President of the Republic of Finland Tarja Halonen presents the Millennium Technology Prize to Professor Shuji Nakamura.

**Millennium Technology Prize 2006**

Nakamura: “Using LEDs for lighting could halve the amount of electricity consumed for this purpose”. The 2006 Millennium Technology Prize was presented to Professor Shuji Nakamura in Helsinki for his invention of new sources of light. President of the Republic of Finland Tarja Halonen handed Professor Nakamura the prize of one million euros and ”Peak”, the prize trophy. In his speech of thanks, Professor Nakamura congratulated Finland on its support for humane technological development which improves quality of life.

Professor Nakamura made his breakthrough in 1993, when he stunned the optoelectronic community with the announcement of very bright blue gallium nitride (GaN) based LEDs. Soon afterwards he presented also green GaN-based LEDs, blue laser diodes and white LEDs. These technologies can be used in several applications which improve the quality of everyday human life, such as producing light in an energy efficient and environmental friendly way. LED technology is also well-suited to operation with solar power systems, which makes LEDs ideal light sources for the remote villages of developing countries. Ultraviolet LED technology provides a method to purify drinking water cheaply and efficiently.

According to the chairman of the International Award Selection Committee of the Pekka Tarjanne, professor Nakamura’s achievement can be compared with Thomas Edison’s invention of the incandescent lamp.
The Executive Committee of the Energy Conservation in Buildings and Community Systems (ECBCS) program established a new research project (Annex) in June 2004 called Energy Efficient Electric Lighting for Buildings. Professor Liisa Halonen from the Lighting Laboratory of Helsinki University of Technology was elected for the Operating Agent of the Annex 45.

### Management of the Annex

<table>
<thead>
<tr>
<th>Operating Agent</th>
<th>Subtask A Leader</th>
<th>Subtask B Leader</th>
<th>Subtask C Leader</th>
<th>Subtask D Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland, Helsinki University of Technology&lt;br&gt;Professor Liisa Halonen</td>
<td>France, École Nationale des Travaux Publics de l’État&lt;br&gt;Professor Marc Fontoynont</td>
<td>Austria, Bartenbach LichtLabor GmbH&lt;br&gt;General Manager Wilfried Pohl</td>
<td>France, Centre Scientifique et Technique du Batiment&lt;br&gt;Mireille Jandon and Ahmad Husaunndee</td>
<td>Finland, Helsinki University of Technology&lt;br&gt;D.Sc. Eino Tetri</td>
</tr>
</tbody>
</table>

### Objectives

- Identify and accelerate the use of energy efficient high-quality lighting technologies and their integration with other building systems
- Assess and document the technical performance of existing and future lighting technologies
- Assess and document barriers preventing the adoption of energy efficient technologies and propose means to resolve these barriers

### Annex website:
lightinglab.fi/IEAAnnex45

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## New Doctors in the Lighting Field

**Effects of lighting parameters on contrast threshold in mesopic and photopic luminance range**

**Jaakko Ketomäki**

Jaakko Ketomäki studied in his doctoral dissertation how the visual system behaves in low luminance levels. These so called mesopic luminance levels are typical in e.g. road lighting conditions. As the luminance level decreases, blue light will appear brighter than red light. This effect is called Purkinje’s shift, and it is caused by the different spectral sensitivities of receptor cells in the eye. This phenomenon was studied by measuring contrast threshold with apparatus based on a modified Goldman perimeter. Mr. Ketomäki applied the data from his experiments to the existing models describing the changes in spectral sensitivity of the eye at the low luminance levels. His results showed that the changes in the spectral sensitivity of the eye caused significant differences on the contrast thresholds measured with different light spectra and mesopic luminance levels.

He also concluded that none of the compared models of mesopic vision described mesopic luminance correctly when contrast threshold was used as the visual task.

