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Analysis and comparison of lighting design criteria in green building certification systems —Guidelines for application in Serbian building practice

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ABSTRACT

Green building assessment is currently being introduced into Serbian building practice. Since there is no Serbian certification system which could support building assessment, and especially lighting design evaluation, this paper analyzes and compares the lighting design criteria of three international certification systems, LEED, BREEAM and CASBEE. Specific requirements for each considered criterion, as well as the grading structure and stringency of these systems, are also analyzed. Based on the conclusions of these analyses, a new set of criteria, some of which are original, are offered in order to be incorporated into the future Serbian certification system. Taking into account that the structure of the future system is unknown, the basic applied principle was simplicity for application and, therefore, a single requirement is defined for each criterion. Finally, a hierarchy within the new set of criteria is established for both indoor and outdoor lighting. Mandatory criteria are selected first, while the remaining criteria are divided into two groups based on their relevance. Although predominantly intended for the improvement of Serbian building practice, the proposed set of assessment criteria is general and can be used throughout the world.

Introduction

Procedures for the evaluation of buildings in terms of sustainability have been developed since the beginning of the last decade of the 20th century and as much as 600 methods of assessment exist today (Ebert et al., 2011). The scope of sustainability issues these methods address is various, ranging from a single issue, such as energy efficiency, to a wide range of issues belonging to all three pillars of sustainability (economy, ecology and society). The latter are comprehensive, complex and known as Green building assessment methods or Green building certification systems. They are considered to be objective, containing clear comparison tools for a holistic assessment of a building's sustainability, developed and structured in a way to give transparent building assessment results, followed by the issue of certificate which is suitable for the use in the building market. Constant development of the building market in the direction which encourages and promotes sustainable construction practice through an added value of certified buildings is giving an impetus to the further development of certification systems.

As one of the fundamental elements of building design and also one of the important issues when considering building sustainability, lighting design is being addressed in all of these systems (Liu et al., 2010). The treated aspects of lighting design are also similar within different systems. However, different structures of the systems and criteria definition put those aspects into different categories and define different thresholds and compulsory requirements for every criterion or compulsory criteria (depending on the structure of the certification system). There are only a few compulsory requirements addressing lighting design, and in some systems there are no such requests. Also, current grading is not stringent enough in assessing lighting design issues, which practically means that projects can achieve enough points for obtaining the certificate without improving lighting design in any way.

The research presented in this paper analyzes and compares criteria for the lighting design assessment in three international certification systems: LEED, BREEAM and CASBEE. These systems are chosen because they are distributed over three continents, thus covering the variety of different climatic and building practice conditions. LEED is the only system currently being used in Serbia on several projects, and its criteria and application is already known to a number of local experts. CASBEE is selected as a representative of Asian rating systems with quite a specific assessment methodology, while BREEAM is chosen as a representative of European rating systems.

Since Serbia has no official certification system and the whole sustainable construction practice and market is emerging, the comparison of different rating systems could give useful guidelines for the development of a national system. The aim of this research is to define the criteria by which lighting design could be assessed (not only taking them over from the considered certification systems) and to determine the compulsory criteria which must be addressed in green building lighting design in Serbian building practice. These criteria are expected to be incorporated into the future Serbian assessment method, without proposing their position in the new system's structure.

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Structure of the three compared systems

By definition, a certification system is: "…a way to evaluate the environmental performance of a building against an explicit set of criteria and typically consists of three major components:

1) a declared set of environmental *performance criteria* organized in a logical fashion—*the structure*,
2) the assignment of a number of possible points or credits for each performance issue that can be earned by meeting a given level of performance—*the scoring*, and
3) a means of showing the overall score of the environmental performance of a building or facility—*the output*" (Cole, 2003).

The selection of performance criteria expresses the range of sustainability issues a system can contribute to. The structure and procedures of certification systems are presented in Fig. 1.

In the three analyzed systems, all three components (structure, scoring and output) vary significantly. The major difference is that BREEAM and LEED scoring systems are both based on collecting credits (points) in different categories and summing them up to the total number (percentage) which determines the rating level, while CASBEE is based on the value of BEE (Building Environment Efficiency) indicator.

Unique methodology of the CASBEE structure is derived from the new definition of building efficiency, and is based on the evaluation of building's environmental qualities and loads. In CASBEE, values for these two categories, The Building Environmental Quality and Performance (SQ) and Building Environmental Loads (SLR), range from 1 to 5. They are calculated by the following formulas:

$$SQ = \sum_{i=1}^{m} q_i \cdot K_{q_i} \tag{1}$$

$$SLR = \sum_{i=1}^{n} l_i \cdot K_{l_i} \tag{2}$$

where q_i and l_i represent the achieved levels of performance for ith criterion in categories of quality and loads, respectively, K_{q_i} and K_{l_i} the corresponding weighing coefficients, and m and n the number of criteria in each of these categories. These sums are then expressed as values of the numerator Q and the denominator L, which are between 0 and 100, using the following formulas:

$$\mathrm{Q} = 25 * (\mathrm{SQ}-1) \tag{3}$$

$$\mathrm{L} = 25 * (5-\mathrm{SLR}). \tag{4}$$

The Q/L ratio gives the BEE value. This value is represented by an x/y diagram and a radar chart, giving a clear representation of the building's achieved results in every assessed field. The BEE value also determines the building's rating level and labeling. In addition, the $LCCO_2$ (Life Cycle CO_2) indicator has been introduced in the 2008 revisions of CASBEE and is also given in the final results chart, as an independent indicator of the building's sustainability level (rated with 5 levels of green stars) (CASBEE, 2013).

Also, the major scoring difference between the CASBEE and BREEAM systems on one side and the LEED system on the other is that the former have a threshold for every building rating level within every criterion. Thus every rating level has its own structure of mandatory requirements (prerequisites) and higher standards are set for higher rating levels throughout all assessment issues. This prevents cases of high ratings derived from weights in just several criteria, leaving some issues unaddressed.

