

BEST AVAILABLE TECHNICS AND SUSTAINABLE DEVELOPMENT - FEATURES FOR THE LIGHTING DESIGN

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Abstract - The design of a lighting installation needs to take into consideration the satisfaction of three basic human needs, as prescribed by Standard EN 12464: visual comfort, visual performance and safety. Along these criteria, different aspects should be also considered: the use of the best state of the art technology available on the market, the nature of raw materials used in the process and its energy efficiency, the environment protection or the need to ensure occupational health and safety at workplaces and the risks to it. The paper discusses the implementation of Best Available Techniques and Sustainable Development Strategy at the lighting design. These strategies, while not aimed at the prescription of any specific technique or technology, take into account the characteristics of the concerned installation (technical aspects, geographical location, environmental local conditions). The selection between different available solutions for the considered lighting installation is made at each designing step, with the final purpose of establishing the optimal solution regarding the energy efficiency, the user satisfaction and the environmental protection.

Key words: lighting design, energy efficiency, user satisfaction, environmental protection

1. INTRODUCTION

This paper presents guidelines for the designing of the interior lighting system bearing in mind the applicability of the Best Available Techniques and Sustainable Development. The Best Available Techniques concept requires the assessment of the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. Special consideration are given towards the consumption and nature of raw materials used in the process and its energy efficiency, the need to prevent or reduce to a minimum the overall impact of the releases to the environment, the technological advances and changes in scientific knowledge or the need to ensure occupational health and safety at workplaces and the risks to it. The Renewed EU Sustainable Development Strategy, adopted by the European Council in June 2006, sets out how the needs of present generations can be met without compromising the ability of future generations to meet their needs. The Sustainable Development Strategy

deals in an integrated way with the economic, environmental and social issues.

A variety of types of lighting are available to satisfy for every type of activity and room situation. To ensure the right standard of lighting for a specific room use, the right balance needs to be accomplished between visual performance, visual comfort and visual ambience. The emphasis can be on [1]:

- visual performance, defined by lighting level and glare limitation;
- visual comfort, influenced mainly by colour rendering and harmonious brightness distribution;
- visual ambience, influenced by light colour, direction of light and modelling.

The selectivity of the optimal solution needs to comply also with the requirements of the technical regulations which establish the lighting levels, harmonious brightness distribution, direct and reflected glare limitation, direction of light, modelling, light colour and colour rendering required for the relevant activity. [1]

Performance, efficiency and comfort determine the efficacy of lighting, the impact on the people and the impact on the natural environment. Each different project and location requires a specific study to balance the three components. [2]

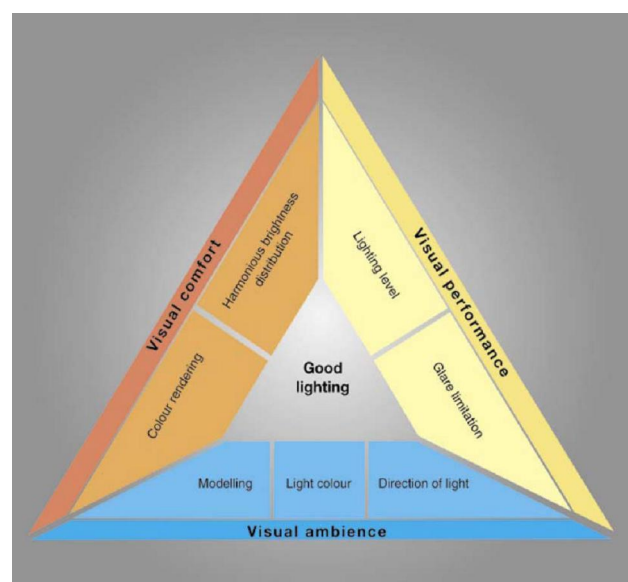


Figure 1. Relation between visual performance, visual comfort and visual ambience [3]

2. LIGHTING INSTALLATION DESIGN

2.1. Application and space requirements

The first step in designing the lighting installation for a specific space is the rigorous analysis of the respective space. Visual comfort and the visual ambience of the space depend on an adequate supply of daylight, the design and colour scheme of the interior and daylight-dependent control of the quantity (lighting level) and quality (light colour, uniformity) of the lighting.

