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Informaţii

EFFICIENT LIGHTING IN TOPICS OF CONFERENCES

Dr. Florin POP, Professor

This issue is based on the papers presented at the international conferences on lighting ILUMINAT 2007 Cluj-Napoca and Osvetlenie (Lighting)'2007 – Varna. It is edited under the frame of the EnERLIn IEE program.

Wout van BOMMEL is a high professional supporter of the overall master plan for an area or city which integrates residential area lighting, road lighting and the aesthetically pleasing lighting of buildings, monuments and structures. Lighting and Emotion are the basic components of outdoor lit environments. The creation of the right emotion is directly connected with the appropriate use of dark and light, with the appropriate use of natural white light on the one hand and coloured light on the other hand and with carefully applying dynamic lighting. An illumination project has to carefully decide exactly what effects are really wanted. For good recognition, the direction of light incidence on interesting details should be such that the soft shadows created emphasise the three-dimensional character of these, which in their turn will help to create additional emotional effects. It is interesting to note that the use of coloured light for the floodlighting of buildings and monuments seems to be dependent upon past experience and cultural background. The negative side-effects of city beautification lighting installations - “light pollution” - should, and can, be avoided, or at least minimised, by a combination of technical and organisational methods, following the guidelines set out in a recent CIE Publication on obtrusive light.

H St GRIF and **Mihaela POP** describe the design, implementation and tuning of a neural controller used in an automatic daylight control system. Their Ph.D. research work propose an automatic lighting control system to maintain constant the illuminance at the desired level on working plane even if the daylight contribution is variable. An experimental model of process was used, a look up table of measured data at the input and the output of process.

Liping GUO, Marjukka ELOHOLMA, and **Liisa HALONEN** analyse the intelligent road lighting control systems. The current status of luminance monitoring is reviewed giving emphasis on road surface luminance monitoring. The measurement results however indicate how significantly the car rear lights and headlights affect the road surface luminance values. A series of road surface luminance measurements were conducted under different weather conditions - dry, snow and wet -, and the measuring results were analysed in order to find out the optimal placement of the luminance meter. The effects of car headlights are significant for road surface luminance monitoring whereas the car rear lights do not have obvious effects on the average luminance values of a large enough measuring area. So it is recommended to orient the luminance meter to the driving direction. When road surface is dry or covered with snow, luminance values are not affected by the measuring distance or the measuring height. In wet conditions, on the other hand, road surface luminances vary with measuring height and measuring distance of the meter. In order to keep traffic safety, current intelligent road lighting control systems exclude road surface luminance as control parameter when road surface is wet.

Jitka MOHELNÍKOVÁ and **S DARULA** work describes a well-executed study concerned with daylight capture and distribution from dormer windows. This is an important issue because such systems are widely used in building refurbishment, and there are no previous studies of these devices. Daylighting on the work plane from selected dormers in an office of a university building was evaluated on the basis of computer calculation and light measurements. Daylighting case studies were elaborated, with influences of separated dormers and alternatively with one continuous dormer of the same glazed area. Results of Daylight Factor calculations show that dimensions, position of dormers in the room and the light reflectance of its inner surfaces significantly influence daylighting utilisation. The study used both computer simulation for a wide range of window configurations, and field measurement for a more restricted range.

B ROISIN, M BODART, A DENEYER, and **P D'HERDT** considering the replacement of incandescent lamps by screwbase integrated compact fluorescent lamps (CFL). There are analyzed the time required for different CFL to reach their nominal flux, and the photometric distribution of various types of lamps. Simulations of these lamps placed in a room were carried out and they did not show great variations of the room illuminance, for the different lamps. At last, looking at the equivalent power of CFLs, it is preferable to divide the power of incandescent lamps by 4 (instead of 5) to obtain the equivalent CFLs power.

János SCHANDA does an exhaustive presentation of solid state lighting and the challenges for CIE produced by the introduction of LEDs into different lighting applications. The past ten years of technological progress increased the efficacy of both the coloured LEDs and of a special sort of white light producing LED family, the LED using a blue light emitting chip and a yellow phosphor converting part of this light into longer wavelength radiation, so that the mixture of the blue plus yellow light produced the sensation of white light. A spectacular increasing of the efficacy and of the luminous flux per LED unit, determines that the LED light sources become a challenge for more and more applications

G ZISSIS, R RUSCASSIE and **M AUBES** provide an overview of the present state of research in the science and technology of light sources. Existing technologies and future challenges for the lighting industry are presented. The efficiency of conversion of electric energy into light by commercial light sources appears to have reached a plateau of about 33% of the theoretical maximum. Thus, the development of revolutionary new light sources having double the efficiency of current light sources can only be based on new scientific phenomena not previously considered for light source applications.

C ŞUVĂGĂU continues his very interesting and exhaustive column, "The Lighting in The New World", with a presentation of the long way of compact fluorescent lamps (CFL) to American residential lighting. CFLs were introduced in the 1970's; however, it has taken more than 30 years for them to gain widespread recognition in the North American residential lighting market. A recent DOE (US Department of Energy) study identified the main barriers and issues that impeded the adoption of CFLs in the US market (almost similar for the Canadian market).

FROM ROAD LIGHTING TO CITY BEAUTIFICATION

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True city beautification with lighting is not an isolated affair. Residential area lighting, road lighting and the aesthetically pleasing lighting of buildings, monuments and structures should be integrated in one overall master plan for an area or city. The final result should have a positive effect on the image created of the area. Image here is important for both visitors (outwards orientation of image) and residents (inwards orientation of image). The effect lighting has on both visitors and residents has much to do with emotion. The paper shows that the creation of the right emotion is directly connected with the appropriate use of dark and light, with the appropriate use of natural white light on the one hand and coloured light on the other hand and with carefully applying dynamic lighting. Guidance is given on how all this can be done while minimizing light pollution.

Introduction

At the start of the 20th century, outdoor lighting was geared towards the purely functional aspect of visibility for motorists. In the fifties of the same century, de Boer was one of the first researchers to add visual comfort to the pure visibility aspect of road lighting [1]. This comfort aspect was felt to be important in view of the fact that high-speed road users were already making use of relatively comfortable motorways for rather long drives: again, traffic safety was the underlying criterion. However, this attention to visual comfort automatically made new road lighting installations more pleasing. So, up until the late seventies of the last century, road lighting, including that within the urban environment, was seen mostly in the context of motorised traffic. One of the first systematic studies into the needs of residents and pedestrians in residential streets, with the emphasis on personal or social security, was carried out by Caminada and van Bommel and published in 1980 [2, 3]. They concluded that in order to provide good security, the lighting in a street should permit of mutual recognition of pedestrians at a ‘safe’ distance, viz. before coming almost face to face.

It was only slowly that the architectural aspect of outdoor lighting started to receive some attention in addition to the functional aspects of traffic safety and social security. Today we are seeing a clear shift of focus towards our general “well-being” or “quality of life”. Seen in this context, it is not surprising that we are now seeing so much interest in lighting as a means to enhance the visual outdoor environment. During the hours of darkness, the visual environment can be "recreated" with lighting. And while this lighting can simply be designed to almost reproduce the daytime situation, it is often more interesting and challenging to create an entirely "new" night-time scene.

Lighting can be used as a means to "beautify" the urban night-time environment, and with right we can therefore use the term "city beautification". True city beautification is not an isolated affair. Residential area lighting, road lighting and the aesthetically pleasing lighting of buildings, monuments and structures should be integrated in one overall master plan for an area or city. The final result should have a positive effect on the image created of the area. Here image has both an outward and an inward aspect. The outward aspect of image is related to the creation of a pleasing effect on visitors to the area. That is to say the lighting helps to promote the area, and so attract visitors, so it has a commercial value. The inward aspect of image is related to the way the lighting affects the residents themselves. It serves to give the area an identity all of its own, which can create a feeling of pride in the residents. The effect lighting has on both visitors and residents has much to do with emotion. This means that good city beautification can only be designed if the emotional effects of lighting are properly understood.

Lighting and emotion

The presence or absence of daylight, viz. light or darkness, has an important impact on our emotions, which may vary from pleasant to cheerless, even to fear. The "quality" of the daylight also has a strong influence. We usually "feel" better under a sunny sky with strong shadows than under a cloudy, diffuse sky. The emotional impact seems to be an immediate one: we "feel" our mood changing when the sun comes out, and children immediately become fearful when they step into the dark. Artificial light can have similar emotional effects, and this holds true both for indoor and outdoor (night-time) situations. Since contrasts can often be made larger in outdoor environments because the dark sky usually forms the background, we can more easily create strong emotional effects with outdoor lighting than with indoor lighting. Figure 1 illustrates what outdoor lighting can do with our emotions. It shows two photographs of the same church lit in completely different ways.

The point here is not that the situation depicted in one of the photographs is any better than that in the other, but rather the fact that we tend to experience two completely different feelings. The church on the left we see as being "pleasantly lighted", whereas that on the right is much more likely to be described as being "scary".

Figure 1 Same church with different lighting, resulting in two completely different emotional feelings.

In these photographs the different effects are obtained by greatly different light-dark contrasts. Another technique that can be used to “play” with our emotions is the use of certain “shades’ of white light. From interior lighting we know that lamps with low colour temperatures (warm-white light) result in a different subjective appraisal than that produced by lamps with high colour temperatures (cool-white light). In road and street lighting, the use of yellow-white (sodium) light has a different emotional meaning to that associated with the use of “whiter” light. The use of saturated coloured light in the outdoor environment has a different emotional effect again. What we especially like about daylight is its dynamic character, viz. the quantity and composition of the light (direction, shadows, colour, clearness and diffuseness) change continuously, especially on sunny days. Dynamic artificial lighting is another technique that we can use to create strong feelings about the night-time environment.

Light and dark

“Light and dark” has two elements in it: the general lightness or darkness and the contrasts between light and dark parts. For example, the church shown on the left in Figure 1 is far lighter than that on the right. This in itself has an emotional effect. But the real dramatic effect of the situation on the right has much more to do with the fact that we have here very large contrasts between the light and the dark parts. Of course, we should realise that while large contrasts produce strong emotional effects, they can also mask very charming details. It is therefore of the utmost importance that the designer and his client get together at the outset of an illumination project to carefully decide exactly what effects are really wanted. For good recognition, the direction of light incidence on interesting details should be such that the soft shadows created emphasise the three-dimensional character of these, which in their turn will help to create additional emotional effects. Too often we see that buildings and monuments are simply "flooded" with bright light, without producing any shadows or contrasts. In fact the church shown on the left in Figure 1 is an example of this. The building depicted in Figure 2, on the other hand, has carefully designed shadows, and lighter and somewhat darker parts create an agreeable and interesting picture that invites the observer to explore further. These photographs also illustrate that a high brightness alone is certainly no guarantee of an acceptable end result – on the contrary, it actually increases the chances of light pollution (see Section on Light Pollution).

Whiter light

At the World Exhibition in Paris in 1881, the new incandescent lamp was introduced to a wide public. Slowly, incandescent lamps took over from gas lighting.

Both types of lighting combine a very good colour rendering with a white colour appearance. Until 1932, no new electric light sources were introduced, which meant that the world became accustomed to a white night-time outdoor environment.

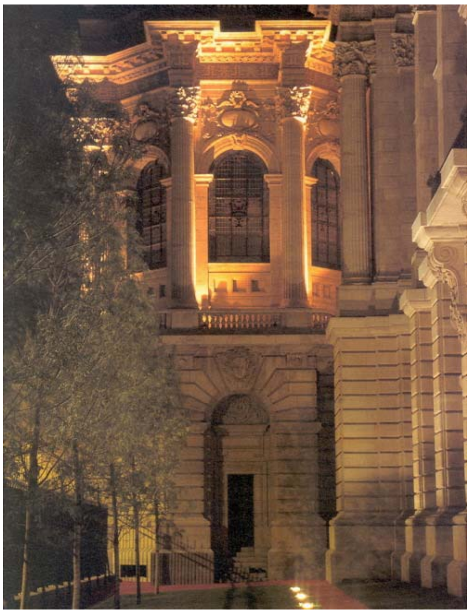

Figure 2 Subtle use of shadows and soft light, alternated with somewhat darker parts, invites further exploration.

In that same year, the first gas discharge lamp was used in an installation. This, the low-pressure sodium lamp, became a very economical (today more than 175 system lm/W - see Figure 3) and technically good solution for use in road lighting. In 1932 a second gas discharge lamp, the high-pressure mercury lamp, was introduced. Whereas the low-pressure sodium lamp "coloured" the outdoor environment in shades of yellow, colour rendition being non-existent, the much less efficient high-pressure mercury lamp (maximum 60 system lm/W - see Figure 3) offered the possibility to have the outdoor environment lit with white light. These lamps, in spite of their poor colour rendering (R_a of 40) were therefore widely used in built-up areas. Nonetheless, more economical light was called for in road lighting, particularly in built-up areas. The answer was the high-pressure sodium lamp, introduced in the late nineteen sixties. This lamp combines moderate colour rendering (R_a in the 20-ties) with yellow-white light with a very good efficacy (between 100 lm/W and more than 120 system lm/W – see Figure 3) and a long, reliable lifetime. After the energy crisis in the early nineteen seventies, this yellow-white lamp became the standard in road lighting in built-up areas. As a consequence, it now “colours” our night-time outdoor environment yellow-white.

Only small, minor roads where low lighting levels are accepted are sometimes lit with white compact fluorescent lamps developed after the energy crisis (system lm/W around 75 – see Figure 3). The white colour of these outdoor environments is much appreciated, probably because it evokes a positive emotion. What was needed, however, was an efficient, reliable source of white light capable of lighting whole built-up areas in this natural white light. So far, the metal halide lamp, an efficient version of the mercury discharge lamp with metal halide additives, resulting in white light of good colour rendering, has not yet provided the answer. This is because compared with sodium lamps, the lifetime of metal halide lamps was not good enough to replace the former in road lighting.

The same metal halide lamp does, however, produce good results in sports stadiums and other floodlighting installations, where the hours of use per year are much less than in road lighting. Luckily, however, in this very year 2005, a special revolutionary version of a metal halide lamp is being introduced that will enable the world to turn its yellow-white outdoor environment back into natural white!

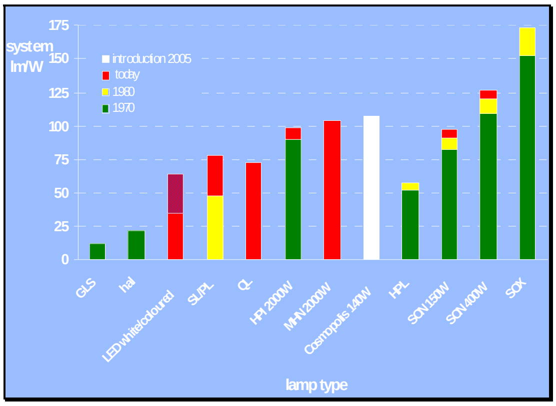

Figure 3 Luminous efficacy of lamps employed in outdoor lighting (efficacies based on wattages typical for outdoor lighting applications)
GLS = incandescent lamp
Hal = halogen lamp (for flood lighting)
LED = light-emitting diode (solid-state light)
SL/PL = compact fluorescent lamp
QL = long-life induction lamp
HPI = metal halide lamp (for flood and sports lighting)
MHD = single bulb metal halide lamp (for flood and sports lighting)
Cosmopolis = new type of metal halide lamp (introduction 2005)
HPL = high-pressure mercury lamp
SON = high-pressure sodium lamp
SOX = low-pressure sodium lamp

This lamp, the Cosmopolis, draws on high-pressure sodium techniques and has a specific dose of certain metal halides. It combines high efficacy (at its introduction, more than 100 system lm/W – see Figure 3) with a long, reliable life approaching that of high-pressure sodium lamps (90 per cent survival rate at 12 000 – 16 000 hours). The 140 W version has an even higher efficacy than that of the 150 W high-pressure sodium lamp! Further efficiency improvements are obtained because of the compactness of the lamp, resulting in a better optical performance in luminaires. It can be expected that this new lamp type will indeed dramatically change the appearance of our night-time outdoor environment [4].

Coloured light

It is interesting to note that the use of coloured light for the floodlighting of buildings and monuments seems to be dependent upon past experience and cultural background. In Asia, coloured light has always been an instrument used to give extra emphasis to the floodlit object, with rather saturated colours often being employed. In America and Europe, the use of coloured light is more recent, and especially in Europe, somewhat softer colours are often used. It should be noted here that different colours sometimes have different emotional responses in different parts of the world.

Coloured light can have a strong impact on the object itself, but also on the whole of the night-time environment. Careful discussions with the owner of the object being lighted on exactly what effects are wanted and what the possible consequences may be for the neighbourhood are very important in order to avoid disappointments or problems with other users of the neighbourhood.

Until recently, colour filters attached to conventional light sources were mostly employed to produce coloured light. But coloured metal halide lamps that emit coloured light have now become available. These give saturated colours more efficiently because no filtering is required. Light-emitting diodes (LEDs) or solid-state lights have already been in use for some years for coloured ornamental, festive or advertising lighting. Here the goal is that the eyes of the observer look straight into the light source (in a way, a kind of "signalling" lighting), which means that relatively low-power LEDs can do the job. High-power LEDs have now been developed with such high lumen packages and efficacies (see Figure 3) that they can be employed for real floodlighting of objects. They are available in many different colours, and in white as well, and have long lifetimes and can be easily regulated in light output between 100 and 0 per cent. LED luminaires for floodlighting purposes consist of an array of many individual LEDs that all have there own tiny reflector. With these small optical units, narrow light beams can be obtained that were once impossible. Figure 4 shows a typical LED-line luminaire with a near-parallel beam. Thanks to this narrow beam, floodlighting installations can now be produced where the luminaires themselves are positioned very close to or against the object being lighted. This offers a unique possibility to create special effects because the grazing light incidence enhances any unevenness of the construction material, and thus the character of it. Installation of the installation is usually easier and more economical, and it can be more easily maintained.

Furthermore, the risk of producing disturbing light pollution is minimised. Figure 5 shows an example of an installation where LED-lines are placed against the lighted chimney itself.

Figure 4 Near-parallel beam of LED-line

Figure 5 Example of an installation where LED- lines are placed against the lighted area itself.

Dynamic Light

One of the many qualities that are so much appreciated with daylight is that it varies so much. It is, in a word, dynamic. It is therefore not surprising that dynamic lighting is also being employed in city beautification. For festive and advertisement lighting, successions of rapid changes in colour and brightness are used, the aim being to attract the attention of passers-by.

LEDs are very suitable as sources of dynamic light: they are easy to regulate, and allow mixing of different colours to creation a wide variety of effects using a relatively simple technology. The extremes here are the LED video screens that can have enough brightness to be used even during the bright hours of daytime. A far more subtle use of dynamics in lighting is the slow and gradual change of brightness and or colour. This often "invites" the observer to explore the object and its changing visual impression further. We are seeing more and more examples of where these kinds of dynamic light changes are also used as a means to communicate. The communication message can employ a change of brightness and or colour pattern to indicate the time, the temperature, the weather forecast, and even whether or not a facility is open. And it is not beyond the bounds of possibility that residents, working together, could influence the lighting of the object(s) concerned via their neighbourhood internet.

Lighting and the restriction of light pollution

City beautification can give rise to obtrusive light, which is defined as light where it is not wanted and not needed. Obtrusive light is spill light, and as such it has direct negative consequences for the efficiency of the installation. More importantly, it can evoke strong negative emotions and have adverse effects on traffic safety. And the "disappearance" of the night sky because of sky glow interferes with both amateur and professional astronomical observations. All this is often referred to as "light pollution".

Fortunately, these negative side-effects of city beautification lighting installations can be avoided, or at least minimised, by a combination of technical and organisational methods. To this end, in 2003 the CIE produced a "Guide on the limitation of the effects of obtrusive light from outdoor lighting installations" [5]. If the recommendations set out in this Guide are applied correctly, it is possible to not only minimise the amount of "spilled" light, but also to actually increase the efficiency of the installation concerned. The Guide gives restrictive values for different photometric parameters resulting from the installation, the most important of which are: vertical illuminances on neighbouring properties, maximum luminous intensities for luminaires in directions where views of bright surfaces of luminaires are likely to be troublesome to residents, and upward light ratios to limit sky glow. All limits are dependent upon two different aspects:

- The level of brightness already existing in the area (in the CIE Guide called "lighting environment")
- The time (in the evening or night) that the lighting is to operate.

If the brightness of the environment is low, the risk of producing disturbing obtrusive light is high, and consequently the illuminance and intensity limits are stricter. In brighter surroundings, the risks are lower, because the contrasts between any possible obtrusive lighting and the bright surroundings are smaller, so the limits are therefore also less strict. Four different categories or zones of lighting environments are defined as E1 to E4 and given in Table 1. Stricter limits are given for the lower E zones.

In order to achieve a proper balance between the interests of the "users" of the lighting on the one hand and those of the residents on the other, two sets of limiting values (see above) are given for each situation: one with higher (viz. less strict) values for use before a "curfew" hour and the other with lower (stricter) values for use after that curfew hour. The relevant authorities should set the exact time of the curfew hour.

Zone	**Surrounding**	**Lighting environment**	**Examples**
E1	Natural	Intrinsically dark	National parks or protected sites
E2	Rural	Low district brightness	Industrial or residential rural areas
E3	Suburban	Medium district brightness	Industrial or residential suburbs
E4	Urban	High district brightness	Town centres and commercial areas

Table 1 Environmental lighting zones

Conclusion

The effect that city beautification lighting has on both visitors and residents has much to do with emotion. The lighting should, and can, be aimed at giving rise to positive emotions. For this a deep understanding of the underlying causes, some of which are dealt with in this paper, is essential. The negative emotional effect of obtrusive light should, and can, be avoided by following the guidelines set out in a recent CIE Publication on obtrusive light [4]. New developments in this respect should be followed, because new research on this subject is being carried out that will probably lead to further and refined rules [5]. A wealth of new products, such as LEDs and new, innovative metal halide lamps, together with more compact luminaires, offer totally new possibilities for city beautification, thus helping to make our night-time environment one that fits in with our endeavours to achieve a better quality of life.

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Wout van Bommel, Philips Lighting, has more than 35 years experience in lighting application, ranging from outdoor and indoor lighting to non-visual biological effects of lighting. For the period 2003 – 2007 he was president of CIE (Commission Internationale de l’Eclairage) and he is for the period 2008 – 2011 Board member of IDA (International Dark sky Association).
In 2004 he was appointed consultant professor at the Fudan University in Shanghai.

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FLUORESCENT DAYLIGHT CONTROL SYSTEM BASED ON NEURAL CONTROLLER

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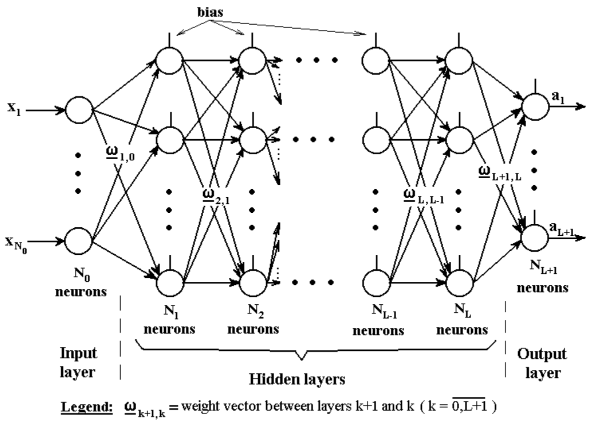
The paper describes the design, implementation and tuning of a neural controller used in an automatic daylight control system. The automatic lighting control system (ALCS) attempts to maintain constant the illuminance at the desired level on working plane even if the daylight contribution is variable. Therefore, daylight will represent the perturbation signal for the ALCS. The mathematical model of this process is unknown. The applied control structure needs the inverse model of the process. For this purpose, an experimental model of process, a look up table (LUT) of measured data at the input and the output of process, was used. The transformation given by the LUT is not single-valued, so this inverse model obtained by using the LUT is a gross approximation of the actual inverse model of process. Even if the inverse model of process is not the best solution, a set of settings was obtained for a neural controller like ALCS satisfies the imposed performances.