The dissertation can be found at [http://lib.tkk.fi/Diss/2006/isbn9512283344/](http://lib.tkk.fi/Diss/2006/isbn9512283344/)
Comparison of LED-based Light with Traditional Light Sources

Sophie Boissard, Marc Fontoynont, Pascale Avouac-Bastie

The objective of the work was to evaluate whether LED-based lighting can give a more relevant and more appropriate light than halogen or fluorescence lighting. To this aim, we carried out visual colour experiments to compare traditional light sources and LED-based light sources, and we used chromatic comparison instrument to evaluate the perception of objects under different lightings.

The chromatic bench

Realised with the contribution of Philips lighting, the chromatic bench is composed with 3 identical boxes located one against the other. Each of them is lit by a diffusing light source hidden in their upper or lower surface. The central and the left box are illuminated with 6 colours of LEDs: cool white, warm white, cyan, green, amber and red, and the right side is illuminated with halogen or fluorescence.

The intensity of each source can be adjusted with the help of a mixing console which enables to obtain various illuminations and various colours.

Experimental procedure

The idea of the experiment was to identify the combination of LEDs which get as close as possible to standard light sources. The samples were presented under a fluorescent light (CRI = 91; Tc = 3900 K) or halogen light (CRI = 96; Tc = 2485 K) and the subjects were asked to adjust the power of each channel of LED to match the reference sources. At the end of each equalization, when both lighting could be compared visually, each observer was asked to:

- estimate how close the LED mixing was to the reference source
- choose which light appeared the best in colour rendering.

Two targets were presented to the observers:
- A chart of colours
- A picture of a painting by Vermeer.

46 persons, 11 females and 35 males, participated in the experiment. 17 were expert in lighting or in colour, while the rest were naïve observers. Their age range from 22 to 62. Most of them had glasses (31) but all subjects had normal colour vision.

Results

Both comparison (with the Chart or with Vermeer’s painting) lead to the same conclusions concerning the estimation of the difference and the best colour rendering. Nevertheless, observers found that the equalization on a concrete scene (Vermeer’s painting) was easier.

It seems possible to find mixtures of LEDs with lighting situations rather similar to halogen or fluorescence, and that they are often preferred in colour rendering. Indeed, 75% of the observers estimated to have found a light close to fluorescent and 80% succeeded in matching halogen.

Concerning the estimation of the best colour rendering, in most cases, LED-based light was preferred by the observers and it was estimated to have a better colour rendering than halogen (for 73% of them) or fluorescence (for 44% of them).

The results obtained with perception of LED-based lighting are rather positive. This seems to mean that although the Colour Rendering Index computed with standard CIE method is low for such sources, they are accepted and often preferred.

Acknowledgment

The authors gratefully acknowledge Philips for their contribution in the development of the experimental setup.

Authors: Sophie Boissard, Marc Fontoynont and Pascale Avouac-Bastie

Laboratoire des Science de l’Habitat
Ecole Nationale des Travaux Publics de l’Etat, Vaulx-en-Velin, Lyon, France
Management of Lighting Efficiency and Human Needs

Peter Dehoff

Energy efficiency and the reduction of CO₂ emissions are issues of huge public interest. The Kyoto protocol has had a large political influence on national and international legislation. In Europe a number of directives have been issued. The most important of these is the European Performance of Buildings Directive (EPBD) and its related standards. In CEN TC 169 “Light and Lighting”, WG 9 has delivered the draft standard prEN 15193-1 “Lighting energy estimation”.

LENI

The Lighting Energy Numeric Indicator (LENI) has been established to show the annual lighting energy required to fulfil the illumination function and purpose in the building specifications.

\[ \text{LENI} = \frac{W_{\text{light}}}{A} \text{ kWh/m}^2/\text{year} \]

ELI

The Ergonomic Lighting Indicator (ELI) -as developed by the author-, in addition, takes into account the lighting requirements as stated in EN 12464 “Lighting of workplaces”. Those need to be fulfilled before looking at energy efficiency. Parameters with the matching quality criteria are in the table below.

These parameters are just some of many but they are the most commonly used in lighting. This selection is a useful approach to indicate the ergonomic value of the installation.

Test

A test environment was set up to measure energy consumption. In a three storey building two office rooms (reference R and optimised O, 16 m²) three levels of ergonomic quality in lighting were installed.

