Light in Engineering, Architecture and the Environment

EDITED BY
K. Domke
and C.A. Brebbia

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Light in Engineering, Architecture and the Environment

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Preface

The light – a mysterious, weightless, almost non-material substance, that surrounds all of us, that brings the peace of the day at every dawn, that extends the space around us, making it accessible to our senses and that impacts our life, activity and esthetic sensations. The symbol of divinity, life, truth and beauty. A force that guarantees life throughout the Earth's entire biosphere. Human civilization is a history of the man's struggle to control and subdue light: the first camp fires, torches, cressets, candles, kerosene lamps and at the end all possible kinds of electric lamps, each one more efficient than the previous one – such are the stages of the rise of our civilization. Our efforts yield increasingly spectacular results. Our current, very efficient light sources let us disregard the rule of day and night. Not only can we freely shape our light environment, but also use the light to send information, cure ailments and enhance our esthetic sensations.

The light is the key and unifying force to all the book's sections. The light for architectural purposes, required by people indoors for work and leisure, the light that models architectural shapes from inside and outside to make them more attractive, the light in the road that makes it safe and accessible even at night, the light boosting our activity and bringing us relief in sickness and suffering.

Scientist dealing with lighting technologies, architects and experts in other fields of science and art related to the use of light met in Poznañ, Poland, in 2011. The meeting was a chance for an in-depth discussion on various aspects of the use of light for all kinds of technological purposes, art, medicine and environment. New calculation methods and tools, computer aided visualization of illuminated objects, improvements in design of architectural objects and construction of lighting equipment, issues related to improvements in their operating, measurement of quantity and quality of light and efficiency matters were the meeting's main topics. The book's sections present the most interesting papers presented during the Conference. The First International Conference on Lighting in Engineering, Architecture and the Environment was organized as a venue to share concepts in technology, art and human arts. The marriage of the sacred and the profane seems to actually enrich both sides, rendering the works of man both better in terms of technology and their symbolism more easily understood.

The Editors
Poznan, 2011

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Section 1
Architectural lighting design and applications

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The dynamic lighting technique in indoor architecture

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Abstract

Light has a significant effect on the whole biological parameters of people. Its influences are found in many areas including the following:

- By means of human sight, light organizes the relationship between men and both living and lifeless of all creation in its entirety.
- The releasing into the human body of hormonal substances such as melatonin and cortisol are influenced by the light that, consequently, influences the well- being status of people such as body temperature, alertness and so on.
- The alternating of daytime and night time, that is the alternating of light and darkness, sets significantly the so called "biological clock" of man. According to that previously reported, light has a direct and significant impact on the behavior of people. So, while the emphasis in the past may have been primarily focused on the visual effects of lighting, the present efforts of research are focused on discovering the biological effects.

"Dynamic lighting" is an advanced technique that tries to bring the dynamic of daylight in indoor environments with the aim of creating a stimulating "natural" light that may enhances people's sense of well-being. According to this objective, the Authors have applied, using specialist software, the dynamic light technique to a model of minimalistic architecture used as offices, museums and exhibition halls. By the previous technique, people could control their own space according to their needs, mood and task, creating the right atmosphere by "dynamic light" to improve performance and motivation of their own job.

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This paper wants to show the first step of results obtained in the case study by technical solutions suggested.
Keywords: dynamic light, well-being, comfort, minimalist architecture.

1 Lighting and biological effects

We normally think of the eye as an organ for vision, but due to the discovery of additional nerve connections from recently-detected novel photoreceptor cells in the eye to the brain, it is now understood how light also mediates and controls a large number of biochemical processes in the human body. The most important findings are related to the control of the biological clock and to the regulation of some important hormones through regular light-dark rhythms. This in turn means that lighting has a large influence on health, well-being and alertness. Light sends signals via the novel photoreceptor cells and a separate nerve system to our biological clock, which in turn regulates the circadian (daily) and circannual (seasonal) rhythms of a large variety of bodily processes. Figure 1 shows some typical rhythms in human beings. The figure shows only a few examples: body temperature, alertness, and the hormones cortisol and melatonin [1].

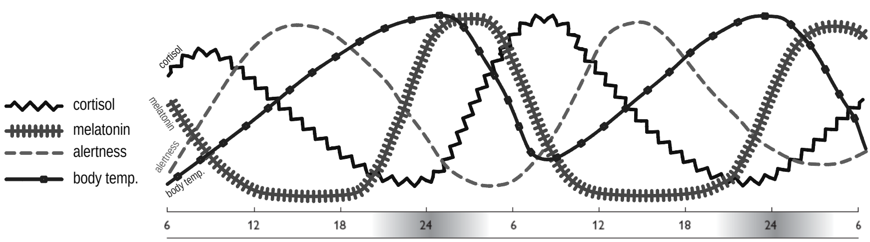

Figure 1: Some typical rhythms in human beings.

The hormones cortisol (“stress hormone”) and melatonin (“sleep hormone”) play an important role in governing alertness and sleep. It is the rhythm of day and night, of light and darkness that synchronises our biological clock. Accordingly, light has a direct and significant impact on people’s alertness and well-being. So, while the emphasis in the past may have been primarily on the visual effects of lighting, now there is increasing interest in its biological effects too. It is possible, therefore, to use daily dynamics in lighting to improve performance, for example by varying illuminance and colour temperature according to the time of day. Higher illuminance levels with colder light will wake us up in the morning and make us more alert during the post-lunch dip. Low illuminances with a warm colour temperature have a calming effect. Two of the characteristics of light that strongly influence how we feel in a given environment are the brightness and colour appearance of the light. First of all, the light should always be bright enough to facilitate visual task performance, and better visual task performance results in better work performance. Increased lighting levels can also help to counter well-known effects such as the 'after-lunch dip' among day workers [2].

The colour appearance of the light also has substantial biological relevance. For example, the bluish light of morning has a stimulating effect on us, while the red sky of the early evening is relaxing. Daylight – the form of light with which we are most comfortable – is never constant. It changes throughout the day, affecting our emotions, moods, perception and performance [3, 4].

2 The Kunsthalle

The authors have designed a dynamic lighting system for a "Kunsthalle", an exhibition space dedicated to contemporary art, Figure 2. The Kunsthalle was designed to find a balanced relationship between art, architecture and nature. The idea was to create a hinge structure "hybrid" that confers a specific urban identity to the archaeological area of Syracuse, creating a zone filter to the archaeological site of Neapolis, carrying out a connection between the city and the archaeological zone. The project has drawn inspiration from minimalist architects such as Claudio Silvestrin and Tadao Ando.

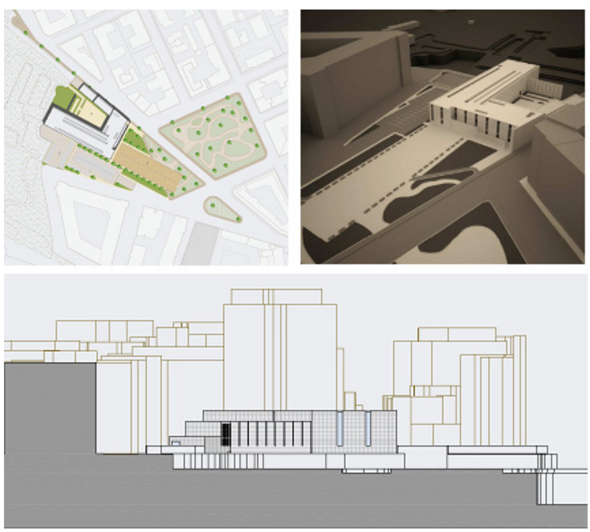

Figure 2: Some views of the Kunsthalle.

In the following sections, a detailed analysis will be performed of the comparison between a standard and dynamic lighting system for the office located in the Kunsthalle. The technical light design will be evaluated, the lighting parameters, the costs and benefits. Then, it will be exposed how the technical light design, applied to the environment taken as a reference, can be applied to the Exhibition Hall.

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3 The standard and dynamic lighting system for an office

As a first step, respecting the limits imposed by current regulations (EN 12464-1), the lighting design of the office located in the Kunsthalle was carried out using first the standard lighting system and then the dynamic lighting. The office is an open space and its dimensions are 17.5mx 5.6mx 3.7m (Figure 3). The office has windows of size 0.2mx 1.70m at a height of 2.0m above the floor. The reflection coefficient of the walls are 0,5. The reflection coefficient of the ceiling is 0,7. The reflection coefficient of the floor is 0,2. The desks and the other furniture have a reflection coefficient equal to 0,3.

Figure 3: The office modeled with standard lighting.

The office lighting equipment has been arranged in three rows of six Philips type lighting fixtures, Savio model, version for mounting on the ceiling containing lamps 54W (TCS760-2xTL5-54W/840 Standard Lighting version and TCS770-3xTL5-54W/865/827/865 Dynamic Lighting version) with micro-lens optic (MLO) that allows Omni-directional Luminance Control (OLC), placed parallel to the facade. It has been calculated the horizontal illuminance level both for the standard scenario and the dynamic scenario using the human rhythm (Figure 5), not taking into account the day-lighting (Figures 6 and 7), using the software Relux.

Table 1 shows a summary of the results obtained using the software Relux for the two scenarios. The different values of total luminous flux of all lamps and, consequently, the different values of average illuminance are due to both the use of different types of lamps that the maintenance of the same uniformity of illumination for the two scenarios. It can be noted that the minimum value of average illuminance, required by EN 12464-1, is satisfied for both scenarios but in the dynamic scenario, with the same rate of luminous flux, the average illuminance is greater than 300 lx compared to the standard scenario.

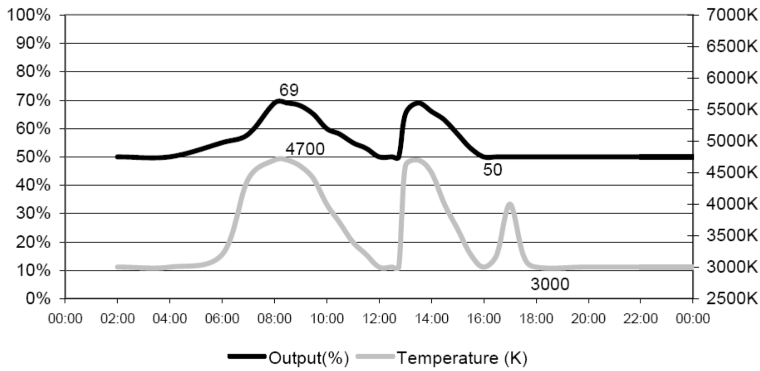

Figure 4: The graphs show the minimum and maximum values for both light output as color temperature.

Table 1: Comparison between standard and dynamic scenario (Relux data).

	Standard Scenario	**Dynamic Scenario**
Calculation algorithm used	high indirect fraction	
Height of evaluation surface	0,75	
Height of luminaire plane	3,70	
Maintenance factor	0,80	
Total luminous flux of all lamps	160200 lm	233118 lm
Total power	2124 W	3204 W
Total power per area (98.00 m^2)	21,67 W/m^2	32,69 W/m^2
Average Illuminance (E_m)	590 lx	910 lx
Minimum Illuminance (E_{min})	91 lx	140lx
Maximum Illuminance (E_{max})	742 lx	1140 lx
Uniformity (E_{min}/E_m)	0,15	0,15
Uniformity (E_{min}/E_{max})	0,12	0,12

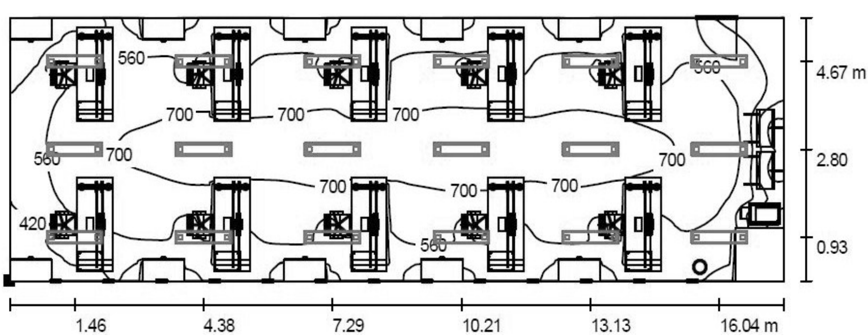

Figure 5: Horizontal illuminance levels for the standard scenario.

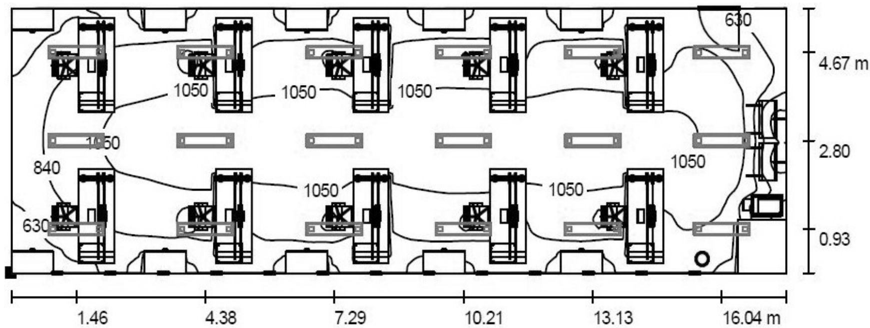

Figure 6: Horizontal illuminance levels for the dynamic scenario.

Tables 2 and 3 show that the values of the luminous flux and the color temperature remain constant over time for the standard scenario, while those values change over time for the dynamic scenario. Moreover, in the two tables the cost of electricity is set out over a year for both scenarios. The cost of electricity for the dynamic scenario is 12% greater than the standard.

The cost of the two lighting systems is the same while the cost of the lighting fixtures for the standard system and the dynamic system is different, which also requires a control unit and a set of modulation device. Consequently, the cost of a dynamic lighting system is greater than 44% compared with the standard

Table 2: Illuminance levels, luminous flux, color temperature and cost for the standard scenario.

Standard Lighting							
h	E_m [lx]	Flux	Tcp [K]	P [kW]	h/year	€/kWh	€/year
8:00/18:00	590	100%	4000	2,124	2400	0,13	662,69

Table 3: Illuminance levels, luminous flux, color temperature and for the dynamic scenario.

Dynamic Lighting							
h	E_m [lx]	Flux	Tcp [K]	P [kW]	h/year	€/kWh	€/year
8:00	709	78%	4400	2,499	240	0,13	77,972
9:00	709	78%	4400	2,784	240	0,13	86,860
10:00	873	96%	3800	2,816	240	0,13	87,859
11:00	728	80%	3500	3,304	240	0,13	71,884
12:00	582	64%	3000	2,080	240	0,13	64,896
13:00	591	65%	4900	2,080	240	0,13	64,896
14:00	591	65%	4900	3,304	240	0,13	71,884
15:00	728	80%	4250	2,400	240	0,13	74,880
16:00	637	70%	4500	2,560	240	0,13	79,872
17:00	819	90%	4000	2,560	240	0,13	79,872
18:00	728	80%	4250	2,499	240	0,13	77,972
						Total	760,87

lighting system. Table 4 shows the cost of the lighting fixtures for the two systems. The cost comparison has been made for 32 luminaire because it is the maximum number of luminaire that the controller can handle and it is convenient to handle the maximum possible number of luminaire.

Table 4: The cost comparison of the lighting fixtures.

	Cost (€)	N	Total (€)
Standard Lighting			
Luminaire TCS760	530	32	16960
Dynamic Lighting			
Luminaire TCS770	800	32	25600
Kit Dynamic Lighting	4000	1	4000
Control unit	700	1	700

Although the cost of a dynamic system is greater than the standard, it has to be remembered that some of the economic losses of a company are caused by the absence of the employees and this is often due to non-healthy lighting. We considered that this part of economic loss attributed to the absence could have been to transform into an economic gain for the company by using a system of dynamic lighting. In fact, the research shows that one of the positive effects induced by the increase on well-being produced by a dynamic lighting is the decrease of the absenteeism that can be quantified from 8% to 12% [1]. The reduction in absenteeism could lead the company to an economic gain and it could help to offset costs of investments over time. Figure 8 shows the cost of construction and management (annual energy cost and maintenance) for the dynamic system and standards.

The graph also shows the economic trend of the investment due to lower percentages of non-absenteeism (8%, 10%, 12%) thanks to the dynamic lighting system.

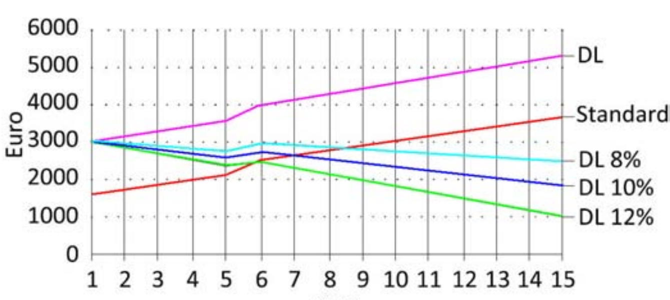

Figure 7: The cost of construction and management.

For the above chart the following program of maintenance was taken into account:

- maintenance lamps: 3rd, 5th, 9th, 11th, 13th year;
- maintenance and replacement lamps: 7th year.

4 The Exhibition Hall

As in the previous section, a modellation of the Exhibition Hall has been performed and applied both the standard lighting system and the dynamic lighting system. In this case, however, we focused on software capable of modeling the dynamic light. To this aim, several simulations with Fryrender software have been performed. Fryrender is a photo-realistic render engine where all the elements involved in the generation of the final image (materials, lights and cameras) are based on physically accurate models. It is not a classical render engine, but a physics simulator that reproduces the governing Laws of light radiation and optics accurately. This light simulation is performed using unbiased integration techniques that ensure that the render will converge to the exact real light balance, provided enough time for the computations.

In the dynamic lighting simulation, the Exhibition Hall equipment has been arranged in two rows of twenty-eight Philips type lighting fixtures, Savio model, version for mounting on the ceiling containing lamps 35W (TCS770-3xTL5-54W/865/827/865). In the standard lighting simulation, the Exhibition Hall equipment has been arranged in four rows of fourteen Zumtobel type lighting fixtures, SLOT model, version for mounting on the ceiling containing lamps 54W (Slot 3x1 54W PMMA LDE IP54). The horizontal and vertical illuminance level both for the standard scenario and the dynamic scenario using the human rhythm has been calculated, not taking into account the day-lighting using the software Relux and then modeling the environment using the software Fryrender.

Figure 8: The images of the Exhibition Hall with dynamic lighting system at different hours of the day.

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Table 6 shows the comparison of the summary of results obtained in the two scenarios. Figure 9 shows four frames of the simulation of dynamic lighting with natural biorhythm. Figure 10 shows the image of the simulation of standard lighting. Figure 5 shows the comparison of the variation of dynamic lighting with the standard lighting.

Figure 9: The images of exhibition Hall with standard lighting system.

Table 5: Comparison between standard and dynamic scenario (Relux data).

	Standard Scenario	**Dynamic Scenario**
Calculation algorithm used	high indirect fraction	
Height of evaluation surface	1,75	
Height of luminaire plane	7,90	
Maintenance factor	0,80	
Total luminous flux of all lamps	747600 lm	532056 lm
Total power	9945.6 W	6496 W
Total power per area (695,72 m^2)	14,30 W/m^2	9,34 W/m^2
Average Illuminance (E_m)	311 lx	311 lx
Minimum Illuminance (E_{min})	122 lx	111 lx
Maximum Illuminance (E_{max})	397 lx	413 lx
Uniformity (E_{min}/E_m)	0,39	0,36
Uniformity (E_{min}/E_{max})	0,31	0,27

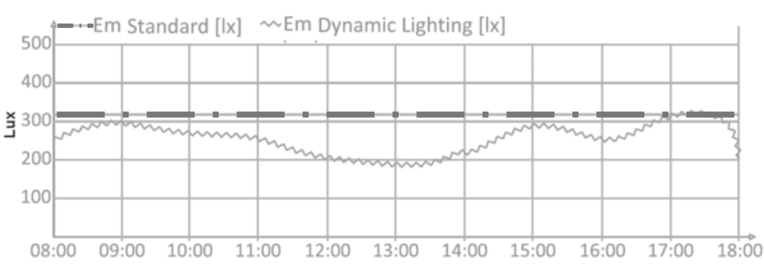

Figure 10: Comparison of illuminance between the dynamic lighting trend and standard lighting.

5 Conclusions

The analysis of the results can lead to the following final considerations:

- The application of a dynamic lighting system surely offers some benefits to an environment: well-being, comfort, relaxation. The benefits are especially evident in environments like offices and they can be assessed economically only as a decrease of absenteeism in the workplace
- The dynamic lighting system can lead to minimum but not significant energy savings compared to standard lighting system.
- As things stand now, the cost of the equipment of a dynamic lighting system is not economical compared with the standard system, however:
- The dynamic lighting system opens new possibilities for artistic lighting of the exhibition spaces and gives them a feeling of open space.

The next step of research will be to verify the energy savings analyzing the dynamic lighting coupled with day-lighting

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Street lighting design for a traditional city: a case study of Jesi, Italy

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Abstract

Crimes rarely occur if potential offenders are aware that there are eyes on the street that can witness, report or intervene in their activities. Lighting has a major role in guarding against criminal assault on public streets at night. The lighting needs to illuminate more than just the actual lighting functions; it also shapes the face of the street and defines the residential environment as a "homely" atmosphere. The residential area in a traditional city is in particular considered in this study. Space syntax models spatial configurations of urban street configurations by using a connectivity graph representation. Such a configuration of connectivity identifies pedestrian access patterns and can be analyzed and selected in a study area. The illumination distribution is calculated and a lighting design framework is suggested.
Keywords: street lighting design, crime prevention, space syntax, traditional city.

1 Introduction

Since the 1990s, along with an increasing concern with outdoor lighting, cities have started to glitter more at night (Jankowski [1]). The cities have aimed to promote and expose more flux on the facets of landmarks, sculptures, monuments, buildings and structures (Lechner [2]). Consequently, illuminating public spaces at night has encouraged people to extend their activities until the night time. By means of the artificial lighting, environments in which pedestrians can quickly and accurately identify objects, and maintain orientation are created. Therefore, the people come and walk in the public spaces in the evening with a sense of safety and security.

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Furthermore, urban lighting has increased urban landscape and improves the overall nocturnal urban environment, which explores the various ways to enhance safety, aesthetics, and mobility of urban contents (Boyce [3]). It is because illumination has increased the ability to perceive and to identify environments after sunset. However, besides being visual clues of spatial perceptions, it is a definer of moods and behaviours of people passing by. Good lighting of a particular space can attract pedestrians to stop by and consider those objects in detail. It can affect the street in how it is perceived and used. Furthermore, it reveals the meaning of objects along the street, park and plaza including monuments and buildings and how those objects are perceived. Since then, night visibility has become one of means for completing urban night life to merge with peoples' needs. The multi-function space, such as communal squares, a promenade, a plaza, etc. has been constructed into the pedestrian network. Also, pedestrian lighting serves to provide safety and reveals its aesthetic and beauty to the city.

At present, most people who lived in urban areas are spending free time after finishing work or study, and their activities in public spaces extend from the daytime to the night time. The qualified need of the illumination of these public environments is increasing parallel with the number of residents. Thus, the level of illumination is increasingly important and should be considered.