1. Introduction

The interest in artificial neural networks (ANNs) increased when the limitation of the types of logical functions a single perceptron could reproduce became apparent. During the sixties became well known that multi-layer networks were capable of reproducing these mappings, but no learning algorithm capable of training these more complex structures existed. Even when the back-propagation (BP) training rule was reinvented in the mid-eighties, it was doubtful whether it would have been useful during the sixties, due to limited computing power available at that time. The BP algorithm is a gradient descent algorithm, which become very popular because of its efficient way for calculating the network's sensitivity derivatives. Multi layer perceptron (MLP) networks are composed of perceptron "type" units or nodes, which are arranged into layers where the outputs of the nodes in one layer constitute the inputs to the nodes in the next layer. The signals received by the first layer are the training inputs and the network's response is the outputs of the last layer (Figure 1 a). Each of the nodes has associated with it a weight vector and a transfer (or activation) function (denoted by *F*), where the dot product of the weight vector and the incoming input vector is taken, and the resultant scalar is transformed by the activation function (Figure 1 b). For a suitable arrangement of nodes and layers, and for appropriate weight vectors and activation functions, it can be shown that this class of networks can reproduce any logical function exactly and can approximate any continuous nonlinear function to within an arbitrary accuracy. [1]



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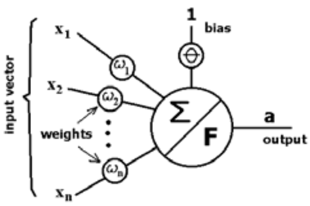


b

Figure 1 Multi layer perceptron network (a) and the configuration of the perceptron (b) [4]

2. The ALCS: experimental stand and block diagram

Figure 2 presents the experimental stand.

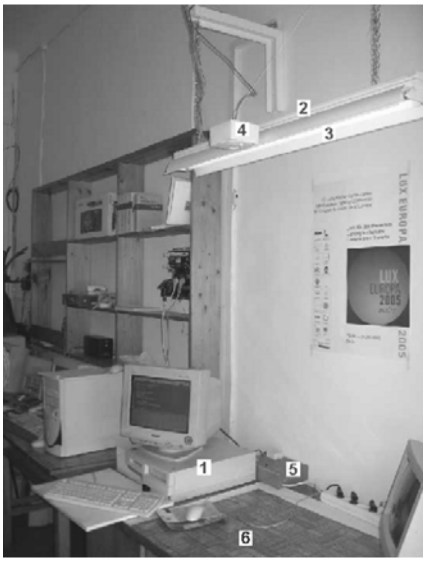


Figure 2 The experimental stand [3]

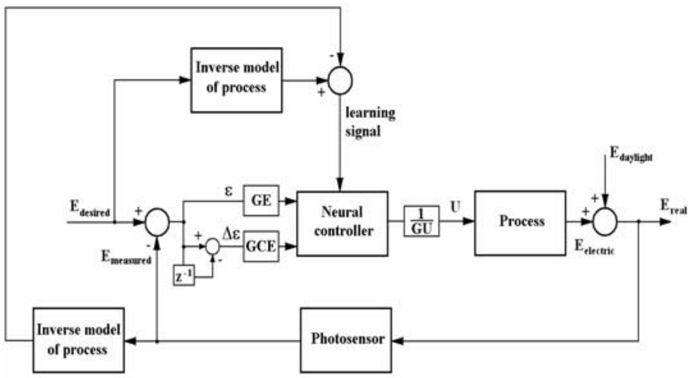


Figure 3 Block diagram of the ALCS

The experimental stand is composed of: (1) calculation equipment (PC IBM compatible, PIII, 433 MHz, 64 Mb RAM), (2) execution element (accomplished with two modules produced by Tridonic company: DSI-A/D converter, digital ballast PCA 2/36 EXCEL) introduced in the lighting body, (3) the technological installation based on two 36 W fluorescent lamps, (4) light sensor (multifunctional LRI 8133/10 sensor produced by Phillips), (5) data acquisition board with two 8-bytes conversion channels (an A/D channel, a D/A channel), (6) working plane.

Figure 3 describes the block diagram of the ALCS where the following notations are made: $E_{desired}$ – the desired illuminance on the working plane; $E_{measured}$ – the measured illuminance on working plane; E_{real} – the illuminance on the working plane; $E_{daylight}$ – the daylight illuminance on working plane; $E_{electric}$ – the illuminance on working plane due to electric light; ε - control error; $\Delta\varepsilon$ - change in control error; U – control action (command); GE – scaling gain for the ε input of controller; GCE - scaling gain for the $\Delta\varepsilon$ input of controller; GU - scaling gain for the output of controller (change in command ΔU). Figure 4 presents the experimental model of the process. This model represents a LUT of measured data at the input and the output of process during night condition. The transformation given by the LUT is not single-valued, so the inverse model obtained by using the LUT is a gross approximation of the real inverse model of process.

The meaning of abbreviation *d8bv*, used in Figure 4, is “digital 8 bits value”. The value 100 lx_{d8bv} represents the equivalent value obtained by conversion with A/D converter of the 500 lx, which represents the illuminance on working plane measured by an analog luxmeter. The value 127 V_{d8bv} represents, by conversion with D/A converter, the equivalent for a d.c. voltage with value 5 V_{dc}.

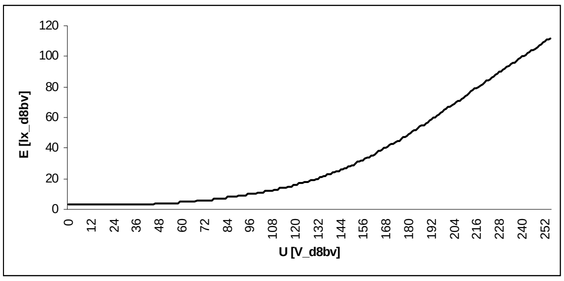


Figure 4 The experimental model of process

The neural controller is implemented as incremental type [2, 7]. The controller, based on the values of ε (control error – the difference between $E_{desired}$ and $E_{measured}$) and $\Delta\varepsilon$ (change in control error - the difference between current control error and anterior control error) will generate the change in control action denoted by ΔU. The control action U (where $U(kT)=U(kT-T)+\Delta U(kT)/GU$) will be applied to the process, in the purpose to maintain the illuminance in working plane close to the desired illuminance $E_{desired}$. T represents the sampling time. For the studies from this paper the desired illuminance has the value $E_{desired}$=100 lx_{d8bv}.

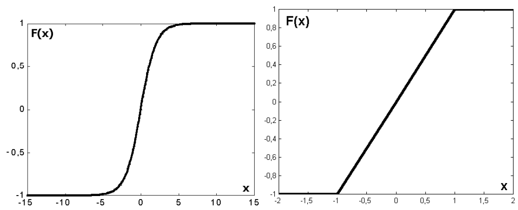
3. Experimental results

The controller was implemented with an ANN with three layers (input layer, hidden layer, output layer). The input layer has two neurons, the hidden layer has six neurons and the output layer has one neuron. The activation function, for the neurons from hidden layer, is the bipolar sigmoid function (Figure 5 a) given by

$$F(x) = \frac{1-e^{-2x}}{1+e^{-2x}} \qquad (1)$$

and, for the neuron from the output layer is the linear function with limitation (Figure 5 b) given by

$$F(x) = \begin{cases} -1, & x \le -1 \\ x, & -1 < x < 1 \\ 1, & x \ge 1 \end{cases} . \qquad (2)$$



a b

Figure 5 Activation functions:
(a) bipolar sigmoid; (b) linear with limitation

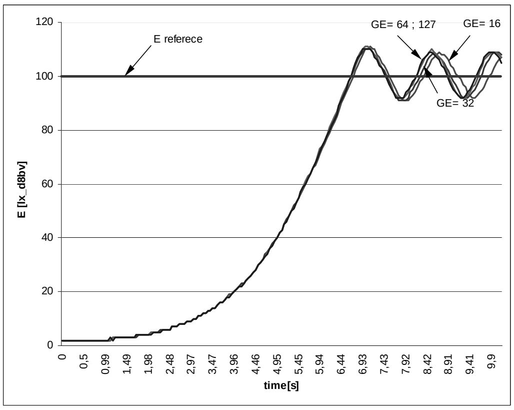
The ANN is trained on-line using the back-propagation training rule.

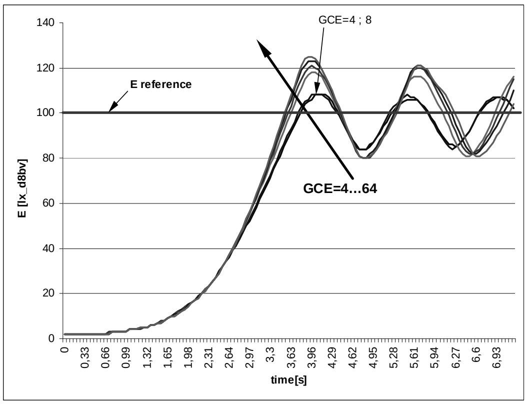
The universes of discourse of the inputs (ε , $\Delta\varepsilon$) and output (ΔU) variables of the controller was fixed to the interval of integers [-(2^8-1); +(2^8-1)]=[-255; 255], due to the 8 bits A/D and D/A converters. The inputs and the output of ANN are scaled [5]. The universes of discourse of the ε , $\Delta\varepsilon$ variables are converted in the intervals [-1; 1]. Due to the linear with limitation activation function of the neuron from the output layer, the output of the ANN has values in the interval [-1; 1]. These values are converted in values in the interval [-255; 255], which represents the universe of discourse of the ΔU variable of neural controller. Finally, the command, *U*, will has a value in the interval [0; 255] V_{d8bv}. For tuning the controller, via universe of discourse of the input/output variables, the scaling gains *GE*, *GCE*, *GU* was used [6, 7]. Figure 6 gives families of step reference responses for different values of scaling gains *GE* and *GCE*. For all situations the steady-state behavior of the ALCS is characterized by not damped oscillations.

The step reference response represents the response of the ALCS when the desired illuminance has the form of a step signal. For the studies from this paper the step signal has: 2 lx_{d8bv} (minimum illuminance produced by the lighting process) for the inferior value and 100 lx_{d8bv} for superior value. The step reference response of the ALCS offers useful information about the transient-state, steady-state and the stability of the ALCS.

In Figure 6.a we may see a minor decrease of amplitude of oscillations as *GE* decreases. A bigger influence in modifications of oscillations amplitude may be seen in Figure 6.b, where the amplitude of oscillations will increase as the *GCE* increase. A family of ALCS step reference responses for *GU* variable it is not necessary because the influence of increasing *GU* is evident. An increase of *GU* will imply a change of command, *U*, with a smaller amount *ΔU/GU* for the same *ΔU*.

Figure 7 depicts the step reference responses family of ALCS for different values of learning rate, denoted by γ. Figure 8 presents a detailed fragment of Figure 7.





a b

Figure 6 Families of ALCS step reference responses of ALCS (*T*=55 ms):
(a) GE=variable, GCE=127, GU=127; (b) GE=1, GCE=variable, GU=64

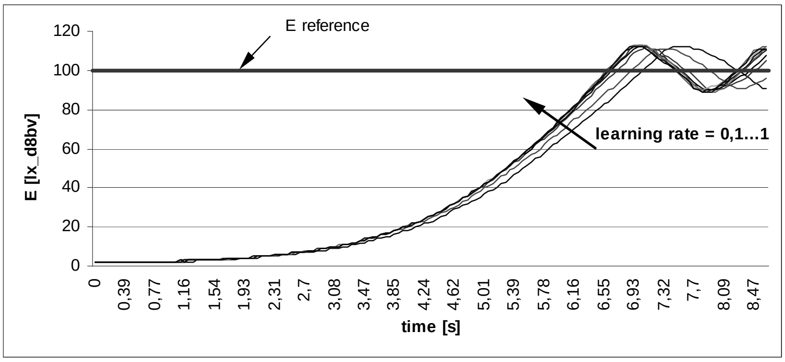


Figure 7 Family of ALCS step reference responses (*T*=55 ms):
learning rate is variable (γ=0.1…1, increment step set to 0.1)

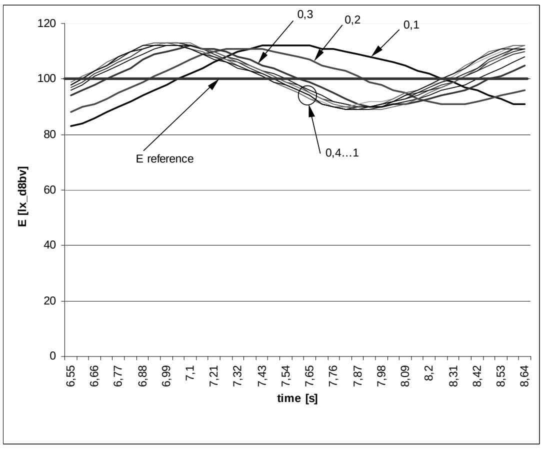
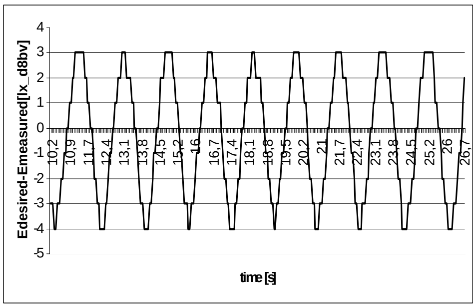


Figure 8 Family of ALCS step reference responses: detail from Figure 7

Figure 9 describes the influences of the sampling time. As the sampling time increases, the amplitude of the steady-state control error oscillations decreases.



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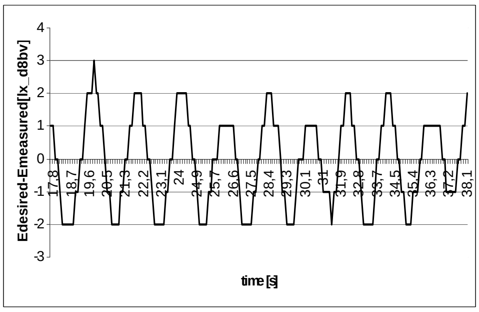

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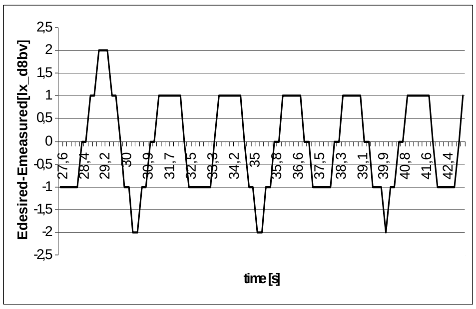


c

Figure 9 ALCS steady-state behavior for different values of sampling time:
(a) T=55 ms; (b) T=110 ms; (c) T=165 ms

For reducing the amplitude of oscillations, during the steady-state, two ways was selected. The first way imply the using of small values for scaling gains (GE=1, GCE=8, GU=16), learning rate γ=0.98, sampling time set to 55 ms and turn off the training of ANN when the learning error is smaller, for example, like value 0.99 (Figure 10). The second way imply the using of big values for scaling gains (GE=16, GCE=64, GU=256), learning rate γ=0.3, a bigger sampling time (165 ms) and never turn off the training of ANN (Figures 11 and 12).

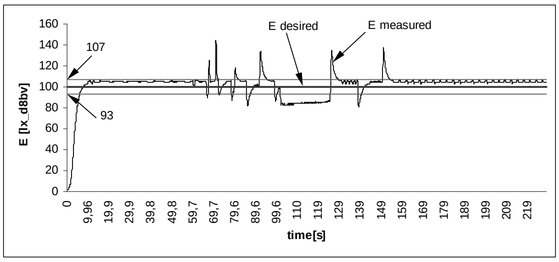
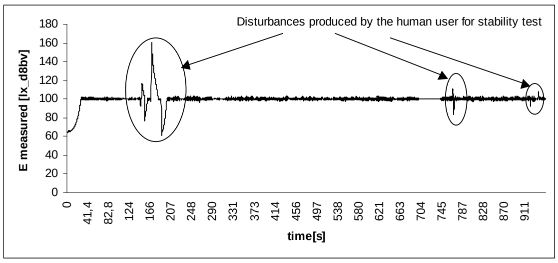


Figure 10 Behavior of ALCS (T=55 ms, GE=1, GCE=8, GU=16, γ=0.98). The training of ANN is turn off when the learning error is smaller like 0.99

As we may notice in Figure 10, the measured illuminance has values around the desired illuminance ($E_{desired}$=100 lx_{d8bv}), in the interval [100; 107] lx_{d8bv} (experimentally, a variation of measured illuminance in the interval [93; 107] lx_{d8bv} was not perceived by the human user). The experimental data was acquired by the night conditions. The stability of ALCS was tested by perturbing the illuminance on working plane by rapidly changing the reflecting surface of the working plane. The weak of this way, is the weak training of the ANN. For example between the 100 and 120 seconds of the horizontal axe, the measured illuminance has values smaller like 93 lx_{d8bv}, even the learning error is smaller 0.99. To solve this problem, the training of ANN when the absolute control error has value bigger like 7 lx_{d8bv} must turned on.

Figure 11 presents the behavior of ALCS (measured illuminance, command and control error trajectories) when the scaling gains have big values (*GE*=16, *GCE*=64, *GU*=256), the sampling time is set to *T*=165 ms and the ANN is trained every time sample. Figure 12 presents details of the control error trajectory depicted in Figure 11c. The experimental data was acquired by the day conditions in the presence of the human users. Figure 11.a depicts the trajectory of the measured illuminance in working plane. In the sectors of the trajectory surrounded by ellipses it was tested the stability of the ALCS by uncovering and covering rapidly a part of the windows of the office where is placed the experimental stand. In order to do this test of stability, first cover a portion of the window of office, turn on the ALCS and wait the ALCS meet the steady-state; second, uncover rapidly a part of the covered widow and wait the ALCS meet the steady-state; third, cover backwards rapidly the part of window uncovered in the second step and wait the ALCS meet the steady-state. As we may see in Figures 11 a, 11 c and 12 c, the ALCS is stable.



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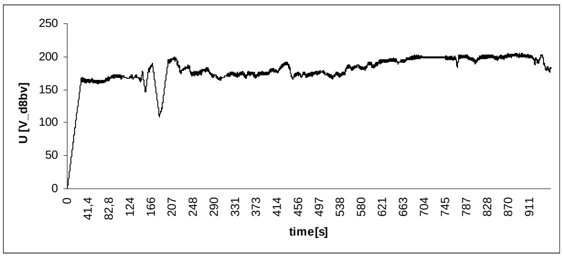

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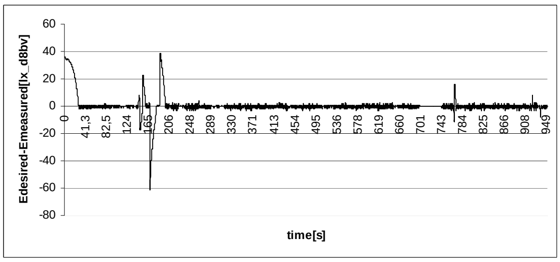
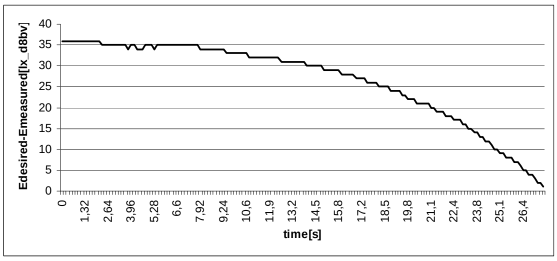


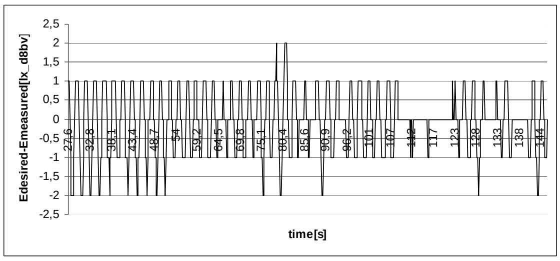
c

Figure 11 Behavior of ALCS (*T*=165 ms, *GE*=16, *GCE*=64, *GU*=256, γ=0.3, ANN trained all the time):
(a) measured illuminance trajectory;
(b) command trajectory;
(c) control error trajectory

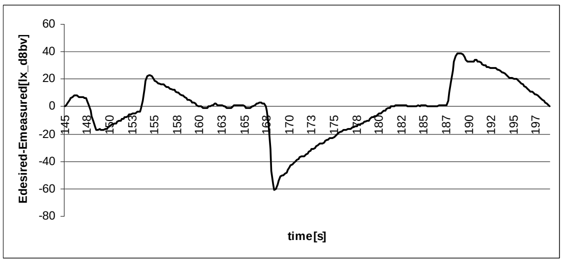
Analyzing the graphics from Figures 12 a and 12 c, we may notice when the ALCS starts first time, its response to meet the desired value of illuminance is slow (the start error control is 36 lx_{d8bv}). For this situation the transient time is about 27 seconds. At the start time the ANN is not trained. Because of the training of ANN when is created, again, a similar condition for ALCS respecting the value of control error, the transient time will be smaller. For example in Figure 12 c, at 189 seconds, a perturbation of the illuminance in working plane for stability test is produced. The error control has the maximum value of 39 lx_{d8bv}. The transient time, time for illuminance in working plane to reach the desired 100 lx_{d8bv} illuminance, has the value 9.825 seconds.

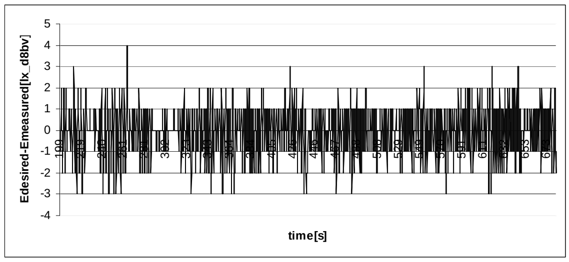
Analyzing the graphics from Figures 12 b and 12 d, the steady-state error control has values in the interval [-3; 4] lx_{d8bv}. The extreme values of the intervals are rarely met. The majority values for error control are in the interval [-2; 1] lx_{d8bv}. From the human eye perception, the human user of the ALCS does not perceive these oscillations.





a b





c d

Figure 12 Details of control error trajectory from Figure 11 c, time intervals:
(a) [0; 27.555] s; (b) [27.555; 145.365] s; (c) [145.365; 198.825] s; (d) [198.825; 682,605] s

4. Conclusions

The proposed structure, used to control the lighting process, need an inverse model of the process. The mathematical model of the process is unknown. To solve the problem, an experimental model of process was used. The experimental model is in the form of a LUT of measured data at the input and the output of the lighting process. The LUT is obtained by measuring the process output data for the all-possible process input data (direct model of process). This experimental model offers a not single-valued transformation of the process input data in the process output data. This implies an approximate inverse model of the process (a transformation of the process output data in the process input data). Even if the inverse model of process is not the best solution a set of settings, for neural controller as ALCS satisfies the imposed performances, was obtained.

For the tuning the neural controller is proposed the tuning via the universe of discourse of the input and output variables of the controller. In [3], for this type of tuning, the domains of the possible values of the input and output variables were modified. In this paper, the universe of discourse is changed by using scaling gains (a convenient way) for the inputs and output of controller keeping the domains of the possible values of the input and output variables constant. The influences of the scaling gains are studied using the step reference responses of ALCS. The tuning process of the controller is completed by supplementary studying the step reference responses of ALCS respecting the influences of the learning rate and the sampling time.