Energy consumption is measured over a whole year at Veru (Versuchseinrichtung für energetische und raum-klimatische Untersuchungen, Fraunhofer Institut für Bauphysik) which is an experimental installation for energy and indoor climate investigations.

The energy-to-ergonomic ratio of an installation might be described as the ratio of the LENI to the ELI.

<table>
<thead>
<tr>
<th>Parameters with the matching quality criteria.</th>
<th>LENI-to-ELI Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance acc. to appropriate standards</td>
<td>GF:R 4.52</td>
</tr>
<tr>
<td>glare control low luminance</td>
<td>GF-O 3.66</td>
</tr>
<tr>
<td>Right amount of horizontal illuminance acc. to</td>
<td>1.FL-R 2.75</td>
</tr>
<tr>
<td>maintained illumination</td>
<td>1.FL-O 1.12</td>
</tr>
<tr>
<td>Direct glare control (UGR ≤ 19)</td>
<td>2.FL-R 3.38</td>
</tr>
<tr>
<td>To avoid reflections on computer screens:</td>
<td>2.FL-O 1.32</td>
</tr>
<tr>
<td>( L_{65°} \leq 1000 \text{ cd/m}^2 )</td>
<td></td>
</tr>
<tr>
<td>Appearance</td>
<td></td>
</tr>
<tr>
<td>space colour</td>
<td></td>
</tr>
<tr>
<td>Bright, open and friendly space</td>
<td></td>
</tr>
<tr>
<td>Natural colour temperature and rendering</td>
<td></td>
</tr>
<tr>
<td>Comfort</td>
<td></td>
</tr>
<tr>
<td>shadows modelling</td>
<td></td>
</tr>
<tr>
<td>Soft shadows, neither too harsh nor too diffuse</td>
<td></td>
</tr>
<tr>
<td>Cylindrical illumination, friendly illumination of faces</td>
<td></td>
</tr>
<tr>
<td>Emotion</td>
<td></td>
</tr>
<tr>
<td>light distribution preference</td>
<td></td>
</tr>
<tr>
<td>Architectural lighting of surfaces and objects in the room</td>
<td></td>
</tr>
<tr>
<td>Personal preference for lighting situation</td>
<td></td>
</tr>
<tr>
<td>Individuality</td>
<td></td>
</tr>
<tr>
<td>own light</td>
<td></td>
</tr>
<tr>
<td>Personal lighting, personal use of switches</td>
<td></td>
</tr>
<tr>
<td>Lighting chosen for individual benefit</td>
<td></td>
</tr>
</tbody>
</table>

The pictures show LENI (energy indicator) and ELI (ergonomic indicator) as subjective response for each room and each installation.

LENI to ELI

The lower the value the better the balance between energy efficiency and ergonomic quality. The optimised installation on 2nd floor has a very good value. Even if the installed load is very high, energy consumption is within a reasonable range while the ergonomic quality is very high. The best ratio is the installation with the highest use of daylight control while the ergonomic value is within a reasonable range. Installations with a low installed load and a low ergonomic value show a poor energy-to-ergonomic ratio.

Author: Dipl. Ing. Peter Dehoff Zumtobel Lighting
Towards Adapted Lighting Control in Low Energy Buildings

Mireille Jandon & Ahmad Husaunndee

Work in Subtask C

Subtask C of Annex 45 will focus on controls that enable users (occupant, maintenance team, facility manager…) to modify the electric lighting according to personal needs and preferences, within acceptable building operative requirements focusing on energy savings. The personalisation and integration of the lighting system with other building systems (daylighting, HVAC, and demand energy management) via the control level will be an important part of the Subtask work.

The subtask consists of five chapters:
1. Definition of requirements/constraints of main actors.
2. State of art of lighting control systems
3. Definition of innovative lighting control strategies
4. Impact of the whole environment concept on lighting control
5. Commissioning process for lighting/lighting control systems

Integrated lighting control

The success of innovative lighting control strategies lies in the fact that it is integrated in a systemic approach of the building. This implies that communication and data exchange between the control components (such as sensors, actuators, electronic ballasts…) of different applications (HVAC, lighting, solar shading,…) becomes a key focus of control strategies. Besides, thanks to the development of non-proprietary communication buses, controllers from different vendors can easily communicate. It is possible to integrate control of HVAC, blind and light, which could enable energy savings, reduction of peak demand and improvement of comfort level.