The visual performance required for the visual task is determined by the visually relevant elements (size of objects, background contrast, luminance of objects) of the activity performed. Based on the visual performance, as well as on the designer experience, the lighting level is selected, which is defined by the illuminance level. The illuminance values recommended for various visual tasks are taken from standard SR EN 12464-1 [4]. The values stated represent the minimum physiological requirements for the visual satisfaction. The values take into account the illuminance decrease, with the increasing length of service, as lamps and luminaires age and become dirty and the reflectance of surfaces in the room declines. To compensate for this decrease, new lighting systems need to be designed for higher illuminance. The decrease is then taken into consideration in planning by the application of a service factor, which depends on the types of lamps and luminaires used, exposure to dust in the room, service method and service intervals.

The recommended illuminance values apply to the task area in which the visual task is performed. The task area can be a horizontal, a vertical or an inclined surface. Task areas typically found are desks, conference tables/areas, the vertical surfaces of cabinets and shelving systems. Outside these task areas, a lower lighting level is permitted because the surrounding space is not used for the performance of demanding visual tasks.

A study conducted in [5] shows that the change in the illumination level is affecting the visual appeal of a space in office buildings: 2000 lx was preferred to 500 lx for the impressions of comfort, spaciousness, brightness, and saturation evaluation.

Higher values of illuminances are frequently preferred by older people. Also, higher values are preferred during the darker months of the year, when they help maintain concentration and motivation. [6]

The lighting level must also permit visual communication and help promote a general sense of well-being, motivation and dynamism. These conditions are met by a balanced distribution of brightness in the visual field. Brightness distribution depends on the uniformity of illuminance, as well as the reflectance of such surfaces and the brightness (luminance) of windows.

It is also important to avoid direct and reflected glare. Direct glare occurs as a result of excessively high luminance contrast, while reflected glare results from the luminance of bright surfaces (windows, luminaires) being reflected on screens. Where these sources of disturbance are not adequately limited, fatigue, underperformance and personnel health problems result. Room-dividers or cabinet partitions can help make glare

suppression measures more effective. The European standard for interior workplace lighting SR EN 12464-1 assesses the glare by the unified glare rating method, based on a formula for glare. It takes account of all the luminaires in a system contributing to the sensation of glare. With computer workplaces, it is essential to ensure that the strain on the eyes from switching constantly between screen, work materials and surroundings is kept to a minimum and that the need for visual accommodation and adaptation is avoided. [6]

Large buildings provide a bigger potential for optimisation of energy consumption. Lighting that is consistently focussed onto individual task areas reduces mean illuminance levels and the average expenditure on energy. It can be also used for light design in the room. By illuminating walls, rooms can be designed to be much more open and attractive; dynamic lighting situations can enhance their visual quality. [7]

2.1. Predetermination of the lighting scheme and lighting installation

The parameters that help define the visual ambience are direction of light and modelling. A good ratio of diffuse light to directional light produces agreeable shadowing. The direction of light is generally determined by the daylight entering the room from a particular direction through the windows. If luminaires are arranged parallel to a window wall, the furthest away row of luminaires can lighten any dark shadows that might occur during the day. As daylight fades, the closest to window row of luminaires can be partially or fully activated to replace the natural lighting.

Part of the expertise of the lighting designer is the ability to find the most suitable combination of lamp and luminaire to light a given environment. Selecting the proper lamp depends upon the lighting requirements of the space. The light colour of a lamp is described by the colour temperature. The way the colours of objects are perceived depends on the colour rendering properties of the lighting. Lamps are divided for convenience into colour rendering categories. Most lamps have a colour rendering index of over 80, reproducing the colours close to natural lighting.

Different types of luminaire are needed for lighting, their selection depending on the nature of the building, the visual activity performed, room dimensions, daylight incidence and interior decoration and furnishings. Together, as individual elements or as lighting groups, they form the building's lighting systems – developed in consultation with all the different specialists involved in office design. The proper luminaire needs to be selected from a range of surface-mounted, recessed, pendant, wall, desktop, table and standard luminaires, as well as spots in a wide variety of power ratings and designs. From this range of available luminaires, selection can be based on:

- **lighting characteristics**

Information on the lighting characteristics of a luminaire is provided by the intensity distribution curve and the light output ratio, which indicates the proportion of lamp luminous flux available in the room. The higher the light output ratio, the greater the efficiency and

economy with which the luminaire deliver the luminous flux of its lamps. The decision for/ or against a luminaire for a particular application can also be influenced by the standard of glare limitation the luminaire achieves (effective shielding of lamps at critical angles), which significantly enhances the quality of lighting.