In the compared certification systems criteria that address lighting design are found scattered throughout different credit categories. Although all of the criteria are in the mutual correlation, they are assessed through different groups, as seen in Table 1. Compulsory criteria represent the most relevant criteria for a certain area. If a criterion is not compulsory, then the project team can decide if they will incorporate strategies to pursue it, depending on the overall planned scoring structure. In this way, some of the important issues regarding green buildings can be overlooked, especially if the scoring for that criterion is low, which represents a disadvantage of such a system.

Criteria and their requirements

This research is based on an analysis of the criteria relevant for lighting design in the selected certification systems. The analysis is conducted separately for each system, based on the description of the criteria and their procedures given in the reference guides.

The LEED system

Lighting design issues are addressed by criteria which belong to three different sections:

- Light pollution,
- Energy efficiency, and
- Indoor environmental quality.

Not taking into account the energy efficiency related credits (there are no separate criteria for lighting design in this section), environmental lighting design strategies can achieve up to 2 points (Core and Shell — CS), 3 points (New Construction — NC) and 5 points (Schools), which is only 2–5% of the overall weighing.

Credits from the Sustainable Sites credit category deal with the selection and development of a building site (USGBC, 2009). As one of the aspects of environmentally responsible site development, *light pollution* issues are addressed. In order to achieve the only possible point for this credit, the project team must treat both interior and exterior lighting.

Interior lighting is addressed by controlling the amount of light which leaves the building during the night, either by reducing the input power of all nonemergency luminaires with a direct line of sight to any openings by 50% from 11 p.m. to 5 a.m., or by shielding those openings with an automatic device for a resultant transmittance of less than 10%. No calculations are needed for the compliance with these measures, just the description and proof of the taken measures.

For exterior lighting, in order to achieve the mentioned point, the project must comply with the maximum lighting power allowance (USGBC, 2009) and must fulfill all the requirements for the light zone in which it is qualified (as defined in *Lighting for Exterior Environments* (IESNA, 1999)). The light zone requirements provide the exact levels of illuminance and the amount of luminaire light trespass (0–10% of the total fixture lumens (USGBC, 2009)). The project team must first determine the light zone and then provide calculations for the light

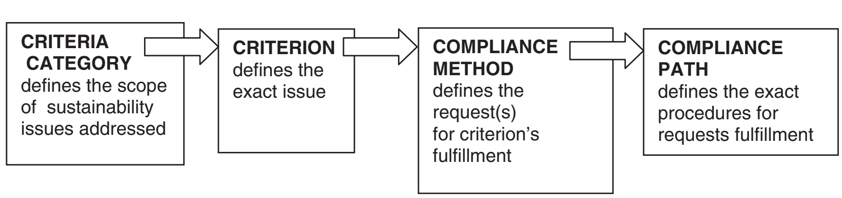

Fig. 1. Schematic representation of structure of certification systems.

Table 1
The criteria relevant for lighting design and their organization in the structure of the three analyzed systems.

Rating system	Criteria category (weighing coefficient)	Relevant criteria	Relevant weighing
LEED	SS—sustainable sites	SS c8. Light pollution reduction	1 point out of 110 possible points
	EA—energy and atmosphere	**EA p1. Minimum energy performance**	**Prerequisite**
		EA c1. Optimize energy performance	1–19 (3–21 for LEED for CS projects) out of 110 possible points
	IEQ—indoor environmental quality	IEQ.6.1. Controllability of systems—lighting	1 point (NA for LEED for CS projects) out of 110 possible points
		IEQ.8.1. Daylighting and views—daylighting	1 point (1–3 points for LEED for schools) out of 110 possible points
BREEAM	Health and wellbeing (15% of total 100%)	Hea 01. Visual Comfort	**1 credit prerequisite** Up to 6 credits (2.8% of total 100%)
	Energy (19% of total 100%)	Ene 4. External lighting	1 credit (0.5% of total 100%)
	Pollution (10% of total 100%)	Pol 7. Reduction of night—time light pollution	1 credit (0.8% of total 100%)
CASBEE	LR1—energy (40% of total 100% for LR category)	2. Natural energy utilization	20% of total 40%
		3. Efficiency in building service system	30% of total 40%
	LR3—off-site environment (30% of total 100% for LR category)	3. Consideration of surrounding environment (33.3% of total 30%)	
		3.3. Light pollution	20% of total 33.3%
	Q1—indoor environment (40% of total 100% for Q category)	3. Lighting & Illumination (25% of total 40%)	
		3.1. Daylighting	30% of total 25%
		3.2. Anti-glare	30% of total 25%
		3.3. Illuminance level	15% of total 25%
		3.4. Lighting controllability	25% of total 25%

trespass analysis and photometric plan from which the light levels are obtained which should comply with the requirements. In the LEED for Schools there are additional requirements regarding trespass calculations related to the sports field lighting. In comparison with some other credits weighted also 1 point (for instance, to get Heat island effect credits, only calculations of percentages of areas which comply with the requirements are needed), this compliance path is very complicated and thus likely avoided to pursue by project teams.

In the LEED system building *energy efficiency* is addressed in the Energy and Atmosphere (EA) credit category, which is weighted with most of available points (33 (LEED for Schools), 35 (LEED for NC) and 37 (LEED for CS)) and has three prerequisite credits, which is more than in any other category.

Credits addressing the building energy efficiency (excluding credits related to commissioning and renewable energy) are EA Prerequisite 2 (EAp2): Minimum Energy Performance and EA credit 1 (EAc1): Optimize Energy Performance. Both of these credits have similar compliance paths, since their objectives are the same, but weighing is different. EAp2 is a threshold for energy savings that every certified building has to achieve (10% for new construction and 5% for major renovation), and EAc1 awards points for further improvement of building energy efficiency (1–19 points for 12–48% (8–44% for major renovation) improvements in Schools and NC, and 3–21 points in CS).

There are three options for complying with these credits, of which the whole building simulation is the most common one, while the other two methods have prescriptive compliance paths that offer a possibility of earning only up to 3 points. The whole building simulation compliance path requires an energy model generated by the appropriate software to prove the energy efficiency achieved by the design measures, including those related to the lighting design.