With space syntax theory that has developed over the past three decades, it has several applications on urban configurations around the world. In this study it was used as a tool to select a particular street which has a high pedestrian movement. Jesi, in Italy, as a case study, is programmed from its spatial accessibility. Finally, the results from the analysis of the luminance values of a selected street are analyzed and then a street lighting plan is proposed.

2 Background

2.1 The importance of Jesi, Italy, its history

Jesi is a town in the province of Ancona in the Marche region, Italy. It is an area of 107 square kilometers with the 97 meters elevation above sea level. It is an agricultural and commercial center in the floodplain on the northern bank of the Esino River, 17 kilometers in distance from the mouth of the Adriatic Sea [4].

From its history, Jesi was probably one of many built Umbrian villages in the 4th century BC to mark the boundary between the territory of the Piceno and Umbria (Fig 1). Jesi was invaded and conquered by the Senones (ancient Gaulish tribe) from France. The Senones had governed the coast area from Rimini to Ancona and settled "Sena Gallica" (Senigallia) as its capital. Its boundary is covered to the south of Esino River, then, Jesi was the last fortified place for the Gaulish tribe against Piceni. After being governed by Senones for more than 100 years, the Senones were defeated by the Romans in 247 BC. Since then Jesi became a colonial town of the Romans (colonia civium romanorum) under the name of *Aesis* (Cherubini [5]).

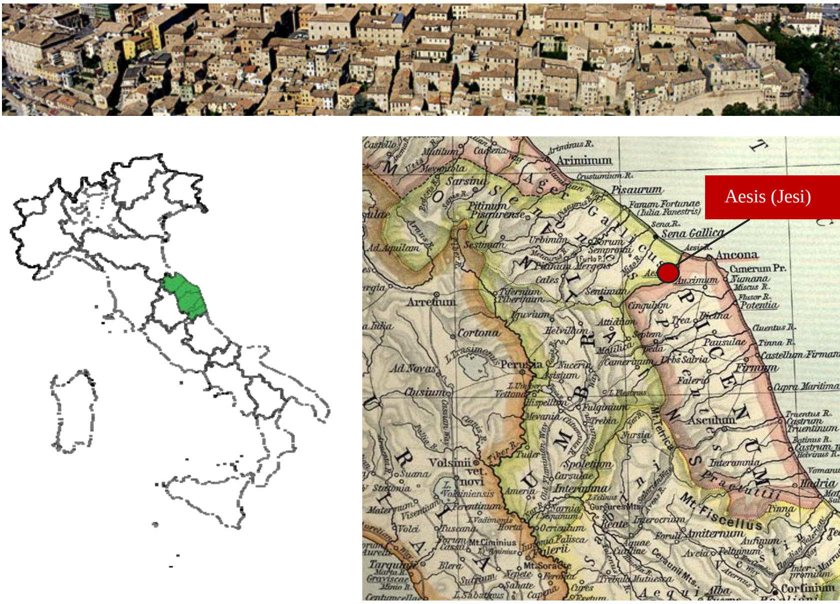

Figure 1: Location and aerial view of Jesi which was between Piceno and Umbria Region during the Roman period. The University of Texas at Austin [6].

When Italy became a part of the Byzantine Empire, Jesi became a diocese town in 680 until 1130, it had become an independent commune with autonomous government. During the 1200s the city was succeeded by local aristocracy (feudalism). With an appointment of a cardinal vicar over the landlords before the authorized constitution in 1353, all of communes and lordships consequently came under control of the Pope.

Around 1470, the population decreased by plague spread out to Marc d'Ancona, therefore, there was immigration in 1471 from the Emila and Lombardia zone which still can be seen by its traces from the street name such as dei Lombardi, Costa dei Lombardi, Fiorenzuola, etc. At the end of the lordship and plague period, the city was to start reassembling in order and recover economy, demography and buildings including new construction of churches and palaces that spread out to the urban areas further outside the old wall until late 1700s.

The city remained under the dominion of the Church until the advent of the troop of Napoleon in 1797. Until 1808 with an annexation of Marche under Napoleon's kingdom of the Roman Republic (Repubblica Romana), Jesi became one of the capitals of the district department of Metauro (distretto del Dipartimento del Metauro). After the fall of Napoleon at Waterloo, Belgium and success of restoration in 1815, Jesi became autonomous and the unity of Italy among the municipalities in the province of Ancona [7].

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Jesi has a long history and sophisticated experience of designed urban spaces through its history. Consequently, Jesi recognised the need to retain its appeal by exploiting the historic and contemporary cultural assets. Therefore, illumination design has increased and is found to be essential for reaching its aim of revealing the city's history importance in the present.

2.2 Space syntax theory

Hillier and Hanson published a syntactic theory for the pattern of space and interaction in the built environment in *The Social Logic of Space* in 1984. From that book they argued that buildings, towns, and cities have complex spatial properties that translate into sociological rules which affect how people relate to one another. They urged that space is not as the background to human activity, but as an intrinsic aspect of everything human beings do. Furthermore space seemed to identify structures which linked the social and the spatial. Consequently, space is able to give expression to social meanings. Within the framework on both the common physical and social ground in the city, space syntax theory and method has begun. Through the research team led by Bill Hillier and Hanson at the Bartlett School of Architecture and Planning, University College London, space syntax has developed since the late 1970s in reading urban configurations.

Space syntax is based on the concept of spatial configuration which means, in syntax terms, relations between spaces which take into account other relations in various spaces of a system. It can describe some aspects of how we use or experience space and to see how buildings and cities are organized in terms of geometric ideas. Moreover, in terms of relation between spaces, it can represent the inter-relations between the many spaces that make up the spatial layout of a building or a city. Then, space syntax is an alternative for quantifying and describing urban form influences on spatial formation by decoding a set of spatial properties of the layout (Hillier [8], Hillier and Hanson [9]) Therefore, space syntax is able to express the property of space in spatial configuration and distinguish social characteristics and their meanings that are imprinted and function in spatial layouts.

Space configuration measures of relation between spaces in graphs, and theorizes them in terms of their potential to embody or transmit social ideas, and then turns them into measures and representations of spatial structure by linking them to geometric representations of the system of spaces under examination. Providing a measurable scale from *segregation* to *integration*, enabled statistical comparison of different spatial forms across cultures, and investigated the average relations for the whole complex. Then, the space syntax program is a tool that presents the effect of spatial layout on functioning in the layout and is expressed through the computer program. Technically, it draws the longest line of the sight that is traced over every street segment in the layout. Then, certain descriptors of the layout are devised to measure an overlap counts as a connection. It is calculated how each street segment is connected in the layout. These descriptors (integration or segregation) can then be analyzed mathematically to predict spatial behavior without concerning any information on origins, destinations, or individual motivations (Penn [10]). Consequently, space syntax provides an assessment of the amount of pedestrian movement generated solely by the spatial configuration of the layout, independent of any land uses that may attract movement. The visually integrated spaces are the area which has result in high overlap counts of visual lines. Therefore, the integrated spaces are the places that contain high probability of people passing through, while the segregated spaces result in the converse.

Even though theory and method of space syntax has been leveled against on its lacks of sociological sophistication and complexity of real life situations, but it has published a great deal of development over the past two decades. This has been due to three factors largely; the wide range in application of space syntax into building and settlement types (Hanson, [11, 12]; Hillier, [8]; Peponis et al. [13], etc.) the development of sophisticated computer software that has allowed researchers to numerically capture differences in the configuration of spaces (Penn et al. [14]; Turner [15], etc.), and the organization of international symposia on space syntax research (2009, 2007,…, 1997) (Dawson [16]). Results indicate that space syntax is still a useful tool in analyzing spatial formations in built environments.

3 Research scope and procedure

This research is focused on pedestrians who get an effect from luminance in old urban areas of Jesi, Italy mainly, due to these people using urban space in their everyday lives and will receive the most benefits of appropriate lighting in an urban area.

In order to understand how the spatial layout of buildings and cities influences the human movement and social interaction, a space syntax program is introduced as a tool of examination. Since a space syntax program can represent the connected spaces as a matrix, then, the program simulated the connected accessibility by its mathematical properties. The layout of Jesi was drawn and evaluated with its spatial connectivity by UCL Depthmap software. An axial map is created and fed into a program that executes the required calculations. The results revealed the segregated and integrated areas. The area that carries the highest probability of people passing through was selected as a case study in this study. After that the measurement of lighting of the selected area was calculated, analyzed and finally, the proposed street lighting plan is suggested.

4 Results and analysis

4.1 Space syntax analysis

An axial map of an old urban area of Jesi was produced using UCL Dethmap software. Once an axial map is obtained, the calculation of spatial connectivity is begun. Firstly, the study considers the parameter of integrated value. An integration analysis is indicated by color from the most segregated area in blue to the most integrated area in red. The latter analysis reveals the most accessible area in red and lesser accessibility in blue. Moreover the integrated value is analyzed, the degree of correlation between global state measure and local state measure is concerned.

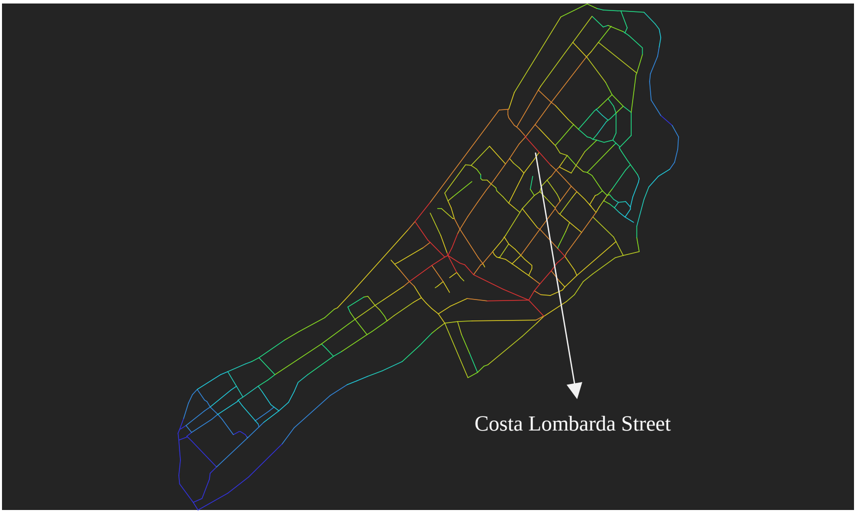

Figure 2: Axial map and an integration value in an old city of Jesi.

The correlation between integration (global state) and connectivity (local state) shows that the whole layout of the city cannot be readable from the parts (R^2=0.085). Furthermore, the result is also reveals that Jesi downtown produces an accessibility of a space in through-movement pattern rather than to-movement pattern (R^2=0.183). Consequently, choice parameter which indicates movements of inhabitants who have better knowledge of the layout than strangers is used as the criteria of locating the case study area. Finally, Costa Lombarda Street which contains both a high integration degree and choice value is selected as a case study for illumination design.

4.2 Land use, characteristics and luminous environment on Costa Lombarda Street

The Costa Lombarda is located on the eastern part of an old city area of Jesi. It partly slopes down from the north to the south with the length of 142.06 meters and approximately 20 meters slope difference from the origin of the street to another end of the street. There are many streets that are separated from and merged into this street including a small plaza and the main plaza of the city which connects at one end of the street. Due to its settlement since the medieval period, the street is not in a continuous straight line. Furthermore, the street's width varies differently along the street. The broadest area is 6.06 meters at the beginning and the narrowest area is set at the middle of the street (2.42 meters).

The Costa Lombarda street is the street that links all sub streets in that area altogether and is filled with the residential units in a block along both sides of the

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street. It is in walking range of the municipal office (commune) and some professional schools that fill the street with people in the daytime. Furthermore, by the street's location, it is surrounded by the facilities of the city such as a sport complex, theater, museum, palace and plaza, etc. which complement to the lively area both in the daytime and nocturnal time.

4.3 Analysis of the luminance measurement

Overall of the luminaries on the Costa Lombarda Street, it has installed 10 lamps at the building wall with unequal distance in each other and an unequal level of height. There are 8 lamps on the east side and 2 lamps on another side of the street. Most of the lamps are installed at a corner of the buildings or at an intersection between other streets and Costa Lombarda Street (Fig 3). The light sources used for Costa Lombarda Street are low pressure sodium (SOX) discharge lamps 70 watt. Since this study is focused on a pedestrian walkway, therefore, the angle between light source and pedestrian surface is considered illumination at 3 positions which are beneath its lamp point, across the street, and between beside lamps. Therefore, the results of pavement luminance at each point of all 10 lamps are measured and compared to the calculated value which is disposed by the point source formula. Simons [17].

$$E = \frac{I_\gamma \cos^3\gamma}{H^2} \qquad (1)$$

where E = illuminance at the receiving surface

I_γ = the luminous intensity at the source when viewed from the direction of the receiving surface

γ= the angle between a line from the source to the surface and a vector normal (perpendicular) to the receiving surface

H= the distance from the source to the surface

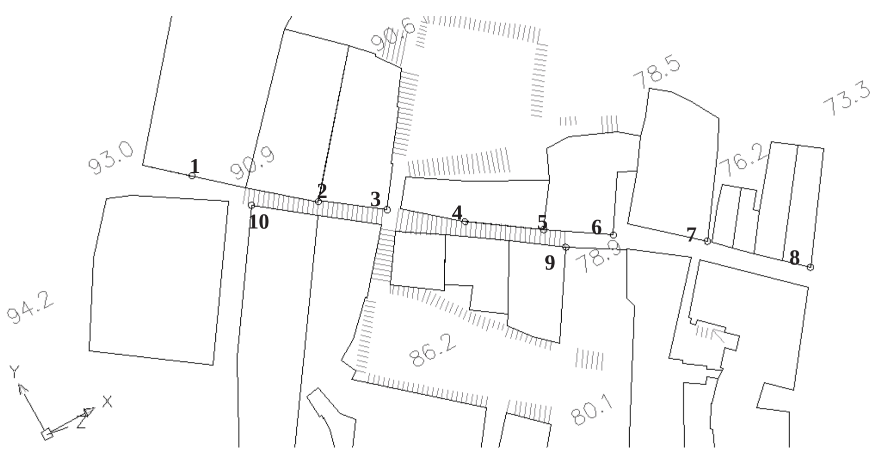

Figure 3: Characteristic of the Costa Lombarda street and its lamps fixture points.

The calculation from its specification of light fixture shows that a light source produced enough luminance value that lay beyond the standard level of pedestrian illumination (CIE standard = 50-100-150 lux). However, some of the light emitting from the theory method also shows that a luminous flux across the street falls into an under-standard level. Furthermore, the luminous flux that is transferred to the next lamps is of quite low value because of distance of settings which is a little bit far apart from each other. It is further revealed that there are pools of darkness at a distance between adjacent lit areas (between fixtures 1 and 2 and between lamp 6 and 7).

Table 1: Luminance value at each point of lamps on Costa Lombarda street (Measured on 8 January 2011 at 20.00).

No	Height (m)	Street Width	Illuminance(E) (lux)					
			Beneath its lamp		Opposite side of street		Beam at the mid-length between lamp	
			Mea	Cal	Measure (Δbeneath)	Cal	Measure (Δ beneath)	Cal
L 1	4.07	4.54	12.9	99.8	5(38.8)	36.5	3.3(25.6)	0.5
L 2	4.35	2.71	10.2	87.3	7.6(74.5)	56.2	3.2(31.4)	5.7
L 3	4.68	3.07	10.1	75.1	5(49.5)	46.6	3.5(34.6)	4.0
L 4	4.53	2.94	10.6	80.4	5.7(53.8)	50.6	3.3(31.1)	3.6
L 5	4.72	2.97	10.7	73.9	7.8(72.9)	77.2	7.3(68.2)	4.6
L 6	4.30	2.78	10.7	89.2	5.6(52.3)	56.1	2.1(19.6)	1.2
L 7	4.27	3.85	14.1	90.6	8.2(58.2)	44.6	2.8(19.9)	3.5
L 8	4.64	3.9	9.5	76.5	4.0(42.1)	41.0	-	-
L 9	3.00	3.11	13,3	183.2	6,1(45.9)	72.1	NA	NA
L10	4,38	3.22	10.1	86.0	4.6(45.5)	49.9	-	-
$\bar{x}$	4.29	3.31	11.2	94.2	6.0(**53.3**)	53.1	3.6(**33.0**)	2.9

Nevertheless, table 1 shows that the luminance values of measuring and calculating are totally different. The experimental results contain much lower value than their calculations and also inferior to CIE standard for pedestrian activity. It is possible to assume that its low intensity result is caused by its covering of dirt, its lamp life nearly terminated, and materials which reflect light beam at low percentage on both of the buildings' wall and pavement. The residential area of the medieval city in Jesi is constructed of a thick brick with brown or dark brown color which can be reflected by an incident illuminant

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beam of only 35–40%. Furthermore, the houses that set along on the street do not add to an increase in illumination to the street because of their function as a storeroom without windows on a ground floor and living function on the above floor. Consequently, there is no addition lighting from the living areas to penetrate to the street. Additionally, when comparing luminance intensity between luminaries at nearly the same width of the street (lamp 3 and lamp 9, and lamp 7 and lamp 8), it is found that a light source which is posted closer to the ground floor gives more luminance intensity than a higher posting. Furthermore, when considering the luminance beam that delivers to the opposite side of the street and the middle length between lamps in a horizontal line, it appeared that the luminance flux transfers its intensity about 50% at plane 90 degrees of light source (C=90°) and 30% at plane 180 degrees (C=180°) respectively. Even though the amount of illuminant of measurement and calculation are different but the pattern of decreasing luminance flux across the street is decreased at the same proportion at 50%. In addition, it is important to note that an irregular pattern of street also effect illuminant. Because of non-geometric streets then, there are some buildings that obstructed the luminous distant streak which is needed to consider on case by case basis.

4.4 Street-luminance suggestion

A well design lighting system for residential areas should accomplish a security purpose for the residents and people passing by at night. For reaching a secured residential area, the brightness of the lighting and the extent of luminance beam are important. The brightness of the area and its neighborhood affects how well the criminal can be seen and how exposed he feels. The brightness of the lighting guarantees a person's ability to detect and recognize other people. In addition, the extent of light beam is helped in which anything can be seen beyond the range of the area lit. Areas will likely always have people in them. The lighting beam controls the extent to which a criminal can be sure anybody is watching. Therefore, the people in the area or overlooking the area from adjacent buildings are able to detect the presence of others and recognize their intentions and actions at a distance.

From the result of measuring it is shown that a quantity of luminance on Costa Lombarda Street does not provide enough luminance for pedestrians who are passing by, and guarantee safety for the residents. For designing lighting illumination to the area of Costa Lombarda Street, it can be done in several ways. Firstly, maintenance lighting fixtures need to be cleaned to let it transfer light to the objects as intensive as its design. Later, the building's façade that line parallel to the street need to be cleaned or the walls painted a brighter color and pavement lightened for gaining more reflection. On one hand, the lamp's height should be dropped, that would help on increasing luminance on the surface. Then, the new prediction of measurement is done under an assumption that a luminance flux will be increased at 50% across the street and 30% between lamps for prediction measurement parallel with a formula calculation (table 2).On the other hand, number of lighting fixture need to be increased, especially at the dark pool area to increase confident detection and recognition to

Table 2: Estimated luminance value of reduced height of lamps at each point on Costa Lombarda Street.

No.	Height (m)	Street Width	Predicted Illuminance (E) (lux)					
			Beneath its lamp		Opposite side of street		Beam at the mid-length between lamp	
			Mea	Cal	Mea	Cal	Mea	Cal
L 1	3.07	4.54	19.35	175.48	7.50	37.35	4.29	0.05
L 2	3.35	2.71	15.30	147.24	11.40	72.82	4.16	0.82
L 3	3.68	3.07	15.15	121.46	7.50	58.55	4.55	0.57
L 4	3.53	2.94	15.90	132.37	8.55	63.48	4.29	0.49
L 5	3.72	2.97	16.05	119.00	11.70	60.31	9.49	0.50
L 6	3.30	2.78	16.05	151.56	8.40	72.55	2.73	0.13
L 7	3.27	3.85	21.15	154.64	12.30	50.00	3.64	0.43
L 8	3.64	3.9	14.25	124.21	6.00	47.42	-	-
L 9	3.00	3.11	19.95	183.17	9.15	34.94	NA	NA
L10	3,38	3.22	15.15	144.30	6.90	61.19	-	-
$\bar{x}$	3,39	3.31	16.83	145.34	8.94	55.86	4.74	0.43

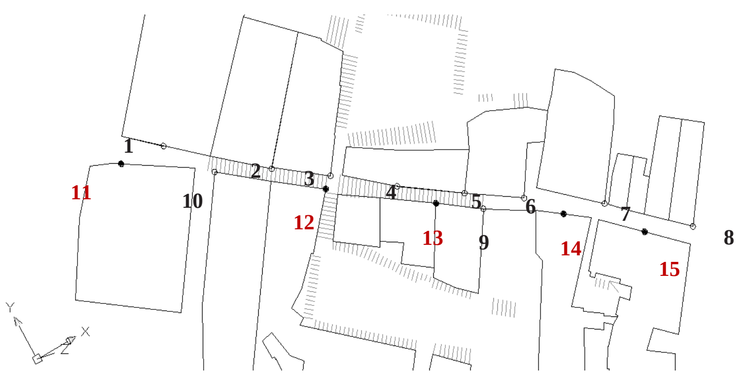

Figure 4: Suggestion of addition luminaries' position on Costa Lombard Street.

pedestrian visibility. The study has suggested adding5 more lighting fixtures on the side of lamp 9 and 10 as shown in figure 4 at the legend of 11-15.

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Nevertheless, providing enough luminance does not alone guarantee good residential lighting. Another important concern of good lighting is the physical characteristic of the targeted area. Therefore, besides calculating luminance to serve enough security purpose, lighting engineers should study and understand areas in parallel, especially street lighting design of a traditional city whose streets are not in a regular angle throughout the line. Furthermore, the luminaries themselves, which produce yellow/orange light, make residents difficult to distinguish new-comers and colors of objects. It would be better if we could switch to white light luminaries instead.

5 Conclusion

This study discusses urban environments and spaces for providing an appropriate street lighting design. The space syntax model is introduced to analyse and sort out the most accessible street to pedestrians in Jesi. The results from space syntax program and illuminance value in the selected area are analyzed. The illuminance values indicate that street lighting on the case study is inappropriate in pedestrian movement and visibility and a suggestion framework is required.

Acknowledgement

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Natural light in traditional architecture of Iran: lessons to remember

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Abstract

Taking into consideration natural light as a key factor in visual perception of the world, traditional architects, as skillful hunters of this phenomenon, always utilized it with regard to general principles of Iranian architecture. Notions such as hierarchy, centrality, balance, unity, which all of them are engendered by symbolic aspects of light as the most direct representative of sun, sky, heaven, truth and especially an omnipresent God; Consequently one can observe several elements or structures like fire temples, “Orosi”s (latticed windows), light wells and many others in Iranian architecture which are created to interact with light.