Finally, we may say that the classical tool (from automatic view) represented by the step reference response becomes a useful tool for tuning a neural controller. This tool offers to the designer the possibility to set, in a logical manner, a neural controller as the ALCS satisfies he desired performances. Using the step reference response of the ALCS the setting of the neural controller in a vague manner is avoided.

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LUMINANCE MONITORING AND OPTIMIZATION OF LUMINANCE METERING IN INTELLIGENT ROAD LIGHTING CONTROL SYSTEMS

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For energy saving reasons, intelligent road lighting control systems are increasingly used and road surface luminance is one possible input parameter. In this paper the current status of luminance monitoring is reviewed giving emphasis on road surface luminance monitoring. In practice many factors may affect road surface luminance monitoring, e.g., different road surface properties under varying weather conditions, orientation of luminance meters, different measuring heights and distances, disturbances of road profile and vehicles on the road. A series of road surface luminance measurements were conducted and the measuring results were analysed in order to find out the optimal placement of luminance meters. The paper ends up with recommendations on luminance metering for intelligent road lighting control systems.

1. Introduction

Intelligent lighting control systems are increasingly applied not only in building automation, but also in outdoor applications such as road and tunnel lighting. The essential idea of intelligent lighting control is that the light levels can be dimmed or switched on/off when needed and meanwhile certain amount of light levels should be maintained. By this way energy consumption can be reduced without negative effects on the provided light quality. The monitoring of light levels then becomes a key issue in intelligent lighting control.

In indoor lighting, occupancy sensors, and light sensors are increasingly employed in office lighting. Light sensors are illumination monitoring devices in the sense that they measure the illuminance of the monitored area [1]. Daylight sensors are also used to monitor illuminance provided by daylight in order to optimize the use of electrical indoor lighting [1]. In tunnel lighting, luminance metering is needed for monitoring the tunnel entrance luminance [2].

For energy saving reasons, intelligent road lighting control systems are increasingly used and road surface luminance is considered as one of the possible control parameters. Monitoring the road surface luminance is very difficult to realize in practice because many factors may affect the luminance measuring, e.g., different road surface properties under varying weather conditions, disturbances of road profile and vehicles on the road.

In this paper, the current status of luminance monitoring is reviewed giving emphasis on road surface luminance monitoring. A series of road surface luminance measurements were conducted and the measuring results were analysed in order to find out the optimal placement for luminance meters. The paper ends up with recommendations on luminance metering for intelligent road lighting control systems.

2. Luminance monitoring and intelligent road lighting control systems

In indoor lighting illuminance monitoring is commonly used because of the need to know how much light can reach the tasks. Light sensors are illuminance monitoring devices employed in indoor lighting to switch on/off or dim the light [1]. The placing of those sensors is probably the most critical phase of lighting control in the sense that this is where most mistakes are made [1]. It is important to ensure that the sensors are oriented towards the working area to be illuminated and that no direct light from the luminaires under control or from the windows reaches the sensor [1]. Some light sensors are installed to monitor outside daylight in order to optimize the use of inside artificial lighting. To be effective, multiple sensors may be needed in order to detect the direction of lighting.

An example where luminance monitoring is needed is in tunnel lighting control. The access zone luminance of tunnel varies with changes in daylight conditions. During the day, the luminance levels in the threshold and transition zones need to be constant percentages of the luminance in the access zone [2]. Therefore, for adequate light control the access zone luminance must be monitored continuously [3]. The most practical solution is to place a luminance meter at the stopping distance, aimed and centred at the tunnel portal [2]. For maintenance reasons, the luminance meter should be mounted between 2 m and 5 m height above the pavement or hard shoulder on the near side of the road [2], [3]. It is also recommended to measure the interior luminance with another luminance meter [3]. Again, it is not possible to measure the luminance from the position of the driver's eye in practice. For practical reasons the mounting height of the luminance meter has to be greater than that of the highest truck, i.e., above 4.5 m. Therefore the measured value is different from the luminance seen by the driver [3].

For energy saving reasons, intelligent road lighting control systems are increasingly used. Two essential missions of an intelligent road lighting control system are monitoring and control. Monitoring lamp status can reduce the maintenance costs by reduced routine inspection and well planned lamp group replacement. Control of lamps can lead to energy savings by lowering the lamp power when less light is enough for traffic according to several control parameters, e.g, traffic amount, road surface luminance, road weather conditions, and so on. An intelligent road lighting control system consists of control centre (host computers), remote terminal units (also called central controllers), light control units (also called local controllers), ballasts and lamps [4].

The control centre is normally composed of computers and management software. The main functions of the control centre are collecting and estimating the information of lamps, making decisions according to control parameters, and saving the operation data. Remote terminal units are installed in the control cabinets of the road lighting installations. With the employment of microprocessor, remote terminal units can collect field information from light control units and send the information to the control center, receive the commands from the control center and transmit them to light control units. Light control units receive commands from remote terminal unit and execute the command, and transmit the status information of lamps to the remote terminal unit. Figure 1 illustrates the basic diagram of an intelligent road lighting control system.

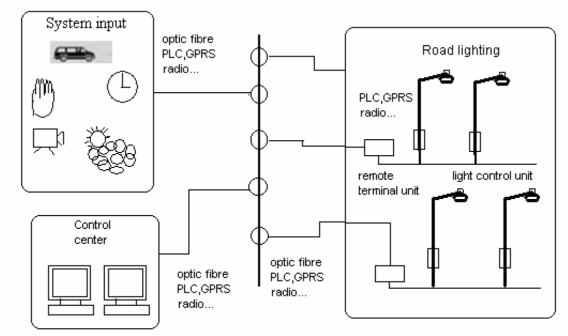


Figure 1 Basic diagram of an intelligent road lighting control system

In the existing installations of intelligent road lighting control systems, traffic amount is the most commonly used control parameter, because the initial motivation to develop intelligent road lighting control system is to decrease the light levels when traffic amount is low so that energy can be saved especially at midnight [4]. At the same time, energy savings should be achieved without decreasing traffic safety. Therefore, other control parameters should also be considered in order to keep lighting quality and explore more potential for energy savings. Road surface luminance is one possible control parameter [5]. However, monitoring road surface luminance is very difficult to realize in practice. Road surfaces luminance levels in road lighting are rather low compared to tunnel access luminances and many factors may significantly affect the road surface luminance measuring, e.g., varying road surface properties under different weather conditions, disturbances of road profile, vehicles on the road and different placement of the luminance meter. Ideally the luminance meter should be mounted at 1.5 m height, in the middle of lane to be consistent with the driver's view of luminances. In practice, it is not realistic to place the luminance meter at this height because the luminance meter will get dirty very quickly, be exposed to vandalism, and heavy snow may block the view of luminance meter. Then it is crucial to find an optimal position for luminance meters so that luminance measurements are reliable and the maintenance of luminance meter is easy and economic. Currently, luminance meters are in practice mounted at 4 to 6 m height attached to a light pole, a bridge or a separate pole. So far, there are no guidelines or instructions that specify where and what kind of luminance meter should be used to monitor the road surface luminance in an intelligent road lighting control system.

3. CCD-based imaging luminance meter and spot luminance meter

At the moment, both spot luminance meters and imaging luminance photometers are used in luminance measurements. Spot meters have been utilized in luminance measurement for over 50 years [6]. An imaging photometer is essentially a CCD (charge coupled device)-based camera connected to computer and it is increasingly applied in laboratory and field lighting measurements. Due to the novelty of the intelligent road lighting control system installations there are no luminance meters designed particularly for luminance monitoring in these systems yet. In some intelligent road lighting control systems, spot luminance meters designed for tunnel lighting control are applied for road luminance monitoring. Generally, luminance meters for tunnel applications measure the average luminance within a cone with a measuring angle of 20^o, and have an output of 4-20 mA DC for a luminance range 0-L cd/m^2 [7], [8]. *L* is chosen by users when ordering the photometer. A common value of '*L*' is 6500 cd/m^2 for tunnel applications. The measuring angle can also be changed according to users' demands.

Intelligent road lighting control systems mainly work during dawn, dusk and night at low light levels. Thus road surface luminance values are actually in a small range, which requires high sensitivity of the luminance meters at low light levels. There are spot luminance meters designed for tunnel lighting with luminance range of 0-32 cd/m^2, and an output of 4-20 mA DC which are used for luminance monitoring in intelligent road lighting control systems. But the observed area can not be selected freely. Once the installation height is set, the maximum measuring area on road surface is determined and the measuring area is an ellipse. The luminance meter averages the luminance values from the ellipsoid area so it does not respond to CEN road lighting measurement standard. At present, both CCD-based imaging photometers and tunnel spot photometers are expensive. With CCD-based photometers the measuring area can be freely selected from the captured images and detailed light distribution information can be achieved with the aid of image processing software. Those are the most important advantages of an imaging photometer over a spot luminance meter when considering road surface luminance monitoring.

4. Road surface luminance measurements

4.1 Orientation of luminance meters

The orientation of luminance meter was studied in order to find out the optimal orientation of luminance meters for road surface luminance monitoring. The measurements were conducted in a four-lane road, VT1 between Kolmperä and Lohjanharju, which is one of the busiest highways in southern Finland. The lighting installation is provided by high pressure sodium lamps with 53 m luminaire spacing. Central reservation separates the two driving directions. The width of each carriageway (two lanes) is 8 m.

A luminance meter can be oriented transversely or longitudinally in relation to the road. Supposing a spot meter with 20^0 viewing angle is mounted at 4 m height, 5.4 m far from the road edge and oriented transversely in VT1, the maximum measuring area on the road is an ellipse with semimajor axis a=4 m and semiminor axis b=1.7 m. Figure 2 illustrates the maximum measuring area for a spot meter with 20^0 viewing angle. Of course it is possible to get a larger measuring area, but in this case part of the ellipse will be outside the carriageway. If the spot meter is oriented longitudinally, and installed at 4 m height and 9 m far from the observed area, the maximum measuring area on the road surface is much larger, an ellipse with semimajor axis a=24 m and semiminor axis b=4 m. The maximum observed area on the road increases with mounting height and viewing angle. If the measuring area is small it may cause inaccuracy to monitored luminance values when there are road markings, snow, or faulty lamps in the measuring area. For a large measuring area, those will not cause big errors because the luminance is averaged over the whole area. With an imaging photometer, the measuring area can be selected from captured images so it is still possible to get the average luminance from a large area even though the meter is oriented transversely to the road. But when luminance meter is placed transversely, it does not correspond to luminances seen by the driver. This is emphasized with wet road surface due to the specular reflections from the road surface. Therefore, it is recommended to orient luminance meter longitudinally to the road, no matter if it is a spot luminance meter or an imaging photometer.

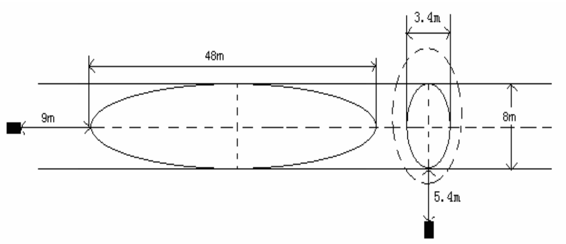


Figure 2 Measuring area of a spot meter with 20^0 viewing angle mounted at 4 m height in road VT1

In luminance monitoring, the effects of car head and rear lights should be considered if luminance meter is placed longitudinally. Road surface luminance measurements were conducted in VT1 in both driving directions to evaluate the effects of car headlights and rear lights on road surface luminances. The measurements were made using an imaging luminance meter LMK Mobile Advanced and analysed by computer program LMK 2000. The luminance meter was placed in the middle of each carriageway on a bridge over the road. The bridge is 6 m high and 32 m far from the observed areas which are between luminaire 1 and luminaire 2 as illustrated in Figure 3. The measurements were conducted at night time in November, 2006 when the road surface was dry. The road surface luminance for each driving direction was measured when there was a car/no cars so that the effects of car headlights and rear lights could be investigated. The measuring results are shown in Figure 4 and Table 1.

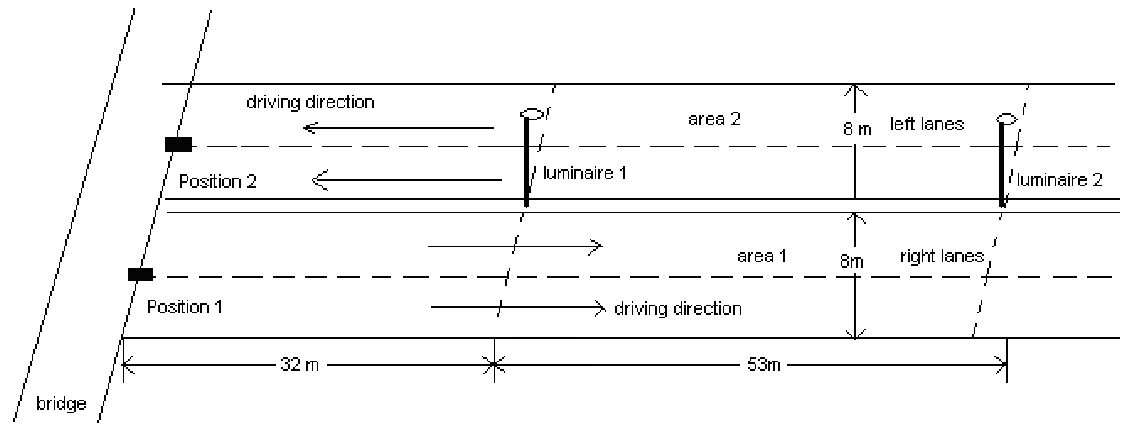


Figure 3 Illustration of measuring positions, observed areas, and driving directions in VT1

Table 1 Luminance measurement results in VT1

Two directions	L_{av} (cd/m^2) no cars	L_{av} (cd/m^2) one car on the road	Increase in L_{av} by car rear/head lights
Right lanes	0.47	0.60	28%
Left lanes	0.34	1.81	432%

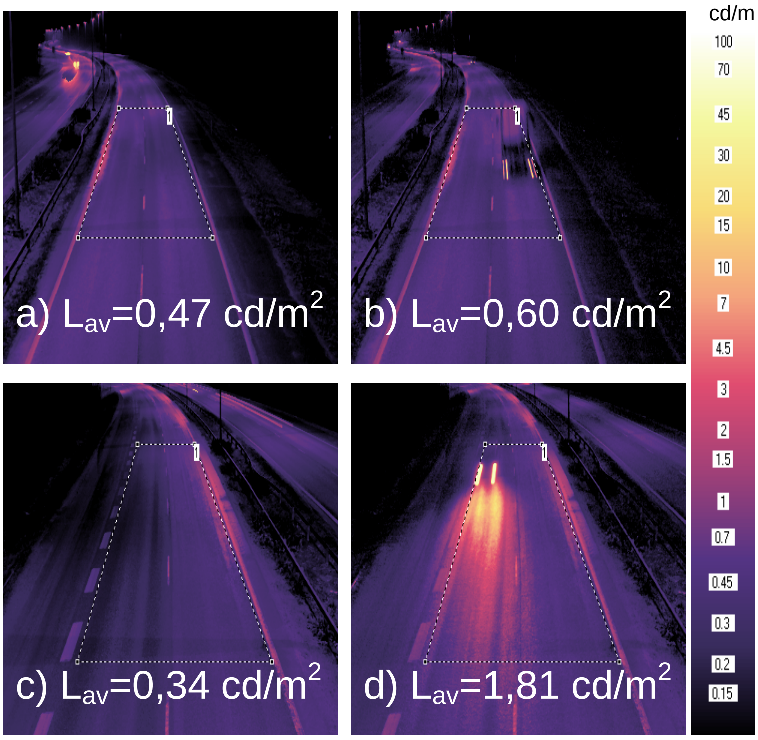


Figure 4 Luminance measurement results in VT1 a) the right lanes with no cars b) the right lanes with the luminance meter oriented to the driving direction of a car c) the left lanes with no cars d) the left lanes with luminance meter oriented opposite to the driving direction of a car. L_{av} is the average luminance of the defined road area.

Even though the measurements were not made from the driver's position, the measurement results however indicate how significantly the car rear lights and headlights affect the road surface luminance values. Car rear lights increase the average luminance of the observed area by 28% and headlights by 432%. In luminance monitoring in practice, the luminance is the average value over time, so the effects of car rear/head lights are smaller than those in the measurements. But the effects of car headlights are still significant for road surface luminance monitoring and may cause malfunction of the road lighting control systems. Therefore, luminance meter for road surface luminance monitoring should be oriented to the driving direction of the road.

4.2 Measuring height, measuring distance and varying weather conditions

4.2.1 Experimental procedures

A series of measurements were conducted to investigate the effects of measuring height, measuring distance and different weather conditions on road luminance monitoring when the luminance meter is oriented longitudinally to the road and to the driving direction. The measurements were made using an imaging luminance photometer LMK Mobile Advanced and analyzed by the computer program LMK 2000.

The measurements were made in a local street with two lanes in Espoo, Finland. The installation is provided by high pressure sodium lamps with 32 m luminaire spacing. Figure 5 illustrates the installation and the measuring positions. The measuring area is between two adjacent luminaires. There are two parts of the measurements. One part of the measurements was made from the same side of the luminaires, 1 m from the road edge, and at different measuring heights and distances. A car with a lifting platform was used to attain measuring heights up to 5 m. The other part of the measurements was made at the driver's position according to the CEN standards, e.g., the observer position was at 1.5 m height and 60m from the measuring area [9], [10]. Three weather conditions (dry, snow and wet) were investigated.

The measurements were made during three nights in February and March 2007 between 22:00 and 23:30 o'clock. The weather conditions and different positions of the luminance meter are given in Table 2. Figure 6 illustrates the conditions under varying weather conditions.

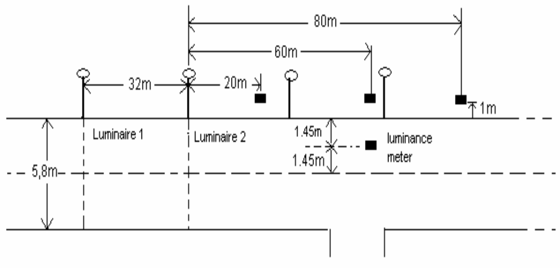


Figure 5 Illustration of installation and measuring position

Table 2 Weather conditions and different placement of luminance meter in the measurements.

Date	12.02.2007	07.03.2007	27.03.2007
Time	22:00~23:30	22:00~23:30	22:00~23:30
Road surface	Snowy	wet	dry
Road Temperature (°C)	-9	1.7	3.5
Weather	Clear	Rain	Clear
Measuring distance (m)	20, 60, 80	20, 60	20, 60
Measuring height (m)	1.5, 3, 4, 5	1.5, 3, 4, 5	1.5, 3, 4, 5

a) b) c)

Figure 6 Photographs of the three road weather conditions, a) snow b) wet c) dry

4.2.2 Measurements from the driver's position

The luminance measurement results under varying weather conditions at the standard driver's position are shown in Figure 7 and Table 3. When the road surface was covered with snow, the luminance distribution was quite uniform and road surface luminance was substantially increased, e.g., for the same observed area 150% more than the average luminance under dry conditions. In intelligent road lighting control systems, the light output can be decreased when road surface or the adjacent areas are covered with snow, so that a constant light level on road surface is maintained. Consequently, great energy savings can be achieved. In this sense, the road surface luminance can be considered as one of control parameters in intelligent road lighting control systems. With wet road surface, the average luminance of the observed area was 36% more than that with dry road surface. However the overall uniformity under wet condition was quite poor compared to dry and snowy conditions. Thus in intelligent road lighting control information is also needed of the prevailing weather conditions, in order not to further decrease visibility by light level adjustment.

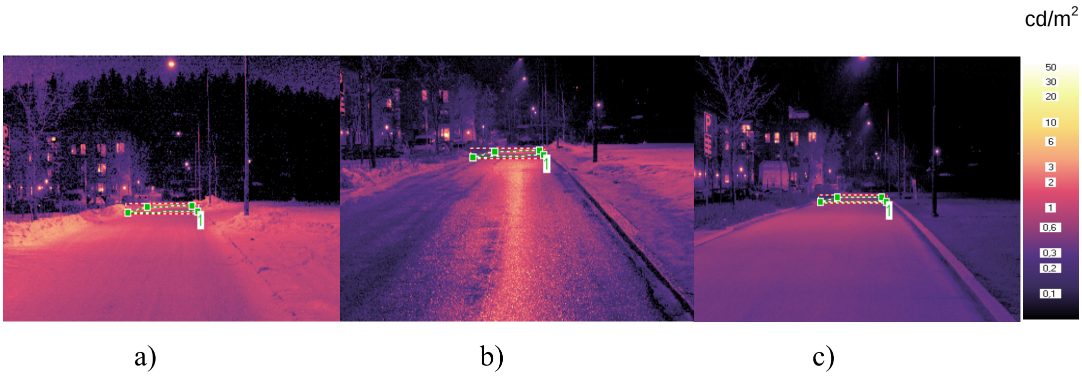


Figure 7 Road surface luminances measured from 60 m distance, 1.5 m height, in the center of right lane under different road surface conditions, a) snow b) wet c) dry. The observed area is the road surface area between two adjacent luminaires.

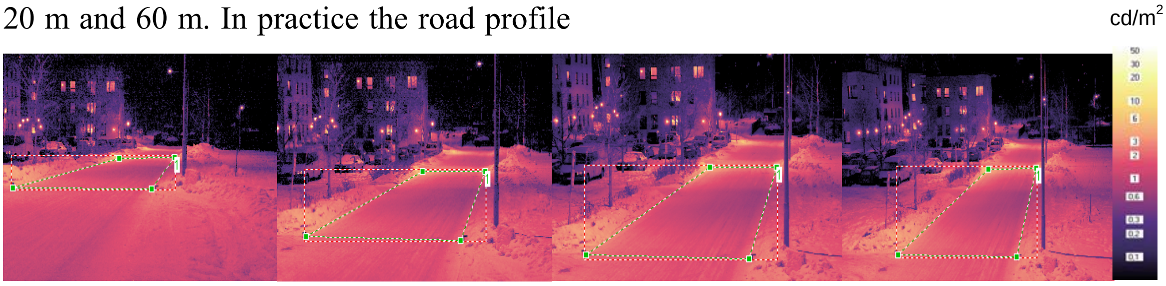
Table 3 Road surface luminance values measured at the driver's position

Road surface conditions	L_{av} (cd/m^2)	L_{av}: L_{av} (dry)	Overall uniformity U_o=L_{min}/L_{av}
Dry	0.56	100%	0.49
Snowy	1.40	250%	0.51
Wet	0.76	136%	0.33

Note: L_{av} is the average luminance of the defined area L_{av} (dry) is the average luminance under dry conditions, U_o is the overall uniformity defined as the ratio of the minimum luminance to the average luminance.

