Lighting in the Building Regulatory System: Overview of the Portuguese Situation

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Abstract

Residential buildings are responsible for a large share of the total energy consumption. It is well-known that the correct use of natural and artificial lighting can improve energy efficiency. However, lighting in residential buildings should meet other requirements: safety, security, health, comfort, well-being and functional performance. This paper presents an analysis of how these requirements have been incorporated in the Portuguese building regulatory system. The analysis focuses on the regulatory framework, certification systems, incentive programs and awareness initiatives. The main conclusion is that the regulatory system lays down provision mainly on functional performance and energy saving. Lighting requirements regarding safety, security, health, comfort and well-being are often neglected or minimized in regulatory documents. Specialized documents and initiatives present a comprehensive approach. Daylighting design is a challenge, due to its complexity, but has potential rewards. New indicators and methods should be used to lay down lighting requirements, preferably in a separate regulation.

Keywords: Daylighting, Artificial lighting, Energy efficiency, Housing

1. Introduction

In a context of growing concern with the environment and its protection, one of the priorities of modern societies is to promote sustainability and rational use of energy. Residential buildings are one of the sectors with higher emission of greenhouse gases and energy consumption. The correct use of daylight in indoor spaces has become an important strategy to increase energy efficiency in buildings, since it minimizes energy consumption for artificial lighting, heating and cooling. Efficient artificial lighting systems are also a well-known strategy to save energy.

However, lighting "goes beyond" saving energy. In buildings, lighting should meet other requirements:

1) *Safety and security* – Adequate lighting conditions prevents accidents and contributes to enhance security. Emergency lighting provides a safe route in case of disaster.
2) *Health* – Proper lighting contributes to a healthier human vision system by avoiding eyestrain and other lighting-related problems. Daylight and sunlight have health benefits for humans such as adjusting the circadian rhythm and balancing vitamin D.

3) *Comfort and well-being* – Visual comfort requires minimizing glare and excessive contrast variations. Daylighting contributes to create a pleasant luminous environment that benefits from its intrinsic qualities (*e.g.*, full-spectral contents, dynamic characteristics along day and year). The possibility of visual contact with the outside is an additional benefit of daylighting through glazed areas.
4) *Functional performance* – Sufficient lighting levels enables users to perform visual tasks accurately and without eyestrain.

This paper analyses to what extend these requirements have been incorporated in the Portuguese policies and regulatory tools. The research questions addressed are as follows:

1) Which requirements on lighting are set in the regulatory framework?
2) How is lighting included in certification systems of construction products and buildings?
3) Are there incentive programs and tax benefits to improve lighting conditions?
4) To what extent is lighting included in training programs and technical documentation?

The following section explains the research methodology. The results are presented in sections 3 to 6, which deal with regulatory framework, voluntary certification, incentive programs and, finally, training and information. Section 6 describes and discusses the conclusions.

2. Research methodology

Key Portuguese documents with provisions relating to lighting, both natural and artificial, in residential buildings were collected. Summaries presented for each topic were based on the analysis of information collected. Final conclusions bring together and discuss the partial results.

The study addressed the building regulatory system, though a wider context was analysed in order to describe its framework. The following types of initiatives were considered relevant to the study due to the reasons mentioned hereafter:

1) Building regulations set minimum quality requirements.
2) Voluntary evaluation and certification systems of the environmental performance of products and buildings are intended to guarantee levels above the minimums set by building regulations.
3) Incentive programs and tax benefits support the implementation of some provisions set by building regulations.
4) Training courses and technical information capacitate technicians who apply or enforce compliance with the building regulations.

3. Regulatory framework

Building regulations set minimum quality requirements to ensure that buildings are safe, healthy, energy-efficient and accessible to everyone who lives and works in and around them. In this section, a summary of the main Portuguese building regulations, with provisions on natural and artificial lighting, applicable to residential buildings, is presented.

National building regulations

The *"General Building Regulation"* (*Regulamento Geral das Edificações Urbanas – RGEU*) is the main Portuguese building regulation (Portugal, 1951). It has been in force since 1951 and sets out general provisions for building, regarding construction, health, safety and aesthetics. To ensure habitability conditions, RGEU includes some basic requirements on daylighting. There are provisions on minimum distance of façades from opposite buildings, minimum size of windows (window area to floor area ratio higher than 10 percent) and minimum distance of windows from obstacles that impair daylighting conditions (*e.g.*, other buildings, exterior walls). There is also a generic provision on direct exposure to sunlight not specified by quantitative requirements (*i.e.*, «*the construction or reconstruction of any building shall be carried out in order to ensure (...) prolonged exposure to direct sunlight*»). When RGEU was approved energy efficiency was not yet a main concern.