Reference for these two credits is the ANSI/ASHRAE/IESNA 90.1-2007 standard (ASHRAE, 2007) with mandatory provisions given in its Section 9 and instructions for baseline case design given in its Appendix G. It gives the maximum allowed lighting power densities for various building types (ASHRAE, 2007), needed for the calculation of the total interior lighting power allowance using the *building area method*. It also gives the maximum allowed lighting power densities for each space function (ASHRAE, 2007), needed for the calculation of the total interior lighting power allowance using the *space-by-space method*. The project complies if the total interior lighting power is lower than the *interior lighting power allowance* calculated using either of these methods. This standard also gives the maximum allowed lighting power density for each exterior surface (ASHRAE, 2007). The total exterior lighting power allowance is calculated when the total calculated lighting power density (for all surfaces) is multiplied by 1.05. The project complies if the total installed exterior lighting power is lower than the exterior lighting power allowance. *These allowances, together with mandatory provisions from Section 9 (9.4), are the only obligatory assessment requirements for lighting design*. Any other energy efficiency improvement by efficient lighting is up to the project team to decide whether to pursue or not, since the performance improvement (expressed in percentage of cost savings and shown through building energy modeling) can be achieved by various energy efficiency measures. Even the mandatory 10% (5%) of energy savings need not to be achieved using any of the efficient lighting design methods.

In the last credit category dealing with lighting design issues, *Indoor Environmental Quality* (IEQ), involving environmental concerns related to occupant's health, safety and comfort are addressed. Each of the two criteria relevant for lighting design, *IEQ c6.1: Controllability of systems — lighting* and *IEQ c8.1: Daylighting and views — daylighting*, is weighted 1 point, except in LEED for Schools where daylighting can earn up to 3 points. Strategies for achieving both of these credits are also related to building energy efficiency. However, requirements for *IEQ c6.1* are mainly intended to provide occupant's comfort, although the integration of individual controls with occupancy sensors provides reduction in overall energy consumption and costs.

The main requirement for *controllability of lighting systems* is that at least 90% of building occupants have individual lighting controls and that shared multi-occupant spaces have lighting systems that meet group needs. In addition, all learning spaces in schools are required to have an adjustable lighting system. Lighting system design should comply with illuminance levels recommended by IESNA. The compliance path for this credit is rather simple and includes providing floor plans with marked areas and lighting systems, the calculated percentage of occupants that have met the criterion of individual lighting control and a short narrative description of the design solutions.

As for the *daylighting* criterion, IEQ c8.1, compliance is more complicated. There are several options, including computer simulation, the prescriptive method, measurements or combination of any of the calculation methods which prove that at least 75% (90% for schools) of all regularly occupied spaces have achieved the minimum requested daylight illuminance.

Glare control measures also need to be listed, but there are no further provisions regarding their effectiveness. It is possible to earn an extra point in the Innovation and Design category by exemplary performance if the designed building contains at least 95% of the area of regularly occupied spaces that fulfills the requirement of daylight factor (for schools 90% of classroom spaces and 95% of all other regularly occupied spaces need to fulfill this requirement).

Like in the case of the light pollution criterion, we consider that 1 point (for CS and NC projects) is still low weighing considering the complexity of the compliance method. In addition, glare control is not properly addressed, since no effectiveness provisions are listed in the compliance documentation.

The BREEAM system

The BREEAM system address lighting design issues in three environmental sections (Health and Wellbeing (Hea), Energy (Ene) and Pollution (Pol)), through three assessment issues:

- *Hea 01—Visual comfort*,
- Ene 03—External lighting, and
- *Pol 04—Reduction of night time pollution* (BREEAM, 2011).

Prerequisites (minimum standards) are defined by specific assessment issues and the number of achieved credits in every issue. The needed number of achieved credits varies depending on the rating level the project is pursuing.

For the *Visual comfort* assessment issue there is one prerequisite credit for all rating levels, stating that all fluorescent and compact fluorescent lamps need to be fitted with high frequency ballasts (BREEAM, 2011). *This is the only minimum standard related to the lighting design issues in this certification system*. Other lighting design issues which are included in the Visual comfort section are:

- *Daylighting*, in which it is possible to achieve up to 2 credits,
- *Glare control and view out*, also up to 2 achievable credits, and
- *Internal and external lighting*, only 1 possible achievable credit.

Daylighting is addressed through several criteria which depend on building function (education, higher education, healthcare, multi-residential, retail, court, industrial, office, prison buildings), as well as on specific space function. The option for achieving 2 points is only available for higher education and healthcare buildings.

The main criterion is the required percentage of relevant building areas (defined as areas occupied continuously for 30 min or more (BREEAM, 2011)) that need to comply with the daylight factor requirement, while the combination of criteria from the *Good practice daylighting criteria* (BREEAM, 2011) is required for some building functions. The required values of daylight factor are 1.5% (living and dining rooms in multi-residential buildings, cells and custody cells in prisons), 3% (occupied patient's areas and consulting rooms in healthcare buildings and patient care spaces) and 2% (all other spaces). Good practice design criteria include uniformity ratio and point daylight factor (criterion A), sky view (criterion B) and room depth (criterion C). Where requested, it is necessary to comply with either criterion A or both criteria B and C.

The set of criteria for achieving an exemplary innovation credit in the Visual comfort section only includes dayligting criteria, at a more stringent level. Daylighting criteria are complied through design drawings and daylight calculations (not specified in detail) in the design stage, as well as through on-site measurements and site inspection in the post construction stage. Strategies for maximizing daylight infill, such as light shelves, clerestory glazing or sun pipes, are defined as borrowed light and need results from an appropriate lighting design software to demonstrate compliance with daylighting criteria.

Glare control is addressed through the requirement for applying glare control strategies in building areas containing reflecting surfaces where glare could cause problems to users. Curtains do not represent an adequate glare control strategy.