This paper, based upon a holistic approach and a qualitative research method-analyses the role of natural light in traditional architecture of Iran. The results of this study reveal that light role in traditional architecture of Iran (in both pre-Islamic and the Islamic period) can be classified in five categories including:

- Climatic function of light
- Psychological function of light
- Aesthetic function of light
- Spiritual and symbolic function of light

Examining the mentioned roles also implies that most of these applications are yet capable of fulfilling human needs in modern and post modern society, another noticeable fact which makes it necessary to re-examine Iranian traditional architecture and revitalize its considerable achievements.
Keywords: traditional architecture, Iranian, natural lighting, climatic, aesthetics, psychological, symbolic, function.

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1 Introduction

As we know, light is a key to human visual perception of the world since a comprehension of matters, colours, patterns and spaces depends upon the light quality and quantity. On the other hand, the multi-dimensional aspects of light function which include psychological and aesthetic roles in addition to climatic and spiritual ones, get several artists and architects such as Luis Kahn, Le Corbusier, etc interested in it.

One of the most famous statement about the light importance is made by Le Corbusier, a well-known pioneer of modern architecture who wrote; "Architecture is masterly, correct and a magnificent play of masses brought together in light" (Le Corbusier [1]).

Similarly, Iranian traditional architects have also learned from their experiences that if they make a good use of environmental light in architecture then they will be capable of transforming the simplest forms and valueless materials to precious elements and decorations. The reason for Iranian architecture being full of light existence is so that one would say traditional buildings wefts are interlaced with light woofs.

Taking into consideration that light role in traditional architecture of Iran has been studied by a wide range of scholars like Ardalan and Bakhtiar [7], Corbin (1977), Ayvazian [10], Stierlin (1969, 1977), etc, it seems that the subject is not a new one, but what makes this paper different from previous ones and reveal its importance is that mentioned researches often were not comprehensive and cover just some aspects of light function. Moreover they didn't propose any classification of them nor a method for its usage in contemporary era. The aim which is followed in this Paper based upon a qualitative research method.

2 Light and architecture

Light and water are the main component of Iranian architecture. In central Iran's hot climate, the water from courtyard pools and fountains cools as it decorates. Water cannot only reflect the light and multiply the decorative themes, it can also serve as a means of emphasizing the visual axes. Like the images they mirror, pools of water are immutable, yet constantly changing; fluid and dynamic, yet static [2]. Similarly, windows as the main source of light in traditional buildings are also distributed with regard to the existent geometrical order of the building so that they could intensify them.

In opposition to the monotonous artificial lighting, which is commonplace in contemporary architecture, light existence in Iranian traditional architecture was never thoughtlessly conceived. Since it is just after regulating light intensity and shaping it carefully that architects let it in. The necessity of shaping the light beams is the common aspect of all light director systems in Iranian architecture which often led to the creation of bright geometric forms inside the building which resulted by geometrical logic of forms, sequence and arrangement of the structure openings.

Examining the lighting systems in traditional architecture of Iran reveals that there were three current methods including;

1- Making use of direct sunlight through limited number of openings.

2-Passing the light through wooden or stone latticed windows which sometime had colourful glasses.

3-Iluminating the interior space through the light reflection off of mirror works, mosaic works or water surface (Vaafi [3]).

Due to the high intensity of sunlight in central Iran, traditional architects often avoid direct light inside the buildings and made use of several components such as porches, wooden or stone latticed windows or roof light wells whose function was to modify the undesirable aspects of sunlight, Fig 1.

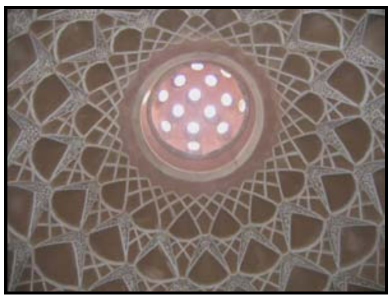

Figure 1: A typical light well in Kashan.

Studying the light role in Iranian traditional architecture approach indicates that its function can be categorized into four main groups:

- climatic function of light
- psychological function of light
- aesthetic function of light
- spiritual and symbolic function of light

all of which will be discussed in the following parts.

2.1 Climatic function of light

Until the 18th and 19th century (contemporary era), determination of position and orientation of a city fabric and its buildings was carried out based upon a model named Ron. Ron is a rectangle inscribed in a hexagonal whose longitudinal direction shows the best orientation for buildings in order to be energy efficient. Generally there were three current Ron including Rasteh, Kermani and Isfahani each of them which were applicable for special cities (Pirnia [4]). It is noticeable that the Ron orientation itself was determined by issues such as weather condition, wind and specially light direction and intensity in a region which indicates the light influence on the architecture and urban planning in macro scale but it is also an influential factor in micro scale Where building spaces in cities like Yazd, Isafhan and Kashan located in hot, arid zones of central Iran are arranged around a central courtyard.

In traditional architecture of Iran, due to the climatic condition of the region, and religious beliefs which resulted in an inward seeking architecture, one can see no opening in the external walls while the inside façade are full of windows facing the courtyard.

Examining the courtyard pattern houses reveals that there are three detectable layers of space located around the main core of light – courtyard – according to the importance of their access to the sun light;

1. The first layer which is just adjacent to the courtyard and includes spaces like Sedari (bedrooms), Panjdari (guest room), Talaar (living room), etc. Fig 2
2. The second layer containing some spaces of minor importance
3. The third layer which consists of servant spaces like kitchen, water storage, food storage, entrance, etc. (Vaafi [3])

It is noticeable that sometimes in small houses, the second and the third layer were merged into one and due to the lack of accessibility to the courtyard and they were illuminated solely be means of roof light wells. These elements though small in size, often make attractive effects, resulted by light reflection from folded shape surfaces of the sophisticated ornament around them and establish a new order in building geometry which emphasizes its visual axes.

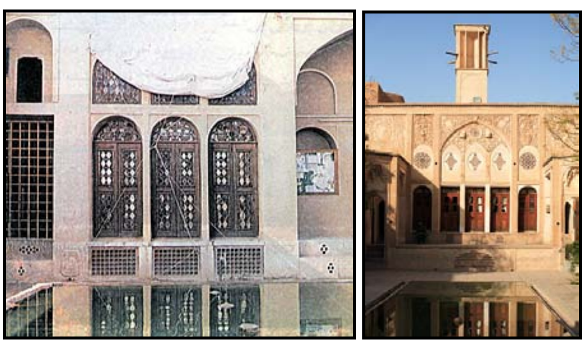

Figure 2: Sedari and Panjdari rooms with latticed windows.

Furthermore, the sunshine angle is influential in size determination of several elements in traditional houses, for example the dept of Sedari and Panjdari rooms and their window's height and width were designed in a way that light could penetrate the interior space as much as it was needed. Moreover the arrangement of living spaces around the courtyard in two different parts named winter and summer zone was based upon the sunshine direction and intensity. Winter zone locating in the northern side of the courtyard contained spaces that faced the south direction hence were suitable places to live in winter. While the summer zone was reversed. Due to such organization in traditional courtyard houses, there was a seasonal and periodical transition in horizontal direction which were influenced by sunshine characteristics.

2.2 Psychological function of light (light as the organizer of human visual perception)

Spatial hierarchy in Iranian architecture are meaningless without light existence In view of light, as a major space component, the overall composition, with adjacent servant spaces, find a particular form of organization, which is centralized and where hierarchies define the general pattern. The order of structure, in which light comes as a containing discovering geometry, commands subsidiary openings, which imposes a disciplined regularity of spaces whilst offering greater complex layers of perception.

Moreover, due to the coherent relation between lighting quality in a space and the importance of its position in the complex, every space in traditional architecture had its own special lighting characteristics which distinguished it from others (Afshar [5]). Consequently the process of visual recognition of space distinctions and their spatial relations would be facilitated for observers and led to what considered by lynch as being influential in giving a feeling of security (Lynch [6]).

This method was also applied in public spaces such as bazaars which were completely inward seeking and didn’t have any opening to the outside. Being dependent on such small light wells, the interior space of bazaar’s were darker than outside which reminds the observer of one of the most dominant principles of Iranian culture and architecture, which is the distinction between inside and outside characteristics, Figure 3.

Figure 3: Vakil bazaar.

In the Bazaar, the rhythm and shining angle of light beams while penetrating the interior space and directing the passengers like night stars, compensates the lack of time estimating and orienting capability which is missed due to the lack of relation to the world outside. Moreover, the courtyards placed alternatively in the path reduce the monotony of space and prevent a sense of claustrophobia. (Afshar [5]).

Light left a profound influence on the architecture of the bazaar in another way too where its interior structure was emphasized by the obvious difference in the lighting intensity of various parts such as the central path or stores. For example, the lighting method in places like “Timche’s” – a square surrounded by some commercial firms – was very sophisticated in comparison to others which refer to their special position in the existent hierarchy.

On the other hand, light can produce qualities like balance, symmetry of centrality, for instance lighting through a light well in the centre of a domed space roof intensifies the centrality of the room. Moreover the oblique radiation of light in such spaces which makes one side brighter than other weakens its symmetrical organization and changes it to a more dynamic one.

2.3 Symbolic and spiritual function of light

Studying the history implies that light and fire were sacred to Aryans, the very first inhabitants of Iran; the belief which led to the construction of many fire temples in Iran as the centers for religious ceremonies. At the beginning, the fire temple structure was open to the sky while later it was covered with a domed roof to protect the inside fire from the wind. These sacred structures were designed based upon circle and square geometry – two perpetual shapes which have profound meaning in Iranian beliefs- since square refer to the earth and everything of earthly matters, while the circle is considered a symbol of the heaven and sky, and the combination of them refers to the unity of earth and the heavens (Ardalan and Bakhtiar [7]).

The ascension of humans’ mind from the earth to the heaven changed the tendencies toward fire worship to sun worship and fire symbols replaced by sun

Figure 4: Iranian fire temple.

ones. The reason for several uses of the word Mitra or Mitreh and its symbol in Avesta and Achaemenid reliefs, Gholizadeh [8]).

Even after the rise of Islam in Iran, light was still considered to be sacred and respectful since it was a powerful symbol of God's essence as is said in the Quran; "god is the light of the earth and the sky. All the lights originate from it. Some evident like sun shine and some hidden …. ." [9]. Therefore Iranians found some aspects in common with the new religion which led to the continuity in their art motifs.

Moreover, the origination of several fundamental concepts of illumination school – A philosophical -Islamic school which was founded by Ebne Sina and Sheikh Suhravardi in the 18th century – such as the unity of existence or disciplines like respecting love, sun, light from previous religions such as Mitraism testifies theses common aspects.

In Iranian architecture, the light metaphor engenders metaphysical connotations, where the Devine is always omnipresent. Light is always a virtue of the sky, of heaven, of truth, of realization, even if brightness is sometimes hidden by shade or darkness. Light and shade are maintained for space perception, while never be in real conflict of meanings. Continuity, passage, the heavenly sphere, stars, centrality, unity are notions and elements of a concept of Islamic architecture, where the environment always remains the impact of the Creator's trace (Ayvazian [10]).

Light, through the succession of sequences bring in life, the symbolism of the supra-natural and the living social connotations of man's passage through earth.

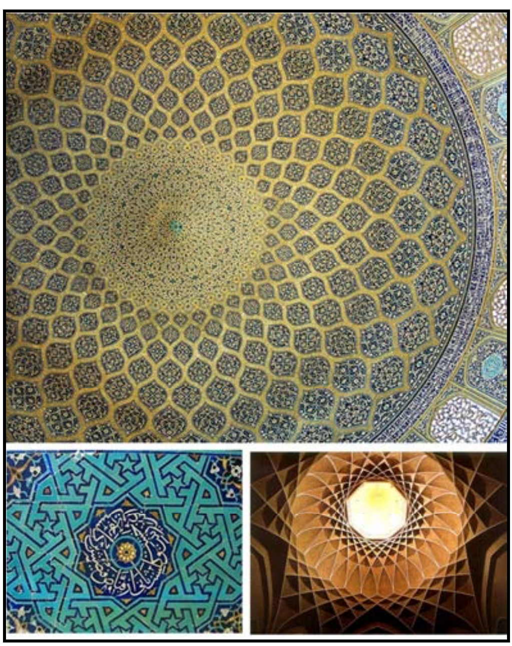

Figure 5: Sun symbol in ornaments called Shamseh.

Light-space is more than an imaginary space, it comes as a life meaning, a receptacle of human soul and man's activities, illuminating senses to the universal existential principles. A relationship is established with a dependence of man towards heaven, where surfaces, walls and roofs become the symbolic embracing envelop for a world-view made of spiritual values of being. There is always a balance between the inversion of light with the general overall spatial geometry of order, spirit and wisdom.

One of the other religious beliefs which reflect on architecture was intensified by means of light application as was the tendency toward maintaining privacy. As a result of this attitude in traditional residential architecture of Iran, before entering the central courtyard, one would pass through a narrow and windowless, hence dark, walkway called Dallaan. The contrast of the darkness in Dallaan space and intensive sunlight in the courtyard led to the disturbance of a person's eyesight for some minutes in which the female inhabitants of the house could cover themselves with a veil (Memarian [11]).

2.4 The aesthetic function of light

2.4.1 Light as an independent entity

Light did not just play a complementary role in Iranian traditional architecture and sometimes have its own visual expression. For instance light beams penetrating the interior space through Orosi windows often create remarkable patterns on the wall or the floor which looks like an artistic painting or a precious carpet. Moreover, light sometimes produces bright and dynamic textures inside where its motion doesn't follow the building geometry so led to the transformation of its static order to a dynamic one (Afshar [5]).

On the other hand, shadow as light also has an effect in Iranian architecture since it is a symbol of life. Shady trees are one of heaven's components which is

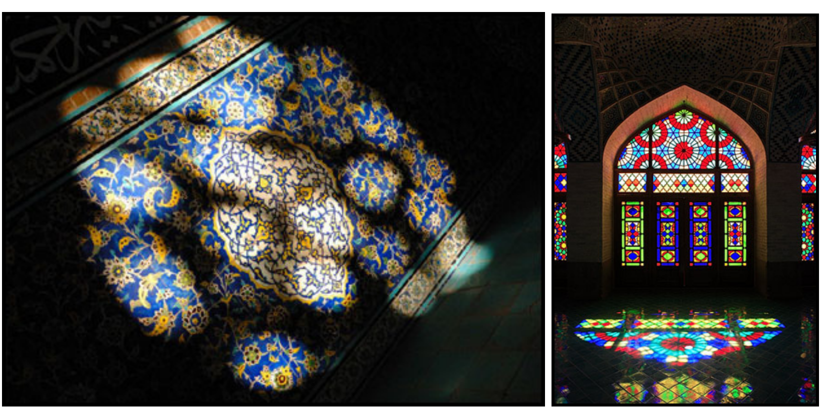

Figure 6: Light; an independent entity. Attractive light effects created by Orosi (right) and latticed (left) windows.

promised in Islam. Furthermore, in Parsi language being in the shadow of someone refers to being protected by him. Sometimes architectural elements produce such weird shadows which can be considered as independent entities. Moreover, the rhythm of adobe domes and vaults shadows in the desert cities of Iran are so eye-catching that they compensate the visual lack of openings in the buildings' facades.

2.4.2 Light as a transformer

Being aware of the high intensity of sunshine in Iran, tradition architects often refracted the light to create aesthetical values. This was carried out by making use of mirror works, mosaic works and any reflective material. Intensifying the magic qualities of Iranian architecture, this method developed its ornaments to a degree of complexity and sophistication previously unknown.

One of these ornaments is named Mugharnass. A honeycomb decoration that reflect and refract light and creates thousands of various lighting effects. While Mugharnass is made of stone, wood or adobes, it is often seems to be an illuminating structure. The reason why many experts believe that Iranian architects were alchemist making gold out of dust [2].

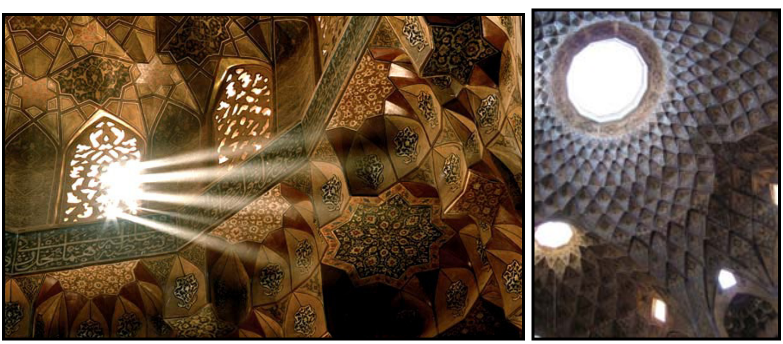

Figure 7: Light as a transformer. The Mugharnass under the dome reflect the light (left: Sheikh Lotfollah mosque), (right: Borujerdiha house).

2.4.3 Light and ornament

As mentioned before, due to the intensive sunlight in central Iran which emphasizes the prominence of reliefs, there is no need to emboss decorations in Iranian architecture (Afshar [5]). Moreover, after the rise of Islam in Iran, the creation of sculptural ornaments were prohibited; the reason which led to a remarkable growth in relief works.

Study of these relief motifs reveals that their hierarchy was often intensified by sunlight where main forms produced strong light effects due to their considerable depth while the subordinary and complementary ones created weak shadows. Sometimes light radiation on such surfaces led to the undesirable complexity and a noticeable increase in the visual information level which may disturb a human's perception of the space. Being aware of this problem traditional architects often used monochrome or inconspicuous reliefs as internal facade decoration which mediated between the impact of the interior space sophisticated ornaments and ornamentless appearance of building external walls, (Khojastepoor [12]).

Traditional architects even took into consideration the light quality in their colour choice for ornaments. For example since most colours are seen bluish or yellowish under the sunlight in Iran, yellow and blue are frequently used in mosaic works. There is also another reason and that is in these colours' permanence through high resistance against sunlight (Afshar [5]).

It is noticeable that one of the most beautiful architectural elements which was designed based upon aesthetical aspect of light are Ororsis, latticed windows with colourful pieces of glass which creates a spiritual atmosphere by producing attractive light effects inside buildings. Moreover, it is an effective tool to reduce the undesirable intensity of sun light (Pirnia [4]).

3 Conclusion

In this paper we discussed the natural light's role in Iranian tradition architecture Based upon the results, the light function in the field of architecture can be categorized in five groups including climatic, aesthetic, symbolic and psychological ones.

Determination of building orientation, the rooms' depth with regard to the sunlight angle and its direction, utilizing several elements like latticed windows to reduce the light intensity and application of light wells on the roof are just a small part of light climatic influence on the architecture.

On the other hand, emphasizing the spatial structure of the building which led to a clear organization of visual perception and leave a good psychological effect on human mind indicate the other aspects of light existence.

Moreover, making use of transformed light (such as the light passed through Orosis), its rhythmic effects or symbolic aspects in architecture refers to its aesthetic function.

Being aware of theses aspects, Iranian traditional architects utilized several outstanding methods of lighting which deserve to be preserved and revitalized while due to the identity crisis and social alienation as a result of multidimensional relation with western countries during 19th century and the consequences of globalization process in the 20th century, most of these precious achievements are going to be forgotten. Nowadays, in a large number of buildings, even in hot arid regions, the external facades are full of windows whose size, position and orientation are determined by architects' taste or temporary fashions and do not have any function but climatic or aesthetic one. Moreover, due to the wide scope of artificial illumination application in contemporary architecture, the lighting quality of interior spaces is often monotonous and static which is undesirable. While, based upon investigations, there are some permanent principles in Iranian tradition architecture which yet are applicable for instance:

- Determination of size, position and form of openings with regard to the quality and quantity of sunlight and also existent desirable perspectives around the building.
- Application of light in the architecture as a dynamic and aesthetic phenomenon.
- Natural Lighting application for emphasizing spatial structure and relations of a building.
- Creation of virtual and dynamic textures in monotonous surface of the façade, walls and floor.
- Designing facades and its decoration with regard to the intensity of sun light.
- Making use of symbolic aspects of light in order to create a spiritual space in the architecture.
- Organizing the visual information and facilitating the perception process by means of lighting methods.
- Reducing the energy consumption vie the maximum use of natural light

Contemporary architects should understand the essence of these principles and allow modern building technology to be a tool in the expression of them. As writes Martin, "Architects working today can take advantage of opportunities that new materials and mass production techniques offer. They have an opportunity to explore and transform the possibilities of the machine age for the enrichment of architecture in the same way that craftsmen explored the nature of geometrical and arabesque patterns. . ." The forms that would evolve from this approach, adds Martin, would have a regional identity, a stylistic evolution and a relevance to the eternal principles of architecture [13].

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Design of parametric software tools: optimizing future health care performance by integrating evidence-based knowledge in architectural design and building processes

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Abstract

The studies investigate the field of evidence-based design used in architectural design practice and propose a method using 2D/3D CAD applications to: 1) enhance integration of evidence-based design knowledge in architectural design phases with a focus on lighting and interior design and 2) assess fulfilment of evidence-based design criterion regarding light distribution and location in relation to patient safety in architectural health care design proposals. The study uses 2D/3D CAD modelling software Rhinoceros 3D with plug-in Grasshopper to create parametric tool prototypes to exemplify the operations and functions of the design method. To evaluate the prototype potentials, surveys with architectural and healthcare design companies are conducted. Evaluation is done by the administration of questionnaires being part of the development of the tools. The results show that architects, designers and healthcare design advisors recon the tool prototypes as a meaningful and valuable approach for 1) integrating and using evidence-based information; and 2) optimizing design processes and health care facility performances. Further study focuses on parametric information relations in Building Information Modelling projects.

Keywords: hospital lighting design, evidence-based design, patient safety, architectural design, building information modelling, parametric design, observation and questionnaires, prototypes.

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1 Introduction

The field in which the studies documented in this paper operate is architectural design practice and research within optimization of contemporary design processes in hospital design with a focus on the role of the architect and how to implement the many facetted factors, parameters, standards and needs from the parties involved in the building process. Experience and studies show that certain issue are involved around the implementation and assessment of Evidence-Based Design (EBD) parameters in hospital design [1].This paper explores how to digitally transcend the sum of evidence-based input parameters into a digital strategy for systemization. The offset is the development of a software based assessment and evaluation method of EBD criteria. As exemplification the paper introduces key topics of investigations in lighting design and patient safety along with a parametric tool prototype developed around architectural design strategies for a patient bedroom at a hospital facility.

2 Optimization technologies in the design process

In recent years technical professions and industries have been developing and embedding innovative technological instruments to calculate or simulate performance of architecture and design. By using optimization and rationalization algorithms upon a structure better design can be achieved [3]. By exploring the fields of architecture, evidence-based design and software technologies a method of approach is invented, one that provides information and evidence to the design process as a way to meet demands and criteria defined in e.g. a hospital project description [2].

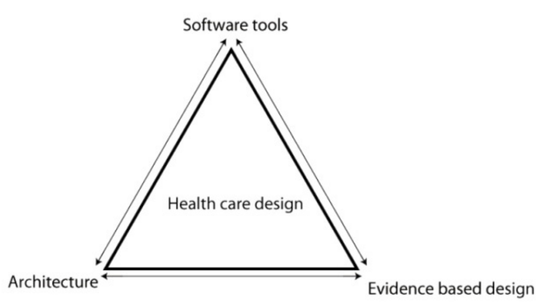

Figure 1: The explorative study from where the parametric tool development is initiated.