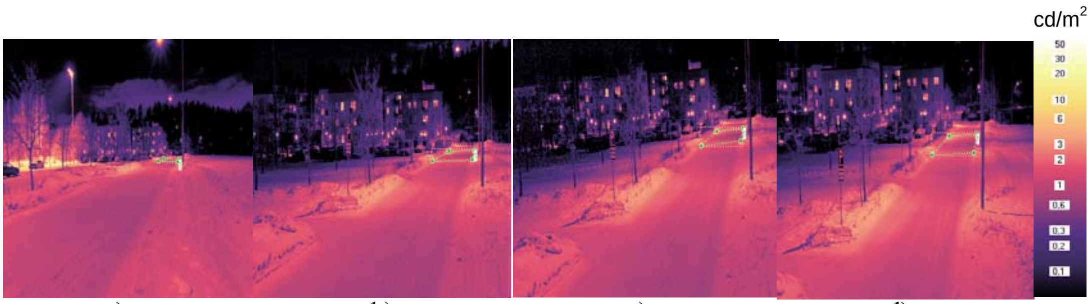
4.2.3 Road surface luminances in snowy conditions

When the road surface was covered with snow, the measurements were made from distances 20 m, 60 m and 80 m. It was possible to calculate the average luminance values of the observed road area measured at distances 20 m and 60 m, while it was not possible to get any average luminance values from the measurements at 80 m distance because the measuring area was too small to be detected by the photometer and the luminaire and traffic sign blocked the observed area. Therefore, when the road surface was wet and dry, the measurements were made only at two measuring distances, 20 m and 60 m. In practice the road profile is seldom completely flat and sometimes there are curves. So it is not recommended to place the luminance meter more than 60 m far from the measuring area. The measuring results with snowy road surface are shown in Figures 8-10 and Table 4. The differences in luminances between different placement of the luminance meter are small and very close to the average luminance measured at the driver's position, e.g., the luminance differences are in the range of -4% ~ 3% of the average luminance measured at the driver's position. The measuring height and measuring distance do not show significant effects on the measured luminances when the road surface is covered with snow.



a) b) c) d)

Figure 8 Road surface luminances measured at 20 m distance in snowy conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m



a) b) c) d)

Figure 9 Road surface luminances measured at 60 m distance in snowy conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m

a) b) c) d)

Figure 10 Road surface luminances measured at 80 m distance in snowy conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m

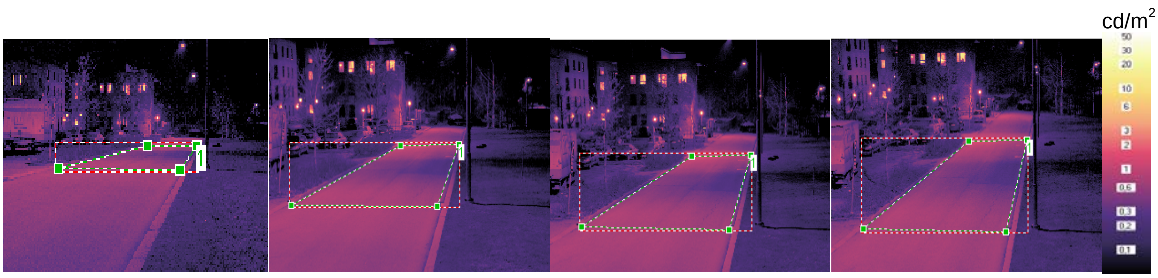
Table 4 Road surface luminance values in snowy conditions

Measuring distance (m)	Measuring height (m)							
	1.5		3		4		5	
	L_{av} (cd/m^2)	L_{av}: L_{stan}	L_{av} (cd/m^2)	L_{av}: L_{stan}	L_{av} (cd/m^2)	L_{av}: L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}
20	1.42	101%	1.37	98%	1.38	99%	1.44	103%
60	1.43	102%	1.40	100%	1.35	96%	1.42	101%

Note: L_{stan} is the average luminance measured from the driver's position in snowy conditions.

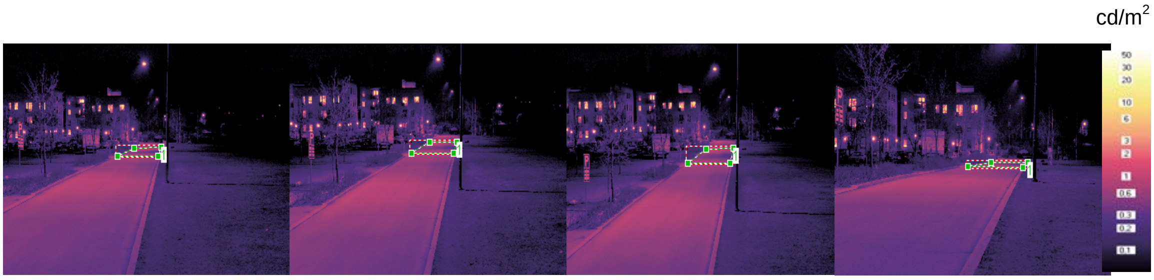
4.2.4 Road surface luminances in dry conditions

The luminance measurement results with dry road surface are shown in Figures 11-12 and Table 5. The average luminance values are close to each other at both measuring distances, 20 m and 60 m, and at all measuring heights, 1.5 m, 3 m, 4 m and 5 m. The luminance differences between different positions of the luminance meter are in the range of -2% ~ 9% of the average luminance measured at the driver's position. The measuring height or measuring distance does not show obvious effects on the measured luminances when road surface is dry.



a) b) c) d)

Figure 11 Road surface luminances measured at 20 m distance in dry conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m



a) b) c) d)

Figure 12 Road surface luminances measured at 60 m distance in dry conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m

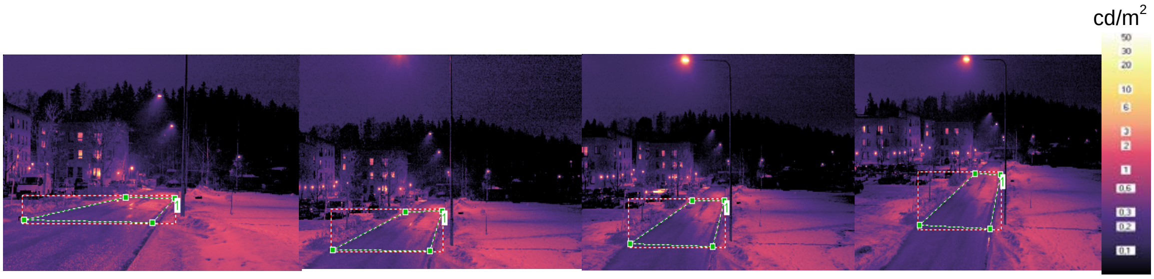
Table 5 Road surface luminance values in dry conditions

Measuring distance (m)	Measuring height (m)							
	1.5		3		4		5	
	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}
20	0.56	100%	0.56	100%	0.55	98%	0.55	98%
60	0.57	102%	0.61	109%	0.58	104%	0.56	100%

Note: L_{stan} is the average luminance measured at the driver's position in dry conditions.

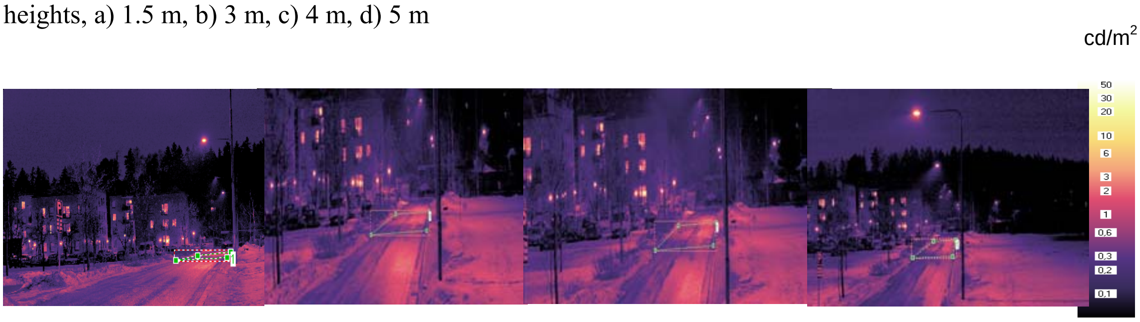
4.2.5 Road surface luminances in wet conditions

The luminance measurement results with wet road surface are shown in Figures 13-14 and Table 6. In these conditions the measuring height and distance have significant effects on the measured luminances. The luminance differences between different measuring heights and distances are in the range of -53%~-3% compared to the average luminance measured at the driver's position. It is quite difficult to find a general rule of how road surface luminances change with measuring height and measuring distance in wet conditions due to different road surface properties and various wetness conditions of road surface. In areas with specular reflections towards the observation point the luminances of the road surface increase substantially and form very bright areas. On the other hand, there are also darker areas which increase in size due to wetness. The road surface luminance measurements indicate remarkable changes caused by wetness to road surface luminances. Compared to the dry road surface the luminances in wet conditions can be either decreased or increased and thus no general rules can be given for using road surface luminance as input parameter for a road lighting control system in wet conditions.



a) b) c) d)

Figure 13 Road surface luminances measured at 20 m distance in wet conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m



a) b) c) d)

Figure 14 Road surface luminances measured at 60 m distance in wet conditions at different measuring heights, a) 1.5 m, b) 3 m, c) 4 m, d) 5 m

Table 6 Road surface luminance values in wet conditions

Measuring distance (m)	Measuring height (m)							
	1.5		3		4		5	
	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}	L_{av} (cd/m^2)	L_{av}:L_{stan}
20	0.59	78%	0.45	59%	0.36	47%	0.36	47%
60	0.67	88%	0.74	97%	0.72	95%	0.58	76%

Note: L_{stan} is the average luminance measured at the driver's position in wet conditions.

4.3. Discussion

The measurement results under varying weather conditions are summarized in Table 7 and the trendline of road surface average luminance is shown in Figure 15. When the road surface was covered with snow, the luminance values are substantially higher than those in dry and wet conditions. For an intelligent road lighting control system, this indicates the possibility to decrease the light levels so that energy saving can be achieved.

As listed in Table 7, the standard deviation of the average luminances when road surface was covered with snow is 0.03 cd/m^2, average value of the luminances is 1.40 cd/m^2, and the ratio of the standard deviation to the average luminance is 0.02. In dry conditions the ratio of the standard deviation to the average value is 0.03. So when the road surface is dry or covered with snow, different measuring distances and measuring heights do not introduce relevant variations on the measured road surface luminance values. While under wet conditions the standard deviation of the measuring results is 0.15 cd/m^2, which is much larger than that under dry and snowy conditions. And the ratio of the standard deviation to the average value is 0.27, which is much larger than those in dry and snow conditions. These differences indicate that in wet conditions luminance measuring is affected more significantly by the measuring height and measuring distance than in dry and snow conditions.

When the road surface is wet, the average luminance values change significantly with measuring height and measuring distance of the luminance meter. The average luminance values of wet road surface may be higher or lower than that of dry conditions depending on the placement of the luminance meter, the road surface properties and the wetness of road surface. Therefore road surface luminance is not a reliable control parameter in wet conditions. A practical solution is to exclude the road surface luminance information in wet conditions from the control parameters.

As discussed in chapter 4.1, when the luminance meter is oriented longitudinally to the road and to the driving direction of the lane, the effects of car rear lights are not significant. While when full of cars, road surface luminance can not be used as control parameter any more because it will be not possible to measure the real road surface luminance. In this case, other control parameters should be used, e.g. traffic amount and speed. More research work is needed to find out which other possible control parameters could be used in intelligent road lighting control.

Table 7 Average road surface luminance values in different weather conditions

Measuring height (m)	L_{av} (cd/m^2) Dry		L_{av} (cd/m^2) Wet		L_{av} (cd/m^2) Snow	
	Distance 20 m	Distance 60 m	Distance 20 m	Distance 60 m	Distance 20 m	Distance 60 m
1.5	0.56	0.57	0.59	0.67	1.42	1.43
3	0.56	0.61	0.45	0.74	1.37	1.40
4	0.55	0.58	0.36	0.72	1.38	1.35
5	0.55	0.56	0.36	0.58	1.44	1.42
σ (cd/m^2)	0.02		0.15		0.03	
L (cd/m^2)	0.57		0.56		1.40	
σ:L	0.03		0.27		0.02	

Note: σ is standard deviation. L is the average value of luminances measured at different measuring heights and measuring distances.

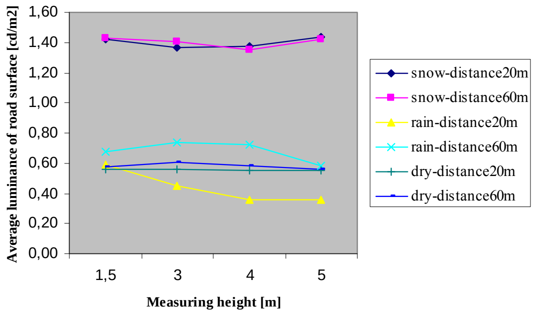


Figure 15 Average luminances measured at different heights (1.5 m, 3 m, 4 m, 5 m), distances (20 m, 60 m) and weather conditions (dry, wet, snow)

5. Conclusions

In intelligent road lighting control systems, road surface luminance is considered as one of the possible control parameters. Monitoring road surface luminance is then necessary and many factors should be considered in the optimization of luminance metering.

In practice, normally it is not possible to place the luminance meter at driver's position. In order to get larger observed area and simulate the driver's view, the luminance meter should be oriented longitudinally to the road. Meanwhile, the effects of car headlights are significant for road surface luminance monitoring whereas the car rear lights do not have obvious effects on the average luminance values of a large enough measuring area. So it is recommended to orient the luminance meter to the driving direction. For a spot luminance meter, the measured area increases with mounting height and viewing angle of the meter. For both spot meters and imaging photometers it is recommended to place the meter at ≥ 3 m height in order to keep the lens clean, prevent it from vandalism, and from blocking by obstacles on the road. Currently, only spot luminance meters designed for tunnel applications are used in intelligent road lighting control systems. In this case the observed area is an ellipse which is defined by the mounting height of the meter and the width of the road. With a CCD-based imaging photometer, the measuring area can be freely selected from the captured images and detailed light distribution information can be achieved with the aid of imaging processing software.

For luminance monitoring, it is not recommended to install the luminance meter far from the observed area, e.g., measuring distance should not be more than 60 m. As in practice the road profile is seldom completely flat and sometimes there are curves, it is quite difficult to measure the road surface if the luminance meter is far from the observed area.

When the road surface is covered with snow, the average luminance is substantially higher than that with dry and wet road surface. When road surface is dry or covered with snow, luminance values are not affected by the measuring distance or the measuring height. In wet conditions, on the other hand, road surface luminances vary with measuring heights and measuring distances of the luminance meter. In wet conditions, visibility is reduced but the road surface average luminance may be higher than that under dry conditions due to specular reflections. If the lamp dimming levels change with the average road surface luminance, the lamp will be dimmed down and visibility will be reduced further. In intelligent road lighting control systems, one practical solution is to exclude the luminance information of wet road surface from the input parameters in adjusting light levels.

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EVALUATION OF DAYLIGHTING FROM DORMERS

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Dormers have found wide applications in the design of new buildings and also in the renovation of spaces at top floors of existing buildings. The visual comfort for required visual activities in attic rooms illuminated by dormers depends mainly on the dimensions of the dormer and its position with respect to the utilisation area in the room. Daylighting on the work plane from selected dormers in an office of a university building was evaluated on the basis of computer calculation and light measurements. The daylighting case studies of influences of separated dormers and alternatively with one continuous dormer of the same glazed area were elaborated. Results of Daylight Factor calculations show that dimensions, position of dormers in the room and the light reflectance of its inner surfaces significantly influence daylighting utilisation.

Keywords: Dormers, windows, daylighting, illuminance, visual comfort, building design, visual comfort.

1. Introduction

The utilisation of attics and under-roof spaces for rooms with visual task requirements is the contemporary trend not only in residential but also in commercial buildings. Dormers yield a good solution for maximising floor area with appropriate height of rooms in attics. Their design is limited by several requirements, e.g. respecting architectural style specifications of the building, access to solar radiation and daylighting, occupancy specifications. The positions, dimensions and shapes of dormers on roofs seem to be important not only for aesthetic design but also for creation of the indoor visual comfort.

Design requirements for visual comfort and daylighting in buildings ensure minimal levels of indoor illuminance uniformity in buildings [1], [2], [3]. To satisfy these requirements the design of dormers should be optimised with respect to their construction, dimensions and shape as well as to the size of their glazed area and position on the roof.

The evaluation of influence of various dimensions and positions of dormers was carried out in a few daylighting studies which were completed with respect to standard requirements for indoor illuminance valid in the Czech Republic [3]. As an example, daylight in an attic office with dormers in a real renovated building was evaluated. This building is located in the campus of the Faculty of Civil Engineering, Brno University of Technology in the Czech Republic [4]. The dormers were designed and constructed with short relative distances (see Figure 1 a). As an alternative design solution one continuous dormer with windows in its front wall was offered. The architect did not use this proposal because the continuous dormer would be disproportional to the architectural concept of the existing building.

a) View of the part of the facade with dormers.

b) Interior with dormers.

Figure 1 The renovated building with dormers

2. Study of daylighting in rooms with dormers

The daylighting in two selected attic rooms of the renovated building with dimensions 2875 mm x 5280 mm and 6070 mm x 5280 mm of the floor area was evaluated (see Figure 2). Room I was illuminated by one dormer and in room II two identical dormers were investigated. The dormers and windows were designed in a symmetrical position in the room plan. The distance between dormers in room II was 1 m. The clearance height of both rooms was from 1.2 m to 4.0 m depending on the slope of the saddle roof.

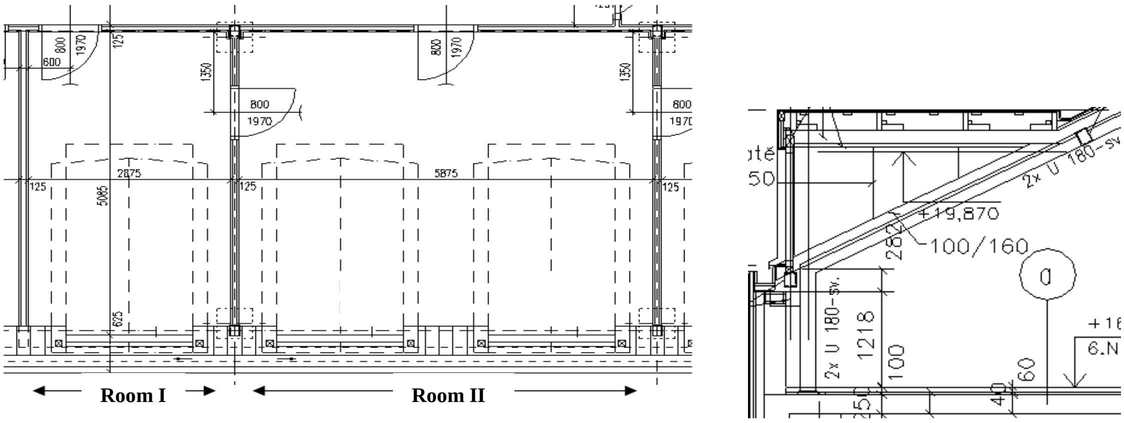


Figure 2 The part of the plan with room I and room II in the attic and the dormer section

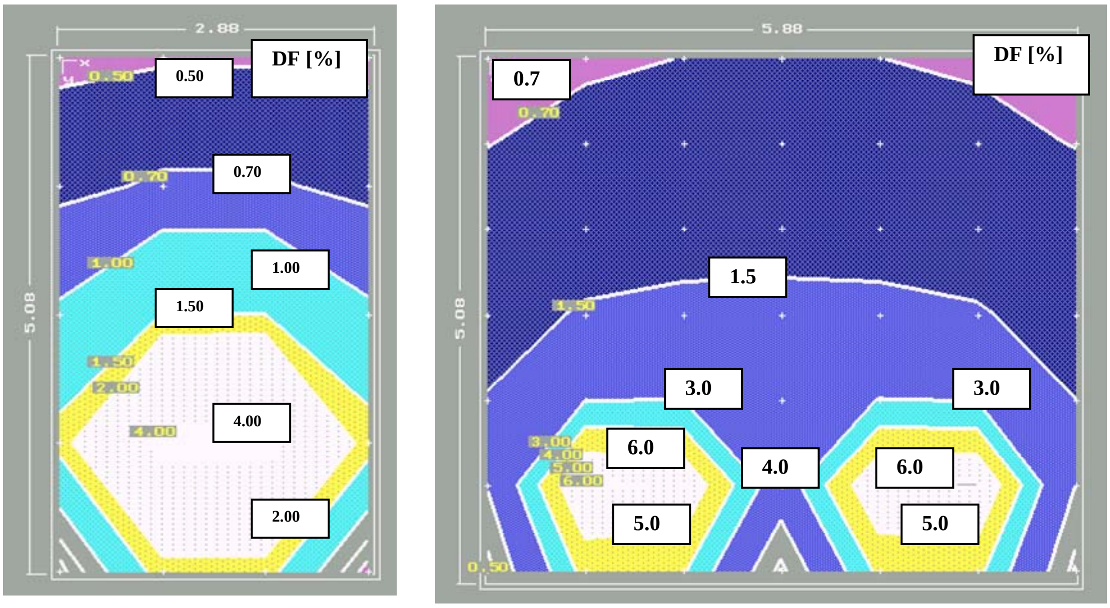
The interiors of rooms were equipped with grey furniture; white surfaces of walls and the soffit ceiling were plastered. Light grey colour of PVC floor covering was used. The width 1800 mm, height 1450 mm of the identical windows and their sill 1200 m in both rooms were considered.

Daylighting expressed by Daylight Factor on the work plane under the CIE Overcast Sky conditions was calculated to identify effects of two design concepts: first with several dormers in the room and second with one continuous dormer located in the same position and with identical glazed area of windows. The following input parameters for calculation were considered in this study:

- Reflectance of interior surfaces, i.e. ceiling $\rho = 0.80$, walls $\rho = 0.50$, floor $\rho = 0.30$ and white plastic window frames $\rho = 0.80$.
- Reflectance of the ground surrounding the building $\rho_T = 0.10$ (dark colour).
- Height of the floor level over the ground level h = 17 m.
- Glass transmittance $\tau = 0.81$ (double glazing, clear glass).
- Light loss factor considering dirt on internal surface $\tau_{pi} = 0.90$ and on external side $\tau_{pe} = 0.80$ of glazing.
- The typical overcast sky conditions expressed by external illuminance $E_{ext} = 5000$ lx [5].
- Height of the work plane over the floor 850 mm.
- Daylighting was computed by the computer program DenDql [6]. Its algorithm of light propagation is based on the Radiosity method respecting CIE Overcast Sky with gradation of sky luminances 1:3 from horizon to zenith and the worse daylight climatic conditions, very often occurring in Central Europe [7], [8].

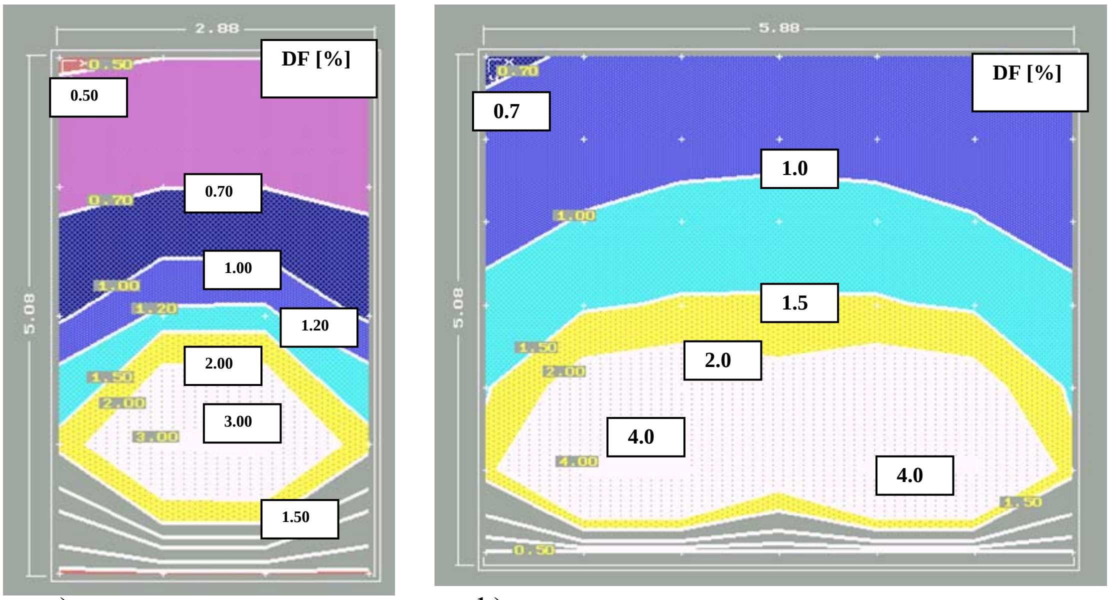
The isolines of resulted illuminances on the work plane in rooms with separated dormers are shown in Figure 3. It can be noted that illuminance distribution on the work plane in the room with one continuous dormer differs from that in the first case (see Figure 4 as well as Figure 3). The uniformity of Daylight Factor distribution on the work plane is deformed in the zone close to the facade due to longer distances between separate dormers and their special indoor shape. Calculation results of the daylight evaluations are summarised in Table 1 for both rooms I and II with dormers and windows.