Internal and external lighting requirements rely on illuminance levels in accordance with the *CIBSE Code for Lighting 2009* (CIBSE, 2009) (compliant to BS EN 12464-1 (BSI, 2002)) or any other relevant industry standard. *CIBSE Lighting Guide 7* (CIBSE, 2005) is relevant for areas where computer screens are regularly used. Also, there are additional requirements regarding occupant lighting controls and light zoning for every type of building and space function. Areas used for teaching, seminar or lecture purposes should have lighting controls provided in accordance with the *CIBSE Lighting Guide 5* (CIBSE, 2011). External lighting requirements are in accordance with *BS 5489-1: 2003+A2: 2008 Lighting of roads and public amenity areas* (BSI, 2008). The compliance requirements are the same as in the previous environmental section.

The aspect of *energy efficiency* in lighting design is addressed in the Energy section, issue 3, External lighting. The criteria for this aspect are based upon the required values of luminous efficacy in relation to the color rendering index and lamp wattage. The better color rendering and greater wattage of the lamp, the higher value of luminous efficacy is requested (50–80 lamp lm/W). Also, external light fittings need to be controlled through a time switch or daily sensor.

The *pollution* section, issue 4, Reduction of night time pollution, is addressing problems of upward lighting. This section involves:

- external lighting strategy, designed in compliance with *ILE Guidance notes for the reduction of obtrusive light* (ILE, 2005),
- all external lighting, which must have the option for automatic switch off between 11 p.m. and 7 a.m., and
- illuminated advertisements, which must be designed in accordance with *ILE Technical Report 5—The Brightness of illuminated Advertisements* (ILE, 1991).

In order to comply with these requirements project team must provide design drawings, specifications or external lighting calculations.

The CASBEE system

In the Japanese rating system lighting design is addressed in the Loads Reduction (LR) section, through *Energy* and *Off-site Environment* loads analysis, as well as in the Quality (Q) section, through *Indoor Environment* quality evaluation (JSBC, 2011). Levels of assessment for every criterion vary depending on the rating level that the project is aiming to achieve. The obligated minimum for every criterion is the one defined for the lowest Level 1. The higher the rating, the more demanding and stringent reference levels and criterion requests.

Energy efficiency is weighed by the difference in CO_2 emissions between the evaluated and the reference building. The reference building is defined in the *Energy Saving Law* (ECCJ, 2008) through PAL (Perimeter Annual Loads) and CEC (Coefficient of Energy Consumption) indicators. Reductions in CO_2 emission of the evaluated buildings are calculated in four segments of the *Energy* (*LR1*) section: *Building Thermal Loads* (*LR1.1*), *Natural Energy Utilization* (*LR1.2*), *Efficiency in Building Service Systems* (*LR1.3*) *and Efficient Operation* (*LR1.4*). Aspects of lighting design are evaluated in two of them: *Direct Use of Natural Energy* (LR1.2.2.1, as a part of *Natural Energy Utilization*) and *Efficiency in Building Service Systems* (LR1.3).

Direct use of natural energy is a criterion which evaluates the reduction of CO_2 by unconverted use of natural energy, primarily daylight and natural ventilation. In order to achieve Level 3 of the assessment, at least 80% of private areas need to have two exterior walls with openings. For levels 4 and 5, other building measures to enhance efficiency need to be provided, but they do not address lighting design. This criterion is enabling designs of buildings like apartments and schools, which often use daylighting and natural ventilation measures as basic energy saving measures, to achieve scoring for these efforts separately from scoring for the overall energy efficiency. In this way essential low-tech solutions for green buildings are promoted.

In the *Efficiency in Building Service Systems*, ERR (Energy Reduction Rate) is used as an indicator for weighing. It expresses the rate of reduction in primary energy consumption for equipment systems (JSBC, 2011), and is calculated as a ratio between the total amount of energy saved and the standard primary energy consumption in the evaluated building. Since CASBEE includes all energy consuming systems (JSBC, 2011), lighting is not separately treated. ERR value of 5% corresponds to Level 3, and ERR over 35% is the Level 5 threshold.

Light pollution is addressed in the LR3.3 section, Consideration of Surrounding Environment. It is thoroughly analyzed through the following sections: *Outdoor Illumination and Light that Spills from Interiors* (*3.3.1*) and *Measures for Reflected Solar Glare from Building Walls*

(*3.3.2*). In the first section (3.3.1) countermeasures against light pollution from billboard lighting are also weighed. Both efforts to reduce light pollution produced by billboard lighting and light that spills from interiors and outdoor illumination are weighted with one or two points each, which makes the total number of possible points from 0 to 4, corresponding to Levels 1 to 5. Points are given based on compliance with *Light Pollution Countermeasure Guidelines* (MOE, 2006), depending on whether some or the majority of considerations and checklist points from this manual are satisfied. These measures include:

- lighting specialist engagement,
- appropriate illuminance levels and illuminance ranges,
- overall luminous efficacy (for input power of 200 W or more at least 60 lm/W is recommended, and for input power below 200 W at least 50 lm/W),
- coefficient of equipment utilization,
- upward light output ratio (depending on a type of lighting environment),
- glare and extreme contrast reduction measures,
- operation and management plans (considering issues like adjustable brightness or total shut-off, cleaning and lamp replacement plans…), and
- compliance with district development.

Measures for addressing billboard lighting given in *Matters to consider in billboard illumination* in *Light Pollution Countermeasure Guidelines* (MOE, 2006), include consideration of light leakage, quality of light (light must not flash, move or be colored) and energy conservation by encouraging use of light sources of high luminous efficacy.

Measures for reflected Solar Glare from Building Walls (*3.3.2*) address light pollution caused by buildings, by mitigating glare cast on the surrounding buildings by reflection of daylight from walls. Project teams are encouraged to use computer modeling to identify the impact of reflected light and act with countermeasures such as various surface treatments (anti-reflection films or glass coatings) or adjust the angle at which the glass is mounted. Levels 1, 4 or 5 are achieved if, respectively: reflected light from the building affects the surrounding area, does not affect the surrounding area, or does not exist. This issue is very important, especially in high density areas, and needs to be considered in the early stages of the design (otherwise, measures for the glare reduction can be complicated or expensive to incorporate).