Functional levels

Control within a building can be split into 3 functional levels: service, plant and zone level. Service level deals with the overall building energy management. Plant level is concerned about the control of the central technical equipment and its interactions with equipment distributed in specific zones. The zone level analyses the interactions between applications at the zone level only, the zone being one or a set of rooms.

Data between controllers

A good integration can be achieved through a limited data exchange. Therefore there is a need to define the data to be exchanged between controllers:
- Between service, plant, zone levels
- Between applications within a level.

At the zone level the different applications shall enable to reach predefined goals, for example:
- Provide requested thermal comfort
- Provide requested illuminance level
- Avoid glare or provide requested contrast level.

Sharing of equipment is also an important issue in order to achieve proper integration of control strategies. In order to maintain a good indoor climate the control system can generally act on the applications shown in Table 1.

Table 1. Applications involved in control strategies.

<table>
<thead>
<tr>
<th>Application</th>
<th>Visual Comfort</th>
<th>Thermal comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar protections</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Lighting system</td>
<td>o</td>
<td>X</td>
</tr>
<tr>
<td>Heating system</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Cooling system</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

"X" implies a main actor
"o" implies a secondary or minor actor

The table above illustrates the idea of sharing actuators. There is also a possibility of sharing some sensors in an integrated control approach as summarised in Table 2.

Table 2. Sharing of sensors.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Visual Comfort</th>
<th>Thermal comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature sensor</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Indoor illuminance sensor</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Outdoor illuminance sensor</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Presence sensor</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

"X" implies a main actor
"o" implies a secondary or minor actor

Continued on page 7.
Energy Savings with a Modern Lighting Controls System

Hans Baaijens

In this article it is shown, that by applying the Philips ActiLume lighting controls system in a small office, a 44% net energy savings for the lighting system can be realized on a yearly basis.

Energy savings with lighting controls

When we want to consider the energy savings with a lighting controls system, we need to answer three questions:

- What fraction of the required illuminance level during office working hours is supplied by the natural daylight?
- What is the effect of occupancy control?
- What is the energy efficiency of the lighting controls system, i.e. which fraction of the power consumption is not used for artificial light generation?

Occupancy control

In Ref. 3 a case study has been described of energy savings by occupancy control. For a small office, 30% energy savings have been found.

Energy efficiency of the lighting controls system

The lighting controls system dims the artificial light level when there is enough daylight available, or switches off if the room is unoccupied. The electronics that is needed for this consists of:

- a microcontroller, containing embedded software with control algorithms
- sensors for occupancy detection and light level measurement
- ballasts for dimming the fluorescent lamps.

It is the challenge for the lighting controls manufacturer to enable operation of the lighting controls system with lowest possible energy losses in the electronic components. 'Energy losses' is the part of the power consumption that is not used for light generation.

If we consider a modern, state-of-the-art lighting controls system like the Philips ActiLume product (see Ref. 4) combined with HF-R EII DALI ballasts and TL5 lamps, we have the following situation:

- microcontroller losses: 1 W power consumption for the ActiLume system (microcontroller, occupancy sensing and light sensing), both during standby as well as during operation (named 'parasitic power').
- Ballast losses:
  - 0.35 W power consumption for the HF-R EII ballasts during standby.
  - Dimming losses: during dimming when the room is occupied, approximately 8% of maximum power level is not used for light generation. This energy is used to heat the filaments of the TL-5 lamps, which is necessary to enable the dimming (note that in case of future LED luminaires of equal efficacy (lm/W), this problem will not be present and more energy savings are possible in theory compared with fluorescent tubes).