It is evident that levels of daylighting differ in dependence on the dimensions of the dormer, its position and optical properties of inner surfaces. When room I was equipped with one dormer minimal values of Daylight Factor were in the range of 88 – 94 % of those calculated in room II which was equipped with two dormers. Similar trend was observed in the occurrence of maximal values of the Daylight Factor. These values dropped to 72 – 74 % in room I in comparison to those found in room II. This fact can be explained by the so called “tunnel effect” which reduces solid angle covering the contribution of skylight and indoor surfaces producing reflected light.



a) **b)**

Figure 3 Isolines of Daylight Factors DF in [%] on the work plane in
a) Room I with one dormer.
b) Room II with two separated dormers.



a) b)

Figure 4 Isolines of Daylight Factors DF in [%] on the work plane in
a) Room I with the window in the one continuous dormer.
b) Room II with two windows in the one continuous dormer.

Table 1 Daylight Factors in room I and room II

Daylight characteristics	**Room I**		**Room II**	
	One dormer	**One window**	**Two dormers**	**Two windows**
Minimal value of DF_{min} [%]	0.40	0.47	0.45	0.50
Maximal value of DF_{max} [%]	4.45	3.17	6.13	4.26
Average value of DF_{aver} [%]	1.31	1.02	1.90	1.40
$r_1=DF_{min} / DF_{max}$ [-]	0.09	0.15	0.07	0.12
$r_2=DF_{min} / DF_{aver}$ [-]	0.31	0.46	0.24	0.36

The comparison of resulted Daylight Factor values in rooms with dormers and windows shows that the minimal values in the room with dormers have to be reduced by 5 – 10%. Different situation can be observed when maximal values of Daylight Factor are compared. In this case higher values were found in the room with dormers (see second line in Table 1), so the increase of the Daylight Factor from 40 to 43% can be expected.

As influence of the sill size on the interior illuminance was not evaluated, in the next step four configurations of windows in the dormer with similar dimensions and various sills were designed as follows:

- Variation 1: width 1800 mm, height 1450 mm and the lower sill 900 mm.
- Variation 2: width 1800 mm, height 1450 mm and the higher sill 1550 mm, the window lintel is shifted more towards the roof ridge.
- Variation 3: width 1800 mm, height 1200 mm and the middle sill 1200 mm, the window width is dominant.
- Variation 4: width 1200 mm, height 1800 mm and the middle sill 1200 mm, the window height is dominant.

The glass transmittance of windows, dimensions of room I and position of dormer in the plane were consider the same. The wall reflectance was increased to the value of $\rho=0.80$ to achieve higher illuminance differences between designed variations. Results of calculation of Daylight Factor are presented in Figure 5 and documented in Table 2.

It is clear that the most convenient design is Variation 2, due to higher window sill which gives daylighting of sufficient intensity and uniformity. The lower window sill causes non-uniform distribution of illuminances on the work plane. Very high illuminances can be expected close to the window and low illuminances on the opposite side of the room. When resulted illuminances from rectangular windows were compared, the solution with the higher and shorter window (Variation 4) gave more uniform daylighting than that with the wider and lower window (Variation 3).

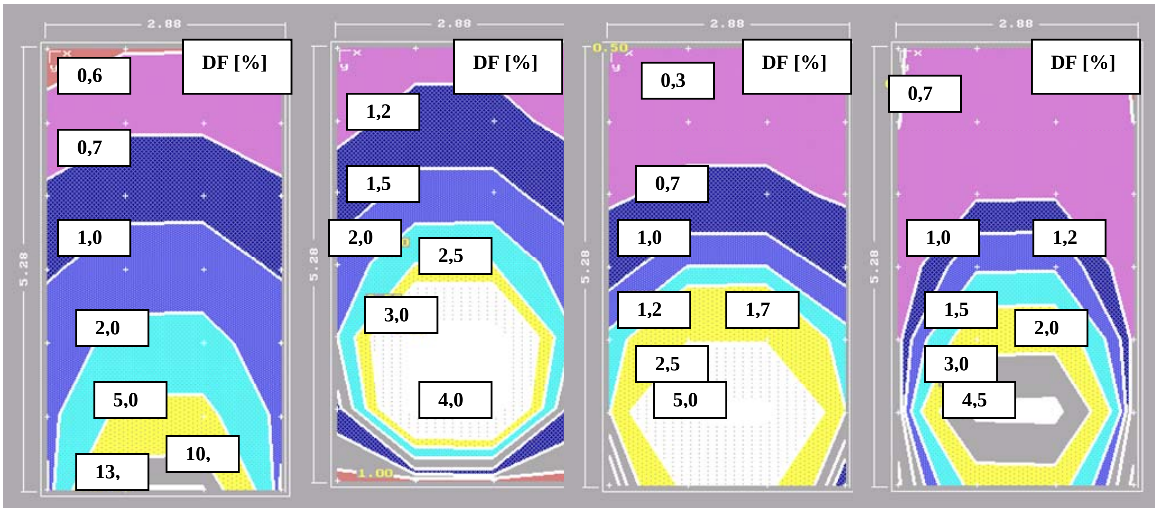


Figure 5 Isolines of Daylight Factor DF [%] distribution on the work plane calculated for four various room configurations.

Table 2 Daylight Factors in various rooms with dormer

Daylight characteristics	Variation 1	Variation 2	Variation 3	Variation 4
Minimal value of DF_{min} [%]	0.47	0.82	0.30	0.67
Maximal value of DF_{max} [%]	13.80	5.61	6.73	5.33
Average value of DF_{aver} [%]	4.34	2.54	2.05	2.24
$r_1=DF_{min} / DF_{max}$ [-]	0.03	0.15	0.05	0.13
$r_2=DF_{min} / DF_{aver}$ [-]	0.11	0.32	0.15	0.30

3. Daylight measurements

As studies of daylighting in rooms with dormers are rather scarce and results of measurements in these spaces missing it was decided to verify calculated values of Daylight Factor by measurements. The digital illuminance meter LX 105 LUTRON was used for the illuminance measurements (measuring range 0-50000 lx, serial number L404120).

Daylighting in grid points on the work plane 850 mm over the floor (see Figure 6) was measured in room I during a chosen overcast day. The exterior illuminances were measured on the non-obstructed horizontal outdoor plane three times, i.e. in the start, in the middle and in the end of the experiment. In this way, from the taken values the average exterior illuminances were calculated. Because the measurements were repeated three times, three exterior illuminance levels from E_h = 6692 lx to E_h = 6915 lx were found. The comparison of the final evaluation of Daylight Factors determined from measurements and calculations is presented in Table 3. Generally it can be stated that higher values of illuminances were measured in all investigated points. The smallest differences of 20% were calculated in the zone close to the window. In the deeper parts of the room differences were raising from 65% to 83% while the highest 225% were found in the part opposite the dormer window. Such higher differences between measured and calculated Daylight Factors can be explained by limitations and processing of measurement and evaluation methods.

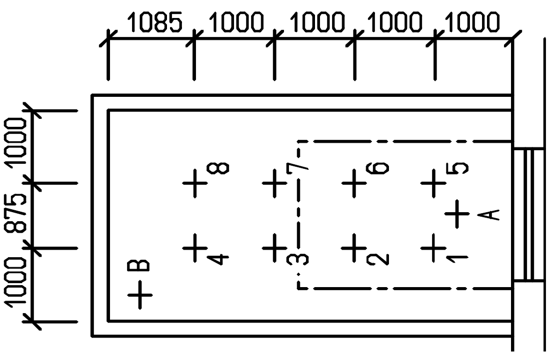


Figure 6 Scheme of the grid of measuring points on the work plane

When one illuminance meter is used to measurements of exterior and interior illuminances during no ideal and stable overcast conditions then the exterior daylight conditions cannot be correctly determined. Moreover, changes of sunheight during day have to be also considered. Therefore it is important to measure interior and exterior illuminances simultaneously.

To carry out daylighting by measurements in situ in accordance to requirements of CIE Overcast Sky model correctly is a very difficult task. The main problem is to find appropriate day with these conditions. Results of measurements in the presented case study show that sky luminance gradation in front of the window differed from CIE overcast sky gradation 1:3. Seeing that Daylight Factors in the deep part of the room were measured 3.6 times higher than calculated indicates higher sky luminances close to the horizon, i.e. exterior daylight conditions different from standardised overcast.

Table 3 Comparison of measured and calculated data

Point on the work plane	**Measurements**		**Calculation**
	Illuminance *E* [lx]	***DF* [%]**	***DF* [%]**
1	365.2	5.4	4.45
2	241.5	3.6	2.16
3	130.5	1.95	1.09
4	88.4	1.30	0.40
5	359.7	5.30	4.45
6	240.1	3.50	2.16
7	138.2	2.05	1.09
8	89.9	1.30	0.40
A	448.8	6.60	5.86
B	87.0	1.30	0.36

4. Conclusion

When renovating buildings with pitched roofs investors can require installation of dormers in attics. Generally it is valid that optimal daylight conditions in attics with dormers depend mainly on their window dimensions, position on the roof and optical properties of inner surfaces. Rectangular shape of the dormer window with higher vertical size is a more convenient solution than window with higher horizontal size. Moreover, light transmittance of window glazing and reflectance of inner surfaces can significantly improve daylighting in attics, therefore values of these parameters should be as high as possible.

Daylighting is one of major requirements for creating a healthy indoor climate in buildings. As dormers can contribute to daylighting solutions in attics, several configurations of dormers in two real rooms were investigated. Results of the Daylight Factor calculations and illuminance measurements were presented in this study to show that

- The continuous dormer gives better daylight uniformity in rooms than separated dormers of the same glazed area and position on the roof.
- The separated dormers give higher illuminances directly under the dormer, i.e. close to the window. It is caused by the reflectance of inner surfaces in the dormer.
- Higher indoor illuminances can be expected when dormers are designed closer to the roof ridge.
- Higher windows in dormers give higher illuminances than wider windows with the same sill and glazed area.
- Differences between measured and calculated values can depend on the depth of the room.
- The real sky luminance gradation has to be checked at least at the start, the middle and the end of the measurement to insure the conditions required by CIE Overcast Sky standard.
- The simultaneous measuring of exterior and indoor illuminance with two illuminance meter is needed for correct evaluation of Daylight Factor.

Acknowledgement

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Daylighting was calculated using the computer program DenDql, author Ing. T. Maixner, DQL, CR.

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ON THE SUBSTITUTION OF INCANDESCENT LAMPS BY COMPACT FLUORESCENT LAMPS: SWITCH ON BEHAVIOUR AND PHOTOMETRIC DISTRIBUTION

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When considering the replacement of incandescent lamps by screwbase integrated compact fluorescent lamps (CFLs), we must ensure that the CFL will provide satisfaction to the users in order to avoid the hark-back to the inefficient technology of incandescent lamps. One of the possible reasons of the users' disappointment is the perception of the quantity of the luminous flux of these lamps. The first cause of this bad perception is the lamp photometric distribution which can affect the illuminance of the task areas and the background environment. The second is the time it takes before the nominal flux of the lamp is reached.

The first objective of this paper is to analyze the time required for different CFL to reach their nominal flux. While some lamps start rapidly (1.5 minutes to reach 90% of the nominal flux), others require a very long delay to reach their nominal flux and to stabilize (more than 15 minutes to reach 90% of the nominal flux). This delay is difficult to foresee and differences appears even for same type of lamp (model and brand), for different powers.

The second objective of this paper is to determine the photometric distribution of various types of CFLs. While quad and three tubes lamps have very different photometric curves (radiating more horizontally than vertically) compared to incandescent bulbs, the photometry of CFL with bulbs is very similar to the photometry of incandescent lamps. Simulations of these lamps placed in a room were carried out and they did not show great variations of the room illuminance, for the different lamps.

Keywords: Compact fluorescent lamp; Photometric distribution, Warm-up time, Energy savings.

1. Introduction

The use of screwbase Compact Fluorescent Lamps (CFLs) can reduce drastically the lighting consumption of dwellings. The replacement of standard incandescent bulbs (GLS) by CFLs can enhance the luminous efficacy by about 75%, resulting in a reduction of the lighting installed power and, therefore, of the consumption. But beside all the advantages of CFLs (high efficacy, longer lamp life time), some barriers have impeded their spreading. These barriers were flashing and flickering, noise, warm-up time, cost, lifetime, size, colour and light output equivalent [1]. These last years, lots of improvements have been made to reduce the size and by now, nearly all CFLs are using electronic ballasts reducing thus flickering and noise [2]. The cost is not a really relevant problem because, as CFLs have a lifetime much higher and consume less than traditional incandescent lamps, the return of investments on CFL is quite short [3]. The resulting mains barriers are thus lifetime, colour, warm-up time and light output equivalent.

Some studies focus on these points. In [4], Serres analysed the stabilisation time of integrated CFLs. He concluded that some CFLs should be operated for more than 2 hours to reach their nominal flux. However, his study is quite old and evolution on CFLs these last 10 years are huge. The study on the distribution of different CFLs for a table lamp is performed in [5]. The conclusions are that the lamp position and geometry can have a significant effect on the light output, distribution and shade losses. In [1], the colour and the warm-up time of different CFLs were measured. For the colour, results show that colour temperature and chromaticity coordinates can vary widely. These variations have been found between manufacturers but also within manufacturers' own CFL product line. Concerning the warm-up time, all the tested lamps needed less than 23 seconds to reach 80% of their nominal flux.

The objective of this paper is to analyse two of these four barriers; the warm-up time and the photometric distribution of different kinds of compact fluorescent lamps.

In the first part, the measurement method and material are presented, ass well as the tested lamps. The second part presents the results of these measurements. Analysis of these results leads to some advices to replace incandescent lamps by CFLs.

2. Materials and Methods

This section presents the tested lamps and the methodology to measure their photometric distribution and their warm-up time.

2.1 Lamps tested

During this study, 12 lamps (10 CFLs and 2 incandescent lamps also called General Lighting Services - GLS) were analyzed. These lamps can be sorted according to their shape and power. Table 1 presents the different sorts of lamps tested.

2.2 Photometric bench

Measurements were carried out on a test bench in a black room (see Figure 1). The bench consists of an illuminance meter (Hagner EC1-X) placed on a mobile carriage; a lamp socket on a stand with 2 orthogonal axes of rotation and of shielding screens to avoid external reflections. The relation between the measured illuminance and the lamp intensity is given by the following relation:

$$E = \frac{I \cos(\theta)}{d^2} \qquad (1)$$

where E is the illuminance, I the intensity, d the distance between the lamp and the receiving surface and θ the angle between the normal of the receiving surface and the direction of emission. In our case, *d* was fixed to 1m and $\cos(\theta) = 1$.

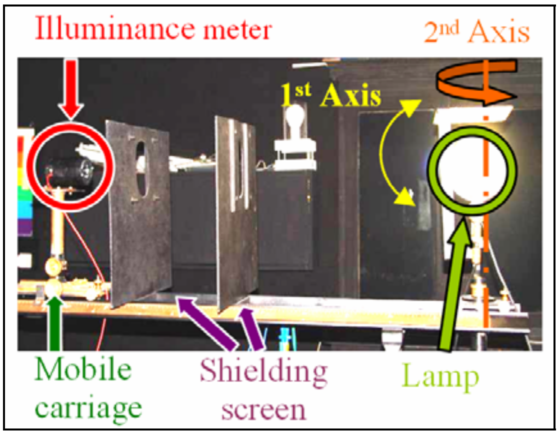

Figure 1 The photometric bench

Table 1 Descriptions of the tested lamps

Acronym	Name	Shape	Power	Warm-up
MCE	Megaman Cat's Eye	Globe with Phosphorescent coating	11W	/
MCR	Megaman Compact Reflector	Reflector	7W	/
OF	Osram Facility	Triple tubes	14W	Quick start
PG	Philips Genie	Triple tubes	11W 15W	/
PS	Philips Softone	Globe	12W 20W	/
PT	Philips Tornado	Twisted tubes	20W	/
SBS	Incandescent Sylvania Brilliant Satin	GLS frosted bulb	60W	/
SCC	Incandescent Sylvania Classic Clear	GLS clear bulb	60W	/
SML	Sylvania Mini-Lynx	Quad	11W	Fast start
SML	Sylvania Mini Lynx	Triple tubes	15W	Fast start

2.3 Warm-up time measurement

Before testing, the lamps were seasoned 100h in vertical base-down position [6].

Illuminance measurements are taken every 10s after switching on the lamp. The measurement stops when there were no significant changes in the values within 1 minute. The values of illuminance during the warm-up can be divided by the nominal value (value after warm-up) in order to get the relative flux.

2.4 Photometric measurement

To obtain the photometric distribution of the lamps, values of intensities were obtained for different angles following the two axes of rotation of the lamp (see Fig.1). Elevation (θ) was varied by steps of 10° from 0 to 180°. Azimuth (φ), was varied by steps of 45° from 0 to 360°. Figure 2 shows the two angles for the lamp *"Sylvania Classic Clear"*.

With these values, the 3D photometric distribution is represented by 138 points and the photometric curves can be traced for the C0-C180, C45-C225, C90-C270 and C135-C315 planes.

Values of intensities can also lead to the calculation of the luminous flux of the lamps. This calculation is made by spherical integration.

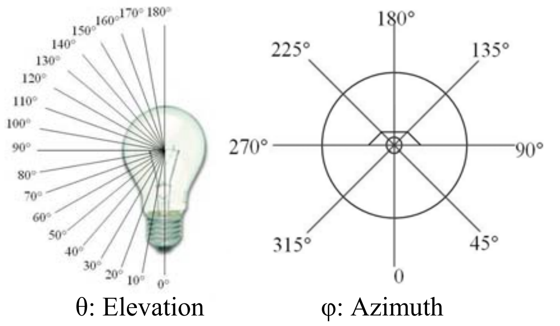

Figure 2 Elevation and Azimuth angle for the "Sylvania Classic Clear" lamp

The relation between flux and intensities is:

$$\Phi = \iint_{4\pi} I d\omega \qquad (2)$$

where Φ is the luminous flux and I the intensity. Eq. 2 can be written using the Azimuth and Elevation:

$$\Phi = \int_{\theta=0}^{\pi} \int_{\varphi=0}^{2\pi} I(\varphi,\theta) d\varphi \sin\theta \, d\theta \qquad (3)$$

2.5 Top-Side-Bottom contributions

Another representation of the photometric distribution of the lamps can be made. For each lamp, the intensity diagram can be divided in three areas: the top section, the bottom section and the side section (see Fig. 3). The top section is the area delimited by elevation angles from -60° to +60°. The side section is the area delimited by angles of elevation from 60° to 120° and from 240° to 300°. The bottom section is the area between 120° and 240° of elevations.

The light contribution can be calculated for each of these sections. This contribution is computed by calculating the area of the photometric curve comprised in each section relatively to the total area of the curve. This representation, which we called Top-Side-Bottom (TSB) gives an idea of the type of lamp distribution; an isotropic source has a TSB of 33-33-33 while an ideal narrow reflector lamp will have a TSB of 0-0-100.

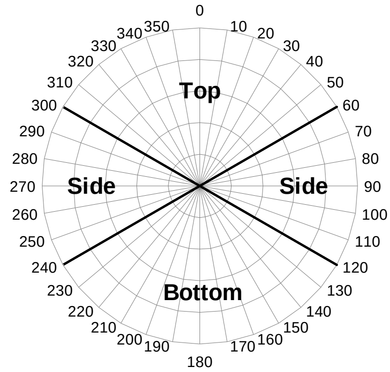

Figure 3 Top-Side-Bottom representation

3. Results

3.1 Warm-up time

The following figures (Figure 4 and Figure 5) present the relative output flux after switching on the lamps.

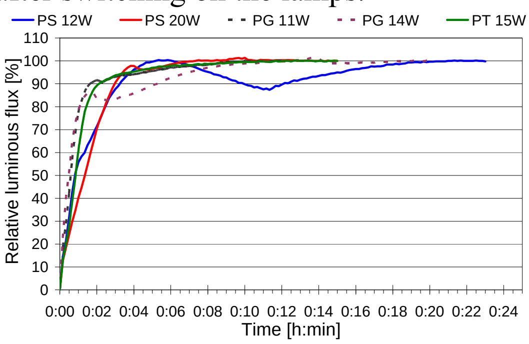

Figure 4 Warm-up time for the Philips lamps

In the Figure 4, we can observe that for two lamps of a same model (PS) but of different powers (12W and 20W), the starting behaviour is very different.

In Figure 5, we see that the incandescent lamp (SCC) has an instant start and is thus different from the CFLs. The relative flux of some CFLs (MCE and MCR) fluctuates heavily while the stabilisation of other (OF, PG, PT) is clearly faster.

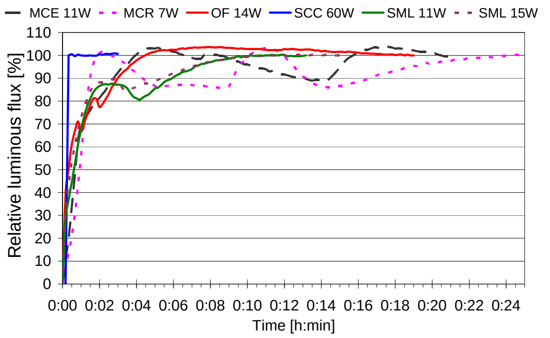

Figure 5 Warm-up time for the other lamps

3.2 Photometric distribution

After analysis of the photometric distribution, it appeared that all the lamps of a same shape have the same distribution. So, in order to present clear and comprehensible results, photometric distributions are presented only for the different shapes of lamps and not for all the tested lamps. Figure 6 shows the photometric curves for the different lamp shapes, for 1000 lm incident flux. These curves can be very different depending on the shape of the lamp. Frosted incandescent lamps are quite isotropic except from the base side of the lamp.

Clear incandescent lamps are even more isotropic but the curve is not so smooth due to the sight of the filament and its reflection in the bulb of the lamp.

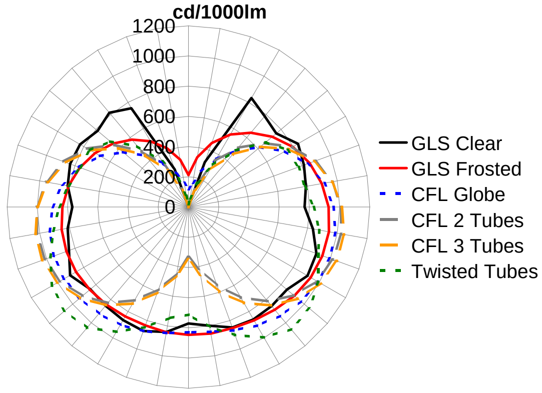

Figure 6 Photometric curves for different shapes of lamps

The curve for CFLs with globe is quite the same as for frosted incandescent lamps. The distribution of the CFLs with quad or triple tubes is rather different compared to the incandescent lamps. These CFLs radiate more horizontally at the expense of the vertical intensity. The photometric distribution of twisted tubes CFL is very similar to the distribution of incandescent lamps. The Reflector CFL has a very different distribution. Its photometric curve is presented at Figure 7.