Aspects important for occupant's comfort and wellbeing are thoroughly addressed through several issues in the *Lighting and Illumination* (Q1.3) section of *Indoor Environment* (Q1). These issues are:

- *Daylighting* (*3.1*),
- *Anti-Glare Measures* (*3.2*),
- *Illuminance Level* (*3.3*), *and*
- *Lighting Controllability* (*3.4*).

The aspect of *daylighting* is assessed through appropriate values of the daylight factor (Level 5 rating requires values of the daylight factor higher or equal to 2.5%, except for residential and accommodation spaces), orientation of windows (Level 5 rating requires existence of south and east–west facing windows) and existence of daylighting devices (Level 3 rating does not require any daylighting devices). Only basic calculations are required for the compliance with the daylight factor, while other requirements have a descriptive compliance path.

For compliance with *anti-glare measures*, both glare from lighting fixtures and glare from daylight must be addressed. Requests for reduction of glare from lighting fixtures are in accordance with fluorescent lamp glare classifications (G3–GO and V categories), contained in the *Technical Guideline for Office Illumination* (IEIJ, 1992). For daylight glare control compliance, higher rating levels require blinds and/or a combination of other means (curtains, screens, awnings).

Illuminance level assessment is based on compliance with the values prescribed within the criteria requirements for both task and ambient illuminance levels specified for every level of certification. Higher rating levels require both of these values to be achieved.

Lighting controllability is addressed by the minimum area in a room for which lighting control is available and by methods of control. A higher assessment level is awarded for a detailed lighting control or automatic lighting control systems.

The current Serbian legislation and practice

Current regulations for interior lighting design in Serbia date from 1974 (YLC, 1974). These regulations contain requests for appropriate task lighting for almost all relevant purposes. For external lighting current lighting design practice is relying on CIE recommendations. A rule that the window area should represent 1/7 of the floor area has become a common rule in building practice, although this rule should not be generally applied. This rule was imposed decades ago, when prefabricated systems were prevailing in the building industry and window position was in the central area of the wall panel, while nowadays window sizing and position is more flexible, so this should not be followed as a rule anymore. The new set of regulations for energy efficiency in buildings (MEMSPS, 2011) is dealing with lighting design issues in just a few articles. Article 16 refers to the Serbian SRPS EN 15193 standard (ISS, 2012), while *Addendum 14: Technical requirements for energy efficiency in buildings* and *Addendum 14: Requirements for Comfort* give recommendations for maximization of daylight in just a few lines.

Critical analysis and comparison of the three analyzed certification systems

All analyzed criteria relevant for lighting design can be divided into three main groups: energy consumption, indoor environmental quality and outdoor environmental quality.

The energy consumption criteria

These criteria address energy savings that can be achieved through lighting design. They are listed in Table 2 and their corresponding requirements are presented in Table 3, together with evaluation comments.

The indoor environmental quality criteria

These criteria are mostly related to occupant's visual comfort but can also correlate with the energy consumption criteria, such as extent of daylight infill, controllability of lighting systems and illuminance levels (see Table 4). The corresponding requirements are presented in Table 5, together with evaluation comments.

The daylight illuminance level and daylight factor are different parameters, but correspond to each other. Therefore, each of them can be used as an indoor daylight criterion.

Table 2
Energy consumption criteria of three analyzed certification systems.

	LEED		BREEAM	CASBEE	
Criteria category	EA	ENERGY AND ATMOSPHERE	ENERGY	LR1	ENERGY
Criteria	**EA p1. Minimum energy performance** EA c1. Optimize energy performance		Ene 4. External lighting	3. Efficiency in building service system 4. Efficient operation	

Table 3
Requirements for energy consumption criteria.

Relevance	Specific requirement of LEED	Comment
Energy Efficiency (overall)	Maximum lighting power allowance calculation and mandatory provisions from ANSI/ASHRAE/IESNA 90.1-2007 standard (ASHRAE, 2007)	In order to avoid excessive energy consumption, this criterion should be replaced by a set of criteria regarding maximum illuminance level, lamp luminous efficacy and maintenance factor, because, taken together, they provide the minimum space power density (see explanations in Sections 4.1 and 4.2).
Relevance	**Specific requirement of BREEAM**	**Comment**
Energy Efficiency (external lighting)	Luminous efficacy in relation to color rendering index and lamp wattage	This requirement encourages teams to use high quality lamps, but does not restrict the amount of energy used for external lighting, which should be improved. Also, internal lighting is not treated separately, but through the overall energy savings. In addition, lamp luminous efficacy and color rendering index should be treated as independent issues.
Relevance	**Specific requirements of CASBEE**	**Comment**
Energy Efficiency (by use of natural energy)	Percentage of private areas that need to face external walls on two sides	The demand for two side orientation has been formulated in relation to both daylight and natural energy utilization related to ventilation. We consider that natural light usage requests should be considered separately. This aspect is covered in the indoor environmental quality related sections.
Energy Efficiency (building service systems)	Reduction rate of energy for lighting is calculated as a part of the total ERR (Energy Reduction Rate)	Large percentage of energy savings in lighting design should be encouraged.

Table 4
Indoor environmental quality criteria of the three analyzed certification systems.

	LEED		BREEAM	CASBEE	
Criteria category	IEQ	Indoor environmental quality	Health and wellbeing	Q1	Indoor environment
Criteria	IEQ.6.1. Controllability of systems — lighting IEQ.8.1. Daylighting and views — daylighting		Hea 01. Visual comfort	3. Lighting & Illumination	3.1. Daylighting 3.2. Anti-Glare 3.3. Illuminance level 3.4. Lighting controllability

Outdoor environmental quality criteria

Outdoor environmental quality criteria mostly refer to light pollution reduction measures, but also to outdoor comfort in terms of safety and visual quality (Table 6). The corresponding requirements are given in Table 7, together with evaluation comments.