In 2007, a proposal for a new RGEU *(Regulamento Geral das Edificações - RGE)* was presented (CSOPT, 2007). This proposal improved the provisions already set on daylighting and introduced new ones to ensure access to direct sunlight during a minimum period of time. Special requirements to regulate daylighting through patios were also introduced. Provisions on daylighting and sun lighting aim to ensure habitability conditions. No relation with energy efficiency was set. Due to a lack of consensus, the proposal of a new RGEU was not implemented.

The *"Regulation on Energy Performance of Residential Buildings"* (*Regulamento de Desempenho Energético dos Edifícios de Habitação – REH*) applies to the design of new and existing residential buildings (Portugal, 2013b). REH does not lay down specific provisions on daylighting. However, indirectly, it enforces constrains on windows dimensions, solar factor (which takes into consideration the solar heat gains through the glazing systems) and thermal transmission coefficient (which accounts for the thermal insulation between the interior and exterior environments). These limitations can have negative consequences in the indoor daylight conditions, since they may decrease the indoor daylight levels, either by the use of lower luminous transmission glazing systems or by the decrease of net glazing area of windows.

The *"Technical Recommendations for Social Housing"* (*Recomendações Técnicas de Habitação Social – RTHS*) are mandatory for affordable housing developments that benefit from public support (Portugal, 1985). These recommendations set simple qualitative provisions on visual comfort, such as the need of contact with the outside environment, visual properties of surface finishing of walls and equipment, and the possibility to blackout exterior light in bedrooms with shading devices. It also sets provisions that require the use of natural lighting in common and private circulation spaces (*e.g.*, stairs, corridors, halls).

The *"Technical Recommendations for Social Facilities"* (*Recomendações Técnicas para Equipamentos Sociais – RTES*) are mandatory for social facilities that operate with public support (ISS, 2007 & 2010). Some residential buildings are within the scope of these recommendations, such as retirement homes, temporary shelters, shelters for children and youngsters. The RTES set comprehensive provisions on daylight and artificial light, addressing safety, comfort, functional performance and energy saving. These recommendations include general principles, performance goals and verification methods.

Bylaws

In Portugal, local authorities (municipalities) can approve building ordinances and bylaws, covering issues omitted in national regulation, adapting general rules to local conditions, traditions and uses, and regulating matters of municipal authority. Some bylaws set additional provisions to national building regulations regarding energy savings by the use of natural and artificial lighting in buildings (Portugal, 2013a).

Building Standards

Compliance with standards is voluntary, except when Portuguese legal documents make direct reference to specific standards (Portuguese – NP, European – EN or International – ISO), which then become mandatory.

Presently, there are no Portuguese Standards on natural or artificial lighting, but a technical committee is working on this subject. Meanwhile, two European Standards on lighting are frequently used: EN 12464-1 (CEN, 2011) and EN 15193 (CEN, 2007). These standards are mandatory for commercial and office buildings, but most of their contents is used as reference for residential buildings.

The *"European Standard EN 12464-1: Light and lighting – Lighting of work places – Part 1: Indoor work places"* specifies the functional lighting requirements for humans in indoor work places, which meet the needs for visual comfort and performance of people. It also specifies requirements for lighting solutions for most indoor work places and their associated areas in terms of quantity and quality of illumination. In addition, recommendations are given for good lighting practice. According to this standard, besides the required illuminances, additional qualitative and quantitative needs should be satisfied. The lighting requirements in buildings are determined by the satisfaction of three basic human needs: visual comfort, visual performance, and safety. The major parameters determining the luminous environment with respect to artificial light and daylight are: luminance distribution, illuminance; directionality of light; variability of levels and colour of light; colour rendering and colour appearance of the light; glare; and, flicker. The standard specifies values for illuminance and its uniformity, discomfort glare index, colour rendering index, and other relevant parameters.