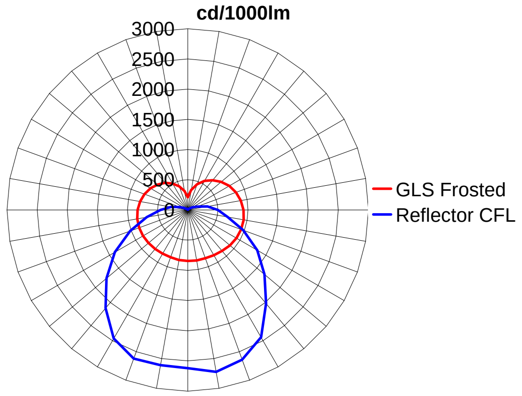

Figure 7 Photometric curves for the Reflector CFL lamp (MCR)

3.3 TSB contributions

Figure 8 presents the Top-Side-Bottom contribution for the different shapes of lamps. We can see that CFLs with globe show nearly the same results as GLS. Quad and Triple Tubes CFLs radiate more to the sides and less to the top and the bottom, as already observed on the photometric curves. Twisted CFLs are almost the same as GLS but the side and the bottom distribution is more equilibrated. Reflector CFLs, as already mentioned, directs their flux only to the bottom.

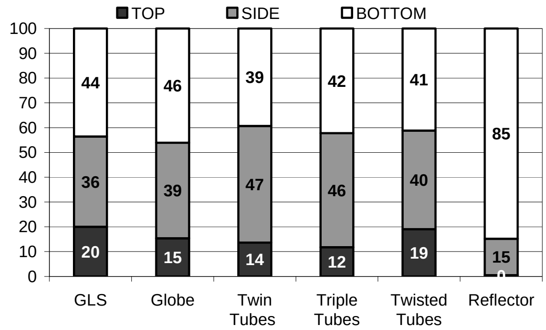

Figure 8 Mean TSB for each shape of lamp

3.4 Luminous flux

Most European lamp manufacturers advise to calculate the power of the substitution compact fluorescent lamp by dividing the power of the previously used incandescent lamp by 5. The total nominal flux of the CFL should be at least equal to the nominal flux of the previously used incandescent lamp.

Figure 9 presents value for the luminous flux as provided by the manufacturer and the measured value of the luminous flux.

We see that the differences between announced and measured luminous flux can be quite large. Nevertheless, we see that for CFLs of power less or equal to 12W, the luminous flux (announced or measured) is less than the flux of a 60 W GLS.

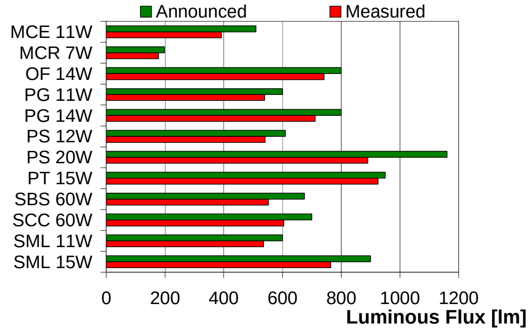

Figure 9 Measured luminous flux and announced luminous flux

3.5 Effect of the shape when using the lamps in a room

The results show that the lamp shapes can affect the photometric distribution. The aim of this part is to study if this difference in the distributions can have an impact of the light distribution in a room.

From the measured lamp distributions, Eulumdat files were created. Then these files were integrated in the software DIALux to make illuminance simulations on a room. The room sizes are 5 m long and 4 m wide with a height of 2.8 m. The reflection coefficients are 0.7 for the walls and the ceiling and 0.2 for the floor. The maintenance factor has been fixed to 0.7. Two lamps (without luminaires) are positioned in the room with respective coordinate (1.25,2) and (3.75,2) at 10 cm of the ceiling. The flux of the lamps has been fixed to 1000 lm. So, only the photometric distributions of lamps change between two different simulations. Fig. 10 gives a representation of the room.

For each simulation, mean illuminances were taken respectively for the workplane (at a height of 0.8 m), the roof, the ceiling, and the walls.

Figure 10 Representation of the room

We can see in Figure 11 that, except for the reflector lamp, the differences in mean illuminances on the different parts of the room are very small.

4. Discussion

This section discusses the results of the measurements and is divided in three parts: the warm-up time, the photometric distribution and the consequences of these results.

4.1 Warm-up time

As observed in Fig. 4 and Fig. 5, the warm-up time of CFLs can be very different. All the lamps have approximately the same comportment to reach 80% of their flux (within 1 to 2.5 minutes). Once this level is reached, most of the lamps present a decrease of the flux before increasing again to finally reach 100%. The time it takes for the lamp to stabilize from ~80% to 100% depends heavily on the lamp. Some of the lamps also present one or two fluctuations between these values. They take thus quite a long time to reach their full flux.

The differences between the warm-up time of the lamps can not easily be foreseen because it seems to be unpredictable. Indeed, even in a same type of lamp of a same brand but of different power, the warm-up behaviour can be very different (PS12W and PS20W).

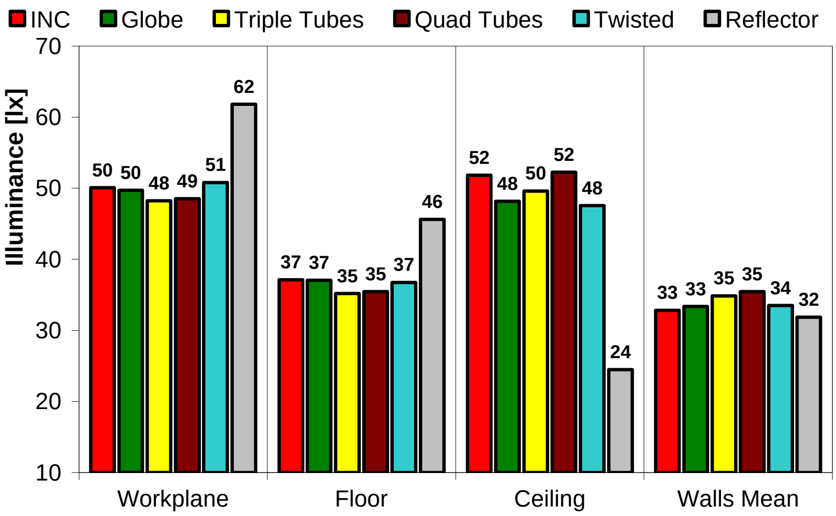

Figure 11 Mean illuminances on the workplane, the floor, the ceiling and the walls

4.2 Photometric distribution

The lamp shape has a great influence on its photometry. The CFLs with a globe present nearly the same photometric distribution as incandescent lamps. As these lamps look like incandescent bulbs, they are good replacement lamps, when visible (not hidden by the luminaries). Naked quad or triple tube CFLs present a great difference in their photometric distribution, compared to traditional incandescent lamps. Most of their flux is emitted horizontally while GLS bulbs emit preferably vertically. However, very small differences were found in the light distribution of the room. The major problem of these lamps is thus not their photometric distribution but their aesthetic aspect. These lamps should be preferably used in closed luminaires or luminaries hiding the lamp. The same interpretation can be done for the twisted tube CFLs. The reflector CFLs are not expected to replace standard GLS bulb but small incandescent reflectors. So the analysis of these lamps is purely informative and no advice can be made. The replacement of GLS bulbs by this kind of lamps is not appropriate because of their difference in their application fields.

4.3 Power, luminous flux and warm-up time

Most of the European manufacturers announce that an incandescent bulb can be replaced equivalently by a CFL having a power equal to the incandescent lamp power divided by five. Luminous flux of the lamps was thus measured. The analysis of the differences between measured and announced flux leads to the conclusions that the method used (integration of measured intensities) is not very precise. However, the manufacturers data's leads to affirm that the division by five is not really correct and that the flux is lower for the CFLs with power of one fifth of the power of GLS. It should be preferable to consider a division of the power by four. In this way, the luminous flux is slightly higher than the one of the incandescent bulb. This higher flux can lead to different advantages. Firstly, it will compensate the differences in the Life Lumen Maintenance Factor (LLMF) between the two kinds of lamps. Indeed, GLSs have a LLMF of 0.93 while CFLs have a LLMF of 0.85 [7]. If, at the end of the life of each lamp, we want to reach the same flux, we must install a CFL with a higher flux. The flux of the CFL must be higher by a factor of $1-\frac{0.93}{0.85}\approx 10\%$ [8].

The second advantageous effect of having a higher flux for the CFLs is that it will compensate the warm-up time. Indeed, let's consider a CFL giving 800 lm (14W CFLs) compared to GLS giving 700 lm (60W). The 700 lm flux is reached for the CFLs when 88% of the full flux is reached. So, the output of the CFL is equivalent to the output of the GLS within approximately 2 minutes. If the CFL had a flux of 700 lm, it would take more than 10 minutes to reach the same flux.

Beside photometry and warm-up time, other parameters could influence the luminous flux of the CFLs and have an impact on the user's perception. These parameters are the lamp position and the temperature but they have not been tested in our study.

5. Conclusion

This paper proposed to analyze two barriers affecting the use of integrated compact fluorescent lamps in domestic applications. The first one concerns the warm-up time of these lamps. The second one focuses on the photometric distribution of the CFLs.

If we look at the warm-up time of the CFLs, we found out that they do not reach their full flux immediately. The time needed to reach their full flux can be quite long and varies between the lamps. Some of them can be “fast”, reaching 90% of their nominal flux within 1.5 min. Others take more than 17 min to reach 90% of their nominal flux. The time it takes to the lamps is quite difficult to foresee when buying them because some lamps have written “fast start” on their packaging but are in fact not faster than others. Without testing them, the warm-up time cannot be predicted.

Concerning the photometric distribution of the different lamps, large difference can be found. The major differences concern CFLs with naked quad or triple tubes which radiate more horizontally. However, these differences do not lead to significant differences for the light distribution in a room. So the conclusions are that the photometric distribution is not a real problem for the use of CFLs.

At last, looking at the equivalent power of CFLs, the conclusions are that most of the European manufacturers give wrong advice on the equivalent power of their CFLs. Generally, users which follow their advice will not be happy with the quantity of light they receive from the lamp. It is preferable to divide the power of incandescent lamps by 4 (instead of 5) to obtain the power of the equivalent CFLs. In this way, CFLs would give more light filling in their inferior life lumen maintenance factor and longer warm-up time.

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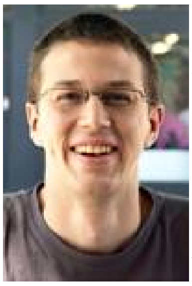

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CENTENNARY OF SOLID STATE ELECTROLUMINESCENCE

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1. Introduction

During the present boom of solid state lighting few people are aware of the fact that the first description of solid state electroluminescence dates back to 1907[1], when Round fund that when a carborundum (SiC) crystal is contacted with a needle, a faint – mostly blue glow can be observed in the vicinity of the point contact. Some fifteen years later Lossew investigated the phenomenon in more detail[2,3,4]. Using present day terminology one would call the effect injection electroluminescence at a metal-semiconductor junction. The efficiency of light generation was however so low that no direct practical application was envisaged.

Some further 12 years later Destriaux described electroluminescence on thin films prepared by embedding ZnS powder in a dielectric matrix and placing this in a high alternating current field[5]. This type of solid state electroluminescence got practical application, although it did not attain the efficiency and widespread practical application that was hoped. It is still used in the form of some electroluminescent displays.

The big breakthrough was achieved when injection got systematically investigated in III-V compounds, i.e. for visible light first in GaAsP[6]. The knowledge obtained by the investigation, and practical use of semiconducting materials enabled physicists to build semiconducting p-n junctions, where the bandgap of the material corresponded to electron-energies of visible radiation, and thus when the injected current carriers recombined light was produced.

From the 1960's on questions of direct and indirect recombination (with their different emission probabilities) got understood, together with other phenomena of non-radiative recombination and the production and doping of higher bandwidth materials. This had as consequence a continuous increase in efficiency and the production of light emitting diodes (LEDs) of shorter and shorter emission wavelength. First red, then amber and finally green light emitting diodes came onto the marked and slowly became the prime sources for signalling applications in house-hold appliances and electronic instruments. They became also used in small, mainly seven segments displays. This application became the first challenge for photometry and colorimetry, as the visual brightness of these red and green displays differed from the measured luminances[7]. Unfortunately little attention was given by the CIE in those days to these findings.

Real attention to LEDs as light sources was obtained only when Nakamura succeeded to close the gap of the hue circle by producing also blue emitting LEDs (see e.g.[8]). This opened up the way for many further applications: using red, green and blue LEDs one could produce any shade of light (within the gamut area of the three basic colours), including white light, thus the application became interesting both for full colour displays and eventually general illumination.

The past ten years of technological progress increased the efficacy of both the coloured LEDs and of a special sort of white light producing LED family, the LED using a blue light emitting chip and a yellow phosphor converting part of this light into longer wavelength radiation, so that the mixture of the blue plus yellow light produced the sensation of white light.

At present one experiences a very rapid increase of the efficacy and of the luminous flux per LED unit, so that the LED light sources become a challenge for more and more applications. While a few years ago one could state that the coloured LEDs are an alternative light source in signalling applications, as they can produce coloured light with higher efficiency as any other general purpose white light source with an external colour filter, and thus became the main light source in traffic signals, but the white LEDs had to find niche applications where they could compete with traditional sources, as e.g. in refrigerated surroundings (as their efficiency rises with temperature decrease, just opposite to that of e.g. fluorescent lamps) or in applications where their high rigidity was of advantage.

White light LEDs compete now a day in efficacy with fluorescent lamps, coloured LEDs become the main sources for large area displays, and the colour changing possibilities of red-green-blue LED combinations make them much desired in artistic applications.

For all above applications the photometric and colorimetric characteristics of these sources have to be measured. CIE was able not to change the fundamental photometric system since 1924, and also its colorimetric system got only slight amendments during the past 76 years. It looks, however, that while it was possible to use the same photometric and colorimetric system while the change came from incandescent lamps to fluorescent and high-pressure gas discharge lamps, some more fundamental considerations will be necessary to cope also with LED lighting. In the following paper some of the questions, where according to the view of the present author new thinking is necessary, should be enumerated.

2. Challenges for CIE produced by LEDs

2.1 Photometric and colorimetric fundamentals

Photometry is built on the $V(\lambda)$ function. As early as 1951 Judd proposed a modification[9] of this function, which was not accepted, as the general opinion of the applied experts was that – for white lights – the difference is too small to be of any practical importance. CIE published the modified $V(\lambda)$ function in xxx as the $V_M(\lambda)$ function[10], but the Meter Convention has still not included it as a photometric actinic function into its system, thus no instrument can be calibrated legally to show photometric values based on the $V_M(\lambda)$ function, despite the fact that it would better describe visual impression we get for the light of a blue emitting LED. The differences are not negligible, as show in Table 1 on the example of a red, a green and a blue LED. The table shows also the effect if using a phosphor coated blue LEDs to produce white light.

Table 1 Luminous flux calculated on the basis if the $V(\lambda)$ and $V_M(\lambda)$ functions

LED light source	Lum. flux calculated using $V(\lambda)$ function	Lum. flux calculated using $V_M(\lambda)$ function
Red LED	12,7	12,7
Green LED	62,5	62,5
Blue LED	6,71	6,79
White p-LED[1]	99,8	100,21

Due to the fact that the brightness of coloured lights does not correlate with luminance (also not if the $V_M(\lambda)$ would be used), and the blue LED will not be used for task illumination, where luminance might be a good measure, this in itself is still not a convincing argument to change the photometric system.

If, however, also the colorimetric characteristics are considered, the situation looks quite different: If one matches e.g. the white light produced by an RGB-LED[1] with that of an incandescent lamp visually and measures the tristimulus values of both lights, one gets considerably different values[11]. Table 2 shows the measured chromaticity co-ordinates of the two lights matched in colour. In this case the calculated CIELAB colour difference – for adaptation to the incandescent lamp light – is $\Delta E_{ab}^* = 10{,}8$.

Table 2 Chromaticity co-ordinates of the light of an RGB-LED and of an incandescent lamp that match in colour visually, and CIELAB colour difference, assuming adaptation to the light of the incandescent lamp

Lamp type	*x*	*y*
Incandescent	0,4513	0,4100
RGB-LED	0,4431	0,3991

CIE TC 1-36 developed *L*, *M*, *S* cone fundamentals[12] that correlate better with the average human eye spectral sensitivities, based on these fundamentals Wold calculated colour matching functions[13] (CMFs), and we tested these not only by using the single white colour match, but also for a number of coloured lights and got the result that the CMFs based on the cone fundamentals provide much better agreement with visual matches then the CIE 1931 CMFs[14].

Figure 1 shows the chromaticities of visually matching lights of an RGB-LED cluster and an incandescent light, both using the CIE 1931 CMFs (Figure 1.a) and those based on cone fundamentals (Figure 1.b). The red diamond shows the measured chromaticity of the reference incandescent lamp, the yellow points are averages of matches performed by our nine observers, their average is shown by the blue rectangle. The yellow ellipse has been

[1] In the following a white light emitting LED configuration if it is produced from three chips emitting in the red, green and blue part of the spectrum, respectively, will be called GRB-LED, and if it is produced from a blue chip plus a yellow phosphor it will be called p-LED.

drawn to show average scatter of the many settings of the observers[2].

Results of a second experiment are shown in Figure 2. Here the incandescent lamp was filtered by a number of colour filters, and visual match was obtained by adjusting the currents of the LEDs. Again Figure 2 a. shows the measured chromaticities, now in the *u*',*v*' co-ordinate system, using the CIE 1931 CMFs and Figure 2 b. shows them for the cone fundamental based system.

As can be seen from the figure the matches become quite good in the white, yellow, red part of the diagram, in the blue part they are sill not hundred per cent good, but the difference between the visual match and the instrumental becomes much smaller by using the new proposed CMFs. Further work is needed in this field, but definitely CIE has to address this question not only from the theoretical point of view of the cone fundamentals, but also for suggesting an (alternative, supplementary?) colorimetric system that can be used also for LED lighting.

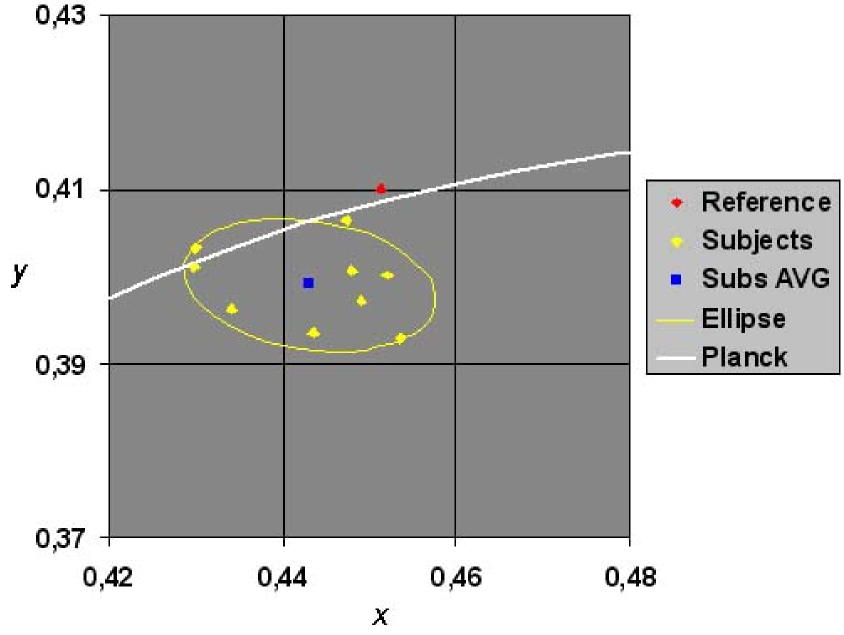
2.2 Practical photometry and colorimetry

Both in photometry and colorimetry one is also faced with the problem, what uncertainty one has to expect by using commercial instruments to measure LED lights. While national laboratories agree already to a few per cent in their measurement results when measuring LEDs, the applied engineer is still let in darkness if practical measurements are to be taken, e.g. coloured LED traffic lights have to be evaluated. There are several recommendations how the spectral mismatch of a photometer should be described in case of LED measurements[15,16,17], but non of these got CIE acceptance yet.

The new draft edition of CIE Publication 127[18] introduced a number of new definitions, helping LED users to get more reliable results – and more importantly – results that can be compared in different laboratories. These are restricted, however, to geometric descriptions (partial flux measurement), and do not deal with the very important question of real application: under what electrical and thermal conditions have the LEDs to be measured. One could argue that these items are outside of the scope of the CIE, but without defining them no meaningful comparisons of the performance of the LEDs can be made. LEDs are highly temperature sensitive devices. With present high intensity LEDs the semiconductor materials are stressed to their limits. Manufacturers like to refer to junction temperature, but the user has access only to the base plate temperature of the LED. Some standardization is urgently needed as users are presently unable to evaluate the available LEDs according to their need. Just think about a big LED billboard, that has to produce a large enough contrast under direct sunlight, at outside temperatures of 35 °C. How can one select the appropriate LED if the temperature dependence luminous flux (or intensity) of the LED, and the relationship between the outside temperature and the chip temperature under the given, pulsed condition is not known?

[2] A detailed statistical analysis of these and further measurements will be given in a subsequent paper.

a)



b)

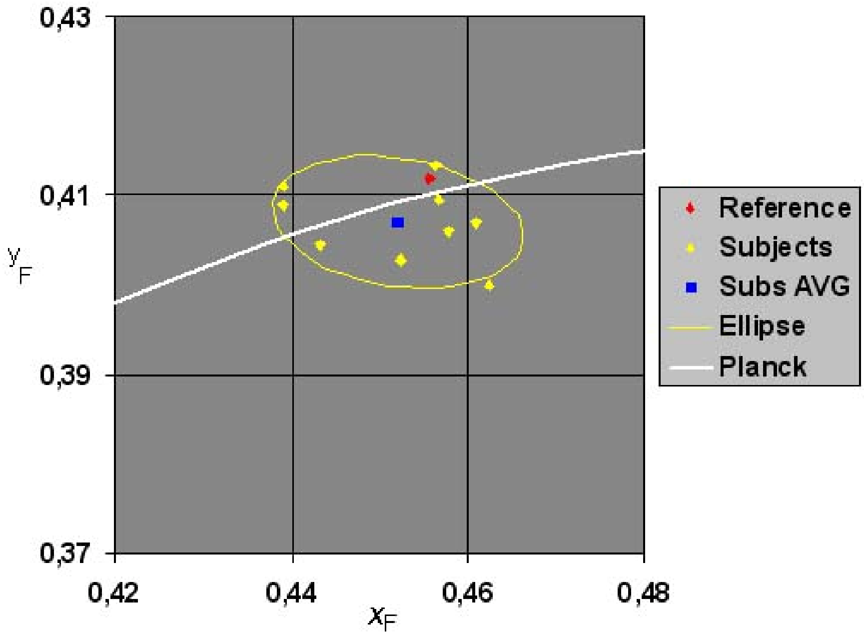
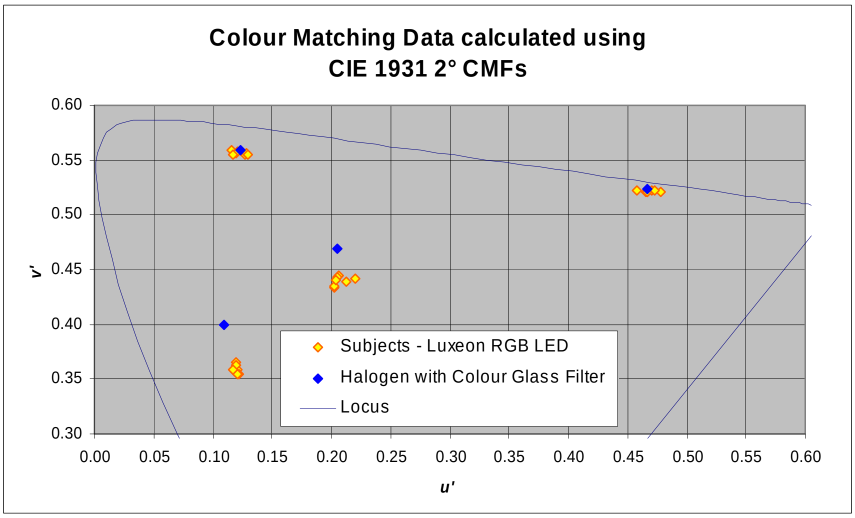


Figure 1 Chromaticities of colour matches between an incandescent lamp and an RGB-LED cluster, a) using the CIE 1931 CMFs, b) using the CMFs based on cone fundamentals.