Contribution of daylight

In Ref. 1, a daylight responsive controls system has been analyzed. Based on a statistical analysis of daylight, a graph has been found that describes the fraction of the energy savings by using daylight (named 'room potential') as function of daylight factor for various work plane illuminance levels. In Germany, legislation requires for an office room a 1% daylight factor and a work plane illuminance level of 500 lux. From figure, we obtain a room potential of about 30% at 500 lux. This means that as a general rule approximately 30% of the required light can be maximally obtained by using daylight in the office space. This is also confirmed by the results described in Ref. 2 (for desks near the window, even 40-50% room potential is possible).

Case analysis

Consider the following installation: a small office with two office workers and four luminaires, each having two 54 W TL-5 lamps and one HF-R-EII ballast per luminaire. Occupancy control switches off the lighting during 30% (=OC) of the time, and daylight reduces the artificial light level with 30% (=DC). We assume that on average the overall reduction factor for the power consumption (=RF) is described by:

\[ RF = (1-OC/100) \times (1-DC/100) \]

which yields a value for RF of 0.49, thus 51% (=1-RF \times 100%) reduction of energy consumption by the lamps.

The net energy savings, based on a total yearly use of the installation (8760 hours of which 2250 hours office working hours) can now be calculated and the result is a net energy savings of 44% on the lighting electricity, see table on next page. Power losses due to controller and ballasts are only 7.5% of the maximum total energy consumed by the lamps, which is limited to 15% of the energy savings. This is a far better situation than the case described in Ref. 5, in which 47% of the energy savings was lost.

Continued on page 7.
The fourth Expert Meeting of Annex 45 was on 5 – 6 September 2006 in Ottawa, Canada. The meeting was hosted by Guy Newsham and Christoph Reinhart from National Research Council, Institute for Research in Construction. There were 22 participants from 9 countries.

### Conclusion

The Philips ActiLume product is a big step forward for energy savings with a lighting controls system compared with the case described in Ref. 5.

### References

4. Philips ActiLume lighting controls system, www.dimming.philips.com

**Author:** Hans Baaijens, PhD Technology Scout, Philips Lighting Controls, Eindhoven, The Netherlands, www.philips.com/lightingcontrols

### Calculation of net energy savings percentage for an office with Philips Actilume controls system in a small office room.

<table>
<thead>
<tr>
<th>Luminaire based control system, 54 W TL-5 lamp</th>
<th>Percentage of total lighting energy usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total yearly lighting energy consumption without controls [kWh]</td>
<td>972</td>
</tr>
<tr>
<td>Total yearly lighting energy savings with controls [kWh]</td>
<td>-496 -51,0</td>
</tr>
<tr>
<td>Total yearly power losses by controls and ballasts [kW]</td>
<td>72 7,5</td>
</tr>
<tr>
<td>Yearly net energy usage of total lighting system [kW]</td>
<td>549</td>
</tr>
<tr>
<td>% net energy savings</td>
<td>44</td>
</tr>
</tbody>
</table>

| Average savings % due to occupancy control | 30 |
| Average savings % due to daylight responsive control | 30 |
| Dimming power losses HFR II Dali ballasts [kW] | 54 |
| Standby power losses HFR Ell Dali ballasts [kW] | 9 |
| Parasitic power of ActiLume control system [kW] | 9 |
| Number of luminaires | 4 |
| Number of lamps per luminaire | 2 |


### Towards adapted lighting control in low energy buildings

**Commissioning**

Furthermore implementing more and more advanced controls in buildings further strengthens the need for application of commissioning methods and tools to ensure that these controls are robust and that buildings reach their technical potential and operate energy-efficiently.

However, documented commissioning methods are currently only available for some conventional HVAC systems and do not address the advanced systems and system combinations (HVAC, lighting, etc…) that are particularly important when targeting for low energy buildings.

To conclude, developing advanced lighting control strategies and/or integrated control strategies can only be effective if they are included in the commissioning process which in fact is the quality assurance procedure.

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**E³Light Newsletter 4**

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**E³Light**

**Annex 45**

Energy Efficient Electric Lighting for Buildings

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**Annex 45 Expert meetings**

5th Expert meeting
18-20 April 2007
Brussels, Belgium

6th Expert meeting
3 - 5 October 2007
Lyon, France

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International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

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November 2006