2.1 Purpose of a digital tool

Focusing on EBD in the design of healthcare architecture is a focus on the relations between the constructed environments, the performance of the building, the users of the building and the perception of space and context.

With regards to the existing research catalogue presented by Ulrich et al. [1] and Frandsen et al. [4] the evidence material herein is found reliable and usable where articles and papers prove relations between the medical sciences and architectural and environmental factors and parameters.

Evidence-based knowledge is used for two purposes; 1) to inform the designer and 2) to derive parameters based on evident material to be programmed in software. In order to increase the productivity in praxis the parametric tool combines information databases with actual real-time design modelling.

A method of approach to support the architects in controlling demands, own visions, and input alongside providing evident baseline data in the early design process, is to develop a system that can hold relevant information and give reliable associative feedback when valid information is needed prior to decision-making. Such a system is a dynamic user-interactive tool based on parametric associative design variables. A tool capable of; linking knowledge, storing information and data, increase communication and ensure validation, evaluation and control of performance in an optimizing process of design and task specific quality of health care buildings.

The development software used in these studies is Grasshopper 3D, a plug-in for the modelling software Rhinoceros 3D, an associative parametric component-based geometric modelling software [5]. Being associative in its nature, a potential prototype-user is able to change the design parametrically without loosing information or having to remodel it from the beginning.

2.2 Parametric setup based on health care projects

The topics lighting design and patient safety are investigated from a parametric and evidence-based design perspective.

The evidence indicates that well-designed physical settings plays an important role in making hospitals safer and more healing for patients and better places for staff to work [1].

Lighting design and patient safety is referred to as relations between the physical factors of plan solutions, interior design, materials and equipment in creating an environment with focus on the staffs and the patient's situation.

Seen from a parametrical point of view these topics pose a straightforward process because of the possibilities of working with floor plans, object location and distance measurement.

Following are exemplifications of parameters regarding light, patient safety and the floor plans used in the tool development:

- Luminance, glare, daylight and artificial lighting
- Single bed or multiple bedrooms
- Height of rooms, windows, doors, interior
- Distance to bathroom, distance to nurse station
- Location of bed, amount of space, boundary space

The software tool identifies and assesses the objects and elements by running evaluations on the floor plan delivered by the architect early in the process. The

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assessment of the floor plan identifies specific facility conditions of the architectural plan and design, where the lighting design and the quality of patient treatment is compromised.

3 Method of approach

The hospital projects Aalborg House of Medicine, Aalborg, Denmark and The New University hospital project at Skejby, Denmark are used as case studies in the understanding of processes, measures and requirements regarding lighting design in health care architecture. The architectural company Friis & Moltke, Aalborg, Denmark, the healthcare consultancy firm ArchiMed, Copenhagen, Denmark and architectural students at Aalborg University, Denmark participates throughout the studies in interviews and surveys to obtain data and evaluation of the proposals and results of the studies and prototypes.

3.1 Computer-supported cooperative work

The method of Computer-Supported Cooperative work is used to unfold exploration of Strategic planning, Human-Computer Interaction and Software engineering, topics relevant for the studies [6, 7].The method focus on practice and work-oriented design research in the development of applications and systems, a view contemplating the more abstract, social and organizational work aspects of user and company practice as opposed to more traditional software engineering with emphasis on physical concrete artifacts in procedures and tasks [6]. Further, the project investigations uncover design aspects around the four main topics: Context, User, Task and Technology [8].

3.1.1 Scenario based design

The tool design phase is initiated by work with scenarios of possible future tasks and tendencies of practice and context, a field of low tangibility regarding the system design requirements [6]. A shift is made into the Human-Computer Interaction (HCI) field with focus on scenario studies of previous and present user practice and work routines and is ended with design in software engineering exploring the tangible tool prototypes, the initial parts of a proposed system model [7]. The scenario-based design model focus on architectural practice in health care design, with EBD as main focus under which the architectural designer is considered primary user and the architectural practice as immediate design context. The scenarios are tested through a survey by a group of selected architects and architecture and design students.

3.2 Design and implementation

Prototyping is used as a method to iteratively develop tool functions as the design exploration progresses [9].

During each design phase, to meet specific user requirements, relational models are developed as separated parts of the whole system. Prototypes are developed when basic functions needs exploration and consist of small scripts that are tested ahead of the design of larger prototypes.

3.3 Prototype evaluation; surveys, user reviews and questionnaires

The prototypes are tested through a survey to test the ability to bridge evidence-based design information with design tasks. The survey is conducted as an expert user review with emphasis on cognitive walkthrough of the users to test the overall usability and functionality of the tools [10]. The main purpose of conducting the user review is to provide:

- A review of the usability regarding evidence-based design of the tool.
- Identification of problematic areas and issues, EBD- and application-wise within the tool for use in development iterations.

The benefit of the tools is assumed through a questionnaire to get concise feedback on specific subjects [11].

4 Prototype development

Based of the empirical studies of the project, prototype development scenarios are conducted in order to determine the requirements and functionality of the tool prototypes.

4.1 Prototype scenario model

The scenario analysis methods of both strategic planning and human-computer interaction reveal information of actors, background and assumptions of work environment, goals and objectives and the sequences of actions and events.

The scenario is the foundation of the prototype application design:

- The user group is limited to only focus on the architect's role as designer in the project process.
- Technologically the focus is on CAD drawing and modelling in 2D and to some extent also 3D.
- The functionalities are that of visualization of undesirable architectural propositions and design decisions.
- The references to evidence-based information regarding design tasks are embedded in the prototype design.

4.2 Prototype development strategy

The prototypes are developed with emphasis on test and trial of the functions derived from the requirement analysis. The descriptions of the prototypes are based on their operational level. Focus is on the implementation of evidence-based knowledge in the actual programming in Grasshopper. The topic is lighting and safety with focus on floor plan and bedroom design of a hospital.

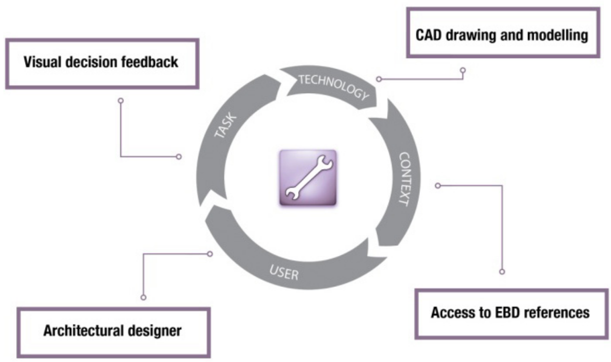

Figure 2: The prototype scenario.

4.2.1 Main purpose and prototype goals

Derived from the scenario models the following prototype goals have been embedded:

- Linkage between design issues and EBD information
- Usage on different scale and detail level in projects
- Weigh user participation through sketch and feedback
- Ability to steer, control and maintain overview of goals and tasks

4.2.2 Parametric definition

The prototypes consist of a set of basic functions each with a predefined number of different operations all of which have specific sets of parameters, definitions and relations to other parameters. The overall method for the parametrical definitions is approached by identification of the following parametric typologies and their relations [12]:

- Driver (parameter)
- Driven (single parameter or set of parameters) and
- Constraining parameters (boundaries, limitations and conditional statements)

4.2.3 Overall prototype functions

The empirical and qualitative data contributes to the parametric setup and scripting of the prototype by the extended clarification of factors and parameters needed to improve the design of the healthcare facilities.

The prototypes offer the architect the possibility to design a room with optimal lighting and patient safety parameters.

The CAD model is either loaded into Grasshopper 3D or the objects are rearranged right away. A list of objects is available for selection, each parametrically connected to the other. The prototype support both 2D and 3D objects in the planning.

Table 1: Bedroom prototype supportive functions.

Design tasks	Prototype functions	EBD functions; lighting design	EBD functions; patient safety	Other functions
Selecting or importing objects	Calculation of free space, room size	Window location, material and size	Size of room and free space for optimal work routines	Participation of user representatives
Arrangement of objects	Managing EBD information	Geographical location and orientation	Minimal space for utilities	Documentation of design criteria
Selection of parameters for the room's specification	Calculate EBD credit value	Experienced view through window	Visibility and distance to nursing station	Design process using the prototype
		Artificial lighting sources, levels and colours	Infection control Distance to bathroom	

The function of analysing the distance and visibility to the nearest nurse station or natural view through the window contributes to the evaluation and assessment of the level of lighting quality and patient safety of the design proposal.

The designer receives an immediate EBD credit score and a list of fulfilment and error notifications on behalf of the design decisions. This serves as documentation of the design process and expected impact on the immediate health care design proposal.

4.3 Case: The bedroom prototype

4.3.1 Purpose

The topic of this tool prototype is lighting design and patient safety and how the near environment of the patient can contribute to a more safe in-house hospital stay with focus on experienced lighting atmosphere [15]. The prototype is based on parameters and evidence regarding the organization of the patient bedroom.

4.3.2 Definition

Evidence-based research indicates that the organization and size of a bedroom and the objects that fill it, contributes to the level of safety, that being levels of hygiene infections, patient and staff injury and infection related deaths [1].

There are 2 entry paths using the application prototype during the design of the bedroom:

- The application requires no detailed layout of the bedroom (CAD drawing/model) prior to the use of the tool.
- The architect loads an already defined CAD outline drawing or model of the bedroom into the prototype for further detailing and assessment.

Table 2: Parametric setup of the bedroom module.

Driver	Driven	Constraints
The objects midpoint, light-emitter vectors	The intersections between objects and emitters	Bedroom size boundaries
The number of objects	The conflict list	The EBD accreditation percentage
The parameters chosen for evaluation		Wall curves intersections with light vectors from emitters

4.3.3 Development

A list of procedural task-descriptions guides the architect through the use of the tool. The architect selects the objects that are to be implemented in the room and relocates them accordingly. Once the locations of the objects are specified the script calculates the objects' midpoints and the distances between the objects to determine the spatial relations and object-free zones. Each conditional criterion is assessed and sent to one of the evaluation scripted lists.

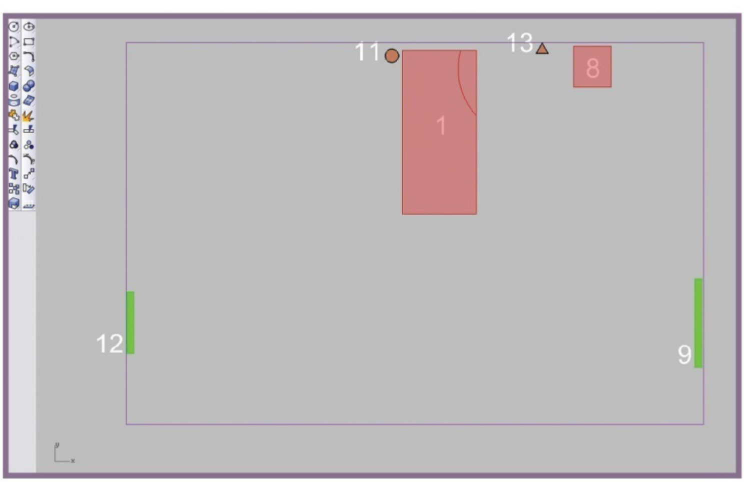

Figure 3: The objects in the top right corner are intersecting and conflicting.

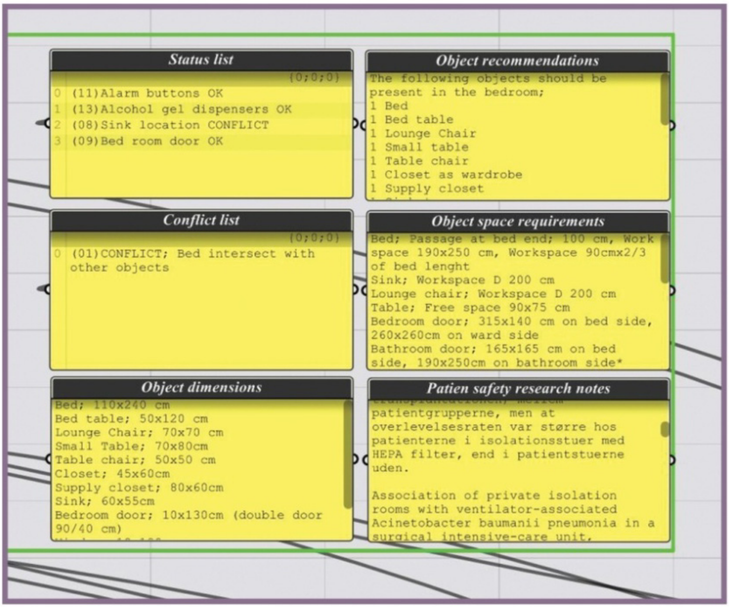

Figure 4: Example of interface when reading the output conflict between bed and sink.

4.3.4 Feedback

A graphical representation of the bedroom is present during the use of the prototype. Specific colours define the relational zones of each of the objects. Intersections between objects are emphasized and an alert message is executed in the alert panel. Light vectors are highlighted upon intersection with objects.

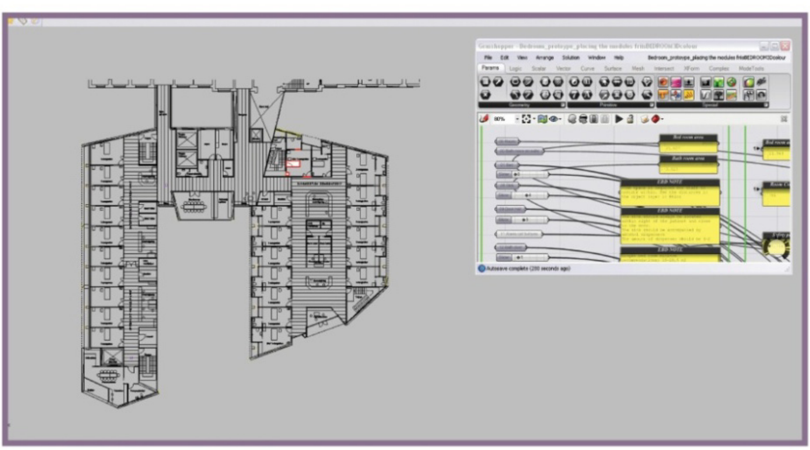

Figure 5: The floor plan of the proposal for the new medical wing at Thisted Hospital.

4.4 Implementation examples of existing floor plans

The bedroom module is used with the plan drawings of the Thisted Hospital proposal, by Friis & Moltke, Aalborg, Denmark, 2010.

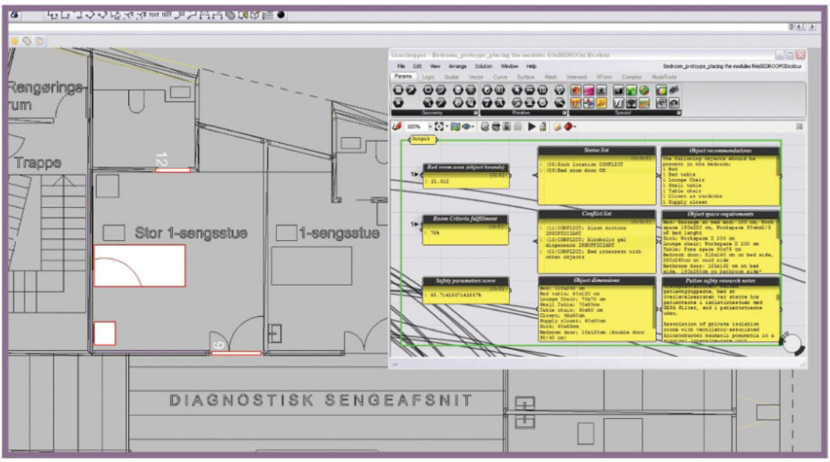

Figure 6: Test of the bedroom plans of the Thisted hospital proposal. Bed and sink is highlighted and in conflict.

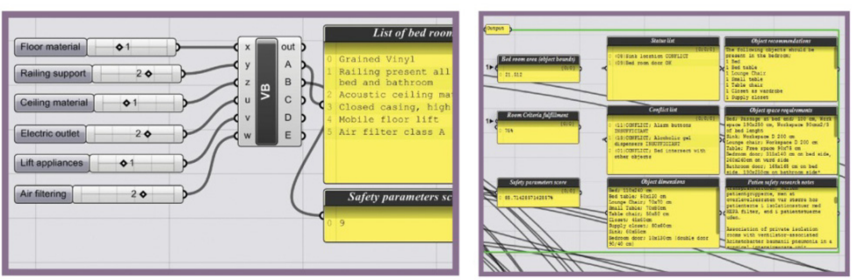

Figure 7: Left: A section of the parameter list of the EBD criteria. Right: Conflict notifications from the test of the Thisted Hospital design proposal.

5 Conclusions

The conclusions in this paper encompass the results throughout the studies and a perspective on future work areas within the study field.

5.1 Project approach and tool methodologies

Investigations are made in the field of architectural practice and design of health care buildings. Empirical methods are used to obtain the knowledge needed to be able to develop the prototypes. The fields of study are; building design process, architectural design process, evidence-based design, lighting design and patient safety.

From the explorations it is found that for the tool to support evidence-based design concepts should encompass the following functions:

- Provide, store and document EBD related data
- Evaluate and control the parametrical defined EBD concepts and criteria in the design proposal

From developing the prototypes it is found that diverse approaches to EBD data are needed in order to both translate it into parametrics, but also fit the assignment of creating a tool of value for the architects. The two types of EBD data used are; 1) guidelines derived from physical work environmental statements e.g. minimal illumination levels at the nurse's workspace and, 2) evidence-based criteria of both descriptive and non-descriptive character, e.g. the view towards natural environments and the perceived space around the patient.

Hence the developed prototypes focus on the evaluation of the physical measures of the bedroom [13]. The specific functionality of the prototypes as well as their construct is tested through an expert user review at the architectural practice.

Through a survey of the prototype development phase the tools are found to be valid and usable in design work, but primarily for the lesser EBD experienced architect and designer. The supportive functions of the tools are more related to the architects' need of support and information, than the control of the actual design plan.

The tools are in general found to hold significant future promise and further development. The feedback from the survey is considered reliable as indicator of the issues and possibilities of the tools.

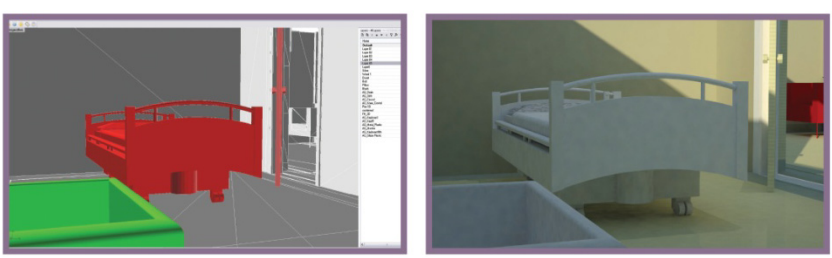

Figure 8: Left: Rendered bitmaps as documentation. In this case the bed is located to close to the door and emphasized. Right: Visual feedback, e.g. natural light and artificial light sources improves the evaluation of the design.

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5.2 Evidence-based design and parametrics

Derived from the expert review at the architectural company Friis & Moltke, Aalborg, Denmark, it is found that the sudden access to the many layers of information normally hidden from the perception of the designer, justifies the implementation of the tools in praxis. The parametric logic of the application is not biased by deadlines, creative visions and preferences regarding specific design solutions. As a knowledge based tool, the applications have the potential of unifying stakeholders across the different parts of the building process by offering standard descriptions of EBD concepts and criteria, listing conflicts and design issues and sharing knowledge and documentation of the design process.

5.3 Future work and development; Embedding evident material documenting perception and sensing parameters

The prototypes are designed to rely on measurable geometrical statements and conditions. Letting the architect choose parameters from a checklist is a method of encompassing non-logistical non-geometrical parameters in the EBD tool. Extending the embedding of evidence on light perception, sensing and experience-based relations of lighting atmosphere [15] pose the next assignments in the development phase of the studies. The EBD tool has a strong possibility to be implemented as a learning tool for architects and designers. The next phase of development will focus on the strategy for creating relational constraints and connections between data, source and references of EBD. The platform to develop in the future should be integrated in the BIM software and the object based modelling concepts, e.g. Autodesk Revit [14]. These technologies have large data capacities and well-established financial foundations meeting new demands and requirements of contemporary innovative markets.

Finding that the architectural design practitioners are willing to apply evaluation algorithms to their design proposals, indicates that this is a field that holds much potential, explorative, academic and financial. The parametric tools displayed in this paper have the possibility to encompass all the information of EBD but it is nonetheless the user of the tool who can interpret the data and rightfully apply it for a specific context. The parametric tool is still just a tool- a support for the architect, the designer and whomever have the interest in applied evidence-based design concepts in architecture and lighting design.

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Application of modern models of sustainable architecture in the use of natural light and effective utilization of energy in schools: a comparative study of Glasgow (Great Britain) and Isfahan (Iran)

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Abstract

This research examines day lighting levels and their impact on pupil's academic performance and health in primary schools. A significant volume of research literature was reviewed and analyzed. The main findings from this analysis were that there is a sketchy evidence to support the notion of daylight having an impact on performance and health. The research conducted a series of empirical studies in a number of primary schools both in Glasgow and Isfahan. The sample of schools chosen were representative of Glasgow city's population as two schools were selected from each part of the city (east, west, north, south and centre); a similar scenario was performed in Isfahan. The main finding, although tentative and slightly infirm, suggested that light levels did affect space utilization in classrooms and pupils seemed happier and more active in sunny classrooms than in shaded ones.
Keywords: daylight, energy, natural light, architecture, sustainable, design.

1 Introduction

Analysis of Iran's aims in achieving sustainable development in which energy utilization plays a significant role is of high priority. Thus accomplishing ways of reducing energy usage, particularly in buildings which use fossil fuels, is an

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important issue. Based on statistics, 38% of Iran's energy is utilized in the construction section, out of which 70% is supplied by natural gas. Official statistics show that over the past 20 years, the amount of usage of fossil fuels in the construction section has multiplied by 4 to 5 times. The same illustrates that the value has increased by approximately 12 times its world value. So, due to this significant rise in energy consumption and to achieve the sustainable development of the country's aspirations, a rethinking of strategies in utilization of this type of fuel is essential. If this rethinking process does not take place, the country will become an importer of energy.

With respect to the effective role of the construction industry in reducing the waste of energy and considering the fact that Iran's climate has many sunny days and also taking into account Iran's traditional architecture in which light is highly accounted for as a separate element, numerous achievable, applicable and systematic results can be obtained. One of the main characteristics of natural light is its consecutiveness and variations during the period of a day. This plays an important role in psychological and physiological well-being. For instance, sunshine within a space can make one flourish and joyful, can affect occupants' moods and induce a feeling of dynamism and movement to a space through a change of quality (from sunrise to sunset) during different hours of a day. Consequently, an appropriate use and exploitation of both daylight and sunlight can result in more advantages to the building user in terms of heat and warmth, brightness and prevention of use of artificial light, which in turn will result in a reduction of energy usage.