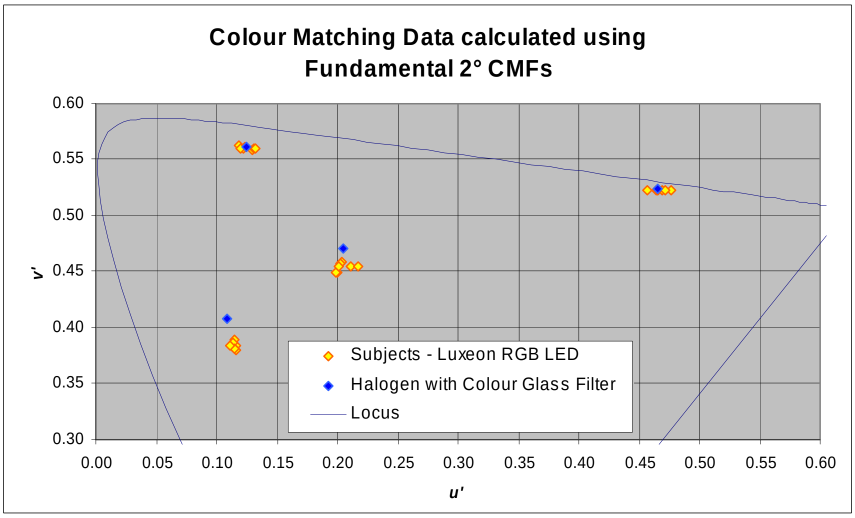


Figure 2 Measured chromaticities of a number of colour matches obtained between visual matches obtained between an RGB-LED cluster and filtered incandescent light. Figure *a* shows chromaticities for the CIE 1931 CMFs and Figure b for those based on the cone fundamentals.

In traditional luminaires only one or a few sources are mounted. In case of LED luminaires we have still a very high number of individual sources. Educators have to preach to the installation managers not to mix fluorescent lamps of different colours in one installation, because this produces undesirable visual impressions. With LEDs the problem is much larger: manufacturers have to bin their products into chromatic and efficacy classes. But what should be the size of the colour bin? How large colour difference do we perceive if say 50 or 100 LEDs are in a luminaire? For white light applications one will not try to look into the luminaire, for coloured ones – however – if it is a signal lamp, one looks directly onto the panel with the LEDs of slightly different colour. What is the physiologically permissible difference among the single LEDs? Questions that CIE vision research should answer, but where a wrong decision might be connected with large costs. CIE should probably make it clear to the manufacturers that the support of research in this area was not needed in the pre-LED area of lighting, thus no answers are ready, but it is in their interest to support research in such fields.

2.3 Colour rendering and LEDs

With the availability of white LEDs a new investigation of the CIE test method for colour rendering[19] started. Since the introduction of the CIELUV and CIELAB colour spaces several attempts were made to modernize the CIE test sample method, without a major success[20] (for a summary description of colour rendering and similar subjects see[21]).

CIE TC 1-69[22], responsible to develop a new descriptor for the colour quality of light sources, is of the opinion that a new index should not replace from one day to another the present colour rendering index, but should complement it, and hopefully replace it, when it becomes clear that it gives a better descriptor of the colour quality of the light the lamp emits than the CIE test method. In the following some thoughts that might help to understand the requirements one might have when a new metric is developed should be presented. These are based partly on literature data, and partly on the experiments conducted in the laboratory of the author and do not reflect any CIE endorsed thinking.

The wish to supplement colour rendering with further quality descriptors is not new. Judd coined the term flattery index already in 1967[23]. The flattery index was intended to describe whether a light source renders colours in a more pleasant (flattery) way than an other source. Jerome discussed the differences between flattery and rendition in detail[24]. Later the word *preference* was used instead of flattery[25]. Thornton's calculation showed that colour rendering and colour preference indices do not have their optimum value at the same spectral distribution[27]. 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[26]. Other ideas went into the direction to develop a colour discrimination index, eventually based o gamut area spanned by the test samples in a uniform chromaticity scale diagram, as there are a number of tasks where the discrimination between small colour differences is important[27,28]. All these can be supported by simulation experiments[29]. Also Davis and Ohno published on improved colour quality metrics[30].

The comfort experience in an interior setting is also influenced by the colour quality of the lighting. Bellchambers investigated visual clarity[31] 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.[32]).

An interesting new approach is based on the hue shifts of a high number of colours. This wouold show which hues are highly distorted compared to a reference and which are rendered correctly[33,34].

2.3.1 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 transformation the colours of the environment stay harmonious[35]. A further papers deal with this subject at this meeting[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 increase or decrease) the result is more acceptable compared to a colour distortion when the colours move in different directions in colour space.

A second approach was based on visual evaluation on the similarity versus dissimilarity of an image when illuminated with one light source or an other[37]. The development of a reasonable colour appearance model[38] 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 it would look under a reference illuminant (CIE D65) and under a test illuminant. With this approach one can test whether it is appropriate to use one single reference illuminant (as supposed by several critics of the present colour rendering test method), or it is more appropriate to define a number of reference illuminants depending on the task for which the lighting is used.

Pilot experiments have shown[37] that if one supposes one perfect reference illuminant (D65) then there will be a number of sources, with different correlated colour temperatures, that will rank higher than CIE standard illuminant A, which – according to the CIE test method – ranks equally high than D65. Experiments are under way with different scene arrangements (living room, office, etc.) to see whether the average observer will select as optimum CCT a different value for one ambience than for an other.

3. Conclusions

The introduction of LEDs into different lighting applications produce a number challenges for CIE. A better description of the fundamental visual functions seems to be necessary to avoid erroneous chromaticity assessments. This could have an influence also on the luminance evaluation - not speaking of the proper description of the brightness of colourer lights.

Colour rendering – or better said – the colour quality description of light sources, LEDs included is a hot topic. We think that our simulation experiment are a good method for such investigations. They 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.

In this respect visual there are experiments under way both in our laboratory and in a number of other laboratories, so that one can hope to get some important results in the near future.

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Dr. János Schanda is Professor Emeritus of the University of Pannonia, Hungary.

He graduated in physics at the Loránd Eötvös University in Budapest.

His PhD thesis dealt with the "Spectroradiometric Investigation of Electro-luminescence". The Hungarian Academy of Sciences granted him the degree of "Doctor of Technical Sciences" for his thesis work on colour rendering.

He retired from the Institute as Head of the Department of Optics and Electronics and joined the University of Veszprém (now University of Pannonia) as professor of informatics. He headed there the Department of Image Processing and Neurocomputing. Since retirement, he is Professor Emeritus and heads at present the "Virtual Environment and Imaging Technologies Laboratory".

During the nineteen eighties and nineteen nineties he worked for the International Commission on Illumination (CIE) as its General Secretary and later technical manager. He functioned also in a number of honorary positions of the CIE. From July 2007 he is the Vice President Technical of the Commission, chaired and chairs several Technical Committees, among others dealing with fundamentals of photometry, colorimetry and colour rendering. At present he is the President of the Hungarian National Committee of the CIE.

Dr. Schanda is member of the Optical Society of America, of The Society for Imaging Science and Technology and of several Hungarian Societies in the fields of light and lighting and optical measurements. He served also on the Board of the International Colour Association (AIC) as its vice-president.

He is on the editorial / international advisory board of Color Res. & Appl., USA, Lighting Research & Technology, UK, Light & Engineering, Russia and Journal of Light & Visual Environment, Japan.

He is author of over 500 technical papers and conference lectures.

Paper presented as Invited Lecture at the International Conference ILUMINAT 2007 Cluj-Napoca, Romania, 31 May - 1 June 2007

THE QUEST OF THE PERFECT LIGHT SOURCE

Georges ZISSIS, Robert RUSCASSIE, Michel AUBES
Universite de Toulouse, LAPLACE

Light is vital for life: Light sources play an indispensable role to daily life of any Human being. Our World cannot be conceived without light. Quality of life, health and, somehow, urban security related with traffic and crime prevention measures depend on light and on its quality. The lighting industry is an important economic factor in Europe, USA and many Asiatic Countries. All in all, lighting is an important socio-economic factor and lighting system development should be an integral part of any Sustainable Development and of any program of improvement of Quality of Life.

This presentation provides an overview of the present state of research in the science and technology of light sources. Existing technologies and future challenges for the lighting industry will be presented.

1. Introduction

Currently, more than 30 billion lamps operate worldwide consuming more than 2 650 billion kWh per year (19% of the global energy production world-wide). If, for an industrialised country, this amount is substantial (e.g. about 11% for France, more than 20% for US) it becomes very important for under-development nations for which lighting is one of the major applications of electricity (i.e. 37 % for Tunisia and up to 86% for Tanzania). Furthermore, the annual greenhouse gas (CO_2) due to this energy production is estimated to be in the order of 1 700 million tons. In the next 2 decades, it can be estimated that the need for light sources will increases by a factor between 1 and 2. More efficient light sources would

- limit the rate-of-increase of electric power consumption ;
- reduce the economic and social costs of constructing new generating capacity ;
- reduce the emissions of greenhouse gases and other pollutants.

In fact, an improvement of 25% in the lamp efficacy corresponds to 250 billion kWh per year energy savings as well as 150 million tons less greenhouse gas in the atmosphere.

2. Some definitions

The quality of a light source can only been defined in terms of the application for which it is designed. As the major application of light sources is lighting, the understanding of the "visual environment" is required before any attempt to optimise the light source. This visual environment consists on the light source, the object and the photoreceptor. In fact, "to see", means, using the photoreceptor to detect, to locate and to identify an object illuminated by a light source (Figure 1).

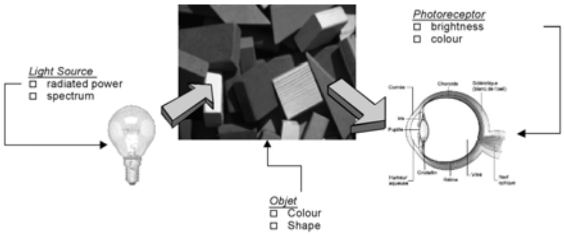

Figure 1 The visual environment

In the triad "source-object-photoreceptor" it is preferable to first examine the second item, the object, because this is a "passive" element with fixed properties. An object is characterised by its shape and its colour. The "colour" is a rather tricky idea because, as we will discuss latter, we "see" colours in our brain only. In fact, objects appear coloured by selectively reflecting or absorbing various wavelengths of light incident upon them. As an example, a red rose appears red to us (this not the case of a bee or a dog…) because it reflects light around 700 nm and absorbs all other wavelengths.

Let now focus our attention to the photoreceptor because its properties largely govern the needed visual properties of sources. In most common cases the human eye is this photoreceptor.

The eye pick up light from the source or the object and transmit the information to the human brain as two different independently perceivable signals: "brightness" and "colour", where colour is further broken down into "hue" and "saturation". The eye perceives different wavelengths and the brain "see" colours. The eye, as photoreceptor, is sensitive to only a narrow band of the electromagnetic spectrum, this band, corresponding to "visible light", stretch from 400 nm (violet) to 700 nm (red). Moreover, it is not uniformly sensitive within this pass band. The sensitivity varies with the illumination level, this is due to the fact two different type of detectors exist in the eye: the cones which perceive colour and necessitate a minimum illumination level of a few candelas per square meter (cd/m^2) and the rods which perceive grey levels corresponding to brightness, they are much more sensitive and faster than cones.

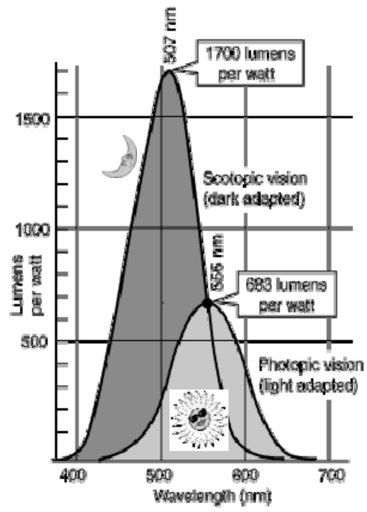

Figure 2 Relative sensitivity of the "standard" human eye under photopic (sun sign) and scotopic (moon sign) vision conditions

The Figure 2, shows the relative response of the "standard" human eye as function of the incident wavelength adopted since 1924 by the C.I.E.The first curve (moon sign) corresponds to the eye response under low illumination level, called scotopic vision. The second one (sun sign), represents the receptor's sensitivity under high illumination level, this is the photopic vision. This latter is the only one concerning lighting design because the eye is "light-adapted" than "dark-adapted" under the most illumination levels produced by the man-made light. The brightness sensitivity is related to energy by the fact that at 555 nm (this wavelength corresponds to the maximum sensitivity of the human eye) a radiant watt emitted by the source is equal to 683 lumens (lm). Thus, the lumen should be considered as a "weighted" power unit taking in to account the human eye sensibility.

The light source is characterised by the radiant power and the emitted spectrum. The efficacy of a lamp is more delicate to define; in fact we will distinguish here the "electrical efficacy" to the "luminous efficiency".

For most seeing tasks, colour perception of illuminated objects is important. If a light source has very little energy radiated in the part of the spectrum that the object can reflects then it look rather black (or grey). The Colour Rendering Index (CRI) is a measure of how well the light source reproduce the colours of any object in comparison to a black body radiating at the same "colour temperature". The CRI of a lamp is obtained by measuring the fraction of light reflected from each of a number of surfaces of specific colours covering the visible spectrum. We arbitrary attributed a maximum CRI of 100 to this light source whose most closely reproduce colours.

Depending on the intended applications, commercial light sources will have different rating for the above characteristics (see Figure 3). The particular application, and the demands of the consumer are the principal driving force in lighting research.

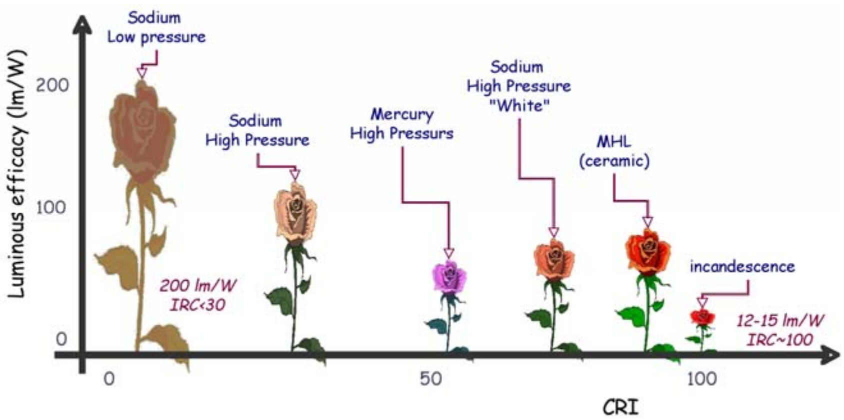

Figure 3 Rating of some electrical light sources according their CRI and luminous efficiency

3. The ideal white light source

It is possible to define the theoretical optimum light source in terms of maximum luminous efficacy at 100% radiant power efficiency for a “white” light source having good colour rendering capabilities. If one were to specify a blackbody-like spectral power distribution in the visible, with zero radiant emission at any other wavelength, then at 100% radiant power efficiency, the luminous efficacy is about 200 lm/W.

However, it proves to be possible to do better than that; radiation in the far red or far blue is not effectively utilised by the eye for either colour response or brightness response, although these extremes are customarily considered part of the visible spectral band. Acceptably good colour-rendering properties may be achieved in a light source, which is radiating in just three narrow wavelength bands: blue, green, and red. Most coloured objects have sufficiently broad reflectance spectra that they reflect light in two or more of these bands, and the eye-brain system accepts a colour definition dependent on the ratio of these two intensities of reflected light. Provided the wavelengths of the emission bands are chosen to be those corresponding to the maximum of the action spectra for the eye response to red, green, and blue, the brightness sensation perceived by the eye can be maximised simultaneously with the colour response. Light sources with such spectra can simultaneously have higher luminous efficacy than any continuous-spectrum source while maintaining nearly equivalent colour-rendering properties.

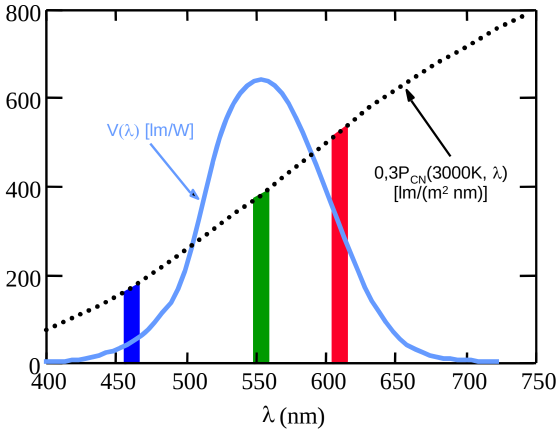

Figure 4 How calculate the maximum nominal efficiency of a white light source

For instance (see Figure 4), consider an ideal source radiating as a black body at 3,000 K the following narrow spectral lines: 450, 555, and 610 nm, the eye photopic response has the values of 51.5, 683, and 343 lm/W at the three wavelengths respectively. The resulting luminous efficiency is approximately 300 lm/W, with the apparent "colour" of the light being the same as that of a blackbody at 3000K (this a realistic CCT value for white light), and colour rendering comparable to this blackbody emitter. This figure of 300 lm/W then represents the probable upper limit for luminous efficiency of a three-wavelength-emitting source having colour rendering acceptable for nearly all-lighting applications.

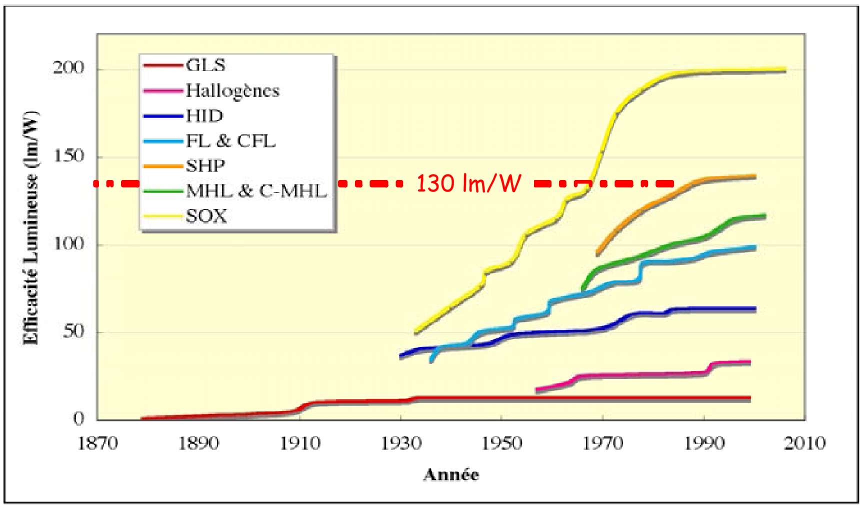

Figure 5 Evolution in the efficiency of some light source families (LEDs are not included in this graphics)

As shown in Figure 5, after increasing steadily throughout the previous seventy-five years, efficiency of conversion of electric energy into light by commercial light sources appears to have reached a plateau of about 33% of the theoretical maximum. No truly revolutionary new light sources have been introduced since the mid-1960's, marked by the debut of metal-halide and high pressure-sodium arc discharge lamps. Light source developments since then have been primarily evolutionary, with incremental improvements in efficiency. Overall system gains in lighting efficiency have in the last decade primarily resulted from the substitution of more efficient sources for less efficient ones (viz. compact fluorescent replacing incandescent). To achieve the continued load-saving challenges that will be required in the future, much greater efficiency improvements, of about a factor of two, will be required. Furthermore, from an environmental point of view a drastic reduction or elimination of harmful substances is required (viz. complete elimination of mercury).

The inability to develop dramatically improved light sources in recent decades has not resulted from lack of effort by the lamp manufacturers themselves. All of the major lamp manufacturers in the US and Europe have for many years maintained significant applied research and advanced development groups unburdened by day-to-day problem-solving responsibilities, but immersed in a highly-focused corporate climate. These groups have been, and continue to be, well aware of the limitations of existing lamps, materials and processes, and have been free to seek out better light-generating phenomena on which to base dramatically-improved products. If such phenomena were known at the present time then these groups would have explored them, modified them as necessary, and exploited them in commercial products. It seems, therefore that a fundamental reason for the present plateau in efficiency of light sources is that the industry has outrun the scientific base that has supported the technology since its inception: atomic physics and spectroscopy, and electron and plasma science, electronics and electrical engineering. Thus, the development of revolutionary new light sources having double the efficiency of current light sources can only be based on new scientific phenomena not previously considered for light source applications.

All the above discussion concerns the two main characteristics of the ideal white lamp, the luminous efficiency and CRI. Furthermore a "good" lamp should fulfil several other requirements. In fact a "good" lamp should:

1. have a high efficiency
2. have a high CRI
3. have a long life
4. produce a stable light level during its lifetime
5. avoid flickering
6. produce its nominal flux instantaneously when turned on
7. be exchangeable with other types of lamps
8. be compact and light
9. avoid harmonic distortion feedback to the electric network
10. avoid environmental harmful materials
11. avoid electromagnetic interference with any other electronic equipment
12. avoid excessive heat and UV rejection
13. be recyclable
14. be inexpensive

RECOMMENDED LITERATURE AND WEB LINKS

1. COST-529 action web: http://www.efficient-lighting.org/
2. Efficient Lighting Initiative: http://www.efficientlighting.net/
3. European GreenLight programme: http://www.eu-greenlight.org/
4. US lighting research office: http://www.epri.com/LRO/index.html
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AKNWOLEDGEMENTS

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He is born in Athens (Greece) in 1964, graduated in 1986 form Physics dept of University of Crete (Greece) in general physics. He got his PhD in Plasma Science in 1990 from Toulouse 3 University (France). Today, he is full professor in the Electrical Engineering Dept of Toulouse 3 University (France). He is working in the Centre de Physique de Plasmas and their Applications de Toulouse (CPAT). He is chairman of the European Union COST-529 "Efficient lighting for the 21st century" network, which regroups more than 70 academic and industrial institutions from 18 European countries. He is permanent member of the scientific committee of the International Symposium on the Science and Technology of Light Sources and he organized several national and international scientific on light sources and plasma technology. He is member of the French National Council of Universities for Electrical Engineering. He is vice-chairman of the Production and Application of Light (PALC) technical committee of IEEE-IAS.

Robert RUSCASSIÉ was born in Montpellier (France) in 1977. He obtained his PhD degree in Electrical Engineering in 2005 from Montpellier II University (France) working on static power supplies optimisation for urban lighting applications. Since 2007, he is Assistant Professor in Pau University. His current research activities are essentially about discharge - supply interaction and discharge lamps. He is also focused on the fields related to renewable energy and related energy savings.

Michel AUBÈS is Associate Professor of Physics and Electrical Engineering at Paul Sabatier University in Toulouse, France. He works on radiative transfer in discharge light sources and on photometrical characterization of light sources in the laboratory LAPLACE (LAboratoire PLAsma et Conversion d'Energie).

Paper presented as Invited Lecture at the International Conference ILUMINAT 2007 Cluj-Napoca, Romania, 31 May - 1 June 2007

THE 4th INTERNATIONAL CONFERENCE ILUMINAT 2007
May 31 – June 1, Cluj-Napoca, Romania

Dorin BEU
Universitatea Tehnică din Cluj-Napoca

The main national and regional lighting scientific event of the year, 'ILUMINAT 2007' international conference, was held in Cluj-Napoca between May 31 and June 1. The conference is already at the fourth edition and under the presidency of dr. Florin POP, professor with the Technical University of Cluj-Napoca. It was the last major event before the 26th CIE Session held in Beijing, with participants from Europe and Asia.