- **electrical characteristics**

The electrical characteristics of a luminaire depend on the electrical components for safe, fault-free lamp operation. Lighting management systems can save as much as 60% of the energy costs of operating artificial lighting; electronic ballasts can achieve not only significantly higher luminous efficacy but also short lamp starting times for flicker-free lighting and lower maintenance costs due to longer intervals between re-lamping. Daylight and presence lighting control systems can achieve significant energy savings in many parts of office and administrative buildings.

A flexible lighting system, individual dimming controls, and multilevel switching are other available alternatives, depending on furniture layout and architecture. For locations with multiple tasks, designers can plan for the task requiring the highest level of illumination and provide dimming capabilities that allow the user to adjust the lighting level in various areas to suit different tasks. Multilevel lighting systems also may be appropriate. If flexibility is not possible, the designer may be forced to choose one criterion over another for the entire system.

The problem of using new light sources in office building is discussed in [8]. The study shows that if the light sources are undimmed, the LED luminaires and the fluorescent lamps have a close luminous efficacy. As the luminous flux is decreased, the luminous efficacy is maintained approximately at the same value for the LED luminaires dimmed using pulse-width-modulation techniques, while the luminous efficacy for the fluorescent lamps and the triac dimmed LED luminaire is decreasing. Regarding power quality measurements, the results showed that the use of a triac dimmer generates higher THDI values, with predominant odd harmonic components.

- **design characteristics**

Design characteristics are also an important factor to consider when selecting the luminaires. The nature of the ceilings in a building may recommend or exclude the use of surface-mounted, recessed or pendant luminaires. Assembly and maintenance are another significant aspect. Well-designed assembly or practical installation accessories can simplify considerably the task of installing luminaires. The appearance of a luminaire (shape of housing, finishes and colours) greatly affects the visual impact of an interior and, along with reliability, economy and stability of value, is becoming an increasingly important criterion for luminaire selection.

2.3. Selecting the proper lighting solution

Major advances in component design have brought considerable improvements in all the lighting equipments. New electronic ballasts and control systems, reflector materials and lamps contribute to higher

luminous efficacy, precise optical control, better glare suppression and lower internal power losses. Greater cost-efficiency is achieved due to the higher light output ratios of modern types of lighting and marked improvements have been made in convenience and safety.

The general requirements that a “good” lamp should have are presented in [9]: a high efficacy, a high color rendering index, a long life, to produce a stable light level during its lifetime, to avoid flickering, to produce its nominal flux instantaneously when turned on, to be exchangeable with other types of lamps, to be compact and light, to avoid harmonic distortion feedback to the electric network, to avoid environmental harmful materials, to avoid electromagnetic interference with any other electronic equipment, to avoid excessive heat and UV rejection, to be recyclable and to be inexpensive.

The right light at the right place in the right quantity stimulates and increase the sense of well-being. In office and administrative buildings in particular, lighting management plays a central role, providing the regulation needed to produce light that activates, motivates and helps maintain contentment and concentration. It also ensures the optimal visual comfort and maximum visual performance that most activities require for effective work.

An important function is the possibility of adjusting the lighting levels in line with fluctuations in daylight; another is to avoid the uniform lighting levels that lead to visual fatigue. The objective of good lighting management is to achieve a dynamic combination of daylight and artificial lighting which harnesses the stimulating differences and interaction between the two. Pre-programmed or variable lighting scenes define mood and direct attention, picking out focal points and creating the right visual ambience. For spaces involving multimedia presentations in particular, effective and individual lighting management is an essential element of interior design. [6]

Another aspect is the economy. Lighting is an important cost factor in the construction and operation of a building. Electric lighting accounts for only 1÷ 2% of the investment costs of equipping and furnishing a workplace. 80% of the total bill relates to personnel expenses, 16% to operating expenses and the rest to construction expenses. Lighting can account for as much as a third of operating costs. So it is all the more important that employees should work efficiently.