Criteria for lighting design assessment useful for the Serbian certification system

A set of relevant criteria for lighting design, together with their hierarchy, is offered, expecting them to be useful when the Serbian certification system is established. It consists of criteria which are defined as mandatory and others which can be graded or assigned to different levels of assessment, according to the given hierarchy and depending on the overall system structure. Based on the conclusions of the analysis of the three considered systems (presented in Tables 3, 5 and 7), the new criteria are defined with or without reference to criteria defined by the analyzed systems. Since each criterion consists of only one requirement, it is possible to combine these criteria within the overall structure. The two subsets of criteria, presented separately for indoor and outdoor lighting, are given in Sections 4.1 and 4.2, respectively.

The criteria relevant for indoor lighting

Combination of general and individual lighting is a request that does not exist as a separate criterion in any of the analyzed certification systems, but as a part of the issue of controllability of lighting systems, addressing occupant's comfort. However, it is also an important design strategy for improvement of the overall energy efficiency, as well as visual comfort. Lighting design solutions which combine general and individual lighting should be encouraged in all projects and should be mandatory for office spaces.

Provision of *occupancy sensors* also does not exist as a separate request in the three analyzed systems, or as a part of the request of some other criterion. Since it is considered a rather simple and effective measure for achieving considerable energy savings, it should be of a high priority for spaces which are not regularly occupied. Determination of such spaces should be given for each building function separately.

Criterion of *the minimum Illuminance level* already exists in Serbian practice, however through outdated regulations, providing basis for occupant's comfort and wellbeing. Fulfillment of this request should be mandatory for all spaces, according to the European standard EN 12464-1 (CEN, 2011), in use in Serbia since 2011.

The criterion of the *maximum Illuminance level*, as well as criteria of *lamp luminous efficacy* and *luminaire maintenance factor* (*LMF*) replace the criterion of the maximum lighting power allowance, since our checks showed that in a lot of cases the requested power density allowances are too stringent. For example, in an office of 20 m^2, where the illuminance level is 500 lx and quality ceiling recessed luminaires with fluorescent tubes are applied (the coefficient of utilization is 0.5, and the luminous efficacy is 80 lm/W), assuming the maintenance factor of 0.8, the total lamp luminous flux and power amount to 25,000 lm and 312 W, respectively. The office power density equals 15.6 W/m^2, which is 30% more than 12 W/m^2 as given by the reference standard [8]. Therefore, the power density allowances should be adjusted for possible application of this criterion in Serbia, following a broad previous study. The value of ΔE_{av},[a] given in the equation

$$\Delta E_{av}(\%) = \sum_{k=1}^{n}(\Delta E_k(\%) \cdot S_k) / \sum_{k=1}^{n} S_k \tag{6}$$

[a] ΔE_k is the percentage increment of the achieved illuminance level in the kth space related to the requested one for that space; S_k is the floor area of the kth space and n is the total number of spaces where the illuminance level is higher than the requested one.

Table 5
Requirements for indoor environmental quality criteria.

Relevance	Specific requirement of LEED	Comment
Occupant's comfort	Controllability of lighting systems	This criterion is easy to achieve and therefore is regarded "an easy point". It is considered that the separation of overall and local lighting and allowing users to control local lighting should be compulsory because it is a basic design requirement for achieving visual comfort.
Occupant's comfort, health and wellbeing	Daylight illuminance level	Taking into account the complexity of the compliance method for this requirement, it is considered that it should be weighted more than it is suggested by LEED. Rating levels determined by percentages of spaces that need to comply with prescript daylight illuminance levels represent a good rating method. The value of 95% of spaces that comply with criteria requirements is too stringent, even for the highest levels of certification, so 90% can be regarded as an adequate demand.
	Glare control measures	Since glare control is not properly addressed by LEED requirements, and it is one of the most important issues of occupant's comfort and wellbeing, it should be a prerequisite demand and its fulfillment should be properly controlled (by computer simulation or site inspection). Project teams should be encouraged to use computer simulation to prove compliance with this and other requirements, especially for higher rating levels.
Relevance	**Specific requirement of BREEAM**	**Comment**
Occupant's comfort, health and wellbeing	High-frequency ballasts for all fluorescent and compact fluorescent lamps	Request should not be limited to high-frequency ballasts, because electromagnetic ballasts of appropriate class are also a means to eliminate the stroboscopic effect. Compact fluorescent lamps should be excluded from this criterion, since they are already working with high-frequency ballasts.
	Daylight factor	This should be a compulsory criterion for all levels. Higher values of daylight factor should be requested for higher levels of certification.
	Point daylight factor and uniformity ratio Sky view Room depth	These criteria should be combined with daylight factor criterion for higher levels of certification, in a way similar to the one applied within the existing structure of BREEAM.
	Glare control	As in LEED, glare control strategies are not properly addressed. They should represent an obligatory requirement. In addition, the compliance method for addressing glare control should be defined.
	Illuminance levels	Should be compulsory and in accordance with any relevant standard. Values for the maximum allowed illuminance levels should also be determined, in order to prevent excessive energy consumption (see Section 4.1)
	Lighting controls	Separation of general and local lighting should be encouraged through lighting design wherever applicable.
Relevance	**Specific requirement of CASBEE**	**Comment**
Occupant's comfort, health and wellbeing	Daylight factor	As in BREEAM, this should be a compulsory criterion for all levels. Higher values of daylight factor should be requested for higher levels of certification. Both daylight factor and point daylight factor should be considered within this request.
	Orientation of windows	This request is one of the important bioclimatic design principles and should be encouraged.
	Daylighting devices	Use of appropriate daylighting devices should be encouraged, especially for higher rating levels.
	Glare from lighting fixtures	Requests for the reduction of glare from lighting fixtures should not be defined only for fluorescent lamps, but also for other types of light sources.
	Glare from daylighting	Anti-glare measures should be obligatory if it is found that glare from daylighting exists.
	Task and ambient illuminance levels	Should be in accordance with a relevant standard and more stringent for higher levels of certification.
	Lighting control	The minimum area in a room (according to room type) for which lighting control is available should be determined. Degree of controllability is well determined by the CASBEE requirements.

should not be greater than 15%. Defined in this way, the criterion of the maximum Illuminance level would prevent the possibility of overlighting. Improved luminous efficacy should be encouraged and a threshold should be set to at least 60 lm/W, which is accomplished by CFLs and LEDs. This measure is restricting unnecessary usage of inefficient halogen and standard incandescent lamps. The exception from this request should be made for humid spaces, spaces where excellent color rendering or spot light is needed (museums, galleries,…) and spaces where children spend time (for health reasons, as explained later). As for the criterion of luminaire maintenance factor, it must not be lower than 0.7, and the maintenance plan which proves that this request is fulfilled must be given.