More importantly, a reduction in energy usage can lead to a decrease in the formation of environmental toxic waste and green house gases such as carbon dioxide. This can be considered as an important step in the prevention of climate change and the earth heating up.

So, a sustainable architectural design demands a pattern that encompasses all values. This combination of environmental goals and the presentation of a suitable method to designers, construction practitioners and energy users will save a significant amount of energy. Actions include:

- Precise and proper understanding of environment and climate of the building to be constructed.
- Accurate consideration of the environment and the effective role of harmonization its relationship with the surrounding environment particularly in public buildings.
- Moving toward sustainability and robustness of the building and attention to effective life cycle of buildings.
- Appropriate use of local construction materials.

This paper attempts to present a number of practicable, comparable and localized solutions to maximize the reduction of energy usage, which can lead to an energy saving of 12 to 45% and a decrease in environmental pollution of approximately 25%.

2 Significance of energy saving in schools

Schools, as an important building typology, can play a significant role in saving energy in terms of fuel and electricity consumption. However, if there isn't any planned program for energy saving at schools, some negative impacts with regards to energy consumption will occur. About 22% of Iran's population, which is around 15 million students, are users of this type of buildings. Undoubtedly, the mentioned population shows the magnitude of the related problem. Consequently if some effective programs for energy saving were to be introduced to the design of school buildings, positive outcomes in terms of sustainability will be gained. Accordingly, school buildings' architecture, if it was based on day light and sunlight consideration and usage, has a prominent role to play in moving toward greater levels of sustainability.

3 Daylight benefits

Natural and daylight not only create a pleasing condition for vision, but also offers some health benefits such as Vitamin D and disinfections characteristics. Furthermore the reliance on this natural source of energy, which is environmentally friendly and renewable, helps reduce the consumption of fossil fuel and, in turn, greenhouse gases.

More usage of daylight in school buildings means a better environment, pleasurable spaces, a money saving strategy, more sustainability, a less energy consumption culture, and so on. However, there are some limitations and obstacles to achieving the above goals. Budgeting requirements, management problems, and the lack of awareness about energy saving are just a few examples.

4 Sustainable architecture and energy

Sustainability as a goal can make us design healthier buildings, robust urban environments and create better future under the umbrella of three main areas: environment, economics, and social justice. Surely, sustainability is known as a multidisciplinary approach, therefore architecture as well as other sciences and fields do play an important role in sustainability. Sustainable architecture for schools, that is energy efficient and maximises the use of natural light, will ultimately make buildings and environments healthier to occupy and better for pupils and teachers. Certainly, climate characteristics, sort of land use, relationship between buildings and geographical attributes, buildings' age, and some other similar matters are known as related factors in the design process of sustainable architecture. Undoubtedly, lessons on sustainability can be learnt from some ancient buildings and monuments if we were to critically examine them. There are some famous monuments in the historical city of Isfahan of which some are known as schools such as CHAHAR BAQ School, KHAJOO School, and also schools of SA'DY, HAFEZ. In these buildings, careful attention was played to the use of local and energy efficient materials, sustainable forms with an excellent capacity for climatic modification, and sensitive facades, all of which were considered to be vital design issues.

4.1 The role of designers

According to the importance of linkage between sustainability concepts and architectural design, the role of architects and interior designers may be redefined to creating some effective artefacts that are sustainable, healthy and energy efficient. There are several practical examples which show a shifting emphasis of architecture to the implementation of sustainable approaches to the design process of buildings.

In a school building with 3900 square meter floor area in Glasgow, Scotland, 23 roof windows were installed in 2009. This resulted in more than 90% of the indoor area gaining daylight, and as a consequence, about 51% energy saving was achieved in terms of a decrease in using artificial lighting, Figure 1.

Figure 1: Roof windows installation in a school in Glasgow.

Another example of using day light is a school with 6700 square meter in USA-Washington in 1988. In this case about 40 roof windows were installed and this action’s outcome was a reduction in building lighting cost of about 87% with reports of more daylight penetration and distribution.

According to UK reports, the average energy consumption in schools includes: 24% for lighting, 29% for heating systems, 10% for cooking, 8% for hot water, 29% for electric equipment.

4.2 Material and method

In this cross sectional study, two cities were selected, Glasgow in the UK and Isfahan in Iran. Data gathering from geographic centres in both cities, daylight assessment according to sun azimuth and altitude were also carried out.

In Isfahan city, there are 568 primary schools with a student population of 130,000, which are scattered across five counties. These schools are divided into

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two categories: private (No. = 380), and governmental (No. =188) schools. In comparison the number of primary schools in Glasgow is 149 with about 36,000 students

The research sample included a number of selected new schools from both cities which comprise 10% of new schools building stock. They have various designs, differ in location and were chosen from four geographical locations within each city (to represent heterogeneous conditions with respect to differences in temperature and other geographical factors). The questionnaire included 50 questions which were distributed to each school. These questions covered issues related to the impact of natural and artificial lights on health, well-being and performance, classroom layout in relation to windows and light penetration, the influence of light on student skills and abilities (writing, reading) and their behaviour. Also, daylight levels at different seasons are taken into account using duration tables to analyse the schools' lighting with respect to orientation of the classrooms (north, east, south, west), the floor of the building where classrooms are located, different months and times in the day. Light measuring instruments have been used to measure the quantity of the light, in Lux, in the classrooms and compare and analyze them. This enables the study to compare light conditions in two classrooms with opposite orientation at the same time.

5 Results

The study also addresses the behavioural role of teachers and students in managing the implementation of appropriate actions for energy conservation and usage, such as:

- Switching off the redundant lamps in the classroom during the day.
- Switching off the lamps immediately after the end of class.
- Controlling windows, i.e. whether they are open or closed to prevent the loss of energy.
- Continuous adjustment and monitoring of school's heating and cooling system.
- Students' appropriate use of warm water systems and adequate consumption.
- Maximum use of natural lighting- installing sufficient number of windows and skylights, and painting the walls with light colours to reduce artificial lighting needs during the day [1].
- Cleaning the lamps and replacing the ones with reduced lighting efficiency.
- Installing electronic sensors that automatically switch off electrical lights when spaces and classrooms are not in use.
- Paying attention to the heating impact of high wattage lamps in summer which may force a need for air conditioning in classrooms.
- Using the minimum necessary lighting in non-activity spaces such as inventories, parking, stairs, corridors, external spaces and toilets.

The research calculated that taking into account these measures will reduce the energy cost between 12 and 17%. This change in the percentages relates directly to the year of construction and the number of students. Studies also show that larger schools and schools with 400 students compared to 200 student schools are more productive in terms of energy savings.

Programs running outside the schools working hours change the costs considerably. Because, these kinds of meeting or extra classes are mainly arranged in the evenings and afternoons, which significantly increases energy consumption and thus demands appropriate management and timetabling.

Student participation in this matter in schools could play an important role in consumption reduction and cost saving. Appropriate distribution of information and reform in norms and behaviours are very important. Actions that can make a difference include:

1. Improving the awareness of students and staff of the importance of energy conservation. All members of the school should participate in activities geared towards making energy saving an educational theme.
2. Using some students as candidates for energy monitoring in each class. They should be encouraged to take responsibility to control switching of lamps, the closing and opening of windows which will have implications for heating and cooling systems.
3. Encouraging and creating incentives for students to become successful promoting and managing energy reduction plans.
4. Rewarding successful schools with respect to factors, such as offering grants to improve building construction and maintenance, invest in low energy air conditioning systems and offering a low relative index of the number of students to space ratio.
5. Providing guidance to students on using appropriate scientific and practical methods, with respect to adopting psychological and sociological principles that can lead to an economic energy consumption style [2].
6. Encouraging voluntary saving which is a better approach in the view of experts. In this approach which is based on education and awareness, emphasis is placed on change in the mindset, increasing the incentives and motivating the people, enhancing the sensitivity of students to an optimum energy behaviour.

6 Recommendations

6.1 Suggestions on user techniques

1. Appropriate social education by schools, public media and newspapers can lead to a change of behaviour toward a more energy efficient attitude.
2. Educating students with related courses in science, that can improve their awareness of issues such energy efficiency, sustainability, green house gases and global warming.
3. Arranging new workshops for architects and other construction related staff, which teach good design practice on passive solar buildings and renewable energy generation [3].

6.2 Suggestions about architecture techniques

1. Appropriate use of standard and double (two layer) doors to reduce air draft and make school air tight.
2. Using double or triple glazed windows, which are energy efficient, since about 40% of energy loss of the buildings is from windows.
3. Controlling the classroom and other public environments in terms of providing necessary degree of warmth and using intelligent central heating systems equipped with measurement sensors of environmental temperature.
4. Isolating and standardizing of coolers canals.
5. Choosing sustainable construction materials, with respect to climate and the type of use in schools.
6. Making the adoption of article 19 of the building regulation compulsory for all current and future educational buildings.
7. Suggesting guidance for using appropriate construction material in buildings' exteriors with respect to climatic condition.
8. Making compulsory the use of entrance compartment with two doors to offset the loss of heat while one is open.
9. Designing external windows and the number of openings in relation to the degree of sun shine, direction and the number of sunny days in the specific locations. (Such analysis is underway in Isfahan which will be done in 8 levels and locations.)
10. Taking into account considerations such as, site analysis, the location, neighbourhood, heights and access.

7 Conclusion

If we compare Isfahan city in Iran with Glasgow in Scotland, it will be obvious that according to the geographic characteristic of Isfahan, a greater reliance on daylight in Isfahan might create more benefits than Glasgow. According to the sun's angles of azimuth and altitude in Isfahan, sunshine duration in Isfahan is about two times that of Glasgow.

Inspired by this fact, that sunlight in Glasgow is less than Isfahan, still aiming for an effective energy management system makes sense, and one way of doing this is maximizing the use of daylight in school buildings. Therefore, implementation of new techniques on maximizing daylight and improving energy efficiency in Isfahan school building architecture creates a sustainable condition. In this regard, a sustainable policy on urban planning and infrastructure management especially for school buildings should be considered. Public awareness of green house effects and the notion that the architecture of new school buildings should be designed according to daylighting and energy saving plans are parallel activities for achieving better conditions for society, environment and economics.

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Qualitative and quantitative daylight optimisation by shading device experimentation

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Abstract

Daylight has been an influential design factor since the beginning of architectural practice, though qualitative concerns, such as atmosphere and effect, have largely outweighed quantitative considerations such as functional and thermal optimisation. This imbalance has only widened as architectural and engineering disciplines have become increasingly specialised, such that architects are exclusively responsible for qualitative design aspects while engineers are responsible for quantitative issues. Thus, the purpose of this body of work was to initiate the design of a prototypical shading structure design which accounts for and encourages overlap between qualitative and quantitative factors throughout the design process. The prototype was developed and tested both by simulation software as well as in physical form as it was constructed and rigorously measured in a unique a full-scale Facade Lab to optimise daylight transmission performance relative to conventional shading systems. Results from the initial prototype test show that even by simply manipulating the singular variable of shading device geometry for an optimised balance of daylight and permissible views, improvements in both categories are immediately achieved relative to comparable conventional shading structures, while using less material. By increasing our quantitative understanding of the cause and effect relationship between shading device design and daylight transmission as well as thermal performance, qualitative design processes can be rigorously measured in an integrated manner. Thus, the research suggests that collaborative common ground can be achieved between architects and engineers from the beginning to the end of the design process, to optimise daylight levels and enhance both the visual experience as well as the thermal performance of architectural spaces.

Keywords: daylighting, interdisciplinary collaboration, shading device.

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1 Introduction

When sunlight passes through tree foliage, it creates irregularly scattered patches of light of various sizes on the ground. This dappled light has an elusive appeal and sitting under a shady tree offers delicate light modulation while providing a direct connection with to nature. The penetrating sunlight patterns, which create the appeal, can be rigorously charted as numerous variants of conical and elliptical rays, as done by Minnaert [1]. Most indoor environments, however, depend heavily on artificial light sources, while any natural light entering the space passes through punched windows in solid walls which can create glare, as the contrast of the unobstructed light is too harsh relative to darker portions of the room, as noted by Augustin [2]. We spend the vast majority of our time indoors, and the built environment that immediately surrounds us is influenced by many factors including scale, proportion, materiality, light, and colour. Historically, architectural research at universities and in the profession has focused primarily on these physical aspects, while issues related to the performance of buildings was conducted by architectural and structural engineers and only rarely connected to spatial explorations. As buildings continue to consume nearly 40% of all energy produced, according to USGBC [3], and as our natural resources are becoming increasingly scarce, the architectural profession has begun to recognise the need for more sustainable building practices.

The ever-pressing issue of energy efficiency must also be balanced with consideration of the human condition and the critical relationship between the human body and the external environment. As noted by Koster [4], the human body has evolved around the conditions of natural daylight. Our circadian rhythms are rooted in the natural cycle of light and dark. The best way forward for architectural design is to look back at our origins while testing and incorporating the latest technologies to optimize building envelope performance. The building envelope must strike an optimal balance between energy efficiency and spatial/formal perception. In terms of minimal internal energy use, the most “efficient” building might have no openings at all, although such an internal environment would be far from desirable due to a complete lack of natural light and views. Herzog [5] establishes that in order to maximise efficiency and perception of space, the transparent elements of a building are the most critical points for consideration, as these transparent surfaces are the primary conduit for thermal exchange as well as sunlight and daylight transmission. In addition to performing as the primary defining aesthetic feature of a building, Leslie [7] notes that the envelope provides an opportunity to enhance and expand upon our relationship with nature in terms of light, air, and views.

However, in most facade design processes, aesthetic issues have been the primary concern of architects, while energy-efficiency optimisation has been almost exclusively the role of architectural engineers. Simulation software has begun to bridge that gap as a collaborative tool, and now the Facade Lab at the University of Texas has been established as a physical full-scale facade testing tool to compliment its digital counterparts. Thus, the Facade Lab is meant to conduct a design process which is informed by two modes of qualitative measurements (virtual and physical) in addition to aesthetic considerations of the shading structure itself as well as view quality. This process is meant to encourage interdisciplinary collaboration between architects and engineers in the academy and the profession, to affect positive change in facade design energy optimization in addition to establishing parameters which can act as inspiration in formal and aesthetic decisions within tolerance margins.

2 The Facade Lab: an innovative daylight testing tool

Based on the need to facilitate experimental research related to the improvement of building envelope performance and to compliment virtual simulation data, the Facade Lab was established at The University of Texas in late 2009 to allow testing of innovative building components and systems, pairing the quantitative analysis of energy performance with the qualitative analysis of space, aesthetics, and design (see figure 1). The Facade Lab consists of a full-scale, single room space with a south-facing facade, which allows for thermal experiments as well as testing in the areas of day lighting, ventilation, and the use of direct and indirect solar energy. The small test box with exterior dimensions of approximately 4m x 5m x 3m (w/d/h) is located on top of a campus building.

Figure 1: View of Facade Lab on platform.

The facility is able to measure the effects of innovative cladding materials and shading systems, which inform the field of experimental research as it relates to sustainable building in two significant ways. First, as an important subsystem within a building, the building envelope's primary task is to regulate the external climate conditions in order to provide comfortable internal conditions for the occupants. As a result, the envelope's performance has a significant impact on a building's overall energy consumption and dramatically influences the load on mechanical building services. Second, predicting a structure's thermal behavior is inherently dependent on the use of real-scale testing facilities, since the relationship between building volume and surface area is a crucial factor with regard to thermal gains and losses as well as energy demand, thus affecting internal comfort.

3 General daylight testing parameters

The Facade Lab allows for careful analysis of each interior plane (wall) of a space with a matrix of sensors which together provide remote readings of thermal and daylight data, as affected by any combination of shading device and climatic instance in time (see figure 2). For example, the ceiling plane, when properly illuminated by a light shelf or other reflective shading device, can carry light deep into a space, which is especially important in commercial buildings with deep floor plates.

Figure 2: View of Facade Lab interior with remote sensor equipment.

The lab also allows for experiments with different materials which yield varying results in terms of thermal property capacities. Metal, wood, and plastic have very different properties in terms of thermal storage capacity as well as reflectance, as noted by Schittich [6], which can be measured quantifiably by the lab. For this particular research and prototypical design, daylight was the measured element of focus, as thermal impact calculations were not performed.

4 Benchmark analysis to establish baseline parameters

The Facade Lab allows for quantitative full-scale testing of conventional facade and shading systems, to establish baselines within the existing built environment.In order to be able to design optimised and innovative structures, it is critical to specifically understand conventional shading structures. Six generic benchmark shading structure types were tested for solar radiation in the specific hot, humid Austin climate in which the Facade Lab exists, via digital simulation processes, and the results were documented in the research of Bader [8].

4.1 Horizontal louvers (Type 1)

The type of horizontal louvers tested in this study consists of blinds which are perpendicular to the surface. They have a depth and a distance between each blind of 30 cm. They span over the entire width of the window (see figure 3a). The horizontal shading devices had a small improvement of 3.24% compared to southwest and 10.55% to the west. Horizontal louvers on the southwest allow 7.31% more solar radiation than for a west orientated surface. Horizontal louvers have a minimum shading coefficient (sc) of 0.47 (west) (see figure 4).

4.2 Vertical louvers (Type 2)

The design of the vertical blinds has a depth and a distance between each blind of 30 cm and covers the entire height of the window wall (see figure 3b). Vertical shading devices on west orientated surfaces provide 10.10% less shading than on the south and also 2.85% less than on the southwest. Compared to horizontal louvers, vertical blinds can only provide a minimum sc of 0.68 (west), no matter the orientation (see figure 4).

4.3 Eggcrate shading structure (Type 3)

Eggcrate shading structures are a combination of the horizontal and vertical blinds as described before. The square type is designed with an opening of 30 cm width/height and a depth of 30 cm (see figure 3c). South orientated eggcrate shading structures deliver the best results with regard to shading. With 4.84% more shading in south than southwest and even 11.57% more shading than west, eggcrate shading structures show a minimum shading coefficient (sc) of 0.39 (west) in all orientations (see figure 4).

4.4 Horizontally orientated honeycomb shading structures (Type 4)

The honeycomb structure consists of symmetrical hexagonal components with a depth of 30 cm. They have a diameter of 30 cm and a circumference of 9 cm, resulting in 20 cm long edges. The maximum component height is 34 cm.

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These honeycombs are wider than tall. They have two horizontal edges (see figure 3d). Similar to eggcrate structures, this type performs best in south. It provides 5.12% more shading than southwest and 10.70% more shading than west. With a minimum sc of 0.38 (west) this type of honeycomb has a similar behavior as an eggcrate type (see figure 4).

4.5 Vertically orientated honeycomb shading structures (Type 5)

This structure is similar to a horizontally orientated honeycomb but rotated by 90 degrees. Thus, the components are taller than wide and have two vertical edges (see figure 3e). This honeycomb, orientated towards south, performs best of all honeycomb structures in type and orientation. With an sc of 0.27, it is slightly better but performs similar on south as the horizontally orientated type. It performs 4.50% (southwest) and 10.65% (west) better than in the other orientations. The minimum sc is 0.38 (west). Comparing the percentages of horizontally and vertically orientated honeycomb structures, it can be concluded that a change of its orientation has a slight impact on the shading performance. In general, vertically orientated honeycombs perform better than horizontally oriented types (see figure 4).

4.6 Vertically orientated honeycomb with 1.4m circumference (Type 6)

The third variation of the honeycomb structure has a circumference equal to the sum of the sides of the square openings of the eggcrate structure, which is 1.4 m. Thus, this honeycomb structure is actually bigger than type 4 or 5 (see figure 3f). Similar, but with 3.69% (type 4) and 3.91% (type 5) less provided shading than other honeycomb types, this type also has its best performance on a south

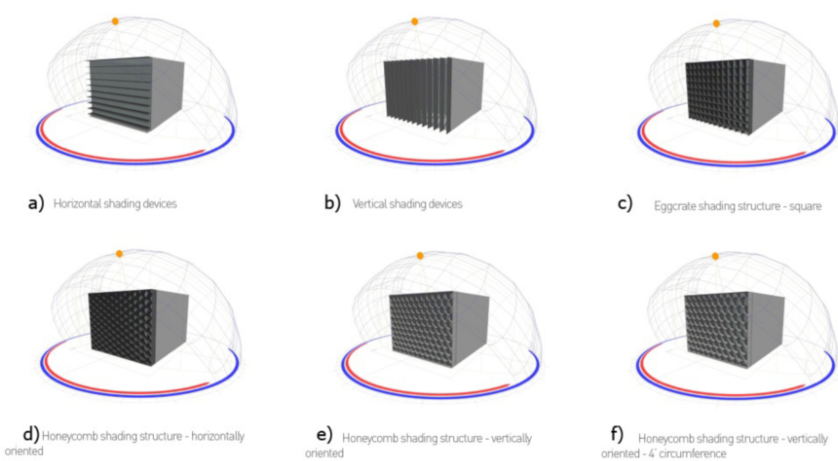

Figure 3: Generic conventional shading device benchmarks.

orientated surface. As expected, it performs in every direction slightly worse than the other types. Compared to the south, this type provides 5.49% less shading in southwest and 11.64% in west (see figure 4).

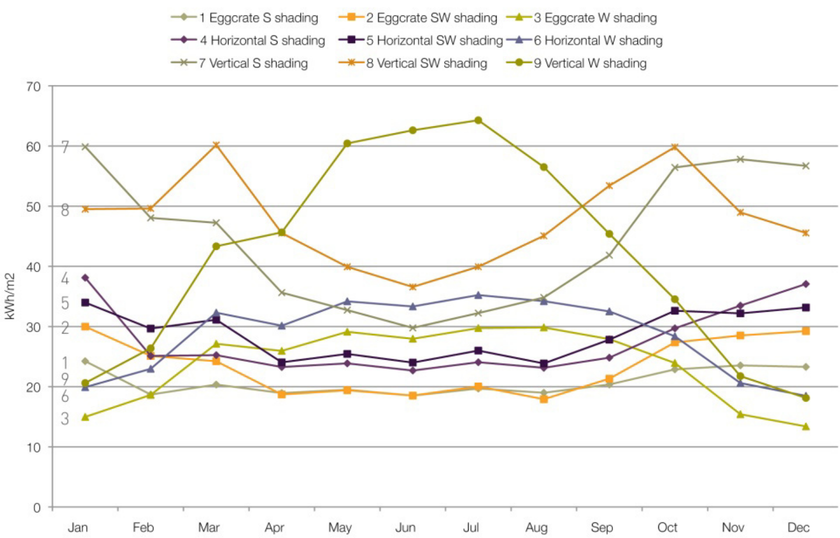

Figure 4: Monthly solar radiation comparison of benchmark shading devices.

5 Prototype design methods and goals

The shading device prototype design began with thorough research including a rigorous analysis of the times when sun shading is needed at the given geographic coordinates and south-facing orientation, and the surface needs of a shading device, based on an understanding of the local sun path, as spelled out by Bader [8]. In the hot, humid climate of Austin, Texas, the summer exterior temperature is above the comfort level more often than not, and thus direct summer solar radiation frequently leads to overheating. In contrast, direct winter sunlight is desired in order to reduce heating loads and electrical consumption by artificial lighting. Therefore, the first shading prototype was designed to provide full shading in the summer and direct solar exposure in the winter, while existing as a static structure, as well as optimising views out from the inside.