The selection between different available lighting solutions needs to consider also the life cycle cost analysis. This takes into account both initial costs (the lighting equipment, wiring and control devices, the labour for the installation of the system) and future costs (operation costs - maintenance and energy), over the lifetime of the whole lighting installation. [10]

Designing a lighting system for optimum functionality and aesthetic appeal calls for knowledge of the different types of modern lighting available and the impact they have. Numerous luminaire systems with different lighting characteristics are available for providing good lighting in office and administrative buildings: from the traditional recessed luminaire for direct lighting through direct/indirect surface-mounted, pendant or standard luminaires for variable light distribution to computerized lighting systems.

2.4. Solution evaluation

The fourth step in the design process of a building lighting installation is the examination, with professional programs, of the proposed solutions. The final optimal solution is selected between the previous proposed solutions (lamp – luminaire combinations, luminaire proper positioning). Through simulation, different parameters are determined: the illuminance values at the work plane for the selected solutions, the uniformity of the illuminance, the total active power and the specific installed power.

2.5. Economical analysis and forecasts

The fifth and final step considers the economical analysis of the solution, and the lighting energy management solutions that can be employed. An efficient lighting system reduces annual operating costs and pays for itself within the space of a few years, even where acquisition costs are relatively high.

Lighting controls are critical for minimizing lighting energy use and maximizing space functionality and user satisfaction. Control techniques range from simple to extremely sophisticated [11]:

- Manual switches are the simplest form of user-accessible lighting control. Minimal compliance with most codes requires individual manual switching for each separate building.
- Occupancy sensors employ motion detectors to shut lights off in unoccupied spaces. The primary detection technology can be either passive infrared or ultrasonic. Some sensors employ both passive infrared and either ultrasonic or microphonic detection. Occupancy sensors are most effective in spaces that are intermittently occupied, or where the lights are likely to be left on when unoccupied.
- Time controls save energy by reducing lighting time of use through pre-programmed scheduling. Time control equipment ranges from simple devices designed to control a single electrical load to sophisticated systems that control several lighting zones. Time controls make sense in applications where the occupancy hours are predictable, and where occupancy sensor automatic control is either impractical or undesirable.
- Manual dimmers serve two important functions. First, dimming lights reduce lighting demand and energy usage. With incandescent and halogen sources, there is the additional benefit of extended lamp life. However, more importantly, dimmers allow people to tune the lights to optimum levels for visual performance and comfort.
- Photo-sensor control systems are used to control electric illumination levels in day lit spaces. A photo-sensor detects the daylight illumination level and sends a signal to a logic controller to switch off or dim the electric lights in response. In *open-loop* systems, the sensor is placed so that it “sees” a representative daylight level, such as looking up into a skylight or out a window. In a *closed-loop* system, the sensor is placed so that it “sees” both the daylight and electric illumination level combined.

Electric energy savings are highlighted for an office building in [12], where different rooms have different light control techniques employed. Thus, 40% energy consumption savings are achieved if occupancy and daylight dimming control are used and 22% if occupancy and manual dimming control are employed compared with a room without dimming and occupancy control. A different study compares the different light control methods used in private office rooms. The use of an occupancy sensor generates 20-26% of energy savings while using automatic daylight dimming controls savings of 21% are achieved, compared to manual switching.

3. ENVIRONMENTAL IMPACT OF ELECTRIC LIGHTING

The environmental impact of lighting is caused by the energy consumption of lighting, the material used to produce lighting equipment, and the disposal of used equipment. Emissions during the production of electricity, the burning of fuel in vehicle lighting and in fuel-based lighting are responsible for most of the lighting-related greenhouse gas emissions. Thermal power generation system has the highest impact on the environment due to combustion fuel, gas emissions, solid waste production, water consumption, and thermal pollution. Electricity generated from renewable energy sources has the lowest effect on the environment.

Hazardous materials (lead, mercury) used in the lamps and ballasts can cause harmful impacts on the environment. Mercury in fluorescent lamps has essentially two different chemical compositions: vapor-phase elemental mercury and divalent mercury adsorbed on the phosphor powder, the metal lamp ends, or other components. At the end of lamp life, most of the mercury is in divalent form. Mercury from fluorescent lamps reaches the environment during the process of incineration, disposal, recycling, or accidental breakage of lamps. Total fluorescent lamp mercury emissions are declining over time as a result of five factors: declining average amounts of mercury used in the manufacturing of each new lamp; growing market preference for thinner lamps with greater energy efficiency and lower average mercury content; increasing recycling rates for linear fluorescent lamps; increasing stringency of mercury control at incinerators; and new state regulations that prohibit fluorescent lamps from being discarded in landfills or incinerators (also reducing breakage during disposal). The compact fluorescent lamps operate in a similar manner to linear tubes, though they contain comparatively less mercury per lamp than most linear fluorescents. Longer term, solid state alternatives such as LEDs offer significant promise for reducing reliance on mercury-containing lamps in the next decade, particularly in applications requiring directional lighting.