Since criteria of *room lighting uniformity*, *color of light* and *color rendering index* (*CRI*) do not exist as separate in the three analyzed systems, and are too often being subjected to the aesthetics and appeal of the design solution, with no regard to occupant's comfort, we consider they should be defined as individual criteria. The main request is that all lamps in a room intended for functional lighting should belong to the same group of lamps according to color temperature (warm, neutral or cold), and that both room lighting uniformity and CRI should be in accordance with the European standard EN 12464-1 (CEN, 2011).

Nighttime reduction of luminous flux is a criterion derived from various criteria in the analyzed systems related to light pollution reduction (see Table 7). However, this criterion is also related to energy efficiency,

Table 6
Outdoor environmental quality criteria.

	LEED		BREEAM	CASBEE	
Criteria category	SS	Sustainable sites	Pollution	LR3	Off-site environment
Criteria	SS-8. Light pollution reduction		Pol 7. Reduction of night-time light pollution	3. Consideration of surrounding environment	3.3. Light pollution

Table 7
Requirements for outdoor environmental quality criteria.

Relevance	Specific requirement of LEED	Comment
Light pollution (interior)	Indoor lighting with a direct line of sight towards the openings input reduction Shielding of openings	In the overall LEED structure these requirements are combined with the exterior lighting requirements. Because of the rather easy accomplishment of these requirements when compared to the ones imposed to exterior lighting, it is considered that they should be rated separately. It is also considered that these requirements do not have to be obligatory since they are easy to achieve and project teams would be eager to pursue them.
Light pollution (exterior)	Lighting power density allowance in accordance with ASHRAE 90.1 standard (ASHRAE, 2007) Requirements of light zones: illuminance level Requirements of light zones: light trespass	It is considered that these requirements should be obligatory since not following these standards can produce light pollution. Also, since these requirements are not easy to achieve and comply with, project teams should be obliged to follow them.
Relevance	**Specific requirement of BREEAM**	**Comment**
Light pollution (exterior)	External lighting in accordance with *ILE Guidance notes for the reduction of obtrusive light* (ILE, 2005)	Making relevant guidelines obligatory, such as those published by ILE (ILE, 1991, 2005) or CIE (CIE, 2003), all aspects of light pollution are covered. For higher levels of certification all of the requirements should be addressed, while for lower levels some of the key aspects should be defined as obligatory.
	Automatic switch off option Illumination of advertisements in accordance with *ILE Technical report 5* (ILE, 1991)	These requirements should be available for additional points or higher level of certification.
Relevance	**Specific requirement of CASBEE**	**Comment**
Light pollution (exterior)	Level of reflected light from facades to surrounding areas	This request is specific for the CASBEE rating system due to the building area density and applied materials in the Japanese building practice, and it is considered that it is becoming more and more relevant for Serbian conditions, so it should be treated.
Light pollution (exterior and interior)	Lighting design in accordance with *Light Pollution Countermeasure Guideline* (MOE, 2006)	As in BREEAM, it is considered that having one set of guidelines that define all aspects of light pollution is the most appropriate method for addressing such a complex issue. It is also considered that aspects of light pollution from interior and exterior lighting should be rated separately.

and therefore should be treated as a separate one. If and where applicable, the measures for the significant reduction of luminous flux during late night hours should be applied. Project teams should describe such measures.

Elimination of flicker and stroboscopic effect is a criterion taken from the BREEAM certification system, where it is a prerequisite for all certification levels. In accordance with the comments (see Table 5), it requires that high-frequency ballasts or electromagnetic ballasts of appropriate characteristics should be provided for all fluorescent lamps.

Criterion dealing with *health risks* does not exist as a separate one in the analyzed systems. However, due to an increasing application of LEDs in indoor spaces, it should be given more significance. The information about LED classification based on the negative effects caused by the blue component of light should be provided for all applied LED light sources. They should belong to group 2 or a lower group. Since children are very sensitive to blue light, more stringent requirements are valid for schools (group 1 or 0) (ANSES, 2010).

Recycling of light sources also does not exist as a separate request in the three analyzed systems, but is often a part of criteria and sections dealing with all materials and their recycling plans. We consider that it should exist as a separate criterion, since both LEDs and conventional lamps (the only exception being incandescent lamps) contain toxic substances (mercury, arsenic) which are recyclable. Therefore, project teams should describe a procedure for their deposit and name the companies where they will be recycled.

As a part of glare control measures, the value of *Unified Glare Ratio* (*UGR*) should be separated as a criterion for all types of light sources, similarly to the criterion *Glare from lighting fixtures* in the CASBEE system (see Table 5). The applied luminaires should be provided with the UGR value tables in order to check if the glare reduction is in accordance with the European standard EN 12464-1 (CEN, 2011).

Daylight criteria and relevant requests should be taken from the BREEAM system, such as *daylight factor*, *daylight uniformity ratio* and *point daylight factor*. Defined in such a way, they completely cover all issues related to window sizing and position, currently not prescribed by any regulations used in Serbia. Daylight uniformity ratio should be considered for higher levels of certification, and point daylight factor should be an obligatory criterion for office spaces.

Daylight glare control should be treated as a separate criterion, similarly to the way it is addressed in all three analyzed systems. Project teams are obliged to consider daylight glare and provide description of the applied daylight glare control measures.