ILUMINAT 2007 conference was organized by Technical University of Cluj-Napoca, Lighting Engineering Center with the support of European research program IEE – EneRLin and Romanian research program CEEX – CREFEN. The main sponsor of this event was Energobit Schreder Lighting, golden sponsors: Luxten Lighting, Osram Romania, Philips Romania and Zumtobel (alphabetical order), and silver sponsors: Energolux, Frosys, General Electric and ElectroDaniella, Moeller Ellectric and Pragmatic Comprest (alphabetical order).

In the opening speech, prof. Wout van Bommel, president of CIE, mentioned new developments that will be presented and discussed in the conference, like LEDs and the new generation of metal halide lamps for road and street lighting and underlined that *'the subject "non visual biological effects of lighting" is becoming rapidly a subject important in designing healthy lighting installations'*. Prof.dr.ing Cornel Bianchi, president of CNRI (Romanian National Committee on Illumination), emphased *the importance of the achievement of an urban comfortable luminous environment, the transfer of the natural light in connection with electrical light inside of the buildings* and the introduction of the Certificate of Professional Competence in Lighting (Lighting Certificate), starting with 2005. In his speech, prof.dr.ing Florin POP said that *'conference allows the best knowledge of new policies and strategies to increase energy and economic efficiency, to mitigate climate change and to foster sustainable development, to build international partnerships among lighting professionals, to emphasize their cooperation'*. He also mentioned that the Lighting Engineering Center of the Technical University of Cluj-Napoca, Romania, is involved in two programs for promoting lighting energy efficiency and energy saving measures in residential buildings: EnERLIn – European Efficient Residential Lighting Initiative, an EIE – SAVE program to promote Compact Fluorescent Lamps in the residential sector, and CREFEN – Integrated Software System for Energy Efficiency and Saving in

Residential Sector, a Romanian CEEX program.

The awards of excellence underline the participants who supported the lighting activity of the Technical University of Cluj Napoca during the last 17 years:

- Prof.dr. Wout van BOMMEL – president International Lighting Committee - CIE
- Prof.dr.ing. Cornel BIANCHI – president Romanian National Committee on Illumination - CNRI
- Prof.dr. Jeong Tai KIM – LAEL - Light and Architectural Environment Laboratory, Department of Architectural Engineering Kyung Hee University, Yongin, Korea
- Prof.dr. Liisa HALONEN, Head of Lighting Laboratory, Helsinki University of Technology, Finland
- Prof.dr. Janos SCHANDA, Professor emeritus of the University of Pannonia, Hungary
- Dr. Koichi IKEDA, Honorary member of the Illuminating Engineering Institute of Japan
- Dipl. eng. Axel STOCKMAR, President of the German National Committee on Illumination.

The two days conference, held at City Plaza Hotel from Cluj-Napoca, presented 44 papers in 7 sessions, with 75 authors. Unfortunately, some of them were not ab;le to attend the conference. The ILUMINAT 2007 conference was an excellent scientific forum which allowed the exchange of ideas and the possibility of discussing many recent developments in lighting.

ILUMINAT 2007 CONFERENCE PROGRAM

OPENING SESSION

Wout van BOMMEL
Philips Lighting, Eindhoven, The Netherlands
CIE president
Professor at the Light Department of the Fudan University, Shanghai
From road lighting to city beautification - Opening Lecture

INVITED PAPERS

Chairpersons: HALONEN Liisa, POP Florin

Jeong Tai KIM
Director LAEL - Light & Architectural Environment Laboratory,
Kyung Hee University, KOREA (Republic of)
Recent research activities of LAEL in Korea

János SCHANDA
Professor emeritus of the University of Pannonia, Hungary
Centennary of solid state electroluminescence

Axel STOCKMAR
President of German CIE National Committee, Germany
Exterior railway lighting design according to prEN 12464-2 CIE S 015

INVITED PAPERS

Chairmen: STOCKMAR Axel, BEU Dorin

Cornel BIANCHI
President of Romanian CIE National Committee
Universitatea Tehnică de Construcții Bucureşti, Romania
Iluminatul urban în România – probleme actuale

Adriana ALEXANDRU
Coordinator of the CREFEN program
National Institute for Research and Development in Informatics, Romania
CREFEN – an informatic system for energy efficiency in residential sector

Liisa HALONEN, Eino TETRI
Head of the Lighting Laboratory, Helsinki University of Technology, Finland

Lighting – energy consumption and energy efficiency

Koichi IKEDA
Illuminating Engineering Institute of Japan
Precise light intensity distribution control of compact luminaire for multi purpose lighting environment

János NAGY
President of The Lighting Society of Hungary, PROLUX S.R.L., Budapest, Hungary
Rolul asociațiilor naționale de iluminat în Uniunea Europeană

Florin POP, Dorin BEU
Head of the Lighting Engineering Center
Technical University of Cluj-Napoca, ROMANIA
Residential energy efficient lighting by promoting fluorescent compact lamps under the frame of IEE programme EnERLIn

Georges ZISSIS, Robert RUSCASSIE, **Michel AUBES**
Coordinator of the EnERLIn program, Deputy director, LAPLACE (Laboratoire Plasma et Conversion d' Energie) Toulouse 3 University, France
The quest of the perfect light source

Session 1: VISION AND COLOR
Chairmen: SCHANDA János, GĂLĂȚANU Cătălin

AHN Hyun Tae[1], **KIM Wonwoo**[1], **KIM Jeong Tai**[1], **MOON Ki Hoon**[2]
[1] Kyung Hee University, Yongin, Korea, [2] KSCFC, Chungbuk, Korea
Subjective images of nightscapes in Downtown Seoul

HATZIEFSTRATIOU Panagiota
Electron S.A. Athens, Greece
Photometry and colourimetry of LED clusters

KIM Wonwoo[1], **AHN Hyun Tae**[1], **MOON Ki Hoon**[2], **KIM Jeong Tai**[1]
[1] Kyung Hee University, Yongin, Korea, [2] KSCFC, Chungbuk, Korea
Glare source in a window for evaluating discomfort glare

MOON Ki Hoon[1], **AHN Hyun Tae**[2], **KIM Wonwoo**[2], **KIM Jeong Tai**[2]
[1] KSCFC, Chungbuk, Korea, [2] Kyung Hee University, Yongin, Korea
An evaluation algorithm on the right of view using graphic programs

YU In Hye, KIM Jeong Tai
Kyung Hee University, Yongin, Korea
An improvement of luminance distribution of a large sky simulator at KH University

Session 2: DAY-LIGHTING AND INTEGRATED SYSTEMS
Chairmen: KIM Jeong Tai, LUCACHE Dorin

BIANCHI Cornel, **BIANCHI Ana-Maria**, **BĂLTĂREȚU Florin**
Universitatea Tehnică de Construcții București, Romania
Iluminatul integrat natural – electric, condiție determinantă în eficiența sistemului energetic clădire

CARTER David - Invited paper presented by Florin POP
University of Liverpool, UK
Towards design criteria for daylight guidance systems

CZIKER Andrei, **CHINDRIŞ Mircea**, **MIRON Anca**
Technical University of Cluj-Napoca, Romania
Management of indoor lighting systems using Fuzzy controllers

GRIF Horațiu Ştefan, GLIGOR Adrian, BUCUR Daniel
"Petru Maior" University of Târgu Mureş, Romania
Fluorescent daylight control system based on B-spline like network with Gaussian-type basis functions

GRIF Horațiu Ştefan[1]**, POP Mihaela**[2]
[1] "Petru Maior" University of Tg. Mureş, Romania, [2] Technical University of Cluj-Napoca, Romania
Fluorescent daylight control system based on neural controller

ŞERBAN Daniela
Technical University of Cluj-Napoca, Romania
Window with two functions, application of solar tehnology

TSIKALOUDAKI Katerina
Aristotle University of Thessaloniki, Greece
Daylight availability as a key parameter for sustainable building design: the case of Greece

Session 3: **INTERIOR ENVIRONMENT AND LIGHTING DESIGN**

Chairmen: KOICHI Ikeda, CHINDRIŞ Mircea

BEU Dorin
Universitatea Tehnică din Cluj-Napoca, Romania
Impactul aderării la Uniunea Europeană asupra proiectanților de sisteme de iluminat din România

MATEI Stelian[1], **JALBA Liviu**[2]
[1] Cape Peninsula University of Technology, South Africa, [2] Microelectronica S.A., Romania
Solid-state lighting systems - guidelines for standards in domestic and industrial applications

SAN MARTIN PARAMO Ramón - Invited paper presented by Dorin BEU
Estudios Luminotécnicos, Universidad Politécnica de Cataluña, Spain
Artificial lighting: health, environment and well-being

Session 4: **EXTERIOR LIGHTING**

Chairmen: van BOMMEL Wout, NAGY János

CHUNG Yu Gun[1], **GONG Young Hyo**[2]
[1] Chungju National University, Chungju, Korea,
[2] Korea Land Corporation, Seongnam, Korea
Outdoor lighting program of Chungju city in Korea

CIUGUDEANU Călin
Lighting Engineering Center, Technical University of Cluj-Napoca, Romania
The European GREENLIGHT programme energy efficient street lighting

GĂLĂŢANU Cătălin Daniel
Technical University "Gh.Asachi" Iaşi, Romania
Field measurement for street lighting – study case in Letcani, Romania

KONG Hyo Joo, **PARK Sung Ryul**, **KIM Jeong Tai**
Kyung Hee University, Yongin, Korea
The effect of light source on light pollution in gas stations

PARK Sung Ryul, **SHIN Ju Young**, **KIM Jeong Tai**
Kyung Hee University, Yongin, Korea
Analysis on surface luminance of shopping building by outdoor lighting

RAYNHAM Peter
The Bartlett School of Graduate Studies – University College London, UK
Public lighting in cities

SHIN Ju Young, **GONG Hyo Joo**, **KIM Jeong Tai**
Kyung Hee University, Yongin, Korea
Luminous environment of different streetscape in Seoul

VASILEV Hristo Nikolov, VELINOV Krassimir Ljubenov[2]
[1] Technical University, Sofia, Bulgaria, [2] University of Mining and Geology "St.I. Rilski", Sofia, Bulgaria
Influence of geometrical parameters and rule requirements on the optimum light distribution of the street luminaires

Session 5: **LIGHT AND ARCHITECTURE**

Chairmen: KIM Jeong Tai, ŢIGĂNAŞ Şerban

GUGLIERMETTI Franco, **BISEGNA Fabio**
University of Rome "La Sapienza", Italy
The lighting design of archeological sites: past and future of Piazza Armerina

SZABÓ Elisabeta, **ZÁGONI Csaba, OLTEAN George**
S.C. PIEME S.R.L., Cluj-Napoca, Romania
Studiu de soluții privind iluminatul Bisericii Reformate din str. Kogălniceanu Cluj-Napoca

ŢIGĂNAŞ Şerban, OPINCARIU Dana
Technical University of Cluj-Napoca, Romania
Dimensiunea culturală a luminii, Discuție între arhitecți

Session 6: **LIGHTING INSTALLATIONS**

Chairmen: BIANCHI Cornel, POP Florin

CHINDRIŞ Mircea, **CZIKER Andrei, MIRON Anca**
Technical University of Cluj-Napoca, Romania
Computation of power losses in public lighting networks

DIGĂ Silvia-Maria, RUŞINARU Denisa
University of Craiova, Romania
Considerations regarding flicker level of interior fluorescent lighting system

FASSBINDER Stefan - paper presented by Dorin BEU
Deutsches Kupferinstitut Düsseldorf, Germany
Saving energy and reducing reactive power through optimal combination of fluorescent lamps and magnetic ballasts

LUCACHE Dorin[1], **SABAG Eli**[2], **LAZAR Ionel**[3]
[1] "Gh. Asachi" Technical University of Iasi, Romania; [2] Metrolight Ltd., Netanya, Israel; [3] Optima Energy Saving Technology S.R.L., Bucharest, Romania
Microprocessor controled electronic ballasts for HID lamps. Metrolight case study

NICOARĂ Dan[1], **HEDEŞ Alexandru**[1], **ŞORA Ioan**[2], **DELIU Mihai**[3], **OANCĂ Octavian**[4]
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Experimental investigation of the harmonic pollution provided by some electric discharge lamps in distribution networks

Session 7: **OTHER APPLICATIONS**

Chairpersons: RAYNHAM Peter, DIGĂ Silvia

FEKETE Judit[1], **VÁRADY Géza**[1], **SIK-LÁNYI Cecilia**[2], **SCHANDA János**[2]
[1] University of Pécs, Hungary, [2] University of Pannonia, Hungary
Optimizing spectral power distribution of car headlamp lighting

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The comparative study between the High Pressure Sodium lamps and the new generation of ceramic Metal Halide lamps

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The Korean Bell, the Conference timer offered by Professor Jeong Tai KIM and LAEL team (2005)

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LIGHTING IN THE NEW WORLD

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The long way of CFL's to the American residential lighting

Compact fluorescent lamps (CFL) were introduced in the 1970's; however, it has taken more than 30 years for them to gain widespread recognition in the North American residential lighting market.

Although fluorescent technology is three to six times more efficient than the ubiquitous incandescent technology, CFL did not gain widespread acceptance or even acknowledgement among US and Canadian consumers until after 2001, despite efforts by electrical utilities and CFL manufacturers.

After a slow start to penetrate the commercial market, the manufacturers and many utilities were eager to cash on the promise of residential CFL lighting. In dense populated US regions as on the east and west coast, the residential lighting energy use is about 2/3 of the size of commercial lighting energy use, accounting for around 10% of the overall electricity use. Also, the average Canadian and US homes sizes increase 22% from 1985 to 2000. Furthermore, in California alone, the average number of lamps per home increased from 34 in 2000 to 41 per home in 2005.

CFLs were first promoted as replacement for the standard A line (standard/ universal bulb shape) incandescent lamp, but the early-models were not ready for prime time, with a host of technical challenges, including bulkiness, low light output and inconsistent performance.

Even if most of the technical barriers were eliminated (the screw-in, integral electronic ballasted CFLs are the norm now), North American residential adoption of CFLs seemed slow in coming, especially compared with European and Asian regions. For example, in 1996 only 10% of the US households had (some) CFL lighting, compared with 56% in Holland, 50% in Germany, 46% in Denmark and 20% in UK. Meanwhile, Japan had CFLs in over 80% of its households.

The reasons behind this significant gap of CFL adoption can be found not only in cultural attitudes toward consumption and electricity costs but also in coordination of national/regional promoting efforts and sales.

What hold the American market behind the other world regions were an amalgam of (relatively) lower electricity costs (around $0.05 in most of Canada and an average of $ 0.15 in US) and high CFL costs compared to low incandescent prices.

A recent DOE (US Department of Energy) study[1] identified the main barriers and issues that impeded the adoption of CFLs in the US market (almost similar for the Canadian market).

Consumers Barriers

Early Performance Issues – in the 80's and early 90's utilities have promoted cheaper models (to keep costs down) while the sizes and shapes were not quite aestically appealing nor properly fitting in the residential luminaires (a 1993 study showed that even with modifications the CFL's still would not fit in over 60% of the fixtures in average US home). Low light levels, delayed start, lack of dimability and poor color rendition were not the only technical impediments, most CFLs being removed in dissatisfaction also for their humming, buzzing and flickering.

Price - was a huge initial barrier with retail prices of $25 to $35 per bulb common in the mid 1980s. Even if the products lasted as long as 10 to 15 incandescent bulbs, they cost more than buying that many incandescents and required the purchase to be made all at once, rather than over time. Today, the residential CFL types are quite affordable and sold for under $5, however still 2-3 times higher than the standard incandescent lamp, but same as halogen lamps.

Consumer awareness and misperception about CFL performance - along with lack of retail availability, might have been bigger obstacles to CFL adoption than physical limitations. A review of studies done in 1992 and 1993 with three different utilities showed 40% of their customers were unaware of CFLs and close to 80% had never purchased one. A 1999 study of customers in the Pacific Northwest, where CFLs had been promoted by local utilities for years, found only 57% had heard of CFLs and of those only 42% had tried them. Many customers were also unaware that CFLs could be used in typical incandescent fixtures. Adding to the confusion was the lack of a consistent name for the new product. Several studies showed that consumers were unsure about the terms "watts" versus "lumens;" consumers consistently underestimated the amount of energy CFLs save or how long they last. A 1995 survey by Phillips of 1,000 consumers found 42% did not know the difference between incandescent and fluorescent bulbs.

Consumers' feared early CFLs: the very word "fluorescent" invoked connotations such as "harsh, cold, glaring, flickering, buzzing, artificial, and ugly" and fluorescent lighting was associated with eye strain, noise, greenish skin tones, and institutional settings. Consumer who had tried CFLs had difficulty believing the energy savings claims because most households were only willing to purchase one or two test lamps due to their high initial cost; thus, the savings would not make enough of a dent in the monthly bill to be noticeable. However, the more people use the CFL products, the more they began to accept them, and even their (unorthodox) shape doesn't seem to matter much if the lighting quality is there.

Manufacturer Barriers

Main manufacturer barriers include lack of profit motivation, lack of marketing, competition from other technologies, and fixture manufacturer issues.

Lack of marketing - a US Energy User report noted that before 1990, CFLs were really not marketed to residential customers at all; despite some isolated media demonstrations they were nearly impossible to find in U.S. retail stores and instead were selling primarily to commercial and industrial customers through wholesale channels. Any residential customer who obtained a CFL likely got it through a utility program.

Marketer failed to educate the public about the CFL technology as a consumer product. A 1999 DOE report noted that utilities and energy efficiency organizations were spending over $23 million a year to try to shift $1 billion of consumer purchases from incandescent to compact fluorescent bulbs.

Competition from other non-incandescent lighting products (such as the halogen infrared PAR lamp and high-performance metal halide lamps) also contributed to the market's slow adoption of CFLs.

Retailer Barriers

Significant retailer barriers to CFL market introduction were lack of awareness and misinformation about the technology, which resulted in a reluctance to commit shelf space to CFLs.

Lack of awareness - wrongfully, retailers relied on manufacturer representatives to train their staff on how to educate consumers about the benefits of their products, set up point of purchase displays, and even maintain inventory on the shelves.

A 1992 EPRI study of lighting retailers found that many saw it as a temporary technology that would be replaced by something else within the decade. This study found chain store lighting department managers had many misconceptions about the technology and seemed to have no more technical knowledge than the average residential customer. A California Energy Commission 1997 study of retailers showed their understanding of energy efficient lighting was surprisingly rudimentary. When asked to name their best-selling energy-efficient products, one-third included standard incandescent lamps. If they did mention fluorescent lighting, they usually mentioned linear fluorescent tubes, not CFLs.

In time, retailers realised the negative significance of the education gap and in a 1999 report on the Northwest LightWise program, 60% of the retailers interviewed still did not feel they had enough information about CFLs to adequately sell the product. Overall they felt unprepared to explain CFL benefits, wattage conversions, power quality, and differences in ballasts. Currently, utility and lighting industry (such as IESNA) education programs made significant changes.

However, even if the retailers could be better prepared to face the customers looking for an energy efficient lamp, the offer could be scarce. A marketing report published in 1999 noted that even in parts of the country where utilities had funded efficient residential lighting programs for nearly a decade, CFLs still occupied only 4% to 7% of the retail shelf space for household light bulbs.

Overall, lack of coordination among manufacturers, utilities, and retailers- constitute additional barriers to CFL market growth in Canada and the United States. The key to surmount these barriers is right in their origins. CFL sales have grown considerably in the last decade. The number of CFL manufacturers alone has jumped from less than 10 to hundreds in the past 15 years.

Numerous utilities programs and the 2001 California energy crisis have significantly increased the retail market share of CFL products, from 0.1% (of all light bulbs) in 1990 to 2% in 2006. However, the incandescent lamps mark 85% and linear fluorescents around 3%.

Help from Governments and Utilities

Presently, CFL stakeholders seem to have learned from past experience. A significant change in CFL market share is due to an impetuous push from utilities across Canada and USA.

Few utilities, have even offered free CFL screw-in lamps. In Canada, BC Hydro offered a free screw-in/ self balasted CFL to every household in British Columbia. As a result, the awareness of CFL technology is now at 90%, by 2006 over 40% of BC households have purchased additional CFL (after the free one) and over 53% (double than in 2,000) households use more than 5 CFL's.

Other utilities have promoted complete hard wired CFL luminaires (especially torchiers -pedestal uplights). A 2006 study shows that more than 11% of all luminaires in average Californian households are CFLs (ten times more than in 2,000), of which 90% were in the 13-26W range and are mostly used in the living rooms and bedrooms.

ENERGY STAR, an energy-efficient product labelling program sponsored by U.S. Department of Energy (DOE) and the Environmental Protection Agency, launched a program for residential light fixtures in 1997. This brought a clearly recognizable North American (available for Canada too) brand to a fragmented marketplace. It gave utilities and regional energy efficiency groups a benchmark of lighting performance and quality around which to rally their marketing strategies. This program inaugurated a number of high-visibility marketplace efforts, including the screw-in CFL and the compact fluorescent torchiere. ENERGY STAR offered national branding and a single set of specifications for manufacturers to design to, and helped consumers (largely unfamiliar with CFLs) to distinguish between better performing lamps and poor performing ones.

The latest help for CFLs is coming though from the political arena. Lawmakers in Australia and Canada are making the bold shift towards replacing the old incandescent Edison bulb with much more efficient light technologies such as CFLs and LEDs.

Australia is set to ban the incandescent bulbs (deadline set for 2010) and says it will cut the country's emissions by four million tonnes by 2012. The move will also cut household power bills by up to 66 per cent.

In February 2007, the Environment Minister of Ontario announced that the Canadian province is considering becoming the first province to follow Australia's lead in banning old-fashioned light bulbs. This is the push Ontario needs to save electricity and would eliminate some of the province's dependence on coal-fired power plants. Replacing every old-fashioned bulb with an energy-efficient one would allow the province to shut down one coal-fired power plant.

Also, lawmakers in two U.S. states - California and New Jersey - and in the United Kingdom have also proposed bills to ban incandescent bulbs.

LED Opportunities and Lessons Learned from CFL's

While considered a developing technology currently restricted to niche applications, (white) LED is a huge promise as both an energy efficient and sustainable solution, something that will probably transform lighting as we know it. Not only have the tiny photonic dots required significant lesser material resources, but at the present R&D effort, efficiencies of 200 lm/W could be reached by 2020.

However, displacing a 130 years old, world wide established and cheap technology (the incandescent bulb) will require a colossal and consistent promoting effort and we can only hope that the lessons of CFL market penetration will be well learned:

- Education, of both consumers and retailers, is critical. The enthusiastic and on-going participation of retailers was recognized by energy efficiency groups and utilities as one of the building blocks of successful programs, and one that needs to be acknowledged sincerely and frequently.
- Mass media is vital to widespread adoption of a new technology.
- Manufacturers should work closely with energy efficiency groups to help establish minimum performance requirements that the manufacturers can meet and the efficiency groups are willing to support.
- Performance is more important than appearance.
- Introduce new lighting technology in niche applications where benefits are clearly defined and performance is not overstated. Initial exposure is highly influential in the market and first impressions count for a lot.
- Accurate incandescent equivalency on packaging is critical.
- Understand that many people will not try a new product until price drops to a range near that of existing products providing similar functionality.

It would be wised for the moment to limit the LEDs to colour or niche applications that require low or moderate illumination.

A significant pathway towards LED market transformation is to consider a different lighting paradigm. For example, rather than using the ceiling mounted, socket and lamp approach, LEDs could be (smaller) integral luminaires located in the proximity of the visual task.

1- "Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market" by PNW National Laboratory, June 2006.

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