Among the measures that have potential for CO₂ reduction in buildings, energy efficient lighting comes first largest in developing countries, second largest in countries with their economies in transition, and third largest in the industrialized countries. [13]

4. STUDY CASE – OFFICE SPACE

An office space of 150 m² was selected as a case-study. The office space corresponds to a group office, according to [5].

The first step in designing the lighting installation for the office space is the analysis of the space peculiarities and work applications. The office room characteristics are: length 15 m, width 10 m, height 3.5 m. The office room has four equal windows covering the wall from the North part, each of them having the dimensions of 3 m x 1.8 m (height 1.8 m). The surface reflection factors are set to 0.20/0.50/0.70, the task area was established at 0.85 m.

The group office is a popular office and work concept, with comfortable size, flexible design and effective communication structure. The illuminance level recommended at working plane was set, according to SR EN 12464-1, at 500 lx. The European standard sets UGR=19 as a maximum permissible glare value for offices.

The second step is the determination of the lighting system parameters and luminaire arrangement. The lamp temperature colour and colour rendering index are selected. The lamp characteristics are neutral white light colour (4000 K) with good colour rendering properties (Ra=80). Desks are positioned at right angles to the window wall. Daylight falls on desktops and workstations from the side, with window glare eliminated by blinds. The artificial lighting units are mounted parallel to the window wall to provide effective task area illumination.

The third step is the selection of lighting system equipments for the office buildings. The lamps need to have the light colour and the colour rendering properties previous set. Two scenarios are considered: T5 28 W fluorescent lamps and 48 W LED luminaire.

For the first scenario, T5 28 W three-band fluorescent lamps, with high luminous efficacy, good colour rendering properties and a long service life are used. The lamps are connected to electronic ballasts, achieving a higher luminous efficacy and longer service life. The electronic ballast permits the dimming function of the fluorescent lamps. For workplace groups, pendant luminaires for direct/indirect lighting give better results. Due to the brightness of the ceiling, the lighting appears more natural, reflections on work materials and screen are reduced, and the better modelling makes faces and objects look more appealing. For a more flexible workplace arrangement, direct/indirect standard luminaires can be used in combination with desktop luminaires. To give a group office an energizing, motivating atmosphere without compromising on clarity of structure, the lighting should emphasize the zone layout of the room. Down lights can be used to provide agreeable, non-directional lighting for service centres, where documents are faxed or copied. Where these facilities are located at the perimeter of the room, indirect wall luminaires are another option. In conference zones, direct/indirect luminaires should be used wherever possible.

The second scenario employs in the office building recessed modular luminaires with 48 W, 3200 lm LED light source and dimmable ballast. The colour rendering

index of 92 and colour temperature of 3000 K make this product suitable for the office application.

The fourth step involves the simulation of both solutions, using the DIALux programme. The purpose of this simulation is to determine the illuminance values at the work plane for the selected solution, the uniformity of the illuminance, total active power and specific installed power. Based on these results, a selection between the two solutions can be achieved.



Figure 2. Simulated office room – first scenario



Figure 3. Simulated office room – second scenario

Table 1 DIALux simulation illuminance levels at work plane level

Light sources	E _{av} lx	E _{min} lx	E _{max} lx	E _{min} / E _{max}
T5 2x28 W	495	112	796	0.226
LED 48 W	527	77	716	0.146

Table 2 DIALux simulation results

Light sources	Luminous flux	Active power	Specific installed power	
	lm	W	W/m ²	W/m ² /100 lx
T5 2x28 W	124800	1488	9.92	2.00
LED 48 W	112000	1680	11.2	2.13

The fifth step considers the economical analysis of both solutions. A comparison needs to be made between the two solutions, with the purpose of finding the optimal one. Figure 4 shows the overall costs of both solutions over lifetime.