The criteria relevant for outdoor lighting

Similarly to the criteria for indoor lighting, criteria of the *minimum Illuminance level*, the *maximum Illuminance level*, *lamp luminous efficacy*, *luminaire maintenance factor* and *recycling of light sources* also exist as separate criteria for outdoor lighting. Value of ΔE_{av} for the maximum Illuminance level in outdoor lighting should not be greater than 20%. Lamp luminous efficacy in outdoor lighting should be at least 80 lm/W, which is achievable by both high-pressure sodium and metal-halide lamps, as well as by LEDs.

Nighttime reduction of luminous flux should exist as a separate criterion since it addresses not only light pollution issues, but also energy efficiency. There should be ways to reduce luminous flux during the late night hours (between midnight and 6 a.m.) for both 25% and 50%. Design teams should describe the undertaken measures. *Light zoning requirements* should be based on the CIE recommendations (CIE, 2003), and address issues of light pollution in a way similar to the criteria in all three analyzed systems. Design teams should be obliged to determine the light zone for each project, since light zoning is not conducted in Serbian cities yet.

Criteria addressing occupant's comfort and wellbeing during the nighttime hours in the outdoor space, such as *exterior glare control from luminaires*, *vertical or semicylindrical illuminance*, *outdoor lighting uniformity* and *high outdoor contrast avoidance*, are also affecting light pollution issues. For higher levels of certification, the relevant data and calculations of these criteria should be provided proving compliance with the relevant CIE recommendations (CIE, 2010).

Level of reflected light from facades to surrounding areas is a criterion taken from the CASBEE system, and should be treated in order to

Table 8
Hierarchy of criteria based on their importance for indoor lighting.

	Criterion	Compulsory	High importance	Low importance
1.	Minimum illuminance level	*		
2.	Elimination of flicker and stroboscopic effect	*		
3.	Daylight factor	*		
4.	Maximum illuminance level	*		
5.	Lamp luminous efficacy	*		
6.	Luminaire maintenance factor (LMF) and maintenance plan	*		
7.	Daylight glare control	*		
8.	Combination of general and individual lighting	* (for office spaces)	*	
9.	Health risks	* (for schools)	*	
10.	Point daylight factor		* (for office spaces)	
11.	Unified Glare Ratio (UGR)		*	
12.	Room lighting uniformity		*	
13.	Color rendering index (CRI)		*	
14.	Occupancy sensors		* (for large buildings)	* (for small buildings)
15.	Nighttime reduction of luminous flux			*
16.	Daylight uniformity ratio			*
17.	Color of light			*
18.	Recycling of light sources			*

minimize light pollution, and raise consciousness about the effect building design has on the surrounding area.

Guidelines for the future Serbian certification system

Finally, in Tables 8 and 9 all criteria described in Sections 4.1 and 4.2 are classified into the three different groups according to their importance for the Serbian building practice. They should be considered as guidelines for the future Serbian certification system, whatever its future scoring structure would be. Criteria are divided into three categories based on the relevance of issues they are addressing in current state of regulations and practice in Serbia: *compulsory*, *high importance* and *low importance*. This system of the classification of the listed criteria is in accordance with the methodology of BREEAM and CASBEE certification systems, where number of criteria to be fulfilled rises with the certification level the project team is pursuing. In this way, buildings which are aiming to achieve a high rating have to fulfill more criteria, some of which may not be relevant for the buildings which only aim to be certified or get a lower rating. Criteria defined as compulsory should be mandatory for all buildings, regardless of the certification level the building is aiming to achieve. Requirements for criteria of high importance are expected to be fulfilled in projects aiming to achieve medium and high levels of certifications (such as silver and gold in LEED, or good and very good in BREEAM), while criteria of low importance are regarded as currently relevant only for projects which pursue a very high level of certification (such as platinum in LEED or excellent in BREEAM).

Table 9
The hierarchy of criteria based on their importance for outdoor lighting.

	Criterion	Compulsory	High importance	Low importance
1.	Minimum illuminance level	*		
2.	Maximum illuminance level	*		
3.	Lamp luminous efficacy	*		
4.	Luminaire maintenance factor (LMF) and maintenance plan	*		
5.	Light zoning requirements	*		
6.	Nighttime reduction of luminous flux		*	
7.	Exterior glare control from luminaires		*	
8.	Vertical or semicylindrical illuminance		*	
9.	Outdoor lighting uniformity			*
10.	High outdoor contrast elimination			*
11.	Level of reflected light from facades to surrounding areas			*
12.	Recycling of light sources			*

Discussion and conclusions

Since there is no Serbian certification system or other regulations which could support building assessment, there is a need for defining appropriate set of assessment criteria for lighting design as an important part of all building certification systems. In this paper the lighting design criteria of three international certification systems, LEED, BREEAM and CASBEE, and their specific requirements were analyzed. Conclusions drawn from these analyses were used as a base for defining a new set of criteria for both indoor and outdoor lighting design. Each criterion is defined by a single requirement in order to enable its easier implementation into the still unknown structure of the future Serbian certification system. The new set of criteria consists of 18 criteria addressing indoor lighting and 12 criteria addressing outdoor lighting. Several original criteria are defined which do not exist in the analyzed systems, such as:

- for indoor lighting: the maximum illuminance levels, luminaire maintenance factor with maintenance plan, color of light, color rendering index, health risks and recycling of light sources, and
- for outdoor lighting: the maximum illuminance levels, luminaire maintenance factor with maintenance plan, vertical or semicylindrical illuminance, outdoor lighting uniformity, high outdoor contrast avoidance and recycling of light sources.

Also, the existing criteria related to energy efficiency based on lighting power density (for both indoor and outdoor) are replaced by a set of three independent criteria: the maximum illuminance level, lamp luminous efficacy and luminaire maintenance factor with maintenance plan, which enable much better evaluation.

In order to facilitate the future implementation of the proposed set of criteria, the hierarchy is established in a way that they are divided into three groups: mandatory, high importance and low importance criteria.

Since environmental building and its assessment is currently being introduced into Serbian building practice, the results of the research presented in this paper can contribute to the better understanding of significance of lighting design and its position in the overall green building certification system's structure.

Although predominantly intended for the improvement of Serbian building practice, the proposed set of assessment criteria is general and can be used throughout the world.

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