399	- 3.28%
Postopnost	2	1	+1
Razpršenost	2	2	0
Lz/DV nebo	2	2	0
Tregenza nebo	3	2	+1
Svetlost 115 elementov neba	povprečna razlika		0.77 %
	RMS razlika		8.63 %

Tabla 3. Povprečna in povprečna absolutna napaka za prvi sklop meritev

	Povprečna razlika	Povprečna absolutna razlika
Horizontalna osvetljenost [*lx*]	+ 0.48 %	5.06 %
Svetlost zenita [cd/m^2]	+ 0.80 %	14.66 %
Lz/Dv [$cd/m^2\ lx$]	+ 0.537 %	13.47 %
Svetlost 115 elementov neba	+ 3.25 %	13.42 %

Tabela 4. Povprečna in povprečna absolutna napaka za drugi sklop meritev

	Povprečna razlika	Povprečna absolutna razlika
Horizontalna osvetljenost [*lx*]	- 1.34 %	5.50 %
Svetlost zenita [cd/m^2]	- 4.60 %	9.51 %
Lz/Dv [$cd/m^2\ lx$]	- 3.31 %	7.14 %
Svetlost 115 elementov neba	+ 2.66 %	8.82 %

9. Zaključek

Rezultati študije so pokazali, da lahko s kvalitetnim digitalnim fotoaparatom nadomestimo merilnik porazdelitve svetlosti neba. Pri tem ima digitalni fotoaparat veliko prednost, saj je njegova resolucija omejena pravzaprav samo z resolucijo CCD elementa. S tem lahko dobimo resolucijo tudi nekaj MIO točk za celotno poloblo, medtem ko večina merilnikov izmeri povprečno svetlost le 145 elementom na polobli, pri čemer je kotna širina vsakega elementa 11^0. Druga prednost digitalnega aparata je, da lahko beleži hitre spremembe na nebu, saj za vsako meritev (skupaj s shranjevanjem podatkov na spominsko kartico) potrebuje le nekaj sekund, medtem ko merilniki potrebujejo tudi do nekaj minut za meritev svetlosti celotne poloble.

Seveda pa ima digitalni fotoaparat tudi slabosti. Ena od večjih slabosti je, da aparat ni odporen na vse vremenske razmere, zato mora biti zaprt pod stekleno kupolo in v zimskem času tudi ogrevan. Druga, še večja, slabost pa je izredna občutljivost CDD senzorja. Tako lahko ob uporabi fotoaparata v jasnem vremenu pričakujemo nepopravljivo škodo na CCD elementu, saj direktna sončna svetloba izžge elemente na svetlobnem senzorju. Če želimo uporabljati fotoaparat tudi ob jasnem vremenu, je obvezna namestitev obroča, ki prepreči dostop direktne sončne svetlobe na senzor ali vsaj pokrivanje fotoaparata v času, ko meritev ne poteka.

Literatura

[1] CIE S 011/E:2003 /ISO 15469.2004 "Spatial distribution of daylight – CIE standard general sky",

[2] Coutelier, B. Dumortier, D. Luminance calibration of the Nikon Coolpix 900 digital camera. 25th Session of the CIE, San Diego, pp. 56-59, 25 juin au 2 juillet 2003,

[3] Tregenza, P.R., Analysing sky luminance scans to obtain frequency distribution of CIE Standard General Sky. Lighting Research and Techology, 2004. 36(4): pp 271-281,

[4] Kittler, R. Darula, S. Perez R., A set of standard skies characterizing daylight conditions for computer and energy conscious design. Polygrafia SAV, Bratislava, June 1998,

[5] Littlefair, P. J. "A Comparison of Sky Luminance Models with Measured Data from Garston, United Kingdom". Solar Energy Vol. 53, No. 4, 1994: pp. 315-322,

[6] Perez, R. Seals, R. Michalsky, J.. "All weather model for sky luminance distribution-preliminary configuration and validation." Solar Energy Vol. 50, No. 3, 1993: pp. 235-245,

[7] Ineichen, P., Molineaux, B., Perez, R. "Sky luminance data validation: comparison of seven models with four data banks." Solar Energy Vol. 52, No. 4, 1994, pp. 337-346,

[8] Perez, R. Seals, R. Ineichen, P. "Modeling daylight availability and irradiance components from direct and global irradiance." Solar Energy Vol. 44, No. 5, 1990: pp. 271-289,

[9] Igawa, N. Koga, Y. Matsuzawa, T. Nakamura, H. "Models of sky radiance distribution and sky luminance distribution". Solar Energy Vol. 77, No. 4, 2004: pp. 137-157

[10] Kittler R.: Relative scattering indicatrix: Derivation from regular radiance/luminance distribution sky scans, Light Research & Technology 25(3), PP 125-127 (1993)

[11] Kobav M. B., Določanje CIE tipa neba na podlagi meritev porazdelitve svetlosti, štirinajsto mednarodno posvetovanje Razsvetljava 2005, Postojna, 2005

Avtorjev naslov:

mag. Matej B. Kobav univ. dipl. inž. el
Fakulteta za elektrotehniko
Univerza v Ljubljani
Tržaška 25, Ljubljana, Slovenija
matej.kobav@fe.uni-lj.si
tel.: 01/47 68 759