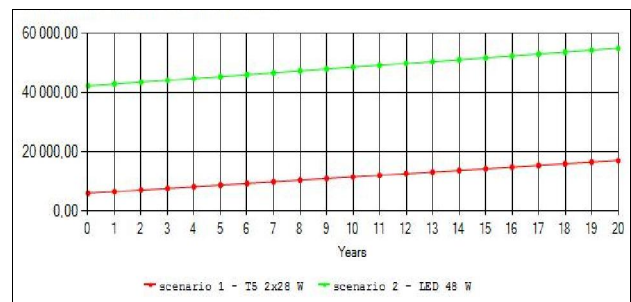


Figure 4. Course of overall costs for both solutions over lifetime

It can be concluded that, even if the characteristics of the LED light source satisfy the office requirements, optimal results can be achieved with the T5 2x28 W light source.

Electric energy gains can be achieved for this solution with the employment of daylight and presence sensors in the office room. In the morning, incident daylight is generally enough for tasks performed at desks close to the windows. The rows of luminaires near the windows are dimmed down; the rows close to them illuminate the furthest away from the window area and makes for a uniform distribution of brightness in the room. At mid-day, the room is illuminated similar. On a cloudy day, the sensor-controlled rows of luminaires maintain the illuminance throughout the room at an agreeably high level. In the evening, the rows of luminaires are equally bright and ensure a harmonious distribution of brightness throughout the room. As soon as different zones from the room are vacated, presence detectors reduce the illuminance or deactivate the lighting from the zone.

4. CONCLUSIONS

The paper presents, step by step, guidelines for the designing of the interior lighting installation. The compliance with the indicated aspects will lead to a lighting solution that respect the visual performance, visual comfort and visual ambience requirements, taking also into account the applicability of the Best Available Technology and Sustainable Development.

The presented case study analyses two possible lighting solutions for a group type office space. Even if both solutions comply with the office building requirements, the comparison between the course of overall costs over lifetime indicate the optimal solution.

5. ACKNOWLEDGMENTS

The presented study is co-financed by the European Social Fund - FSE - through the development of the Project of doctoral studies in advanced technologies – “PRODOC” POSDRU/6/1.5/S/5 ID 7676, Technical University of Cluj-Napoca, Romania.

REFERENCES

- [1] http://www.resourcesmart.vic.gov.au/documents/BP_Lighting_Manual.pdf
- [2] http://www.thornmarketing.com/microsites/education_microsite_uk/pec.html
- [3] <http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc39866.php>
- [4] EN 12464-1:2002: Light and lighting. Lighting of work places. Indoor work places
- [5] Manav, B., Kuçukdogu, M. Ş. - Effects of illuminance and color temperature on pleasantness: a case study for office settings, *Ingenieria Iluminatului*, vol. 7, no. 2, pg. 17. 2005
- [6] http://www.licht.de/fileadmin/shop-downloads/lichtwissen04_offices_office_buildings.pdf
- [7] Zumtobel – The Lighting Handbook, http://www.zumtobel.co.uk/download/ilr_cp_TheLightingHandbook.pdf
- [8] Albu H., Halonen Liisa, Tetri E., Pop F. - Office lighting with currently used and new light sources – *Journal Ingineria Iluminatului – Lighting Engineering*, Volume 12, Number 2, December 2010, pp. 5 – 22. ISSN 2968-9853 online. Can be downloaded from: www.journal.florinrpop.ro
- [9] Zisis G., Ruscassie R., Aubes M - The quest of the perfect light source, *Universite de Toulouse, Ingineria Iluminatului*, vol. 9, no. 1, pg. 71. , 2007
- [10] Tetri, E. - Concepts and techniques for energy efficient lighting solutions. International Conference on Improving Energy Efficiency in Commercial Buildings, “IEECB’08”, Frankfurt, Germany, 2008
- [11] National Best Practices Manual Lighting and Electrical Systems, <http://www.nyserda.org/hps/Files/lightingsources.pdf>
- [12] Bhusal, P., Tetri, E., Halonen Liisa - Quality and efficiency of office lighting, *Proceedings of the 4th European Conference on Energy Performance and Indoor Climate in Building and the 27th International Conference AIVC*, Lyon, France, 2006
- [13] Üрге-Vorsatz, D. - Non-residential buildings for mitigating climate change: Summary of the findings of the Intergovernmental Panel on Climate Change, *Improving Energy Efficiency in Commercial Buildings Conference*, Frankfurt, 2008