The *"European Standard EN 15193: Energy performance of buildings – Energy requirements for lighting"* was devised to establish conventions and procedures for the estimation of energy requirements of lighting in buildings, and to give a methodology for a numeric indicator of energy performance of buildings. This standard specifies the calculation methodology for the evaluation of the amount of energy used for indoor lighting, taking into account the potential savings due to the use of daylight. The standard also provides a numeric indicator for lighting energy requirements (*LENI – Lighting Energy Numerical Indicator),* which estimates energy consumed in electric lighting taking into account potential savings due to daylighting; it is used for certification purposes, and can be used for new or existing buildings.

Table 1. Lighting subjects addressed by building regulations

	Safety & security	Health	Comfort & well-being	Functional performance	Energy saving
Mandatory					
General Building Regulation (RGEU)		✓		✓	
Regulation on Energy Performance of Residential Buildings (REH)					✓
Technical Recommendations for Social Housing (RTHS)	✓		✓		
Technical Recommendations for Social Facilities (RTES)	✓	✓	✓	✓	✓
Bylaws					✓
Non-mandatory					
EN 12464-1			✓	✓	
EN 15193					✓

4. Certification and labelling systems

Green building certification and labelling systems comprise a set of criteria to assess different environmental aspects of buildings. Most existing systems are voluntary since the belief is that construction sector adherence will be due to environmental commitment or to ensure buildings' competitiveness and differentiation. In this section, we analyse how natural and artificial lighting are considered in certification and labelling systems used in Portugal for products and buildings.

EU Energy Label

The *"European Union Energy Label"* is an energy labelling scheme established by Directive 2010/30/EU (EU, 2010). It applies to energy-related products which have a significant direct or indirect impact on energy consumption. The directive was transpose to the Portuguese legal order (Portugal, 2011). Artificial light sources (lamps) are within the scope of this European energy label.

SEEP

The *"SEEP – System of Products Energy Labelling"* (*Sistema de Etiquetagem Energética de Produtos*) is a voluntary labelling system that allows consumers to compare the energy performance of products (ADENE, 2013). This label extends the concept of energy performance classification to products that are not regulated by the Energy Labelling Directive, but are important to housing energy performance.

Windows were the first labelled product classified by SEEP. The classification is obtained by assessing windows performance in the coldest and hottest months of the year, showing their ability to reduce heat loss in winter and overheating in summer.

LiderA

"LiderA" is an assessment and acknowledgement system for buildings and built environment sustainability (Pinheiro, 2010). The system can be used to assess and certify urban and building developments for different uses (*e.g.*, residential, commercial, office and tourism) and applied at different phases, including planning, design, construction, operation and renewal. The evaluation is divided into 6 categories, 22 areas and 44 criteria.

In the category *"Resources"*, area *"Energy"*, characteristics of windows is one of the features assessed in criteria *"C7 – efficiency in consumption and energy certification"* and *"C8. Passive performance"*. In the category *"Environmental comfort"*, area *"Lighting and acoustics"*, criteria *"C26 – Levels of lighting"* assess levels of lighting in each environment of the building, taking into consideration the activities performed and the characteristics of the users (Pinheiro, 2010).

SBTool

"SBTool^{PT}" is a system to assess and certify the sustainable performance of buildings and developments (SBTOOL-PT, 2011). It is based on the international system SBTool (Sustainable Building Tool) developed by iiSBE (International Initiative for the Sustainable Built Environment) in collaboration with a consortium of teams from over 20 countries. The system can be used to assess different types of buildings (*e.g.*, office, residential or other). The evaluation is divided into 3 dimensions, which cover 9 categories and 30 parameters.

In the *"Environmental"* dimension, characteristics of windows are used in the assessment of categories *"C1 – Environmental impact during the building life cycle"* and *"C3 – Energy efficiency"*. In the *"Social"* dimension, category *"C6 – Comfort and health of users"* includes the parameter mean *average daylight factor*. In the *"Economic"* dimension, category *"C9 – Costs along the life cycle"*, energy class of artificial lighting equipment is an additional criteria to the assessment of a parameter on operation costs (Mateus, 2009).

Passive House

"Passive House" is a voluntary standard for energy efficiency in buildings. Buildings that comply with the Passive House criteria can be certified as Passive House Buildings. The system was originally developed in Germany, but it spread and currently there is an association with 16 affiliated organizations. In Portugal, this standard is starting to be implemented by the *"Associação Passivhaus Portugal"* (PHPT, 2013; IPHA, 2015).