After carefully considering the advantages and disadvantages of each generic benchmark shading device type, a honeycomb variant was chosen as the general shape of the unit or module of the experimental prototypical shading device (see figure 5). This decision took into consideration solar performance as well as construction material assembly. First, the honeycomb form loosely mimics the semicircular daily path of the sun. Secondly, the hexagon shape is structurally more rigid than a rectangular form, due to its diagonal members which utilize the structural principle of triangulation. The pattern also uses a minimal amount of surface area to create a lattice of cells within a given volume and the hexagonal forms stack well to reduce material. Lastly, the novelty of the form was a driver in the pursuit to explore undocumented territory in shading device design, as noted by Bader [8].

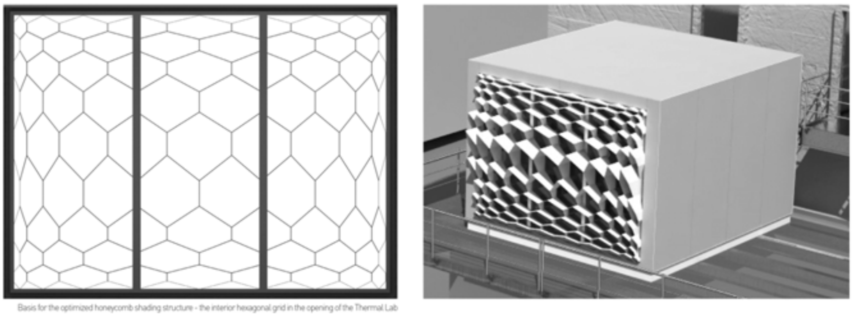

Figure 5: Virtual development of Experimental Prototype Structure.

6 Prototype fabrication and comparative performance results

The experimental prototype was cut out of polypropylene sheets with a CNC (Computer Numerical Control) Router and assembled in units (see Figure 6).Results showed that the optimised honeycomb experimental prototype structure provides the lowest sc for south relative to conventional counterparts, but performs best for southwest and west. For south, the sc is provided by the vertically oriented honeycomb structure. With an sc of 0.27 the structure provides almost 43% more shading than the optimised honeycomb structure. On southwest, the optimised honeycomb structure provides 15% more shading than the vertically orientated honeycomb structure, which provides the second best sc. Similar results for west, where the optimised honeycomb shading structure provides an sc of 0.29 which is 21.2% better than the second best shading structure, again the vertically orientated honeycomb shading structure. But again, the results could also show that the optimized structure only provides more diffuse solar radiation than the others and thus, it simply allows a higher degree of visual comfort with full shading from March until September, the critical months with regard to high temperatures.

Due to the minimised use of material, the experimental optimised honeycomb prototype shading structure is highly competitive to the other benchmark shading devices (see figure 7). Ultimately, it performs third on area of unrolled shading structure and performs best on total volume of shading structure. Even though it has a slightly larger area of visible shading structure than the honeycomb shading structure with a circumference of 1.4m, it provides a high degree of visual contact due to the enlarged openings in defined regions, which provide the same sc as smaller components. Furthermore, the optimised honeycomb form of the experimental prototype offers a unique alternative to conventional vertical and horizontal louvers, and is far more interesting and aesthetically intriguing than conventional louver types (see Figures 8 and 9).

Figure 6: Construction and assembly of experimental prototype structure.

7 Conclusion

Amidst increasing pressure to improve building sustainability, there exists a dire need for collaboration between architects and engineers to optimize quantitative and qualitative building performance, including merging between the two disciplines. By increasing our quantitative understanding of the cause and effect relationship between shading device design and daylight transmission, qualitative design processes can be rigorously measured in an integrated manner,

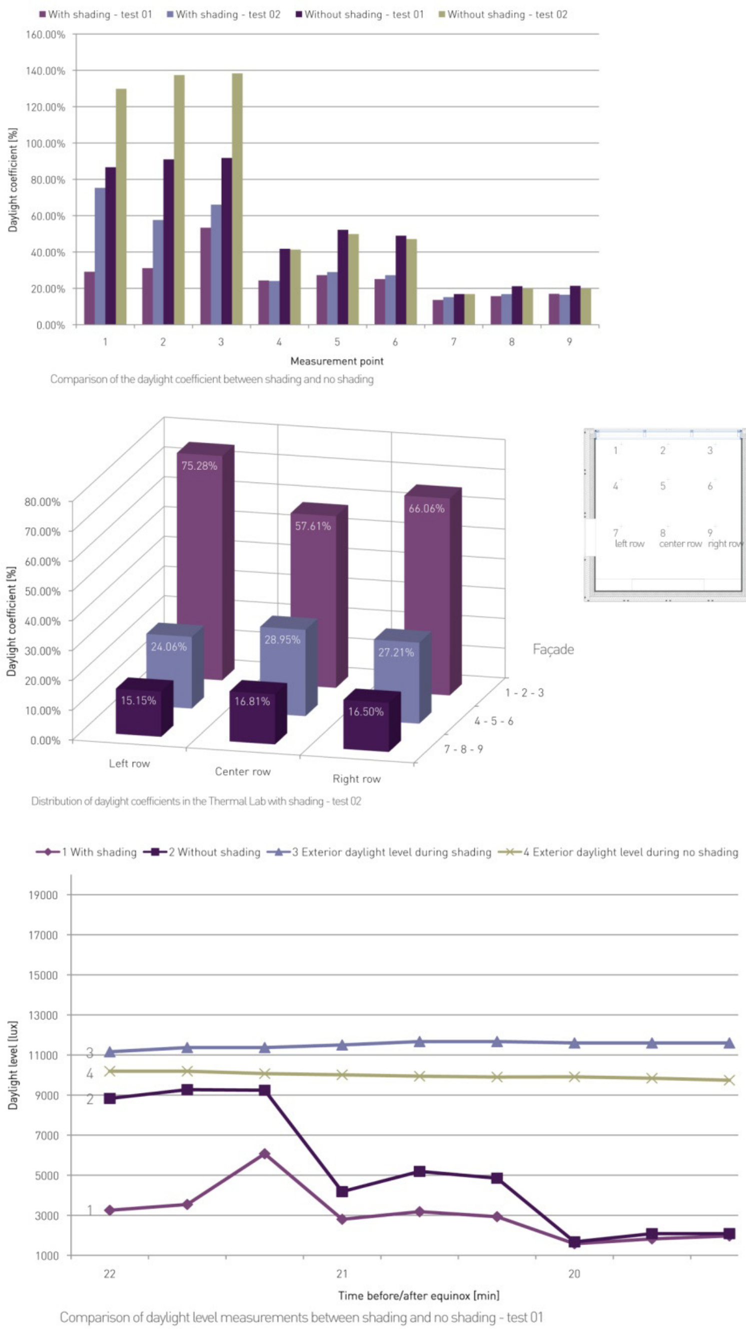

Figure 7: Effect of experimental prototype structure on daylight distribution.

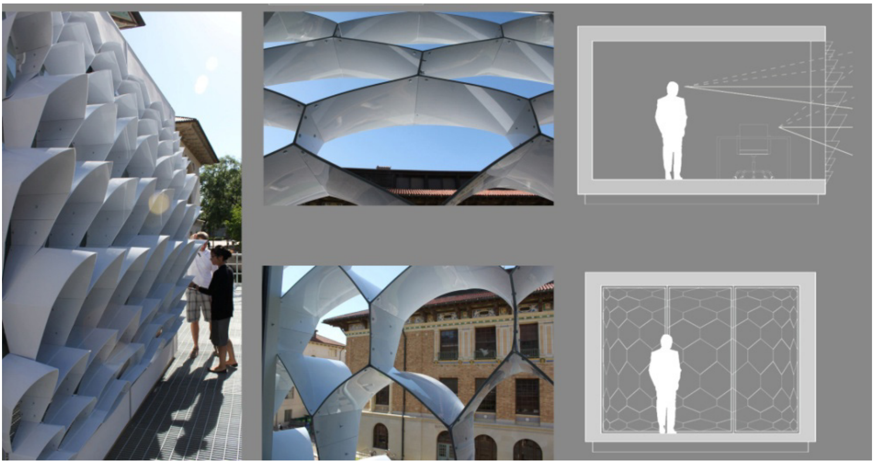

Figure 8: View of experimental prototype shading structure on Facade Lab.

Figure 9: View of experimental prototype shading structure on Facade Lab.

thus creating some overlap between the roles of the architect and engineer. This research suggests there can exist a new middle working ground toward the quantifiable and qualitative design alternative shading solutions with improved functional, ecological and aesthetic properties which can be adapted and applied in future developments in various climatic conditions.

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Pedagogical models from a lighting design studio

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Abstract

This paper discusses a pedagogical approach for teaching a lighting design studio. Anderson's ACT-R theory is utilized to guide the learning process. Anderson's ACT-R theory focuses on three stages of skill acquisition: cognitive, associative, and autonomous stages. These three stages offer implications for teaching lighting. Early cognitivists offered many theories on how people solve problems. While early theorist focused mainly on explaining how people solve problems, contemporary theorist focus on cognitive strategies and information processes people use to solve problems. Knowledge is a key component of information processing in problem-solving. Cognitive Psychologist identified two distinct types of knowledge: declarative and procedural. Anderson notes "declarative knowledge is explicit knowledge which we can report and of which we are consciously aware". Procedural knowledge involves knowing how to execute tasks. Anderson notes "human cognition is always purposeful, directed to achieving goals and to removing obstacles to those goals". ACT-R's main assumption is that knowledge can be classified as declarative and procedural. Declarative knowledge is factual knowledge, while procedural knowledge is how to perform cognitive tasks. Students are taught accurate and elaborate knowledge of lighting design principles to help them problem-solving. Learning is achieved through expository and discovery methods. Expository are teacher centered examples of which include lectures and interactive presentations on lighting systems, as well as field trips to lighting laboratories and showrooms to offer real life context for students. The discovery method is emphasized in hands on experiences. Feedback is given during all three distinct phases of problem solving to correct any disequilibrium students may have. Eventually, students achieve automaticity due to continued practice.
Keywords: architectural lighting, cognitive strategies, lighting design, design problem solving and instructional design.

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1 Introduction

This paper discusses a pedagogical approach for teaching an architectural lighting design studio to third year Interior design students at the University of Oklahoma. Anderson's ACT-R theory [1] is utilized to guide students through the process of learning about architectural lighting design. Anderson's ACT-R theory [1] focuses on three stages of skill acquisition: cognitive, associative, and autonomous stages. These three stages offer implications for teaching a lighting studio and are analogous to stages employed in lighting design problem solving.

2 Literature review

2.1 Cognition and problem solving

Early cognitivists offered many theories on how people solve problems. For example, Wallas [5] identified the following four stages in problem solving: preparation, incubation, inspiration, and verification. Likewise, Polya [6] suggested four stages which rely heavily on cognition: understanding the problem, devising a plan, carrying out the plan, and looking backward. While early theorist focused mainly on explaining how people solve problems, contemporary theorist focus on cognitive strategies and information processes people use to solve problems.

Knowledge is a key component of information processing relevant to problem solving. Cognitive Psychologist identified two distinct types of knowledge: declarative and procedural. Anderson [2] notes “declarative knowledge is explicit knowledge which we can report and of which we are consciously aware” (p. 284). Procedural knowledge involves knowing how to execute tasks [2–4]. Anderson [2, p. 237] notes “human cognition is always purposeful, directed to achieving goals and to removing obstacles to those goals”. Likewise, design problem solving involves solving problems and achieving client/user requirements.

2.2 Anderson's ACT-R theory

ACT-R (Adaptive Control of Thought—Rational) [1] was developed by John Robert Anderson at Carnegie Mellon University. The basic premise is that cognitive tasks humans perform consist of a series of separate actions and procedures. ACT-R's [1] main assumption is that knowledge can be classified as declarative and procedural. Declarative knowledge is factual knowledge i.e. knowledge of facts or how things are, while procedural knowledge is how to perform cognitive tasks. Anderson [2] notes “procedural knowledge is represented as productions or condition-action systems”. For example, the hypothesis is, if certain conditions apply, then perform certain action [2].

According to Anderson, procedural knowledge is acquired in three stages of skill development: cognitive, associative, and autonomous. The first stage, the cognitive stage represents the phase in which “subjects develop a declarative

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encoding of the skill; that is; they commit to memory a set of facts relevant to the skill" [2]. The second stage, the associative stage results out of repeated practice. As a result of which performance becomes smoother and more rapid. This stage fosters practice which leads to proceduralization. As the procedure becomes more automated through practice, automaticity emerges in the autonomous stage.

3 Process

3.1 ACT-R general implications for teaching architectural lighting

Anderson's ACT-R general implications for teaching procedures are the following:

(i) Students must develop an accurate and elaborate declarative representation of the desired procedure (actions) and conditions under which it should be used;

(ii) Teaching can be accomplished using the expository or discovery methods. The expository method is teacher-centered instruction, while the discovery method occurs via discovery;

(iii) Feedback is an important component, because it fosters proceduralization; and,

(iv) Continued practice leads to automatization [2].

The accompanying chart Table 1 summarizes the application of ACT-R theory [1] to teaching sustainable strategies in lighting in the fall 2008, 2009, and 2010 lighting design studio. To apply these strategies in the lighting design studio in the first step, students are guided through the development of accurate and elaborative representation of lighting design principles. Examples of topics covered in lighting design studio to help students develop an accurate and elaborate representation in order to be able to design lighting systems include the following: lighting basics, design process, lighting concepts, lighting plans, reflected ceiling plans, electrical plans, luminaire types, perception and psychological aspects, lamp characteristics, light sources and color, distribution, efficient light sources, efficacy, material efficiency, photometry, lighting controls, energy management, codes, USGBC LEED rating systems, light pollution credit, energy performance credits, etc. This information is developed using the expository method which involves teacher-centered instruction, using interactive presentation lecture formats, as well as field trips to lighting laboratories and showrooms to offer real life context for students. Additional emphasis is placed on teaching students how lighting design plays a significant role in minimizing the impact on the environment.

For example, Winchip [7, p 284] notes "Sustainable design is a concept that focuses on products and processes that protect the environment and conserve energy for future generations. Whenever possible, lighting specifications should reflect the principles embodied in sustainable design. This involves selecting lighting systems that conserve energy and comply with standards, codes, and regulations".

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Table 1: Anderson ACT-R general implications for teaching lighting design.

Task	Process
Develop accurate and elaborate declarative representation of Lighting design principles	Lecture topics covered in Fall 2008 2009, and 2010 courses: • Week 1 - Introduction to lighting, lighting basics, design process, lighting concepts, design elements and principles, and architectural elements; • Week 1 - Lighting plans, Reflected Ceiling plans, Electrical plans. • Week 2 – Lighting Workshop on 3D Studio Max presented by Adam Crespi, professor of art and animation at DigiPen Institute of Technology, Redmond, Washington. • Week 2 - Vocabulary and Luminaire types; • Week 2 - Perception and Psychological aspects; • Week 3 - Field trip Smith Lighting, Oklahoma City, 4101N Walnut Avenue Oklahoma City, Oklahoma; • Week 3 - Lamp characteristics; Light Sources and Color, Distribution, Lumen output, Beam spread, Efficient light sources, Efficacy and Rated life, Material Efficiency; • Week 3 & 4 - Photometry; • Week 5 - Electricity and Electrical Controls; • Week 5 - Outdoor lighting; • Week 6 - Daylighting; • Week 7– Electrical and Wiring lecture by Stan Gralla and Nick Thomas at OU College of Architecture Modelshop; • Week 8 - Energy management, Codes, Economics and Health; Energy and environment; • Week 8 - USGBC LEED Rating Systems – Light pollution reduction credit, Energy performance credits, Controllability of lighting systems credit, Daylighting and Views credit; • Week 9 - Alternative energy systems: Photovoltaics and Wind turbines; • Week 9 - Mechanical systems, Security systems and Fire suppression systems; • Week 10 – Presentation on lighting Historic Spaces and Guest Juror: Dawn Hollingsworth, LC, IALD, Visual Terrain Inc., California, Managing Principal; • Week 11 - Computer Modeling and Visualization in Form.Z, and; • Week 12- Computer Modeling and Visualization in AGI 32 presented by Olivia Flatt, Smith Lighting, Oklahoma City; Note: Course materials, syllabus, lectures, project sheets, and PowerPoint files were posted online at Course website at Learn.ou.edu
Expository Methods (Teacher centered instruction)	Using the expository methods involved teacher centered instruction to help students develop declarative knowledge. The above listed topics were presented in PowerPoint and interactive presentation lecture format and field trips to lighting labs and lighting showrooms in the vicinity to offer real life contexts for students. All these helped students develop an understanding of fundamental principles in lighting.

In the second step, exercises where students learn by discovery are integrated. The discovery method is emphasized in hands-on experiences, some of which include a lighting analysis project, a store lighting design, a fixture design competition project, and a service learning community service project. In the lighting analysis project, student document and analyze three spaces in the vicinity: a store, an office space and a gallery space. In each space, student identify the different layers of lighting, types of luminaire, brightness hierarchy, concept, architectural opportunities and constraints, integration of lighting with 2D and 3D design elements, composition, quality, color, controls, sustainable

Table 1: Continued.

Discovery Methods	The discovery method allowed students to learn through discovery. The following five lighting design projects were accomplished during the semester. Project 1: Lighting Analysis – Lighting analysis of a store, office space, and gallery. In teams, student documented and analyzed three spaces in the vicinity: a Store, an Office Space and a Gallery Space. In each space, student identified the different layers of lighting, types of luminiaire, brightness hierarchy, concept, architectural opportunities and constraints, integration of lighting with 2D and 3D design elements, composition, quality, color, controls, sustainable strategies implemented and user satisfaction. Students documented these criteria using photographs, sketches, images, plans and notes in PowerPoint (Appendix C – Illustrates a group's lighting Analysis project). Project 2: Store Lighting Design - Lighting design of a contemporary brand name store. In this project students designed the lighting and display space for a contemporary brand name store in a metropolitan airport. Students' proposals were required to emphasize sustainable issues, the different layers of lighting, brightness hierarchy, architectural opportunities, composition, quality, color, controls, and integrate lighting solution with 2D and 3D design elements in the space. Project 3: Light Fixture Design - Light fixture design and full scale model of a light fixture. Students were required to emphasize originality, creativity and energy efficiency in the Luraline Light fixture competition. Project 4: Norman Senior Citizen Center – Lighting design of the Norman Senior Citizen Center housed in the old Norman public library building. Interior Design students designed the interiors and lighting along with Graduate architecture students. The project involved lighting a dining hall, gallery, and multipurpose hall Project 5: Restaurant in Nigeria and South Africa – Lighting Design of a restaurant in an urbane setting in Lagos, Nigeria or Johannesburg, South Africa to highlight the country's culture and foods to tourist.
Feedback Component	Feedback was an important component, because it fosters proceduralization. Three distinct Phases are identified for each design project and feedback from the instructor and jurors occurred in these three distinct phases in all four projects. Initial Phase – Information Gathering and Programming This phase involved an analysis of owner and design team preferences, architectural opportunities and constraints, visual and perceptual needs, photometric considerations, security issues, budget, energy code requirements, sustainable strategies, and maintenance considerations. The requirement at this phase was a concise program. Design Concept Phase In this phase, students were expected to develop their concepts to provide appropriate quality and quantity of light for visual tasks performed, respond to psychological needs of the users, and enhance architectural design features. Some common composition techniques to be explored at this stage include mood/atmosphere, sparkle/smoothness, uniform/non-uniform, brightness hierarchy, and way finding. Design Development Phase In this phase, students develop their final design options as presentation drawings and schedules. Presentation drawings included lighting layout, details, renderings, and specifications.
Automatization	Continued practice led to automatization and this was evident by the increase in the quality of the work developed by the students as the semester proceeded.

strategies implemented and user satisfaction. Students document these criteria using photographs, sketches, images, and plans. In the store lighting design project, students design the lighting and display space for a contemporary brand name store in a metropolitan airport. Students' proposals are required to emphasize sustainable issues through using the different layers of lighting, brightness hierarchy, architectural opportunities, composition, quality, color, controls, and the integration of lighting solution with 2D and 3D design elements in the space (Figures 1 and 2). In the light fixture design, students are required to emphasize originality, creativity and energy efficiency in the design of a full scale model of a light fixture (Figure 3). In a final project, usually a service learning or a community service real life project, students emphasis sustainable issues in their solutions.

Figure 1: Store lighting design project by Katya Yarominak, cooper lighting source award of recognition April 2010.

The three distinct phases utilized in lighting design problem solving are information gathering and programming, design concept and design development. The information gathering and programming phase involves an analysis of owner and design team preferences, architectural opportunities and constraints, visual and perceptual needs, photometric considerations, security issues, budget, energy code requirements, sustainable strategies, and maintenance considerations. The requirement at this phase is a concise program.

In the design concept phase, students develop their concepts to provide an appropriate quality of light for visual tasks performed, respond to psychological needs of the users, and enhance architectural design features. In the design development phase, students develop their final design options as presentation drawings and schedules which include lighting layout, details, renderings, and specifications. Feedback is given during all three distinct phases of problem solving in all four projects. This feedback helps to correct any disequilibrium students may have. Disequilibrium is a state of misconception or misinformation. Finally, students achieve automaticity through continued practice as they complete the lighting design projects and advance to upper levels courses.

Figure 2: Store lighting design project by Lindsay rule.

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Figure 3: Fixture design, 1st place winning entry in 2008 Luraline fixture design competition by Marissa Gomez.

4 Conclusion

This paper illustrates how students acquire design skills in an architectural lighting design studio through the utilization of Anderson's ACT-R theory [1] in the instructional process. Using Anderson's ACT-R theory [1] in the instructional process for this lighting design studio has been very effective because since 2008, projects from the lighting design studio have won national design competition and have been widely disseminated. For example, student work from the fall 2008 lighting studio was published in an article titled "Branding with Light-Interior Design Students at University of Oklahoma propose distinctive illuminated Store plans" in April 2009. In May 2008, Marissa Gomez won 1st place nationally in the Luraline fixture design competition. The jurors commended her innovative use of sustainable materials and energy efficient lamp sources in her design solution. In April 2010, Katya Yarominak won a Cooper lighting Source Award of recognition for her store lighting design project.

While architectural lighting is a vast topic, ACT-R theory [1] can effectively help design students gain a better understanding of lighting systems and help them become better designers. Future direction of this research will aim at including more student meta-cognitive strategies such as self-regulation or self-monitoring in the process since Anderson's ACT-R [1] procedure is very systematic and procedural.

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The sound of daylight: the visual and auditory nature of designing with natural light

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Abstract

Students assemble in classrooms without windows. Parishioners attend services in enclosed buildings. Most people spend the majority of daylight hours inside buildings dependent upon artificial control systems without much connection to the benefits of natural elements – especially natural light.