Passive Houses are certified based on a quality check of their design. To verify if certification criteria for residential Passive House buildings is met, some characteristics of windows (*e.g.*, size, orientation, U-values) and shading devices (*e.g.*, shading coefficients) are used (PHI, 2015).

International certification systems

In Portugal the use of international certification systems (*e.g.*, BREAM, LEED) is residual (Pedro & Pina dos Santos, 2011), therefore they are not analysed in this paper.

Table 2. Lighting subjects addressed by certification and labelling systems

	Safety & security	Health	Comfort & well-being	Functional performance	Energy saving
EU Energy Label					✓
SEEP					✓
LiderA				✓	✓
SBTool				✓	✓
Passive House					✓

5. Incentive programs and tax benefits

In order to improve environmental performance it is necessary to change the characteristics of the building stock, whether through interventions in the physical envelope of buildings or through the acquisition of more efficient equipment. Incentive programs and tax benefits can be used to encourage these changes. In this section we identify the incentive programs and tax benefits used in Portugal to improve natural and artificial lighting performance of buildings.

General programs on efficient use of energy

There are no specific incentive programs or tax benefits to improve natural and artificial lighting performance of buildings. However, incentive programs and tax benefits to promote the efficient use of energy in buildings can be used to improve energy performance of windows. Therefore, during renovations low performance windows are usually replaced (*e.g.*, replace single by double glazed windows).

Measure "Efficient Window"

The incentive measure *"Efficient Window"* (*Medida Janela Eficiente*) gives financial support specifically to the replacement of inefficient windows. Its aim was to rehabilitate the windows of about 200 000 homes by 2015. This measure is part of the Portuguese *"National Action Plan for Energy Efficiency 2008-2015"* (*Plano Nacional de Acção para a Eficiência Energética* – PNAEE) (Portugal, 2008).

Phase-out of incandescent light bulbs

The most recognisable lighting related action in Portugal was the phase-out of incandescent light bulbs. Two measures listed in PNAEE implemented this policy (Portugal, 2007; Portugal, 2008): i) to counterbalance the impact of energy inefficient light bulbs on the environment, an additional tax was applied; and, ii) to raise awareness of consumers, there were campaigns of free exchange of incandescent light bulbs. The target was to replace 22,6 million incandescent light bulbs by compact fluorescent lamps (CFL) or light sources of similar efficiency, until 2015.

Table 3. Lighting subjects addressed by incentive programs and tax benefits

	Safety & security	Health	Comfort & well-being	Functional performance	Energy saving
General programs on efficient use of energy in buildings					✓
Efficient Window					✓
Phase-out of incandescent light bulbs					✓

6. Dissemination

To improve the lighting conditions of buildings, it is not only necessary to adopt effective policies in terms of regulations and investment, but also to increase the technical capacity of professionals. In this section, we analyse how lighting is included in the academic education of construction sector professionals and in the technical documentation available.

Training

The curricula of Architecture and Civil Engineering degrees does not specifically address the design of daylighting and artificial lighting. Artificial lighting design is also not systematically addressed in Electrical Engineering higher education. Graduate courses on Interior Design address lighting design. The reduced training on lighting, provided by graduate courses, results in low levels of expertise of most building professionals.

Some architects pursue post-graduate education on lighting, since they acknowledge its importance for architectural design. The Architects Professional Association and other public research institutes (*e.g.*, National Laboratory for Civil Engineering – LNEC), regularly organize post graduate courses on lighting to meet this demand. The level of expertise of these courses range from basic to advanced.

The low relevance that lighting has been given to in major Architecture and Civil Engineering schools is also revealed by the limited scientific output in the area. Research and development on daylighting and artificial lighting is mostly conducted in research and development public institutions (*e.g.*, LNEC).

Technical documentation

Guidelines and manuals are one of the most effective ways to disseminate technical information on daylighting and artificial lighting. Although many documents from other European countries are available, it is important to remember that daylighting is climate and geographically sensitive. Consequently, the use of technical documentation from different climatic origins is not straightforward.

There are some technical manuals and books specially adapted for daylighting design of buildings in luminous climates characterised by the prevalence of non-overcast skies, like Portugal (Carvalho, 1995; Santos, 2011; Santos, 2014). Nevertheless, the lack of manuals with design guidelines on daylighting is acknowledged.