What happened to design integration of the basic knowledge that sunlight is practically free to harness, that the human body relies upon the sun to produce essential Vitamin D, and that humans are innately attracted to the outside world? Some designers have been convinced that energy efficiency overrules basic human needs. Others deem exterior views and natural light to be distractions for building occupants. Conversely, comprehensive design incorporates precisely layered assemblies of materials to be energy, thermally, and sustainably efficient. Natural light can truly define spatial character. Building orientation, fenestration, material surfaces, and ceiling heights all contribute to how natural light will dwell in each space. Design decisions can also affect other considerations such as acoustical properties and the overall experience conveyed to the occupants. Natural lighting is a dynamic design tool that can be an integral part of initial sketches through project design development. Fundamental principles of reflection, refraction, diffusion, and absorption are applicable to both natural lighting and acoustics. This paper will challenge designers to create space where natural light is integral to the building's enclosure and acts as a catalyst to provide acoustical benefits as attention is focused on material selection, arrangement, and detailing. Proposals will be based on precedent studies, current research, and derived from teaching architectural acoustics and natural lighting courses.

Keywords: natural light, daylight, design, building materials, sound, acoustics, architecture, architectural.

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1 Introduction

Seeing and hearing are two primary senses that affect human behavior, attitude, and health. The entire human body is influenced in several ways by the interaction between visual and auditory nuances. Human senses are stimulated by nature, artwork, music, sculpture, and other social forms of expression. Unfortunately, the general public, and sometimes the designers entrusted to developing functional space, do not fully understand how people can be individually and collectively affected by lighting and acoustical environments.

Numerous architects throughout history, in both professional practice and academia, have referred to architecture as the “mother of all arts.” Regardless whether everyone agrees with this statement or not, architecture is responsible for housing specific functions and defining character for inhabitable enclosures in which most of the world’s population spend the majority of their time. Studies suggest that people spend more than 80 percent of life indoors (Baker [1]). We live life within the art form of architecture, so the built environment should ultimately serve the occupants and be environmentally responsive throughout initial design schemes, construction, habitation, and maintenance phases. However, serving the occupants is more than just providing a building that defines enclosed conditioned space. Architecture is what happens when the mundane need for enclosure to accommodate a specific function becomes energized with how that specific function can be tailored to the occupants. Natural lighting is a design tool that addresses numerous physical, emotional, and spiritual needs while animating various building types.

Some architects understand the bigger picture, and some do not. Famed architect Le Corbusier stated, “Architecture is the learned game, correct and magnificent, of forms assembled in the light” [2]. How those forms are assembled can define unique lighting and acoustic qualities simultaneously. Architectural lighting expert William Lam has spent many decades educating architects and the general public about natural light and has characterized a common issue:

> At the beginning of my career as an architectural lighting consultant, I wrote a series of articles in Architectural Record, “Lighting for Architecture” (1959–60), to remind architects that the uncomfortable, unpleasant, unattractive luminous environments characteristic of most of their new buildings were the result of their abdication of lighting design to engineers untrained in design (Lam [3]).

As Lam argues, the disciplinary divisions between architects and lighting engineers are partly to blame.

Most portions of buildings that differ from the traditionally expected enclosure aided by electrical and mechanical systems are typically viewed as “artistic” or “creative” gestures frivolously designed by the architect and are regularly viewed by owners and contractors as unnecessary for basic building function. Cost-cutting measures, instigated by team members who do not value what they deem as “artistic gestures,” diminish intricate details in the name of value engineering. The building and future occupants are stripped of vital design concepts aimed at supporting the intended usable function, and consequently the occupants' welfare is negatively affected. Architects should desire to understand how and why natural light is important and then convey those reasons to the client. When architects design buildings, the resultant spaces need to be more than simple enclosure from the outdoor environment.

Serving human psychological and functional needs is the aim of all architecture. Buildings are built to serve people. Therefore they should enhance the quality of life for their inhabitants and facilitate a healthy environment. Unfortunately, that is not always the case.

> Without question, a causal relationship exists between the indoor environment and human health. The effects of poorly designed buildings, whether in terms of limited access to sunlight or poor indoor air quality, continue to affect the health of building occupants. Sick Building Syndrome (SBS) is frequently associated with issues of indoor air pollution, the absences of sunlight or daylight, inadequate heating or ventilation, poor acoustics, and the presence of asbestos. Lack of sunlight combined with high humidity can trigger the formation of mold and mildew spores, airborne contaminants that may lead to respiratory diseases (Boubekri [4]).

The title of this paper, "The sound of daylight," refers to two concepts. First, the selection, articulation, scale, and locations of materials will define how both light and sound exist in a space. Materials determine the behavior and interaction of light and sound within defined space. Second, personal interaction is an important factor to consider in defining a space. How people use the space and interact with other people results in variations of lighting and acoustical environments. There are universal physical and emotional factors associated with both lighting and acoustics for all buildings and occupancy types, such as health, well being, emotions, production of vitamin D, diurnal patterns, circadian rhythms, task productivity, and sustainability.

Architecture itself can express zeal and become evocative for its function and occupants. The material choices, layers of material assemblies, and spatial relationships among adjacent materials can define a specific and tailored architectural language. Over the years people have learned to create, control, and manipulate artificial light; natural sunlight, however, still stimulates the human spirit (Slingerland [5]). Natural light in architecture can be used to define both visual and acoustical qualities as an expression of purpose while appealing to our senses and meeting human needs.

2 We are visual people

The general public acknowledges visual and thermal discomfort more than acoustical discomfort. Temperature and/or lighting variations within a space typically result in more complaints than do acoustical issues, yet all three areas are intrinsically linked. Mechanical and electrical systems are intrinsically depended upon for human comfort in most occupancy classifications without much concern for natural lighting or passive heating and cooling options. Consequently, poor acoustics are usually deemed as the unavoidable result because most people do not associate noise and acoustical problems with architectural design.

The media is first in line to appeal to our visual nature. Television, printed media, and the Internet heighten our attention to visual culture and experiences. Even most modern music is marketed to appeal first to our visual sense rather than focusing on audio content or musical talent. The performer's clothing fashion, stage set, or hairstyle can create fans. Society has become obsessed with beauty being defined as how something appears to someone else, yet most current architecture is being publicized as the bare essentials of enclosure without much regard for visual appeal. Consequently, the general public is not accustomed to seeing, inhabiting, and experiencing architecture that combines function, beauty, and environmental concerns. The architecture in which people spend most of their lives violates our innate need for natural elements and the beauty they define.

Typically, architecture and design magazines show the glamorous side of a select few buildings in an attempt to convey beauty. The media usually wants to portray the building, or at least the inviting views of the building, as "good design." How could a photograph begin to address the age old question: what is good design? Aside from critics' and armchair architects' social commentary on the imagery, there is another layer of hidden information in those photographs. Good design can be more than what human eyes relate to human brains. The subdued layer of architecture experienced with human ears cannot be appreciated solely through the visual medium, but it can be complementary to natural lighting schemes. People need to hear what architecture creates.

3 How do lighting and acoustical environments relate?

Natural light within buildings is all too often the result of simple, punched openings, usually referred to as "windows," in a planar wall. Aside from music halls and recording studios, room acoustics are usually the resultant by-product of other design decisions without finely focused attention to how the finished space will sound to the occupants or how certain adjacent sounds need to be attenuated. Light and sound both travel in waves, and they behave in similar manners when exposed to various wall assemblies, materials, and finishes. They share the reactionary components of reflection, refraction, diffusion, and absorption. Lighting and acoustics share great potential as crucial functions in programmatic design requirements.

Light is a form of energy that permits us to see. The quality of that light then determines what we see and how we feel within that space. Acoustics is the auditory complement to the visual nature of light. Human emotions are sparked by both light levels and acoustic conditions. These waves of frequencies are not stagnant – they are ever-changing. The natural variation of tones is cast through the atmosphere throughout a typical day from sunrise to sunset. The light is filtered and altered as it passes through, reflects, or refracts in typical atmospheric conditions such as rain, snow, and clouds. The Polish cosmetics industrialist Helena Rubinstein concisely stated, "Daylight reveals color;

artificial light drains it" [6]. The same can be said in relation to natural acoustics.

Along with numerous other issues, architects are charged with the insightful task of selecting and arranging materials for structural, functional, and aesthetic purposes. Here lies common ground. Those chosen materials and subsequent relationships – which at first glance may simply appeal to our senses and appear beautiful or artistic, or may merely define scale and enclosure – suggest specific spatial lighting and acoustical environments. The visual association with surfaces and how the materials are articulated allow the specific dwelling of light. Decisions about materials also relate to the auditory nature of the space. Observers and occupants begin to comprehend the communion of natural light and natural acoustics as they share similar details.

There are various terms associated with defining acoustical qualities, but the most common is *reverberation*. Simply defined, reverberation is the persistence of sound after the original sound has stopped. Classrooms should have approximately half a second of reverberation time for speech intelligibility, while Gothic cathedrals typically have three or more seconds to suit various styles of chanting. Reverberation time calculations are directly based on the total room volume and inversely associated to absorption values of individual surface areas. Acoustically reflective materials create a lively space with longer reverberation times while acoustically absorptive materials deaden the space and do not allow much reverberation. It is possible for small volumes with highly reflective materials to have more reverberation time than mostly absorptive larger rooms. Since room volume and surface finishes define basic acoustical qualities, it is easy to understand where natural lighting and acoustics begin to coexist. Basic descriptive terms such as *piercing*, *diffused*, *soft*, *hard*, *warm*, *cool*, *bright*, and *dull* are ways to conceptualize both lighting and acoustical environments.

Layering and transparency of materials blur the visual and auditory separation between spaces. How these materials relate with light and acoustics define a specific character. Every space has its own signature environment dependent upon how light and sound waves interact with materials. This occurs at a physiological level where human senses interpret orientation, scale, and subtleties of spatial definition (Sheridan and Van Lengen [7]). The aural perception of space contributes to the experiential identity of an environment.

4 Sustainability

The United States Green Building Council (USGBC) defines sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations [8]). This is a generalized definition applicable to most areas of design and construction. What do acoustics have to do with sustainable design efforts, especially pertaining to natural lighting? Although acoustics are generally left out of most sustainability directives, spaces designed with poor acoustics can have deleterious effects on the function of a building. Relative to acoustics, "People's satisfaction was actually slightly lower in green buildings than in regular buildings," says Ken

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Roy, senior research scientist and acoustician at Armstrong World Industries. Not only are acoustics often ignored when creating a green building, but they are also ignored by the organizations defining green buildings (Madsen [9]).

> Although draft standards with some acoustic requirements are under consideration, quantitative acoustic design requirements are not included in current sustainable design standards. The question arises as to whether a building that is not comfortable acoustically, and therefore not fit for its purpose, is actually a sustainable building for its occupants (Field [10]).

In other words, while acoustic consideration may not directly influence energy consumption or life cycle costs, acoustical properties of spaces do have the ability to influence users' behavior in positive or negative ways. While it may be difficult to evaluate quality of design as a property of space in industry standard sustainability terms, aesthetics and spatial quality should not be ignored entirely in favour of quantitative and measurable data associated with sustainability.

Natural lighting and carefully considered acoustics can contribute to an artistically sustainable expression tailored to the intended users. Since daylight is practically free, aside from costs associated with blocking heat gain and UV rays, we should use it more frequently.

> According to the 1998 Energy Information Agency of the U.S. Department of Energy, the building sector is responsible for about 36 percent of all the energy consumed in the United States, more than the transportation sector (27 percent) and an amount almost equal to that used by the industrial sector (38 percent). Lighting is responsible for 30 percent to 50 percent of all energy utilized in commercial and office buildings [4].

Natural light can provide numerous benefits including less dependence on artificial light and hence fossil fuels, incorporation of solar collector panels to convert natural light into usable energy, and, in some climates, aiding in passive heating and cooling needs. Creative and aesthetic uses of natural light not only benefit occupant health and welfare, but the building's carbon footprint also decreases. Humans possess an innate attraction to nature. When natural elements are used in building design, our buildings become more sustainable and connected to their local environments.

5 Studies and statistics

Various studies have examined the effects of both light and acoustics on human beings, yet most designers are either unaware of the studies or do not find value in the results. Human health, productivity, comprehension, and overall happiness are all directly linked to appropriate levels of light and sound throughout the day. Variations of light and sound levels influence learning and retention rates, fatigue, stress, strain, confusion, frustration, morale, absenteeism, illness, privacy, and productivity (Madsen [11]). In fact, the Occupational Safety and Health Administration (OSHA) regulates levels of illumination necessary for various tasks (i.e., visual acuity, occupant safety, egress, etc.) and limits exposure to certain sound pressure levels and frequencies.

Direct sunlight can sometimes be counterproductive, so building design should admit the proper amount of sunlight, use it efficiently, and redirect it for balanced illumination and to avoid glare (Egan and Olgyay [12]). There is a vital difference between the direct light of sunlight and the diffuse light of daylight. Glare and overheating from the sun's direct rays is debilitating in areas where critical visual tasks are common (Loveland [13]). Most studies show natural light creating a positive atmosphere, but only when achieved with diffuse daylight. Studies have documented up to a 15 percent decrease in curriculum comprehension when direct sunlight is present in elementary classrooms [13]. There are also alarming statistics concerning acoustics and speech intelligibility. For example, according to a branch of the Acoustical Society of America (Technical Committee on Architectural Acoustics), the speech intelligibility in most U.S. classrooms is rated at 75 percent or even less (Seep [14]). This value represents how many spoken words a listener with normal hearing can typically understand during a lecture, discussion, or presentation.

As a professor of architecture, I have observed a difference in retention rates among students due to variations in lighting and acoustical environments. Design studio is a large part of all architecture program requirements, yet the environment in which students are expected to spend most of their waking and sleeping hours is probably not always ideal for focused attention and retention rates. Most architecture design studios do not incorporate lighting and acoustical considerations into the design of the learning environment. Design studios are typically large open volumes with concrete floors and planar wall surfaces without much natural light. Some design studios are open to adjacent rooms, which only exacerbates the poor acoustics. Students are then directed to present their projects in open corridors or other locations in which their focus is subject to other students and/or environmental noises. Lecture classrooms are usually not much better. Typically hidden in the core of a building, the rooms are without windows and are not designed for natural acoustics. It is astonishing that most classrooms have parallel planar walls as this arrangement produces flutter echoes leading to decreased speech intelligibility. Selective sound reflection and absorption, raked seating (since good sight lines also produce good sound lines), and natural light should be standard in lecture rooms to enhance student comprehension. If the room is designed for optimum use of daylight with acknowledgement of basic acoustical properties, the finished space will be more accommodating for the function and occupants.

5.1 Natural light

The Heschong Mahone Group, a prominent research entity, appears to confirm what some school designers have asserted based on anecdotal evidence: children learn better under illumination from skylights or windows, rather than from light bulbs. The main theory for explaining this observation is that "daylighting" enhances learning by boosting the eyesight, mood, and/or health of students and their teachers (Heschong Mahone Group [15]). Natural light makes a quantifiable difference.

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An important light study for a mercantile environment was conducted in 1993 by a big box retail store in which the retailer experimented with environmentally based design strategies. The initial daylighting scheme included a large glass arch at the front of the store and skylights over the entire sales floor. In a cost-saving move that resulted in a control group, the retailer decided to install skylights over only half the sales floor. To their surprise, sales per square foot were higher in departments in the day-lit side of the store, even higher than the same departments in other stores without skylights. Department managers whose departments were not under the skylights lobbied to have their departments relocated beneath them [15]. Simply stated, merchandise displayed under daylight attracted more sales.

Another informative study performed by the Heschong Mahone Group examined twenty thousand California, Colorado, and Massachusetts students between 1998 and 2002. Test scores increased as much as 26 percent among students who learned in classrooms filled with natural light [13]. Other statistics show that learning rates are on average 26 percent higher in reading and 20 percent higher in math in rooms with the most natural light.

A study from Alberta Canada, “A study into the effects of light on children of elementary school age,” concluded that natural light has a positive effect on children’s health. Children in classrooms with a natural spectrum of light had 1.75 fewer cavities than children in schools with traditional lighting. It also found that children exposed to high-pressure sodium vapor lighting were absent 3.2 days per year more than students in classrooms with full spectrum light (Hathaway *et al.* [16]). Psychologists and energy efficiency experts alike have long suspected that something as simple as sunshine may help people work more efficiently, learn more, call in sick less often, and sell more merchandise [15].

5.2 Natural acoustics

The Greeks and Romans studied acoustics and were successful with exploring shape and materials, but they did not express absorption and reflection in terms of mathematical equations in a manner that could be scientifically calculated. Since then, thousands, perhaps millions, of acoustical studies and experiments have been performed. The most influential study pertaining to mathematical calculations was performed by Wallace Sabine circa 1895. Mr Sabine, commonly known as the father of modern architectural acoustics, started his distinguished acoustical career studying the newly constructed Fogg Art Museum Lecture Hall at Harvard University that repeatedly produced over five seconds of reverberation. Typically, anything over one second of reverberation in a lecture hall reduces speech intelligibility. Students and faculty, without any acoustical training, instantly noticed the acoustics in the room were not conducive to understanding and learning presented information. As a young physicist, Sabine was appointed to research the room and conclude why such a long reverberation time existed.

Based upon lengthy experiments and research in the lecture hall, Mr Sabine developed the mathematical formulas for reverberation time and time delay gap along with the resultant acoustic behavior associated with building materials and surface contour shapes. He compiled data listing the absorption coefficient of various materials and material assemblies as direct contributors to reverberation time. Overall, his discoveries and innovations in the field of architectural acoustics are world renowned and the basis of modern acoustics.

6 Designing and making with natural light and acoustics

> I use light abundantly, as you may have suspected;
> Light for me is the fundamental basis of architecture.
> I compose with light (Le Corbusier [17]).

Heat gain, temperature differences, wind pressures, dew point values, and relative humidity are all factors that an architect needs to know for schematic design and wall assembly types. These factors must remain at the forefront throughout construction and will ultimately help determine location and attachment of window, translucent panel, sun screen, and light shelf systems that allow natural light into interior spaces and contribute to room acoustics.

Sunlight serves as the link to the outside world when we are indoors, facilitating our essential connection with nature and giving us a sense of time and position in that daily cycle [4]. In addition to their environmental benefits, natural ventilation, fresh air, and natural light contribute to a sense of well being, as does a view to the outside (Boyle [18]). Consequently, initial site selection and programmatic studies are crucial to the successful use of daylight in design. For a design to benefit the most from daylight, natural light must be an inherent design tool throughout the entire design process. The entire team of designers, including clients, occupants, architects, engineers, consultants, and specialists, needs to communicate constantly to ensure the benefits of natural light are not lost or value engineered out of the development.

Acoustical and lighting properties interrelate in various manners. Tectonically constructed overhead planes and soffits typically used as sun screens and light shelves to promote reflection, refraction, diffusion, and absorption of natural light also offer opportunities for the development of acoustical properties. The perceived height and volume of space are decreased as these elements span from exterior to interior. More intimate and directional acoustics result as direct impulses travel less distance and encounter multiple surfaces that promote acoustical reflection, diffusion, and/or absorption at selective frequencies. Upper and lower light shelf surfaces can be articulated and contoured to define visual and acoustical room ambiance per the design intent. The architect can sculpt the manner in which light and sound waves react with various surfaces. Color, tone, and shadow can be expressed for both lighting and acoustics. What was once understood as one large room is now altered by tectonic elements that create varied dimensions and interaction. The lighting and acoustical decisions delineate implied spatial relationships.

Lighting serves various pragmatic, functional, and aesthetic purposes and is necessary to visually comprehend space. The design profession typically defines space as the void contained by enclosure, which can allow and contain both natural light and natural acoustics. Architects can use natural light as a design tool to create levels of intimacy, transition, comfort, visual acuity, and acoustical properties by the selection of materials and how they are arranged. Spatial definition can be the result of predetermined horizontal and vertical layers of materials and air cavities that allow natural light to pass from exterior to interior during the day, that allow artificial light to pass from interior to exterior during the evening, and that create a tailored acoustical environment that facilitates auditory intelligibility and attenuates unwanted noises.

6.1 Acknowledgement of tangible examples

There are countless designs and built examples showcasing natural lighting and natural acoustics. A select few architects have combined studies of lighting and acoustics that serve as inspiration to further research and innovation in this particular field. To name a few, architects such as Le Corbusier, Alvar Aalto, Louis Kahn, Richard Meier, Tadao Ando, and Juha Leiviskä have designed buildings such as Notre Dame du Haut (commonly known as Ronchamp), Vuoksenniska Church, Kimbell Art Museum, Church Dio Padre Misericordioso (commonly known as Jubilee Church), Church of Light, and Myyrmäki Church, respectively, where the lighting and acoustical environments are inseparable. These are just a few examples in which occupants are intentionally introduced to natural lighting and natural acoustics as a particular characteristic of the experience. The architects' attention to building orientation, materials, and construction details allows the finest level of lighting and acoustical intricacies to exist. The key to experiencing great architecture is taking time to look and listen at various times of day.

Ronchamp by Le Corbusier is typically taught as a unique example of form and light in architectural curriculums. It is exemplified as an icon of form. Aside from the lighting environment created from the room volume and deep recesses in the exterior wall leading to various sizes and colors of glass, there is also a definitive acoustical quality to the space. The large volume, extensive use of concrete, wooden pews, and splayed apertures all contribute to a sound that is undeniably Ronchamp. Vuoksenniska Church is usually described in terms of acoustical characteristics, yet Alvar Aalto commonly studied natural light and natural acoustics in tandem. Admirers of Aalto's work find the materials and surface contours working together to promote sights and sounds that are unique to his designs. Regardless of the building type or occupancy group, architects can incorporate natural light and natural acoustics to define a particular experience for the occupant within the specific function of the building.

7 Summary

Why start with daylight? One benefit is that lighting a space with daylight can make people happier, healthier, and more productive. In addition, if you turn the electric lights off, you can also save a great deal of energy [13]. Another benefit is that the thoughtful incorporation of both natural light and natural acoustics as codependent design strategies can ultimately make space the most functional for

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the intended purpose. Overall, design methodology needs to be broader than material choices based solely on single component values. Designers should choose materials that will allow layers of transparency for borrowed light among adjacent spaces, alter wall and ceiling slopes to help direct the light more efficiently, and tectonically assemble building components that provide necessary reflection, refraction, diffusion, and absorption for both lighting and acoustical environments.

When focusing on natural lighting, designers must consider numerous factors including site location, building orientation, climatic conditions, proposed time of day usage, heat gain potential, UV degradation, and other concerns. As decisions are made for natural lighting, architects and designers can also assimilate acoustical parameters not only to reduce dependence upon artificial lighting and sound reinforcement systems, but also to enhance both the overall experience of being in that particular space and the health and welfare of the occupants. Shaping the space yields a specific result for the full benefit of both natural light and natural acoustics. Architecture that incorporates natural light and natural acoustics breaks from static environments and introduces changing conditions that will either elate or deflate occupant attitudes. Attention to detail is the key for the successful marriage between function and nature.

Although acoustics and lighting are traditionally considered as separate aspects of design, they are experientially interconnected. Both lighting and acoustical experts and architects have much to gain by considering acoustical and lighting qualities of spaces together. As the two natural elements are examined and employed for functional design, one begins to understand a sense of “hearing” daylight or the “sound” of natural light.