There is abundant information on electric lighting systems available from local and international lighting manufacturers. The provided documentation covers, not only the products and services that are made available by the manufacturers, but also information on artificial lighting concepts and design (ADENE, 2010). The lack of technical documentation on artificial lighting would not be critical since it is not climate sensitive and extrapolation of information from non-national sources is acceptable.

In Portugal there are no periodic scientific and technical journals devoted exclusively to daylighting or artificial lighting. There are several technical periodical journals in the domain of building (architecture and civil engineering) that seldom publish articles on daylighting and artificial lighting.

Table 4. Lighting subjects addressed by training and technical information

	Safety & security	Health	Comfort & well-being	Functional performance	Energy saving
Education – undergraduate				✓	✓
Education – postgraduate		✓	✓	✓	✓
Technical documentation	✓	✓	✓	✓	✓

7. Conclusions and discussion

Main findings

1) Which requirements on lighting are set in the regulatory framework?

National building regulations, that apply to all residential buildings, lay down requirements on daylighting regarding functional performance, health and energy savings. Requirements concerning safety, security, comfort and well-being due to daylight are only addressed in building regulations for specific types of buildings. Artificial lighting is only regulated for certain types of residential buildings. Building standards on lighting are not mandatory in residential buildings.

2) How is lighting included in the certification systems of construction products and buildings?

The eco-label and certification systems for products and materials apply to windows and artificial light sources. The classification is obtained by assessing the energy performance of these products. The systems of green building assessment and certification especially adapted to the Portuguese context (*i.e.*, LiderA, SBTool) assess functional performance and contribution to energy saving of lighting. Passive House system only assess energy performance of windows and shading devices.

3) Are there incentive programs and tax benefits to improve lighting conditions?

Expenses with the improvement of energy performance of windows are eligible in general programs aimed at energy efficiency of buildings. A specific measure to foster energy efficiency of buildings has not been implemented so far. The phase-out of incandescent light bulbs is the most visible lighting related action in Portugal.

4) To what extent is lighting included in training programs and technical documentation?

With the exception of Interior Design, lighting design is not specifically addressed in the education of professionals that operate in the construction sector. Periodically, post-graduate courses on lighting are organized. Some technical documentation on daylighting design of buildings, specially adapted to Portuguese luminous climate, is available. Technical documentation on artificial lighting is abundant.

Discussion

1. Lighting, both natural and artificial, plays an important role in the energy efficiency of buildings (Figure 1). However one must keep in mind that the main purpose of light is to provide adequate luminous conditions to perform visual tasks. Therefore, requirements associated with creating such conditions should prevail over energy aspects.

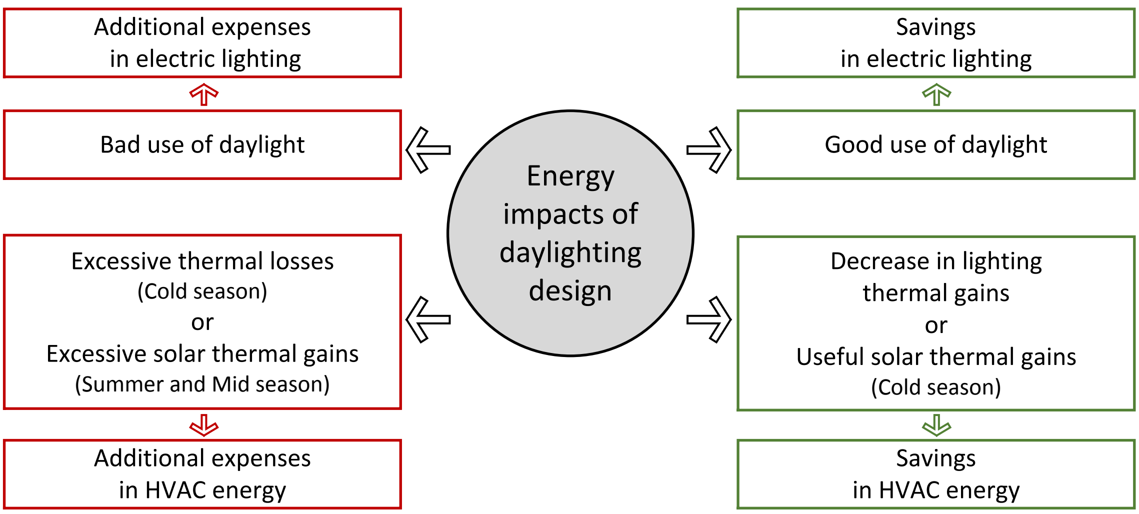

Figure 1. Diagram of the major potential energy-related impacts of daylighting (based on Santos *et al.*, 2008)

2. Provisions set in the *"General Building Regulation"* (RGEU) to enforce functional performance of daylight are simple to use but not specifically directed to quantify daylighting conditions. They should be replaced or complemented with provisions that address the intrinsic visual aspects of lighting related with this requirement (*e.g.*, illuminance level or daylight factor level). Moreover, building regulations should set provisions on comfort and well-being requirements of lighting for all residential buildings.

3. To ensure environmental comfort and rational use of energy, in Portugal, there are specific building regulations on energy efficiency and thermal performance, protection against noise, ventilation and indoor air quality. These regulations lay down general principles, performance goals and verification methods. In opposition, there is no specific regulation on lighting and some provisions set in general regulations adopt a generic functional formulation (*e.g.*, the interior spaces must be adequately lit by natural light). A specific regulation on lighting would be a major improvement.

4. A combination of existing and new indicators can be used to characterize indoor luminous environment. Some research has been accomplished in this subject, such as the proposal summarized in Table 5. A trade-off between traditional approaches (already established and hence easier to implement) and dynamic approaches (climate and user sensitive, more difficult to implement) must be made in order to achieve a proposal acknowledged by the scientific and the building design community. Once accepted, this proposal can constitute the framework of future standards or building regulations on lighting.

Table 5. Key indicators for daylighting and artificial lighting characterization (Santos, 2013)

DAYLIGHTING	ARTIFICIAL LIGHTING
– Daylighting levels – Assessment of Daylight Factors (%) or illuminances (lux) in work planes	– Illuminance levels (lux) and uniformity from electric lighting systems
– Daylight uniformity	– Unified glare rating system (UGR)
– Daylight autonomy (% hours/year)	– Luminance of light sources (cd/m^2)
– Daylight glare control	– Luminance ratios
– Daylight control and modelling (type and efficiency of shading systems and respective control strategy)	– Colour rendering index
– Visual contact with the outside	– Luminous efficacy of light sources (lumen/Watt)
– Insolation (hours /year)	– Installed lighting power density (Watt/m^2) or lighting power density per 100 lux
– Aspect of surfaces (luminance of surfaces – cd/m^2, reflectance of surfaces, type of surface finish and texture)	– Type and efficacy of electric lighting controls
– Preferences, satisfaction, attitudes and behaviours of individuals towards daylighting conditions and associated control systems	– Preferences, satisfaction, attitudes and behaviours of individuals towards indoor artificial lighting conditions and associated control systems

5. The relation between *user* and *luminous environment* depends on the individual characteristics of each user. Therefore, a methodology to characterize or foresee the lighting conditions should include subjective aspects related to expectations, preferences, attitudes and behaviours of users towards the luminous environments and to the associated control systems. If this is not done, the functional assumptions of any lighting design may be tampered.

6. The advent of new highly efficient light sources (*i.e.*, solid state light sources also referred as LEDs) has a parallel with the mid-twenty century situation, when there was the advent of affordable and energy efficient fluorescent light sources. In those days, fluorescent lighting almost relegated daylighting techniques to a second plan. Only the energy crisis in the early 1970's brought-back daylighting techniques to the foreground as an energy saving technique. Solid State Lighting is a new exciting technology, but it must not be a reason to *"shut-down"* buildings to daylight. Electric lighting should only be used when the lighting needs cannot be satisfied with daylight and this remains true in the era of the LED.

Future developments

One of the conclusions of this paper is the need to improve the lighting requirements set in the Portuguese building regulation. Therefore, two relevant topics of research are: (i) which are the adequate indicators to regulate indoor luminous environment that can be properly used by Portuguese building designers, and (ii) how to incorporate in the regulatory documents users' subjective appraisals of the luminous environment.

The experimental daylighting characterization and analysis of case studies should also be pursued in order to enhance and demonstrate the benefits of daylighting to save energy and promote users health, comfort and well-being.

Acknowledgements

The input of Carlos Pina dos Santos and Vitor Campos is gratefully acknowledged.

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