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Section 2
Illumination of architectural objects

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Computer visualizations of architectural building illumination

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Abstract

Computer visualization has recently become an integral tool used in lighting design. Computer visualization is also a form of communication between a lighting designer and people not related to the industry of lighting technology. Generally, lighting projects are implemented on the basis of computer visualization of illumination. This paper presents the significance of computer visualization and illumination. Benefits of designing lighting based on computer visualization are described. The article also contains, out of theoretical consideration, various eye-realistic visualizations of architectural buildings.
Keywords: lighting technology, illumination, computer visualization.

1 Introduction

The application of computer graphics can be seen in almost every area of life. Computer visualization in the field of lighting technology has recently become the inherent tool used in lighting design. Appropriate lighting equipment for a particular 3D model of illuminated object is selected. There are also many variants checked to obtain several most suitable illumination concepts. A lighting design, usually based on visualization, is completed with the use of lighting technology. The governing goal of photorealistic computer visualization is to present images generated by a computer to cause an impression of a real photograph. However, the main goal of illumination is to create an artificial image of the object by using light, to emphasize its attractiveness, draw attention to architectural details, embellish the surroundings and to ensure appropriate safety level.

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2 Objects illumination

The term “illumination” comes from the Latin word “illumino” which means ‘to light up”, “to adorn”. In recent years, the interest in illumination has increased. That is the effect of development in the area of lighting equipment but also the increase in social awareness of light, which plays a very important role with regard to safety and esthetics. As a result, illumination can be designed and realized in order to evoke emotional impressions, to shape mood or to ensure safety. Developing illumination concepts requires the assessment of:

- esthetic criteria which mainly determine the number of object observation directions, object location, historical significance of the object, façade characteristics,
- technical criteria related to the selection of appropriate lighting equipment and methods of arrangement and securing of luminaires,
- economic criteria related to the predicted costs of illumination investments,
- conservation criteria.

The illumination is realized using one of the three following methods [1]:

- flood lighting,
- spot lighting,
- mixed lighting, combining flood and spot lighting methods.

Until recently, flood lighting, a method which requires the use of small number of low-powered luminaires, has been used in the realization of architectural objects illumination. Due to the development in light sources, spot lighting, a method that requires the use of a large number of low-powered luminaires, is currently used more and more often. This method allows to realize illumination, which emphasizes with greater accuracy and accentuates architectural details of the object. The method also allows for a more comfortable use of the play of light and shadow [1, 4, 5].

3 Computer visualization

The computer visualization of illumination consists in realistic reconstruction of objects in computer virtual space. There are many programs to create 3D graphics and they can be divided into two groups: modelers and renderers. The latter ones are used to visualize illumination as they generate three-dimensional images and allow applying textures and light effects [4]. Such programs include, e.g.: 3D Studio Max, LightWave 3D, 3D VIZ. The visualization may be also made in technically advanced light design programs, such as Relux Professional and DIALux.

The article presents the process of creating the visualization of an illuminated object in 3ds Max program. The work on computer visualization starts with creating the building’s geometrical model, based on architectural plans or object photographs (figs. 1–3). Materials are applied to the existing grid to create the

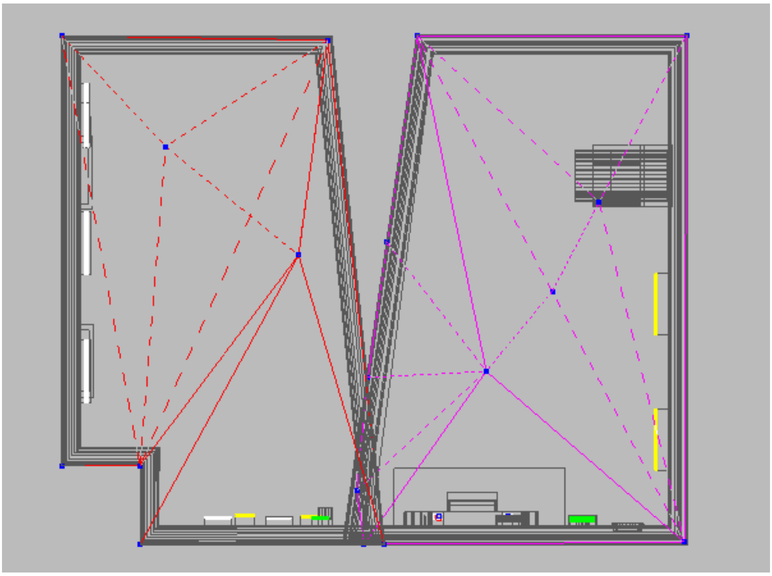


Figure 1: Model of object – top view.

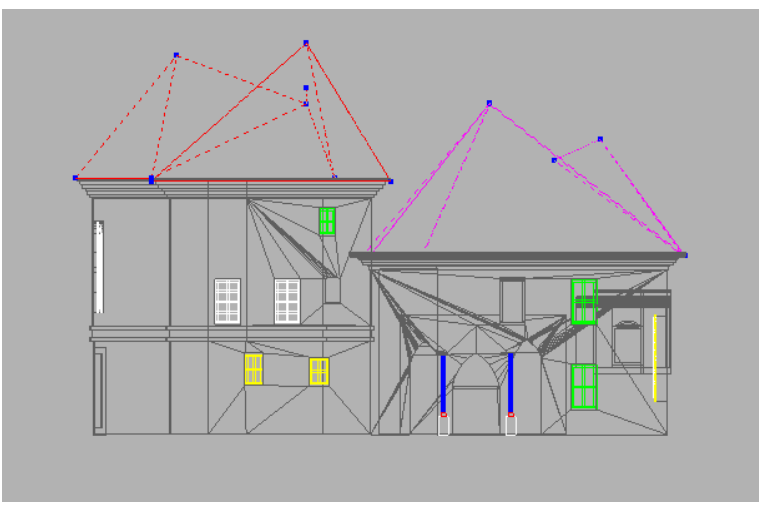


Figure 2: Model of object – front view.

building's texture (fig. 4). Computer visualization allows us to simulate the emission of light from a luminaire and the reflection or refraction of light from an illuminated surface.

Appropriate materials are selected and assigned to particular elements of a scene after the object model is designed and created.

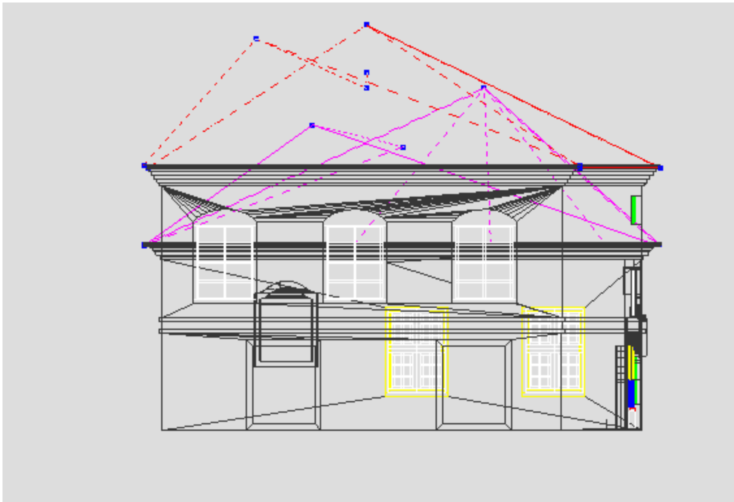
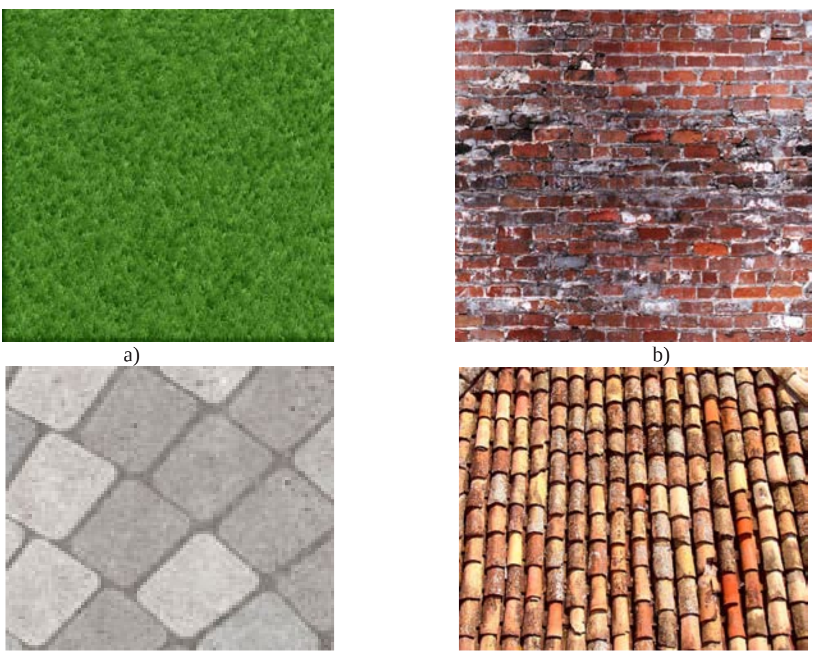


Figure 3: Model of object – left view.



a) b) c) d)

Figure 4: Materials used to create the scene and the object a) grass, b) brick used as the object's façade texture, c) set stone, d) roof tile.

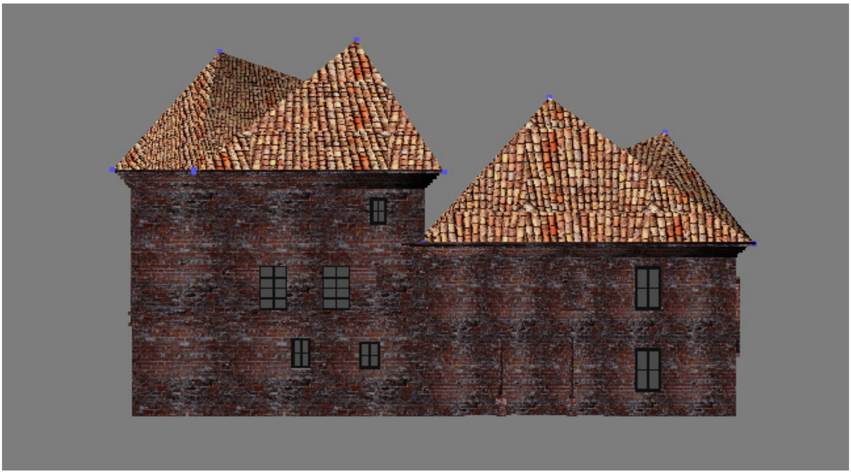


Figure 5: Model of object with assigned materials – front view.

Figure 6: Model of object with assigned materials – left view.

There are many advantages to designing illumination by means of computer visualization. The fundamental benefit is the possibility of analyzing and testing many variants of illumination taking into accounts the object's architectural style, its dimensions and historical outline. In visualization, it is possible to test any amount of light equipment and to locate it in places that are inaccessible in the field. Changes that may take place in the future (e.g. façade color change) may be also taken into consideration when creating the object's geometrical model. Thanks to visualization it is also possible to control and minimize the amount of unwanted light in the environment, as well as to compare the way an object looks during the day and at night. When designing illumination with computer visualization, one may create any scene that illustrates the object's surroundings or accurately place a modeled object on a photograph in which adjacent buildings, sky, street, lamp posts, trees have really been photographed [1–3].

Graphic programs not only create photorealistic images of illuminated objects but also offer other advantages. It is possible to enter data, such as photometric solid of real luminaires, maximum luminous intensity, luminous flux, types of light sources and color temperature.

Computer visualization of illuminated objects requires from the designer both good knowledge of lighting technology, of computer graphics and the ability to model objects. This method of illumination concept presentation is particularly important for architectural illumination because it allows to predict virtually all light effects and to verify the amount and type of essential equipment.

4 Illumination concepts

Appropriate illumination equipment should be selected to achieve decorative illumination of an object. Several object illumination concepts may be analyzed during the realization of a project, and finally the best solution in terms of esthetics and economy may be chosen. Thanks to computer programs, it is possible to see the obtained effects of visualization from every direction and perspective, which is particularly important when designing illumination.

Object computer visualizations that depict three illumination concepts are presented in the article. The first variant was created with the use of sodium light

Figure 7: Computer visualization of illumination with the use of sodium light sources – perspective view.

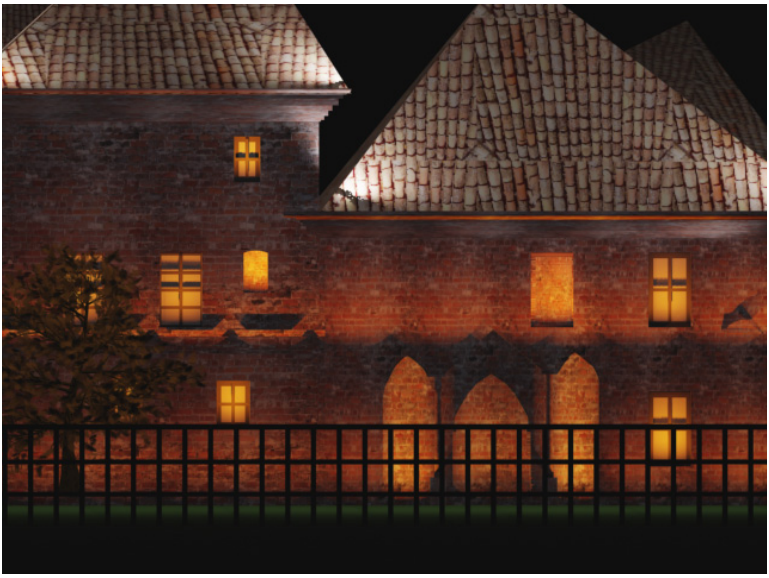


Figure 8: Computer visualization of illumination with the use of sodium light sources – front view.

Figure 9: Computer visualization of illumination with the use of metal halide lamps – front view.

sources that intensified the “warm” impression of the building’s brick facade. At the same time, the roof is illuminated with metal halide lamps (figs. 7 and 8).

Figure 10: Computer visualization of illumination with the use of metal halide lamps – perspective view.

Figure 11: Computer visualization of an object illuminated with metal halide lamps and sodium lamps – perspective view.

The second illumination concept presented in the form of computer visualization is based on the illumination of an object with metal halide lamps that cause the effect of whitening of the façade. The roof is also illuminated with metal halide lamps (figs. 9 and 10).

The third variant of object illumination assumes the use of sodium lamps and metal halide lamps. Various light colors for building illumination make the final image of object illumination definitely more attractive. In this case, object elevation is illuminated with metal halide lamps, whereas details in the form of alcoves are illuminated with sodium lamps (fig. 11).

The following figures present the simulation of the object's daily illumination. The surroundings of the building are enriched with grass, sett stone,

Figure 12: Photograph of the sky used in the background of object visualization.

Figure 13: Simulation of daily illumination – perspective view.

Figure 14: Simulation of daily illumination – perspective view.

trees, while the sky in the background has been pasted from a photograph (figs. 12 and 13).

5 Conclusions

Thanks to computer programs, it is possible to create many variants of visualization that present various illumination concepts. Computer visualization of objects illumination shows the image of the illuminated object. It also presents a building with all details and the play of light and shadow. All this allows to choose the most favorable and desirable version in final stage. Appropriate lighting equipment has to be selected to realize the visualization of decorative illumination. Each simulation of illumination is possible thanks to specific light beams and input data of the used equipment. At present, there are many manufacturers of luminaires and sources of light and this creates a lot of possibilities for selecting appropriate illumination equipment.

Computer visualization enables the assessment of the final esthetic effect of every version of illumination. The number of luminaires and the type of light sources can be verified. The final assessment of visual effect is always subjective; it is a matter of individual taste of the appraising person.

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Some aspects of architectural lighting of historical buildings

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Abstract

The aim of night illumination is to recall the whole object image, as it is in the daylight city panorama. In building illumination we reach for solutions which are suitable for object function and architecture. Illumination with light cast from different directions is to expose details of the object's architecture by play of light and shadow on facades and details of the building. Architectural lighting is also often used inside. Architectural interior lighting uses a number of formal solutions, in which light is emitted from behind the edges screening the luminaires. This kind of solution gives indirect illumination of ceilings or walls and light sources are invisible.

This article discusses the role, tasks of illuminating, and architectural lighting and presents lighting effects obtained for design implementation, where the architecture and indoor arrangement or the building's façade architecture were linked with architectural lighting.
Keywords: lighting engineering, architectural lighting.

1 Introduction

The modern lighting techniques, applied for creating the monuments nocturnal appearance, should include aspects concerning the architecture as well as symbolic meaning of the illuminated facilities or buildings. The realization of these principles is connected with the experience and imagination of the designer as well as with the technical possibilities, i.e. mainly with the parameters of applied light sources and luminaires.

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2 Indoor illumination

The illumination is particularly important in the interiors of the commonly accessible historical facilities or buildings, particularly when they become the location for various cultural, artistic and special events. In the mentioned interiors the lighting, apart from its usable functions, is also used for illumination functions, when by the illumination there are considered actions with use of the lighting for the purpose of creating atmosphere, exhibiting with use of the light elements and details of the architecture and creating in the interior space the specific sight guide leading through its more important elements. It is necessary to look for such solutions that could bring the required lighting effect without disturbing too much these interiors' character [1, 2].

The proper lighting inside interiors of the historical buildings or facilities, should meet requirements put by the usable function, physiology of seeing process and need of the appropriate exhibiting the symbolic, historical and esthetic values of illuminated interiors.

The particular challenge for the lighting realization, are the interiors of the sacral facilities or buildings. In the sacral space, there are taking place the direct interactions between symbols, liturgy and architecture and for that reason every design of the lighting should take into consideration these church elements. The light in the church has got a significant influence on the church functioning, its perception by the participants and visitors. The artificial lighting should imitate, if possible, the natural lighting. It should also help the participants in concentrating their attention on the liturgical ceremony actions and even possibly underline them. It is necessary to remember that the lighting should help with perception and not disturb.

During performing the liturgical ceremony, the vertical illuminance should be dominating for the purpose of concentrating the attention of the participants on the ceremony course. The lighting should be installed in such a way to create a kind of the light hierarchy where the altar becomes the most important.

The light should provide comfort to the participants as well as the possibility to admire the architecture and decorative interior of the church. The lighting system should also be designed to include conditions influencing the operation and function of the church.

Until now, inside the sacral facilities interiors, there have been used mainly the chandeliers and wall luminaires with standard incandescent light sources. Such lighting has been very often insufficient and provided limited possibilities to adopt the light quantity to needs.

However, sill more often there are applied the modern lighting systems. Within these systems, there are used new energy-saving and durable light sources as well as the appropriate luminaires. The historical chandeliers or wall luminaires can become the decorative elements only for the purpose of underlying the interior character.

The need of creating the atmosphere of concentration or self-communion with distributing at the same time the lighting accents appropriately to the needs of the liturgical ceremony and occasional events (such as wedding ceremonies), causes

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that the good solution consists in applying a number of luminaires having the appropriate technical and photometric parameters. These luminaires should be installed in the way that possibly harmonize with the architecture of the church interior or with the architecture of the fragment of the interior, without disturbing the interior esthetic of such specific facilities or buildings.

Obtaining the appropriate lighting effects without exhibiting luminaires is possible with use of the light sources characterized by high lighting efficiency with relatively small dimensions.

In order to illuminate the chancel and the altar for liturgical purposes, projectors with metal halide sources with the intensity of 20 to 150W giving warm light might be very useful. To illuminate the architectural details, sculptures, polychromy etc. low-voltage halogen sources with the power of 20 to 100W are often used, with properly distributed luminous intensity. Ceilings, cornices, niches, etc. architectural details may be displayed using linear sources of light, i.e. by various types of fluorescent or LED lamps. Big advantage of such sources of light is their diversity, durability and high luminous efficiency as well as the possibility to adjust the luminous flux.

An example of such realization is the lighting system applied in the church of Virgin Mary Sorrowful in Poznań – fig. 1.

Figure 1: Interior of the church of Virgin Mary Sorrowful.

In the lighting system of this interior, there have been used the traditional solutions – i.e. hanging lamps with applied modern fluorescent lamps as well as flood-lights fitted in the ceiling and located over cornices the specially fabricated luminaires equipped with the compact fluorescent lamps and spot halogen lamps.

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3 Illumination of the historical buildings

The monumental buildings illumination is a particular task. The facilities or buildings outline viewed in a daily light is less distinct, even in case of facilities or buildings of rich architecture, because the daily light produces flood lighting that in practice illuminates elevations in the uniform way.

The nocturnal illumination with use of the light arriving from different directions, allows completely different configuration of the building body and elevation elements, i.e. windows, portals, columns, attics, towers, domes, etc. The illumination is an occasion to create with use of the light the requested atmosphere and produce or create with use of the light the symbolic meaning of the facility or building. The atmosphere can be formed by the lighting dynamics and light color.

The lighting dynamics can express itself in the illuminance diversification on the elevation elements and in creating lighting plans. It can be achieved by repeating the light spots and shadows adopted to the rhythm of the elevation architectonic elements. Operating the light plans gives the illumination lighting depth through showing for example outlines of finials on the background of the walls illuminated in the further plan.

The light color in the illumination co-create the atmosphere together with the light dynamics. The light color should harmonize with the elevation coloring or color of the facing material used to cover architectonical elements.

The illumination becomes also the factor that informs about meaning and significance of the illuminated facility or building. The view of non illuminated facilities of buildings very often becomes the cause of memorizing the negative impression. This impression results also when the elevation luminance of the illuminated facility or building is too low when comparing with the high luminance of the street lighting. Therefore it is so important to analyze the facility or building surrounding.

The elaboration of the illumination project is connected with the necessity of evaluating a number of conditions which influence the finally accepted technical solutions.

Generally speaking, such issue includes the evaluation of:

- esthetical and emotional aspects,
- technical and economic aspects.

The esthetical and emotional criteria are mainly related with the analysis of site prospective of the facilities or buildings, their historical value and importance, architecture attractiveness, etc.

The technical and economic criteria are related with the choice of the appropriate light sources and luminaires, location and assembling, power and control system.

Over a half of monuments in Poland are sacral facilities or buildings. Their role and importance in the history caused that churches and monasteries became the real treasury of the most valuable art pieces and monuments of the material culture history and moreover the architecture and interior decorations became the regional history record of the regional society and the nation as a whole. There are many cities where the church is the only monumental building. The importance of this fact results in the installed illuminations.

The modern lighting techniques, utilized to create the nocturnal appearance of the monuments and monumental buildings, should include aspects related with the architecture as well as with symbolic representation of the illuminated facilities or buildings.

The realization of these principles is strictly conditioned by the technical possibilities, i.e. the implemented illumination method and parameters of the applied light sources and luminaires.

In the illumination designing practice, there is applied the flood-lighting method and spot-lighting method or both of them mixed together at the same time. Each of the methods is creating different conditions for the realization.

Until not long ago, the most of the facilities or buildings has been illuminated with use of the flood-lighting method by using for this purpose a small number of the high power luminaires. This method has been found appropriate for illuminating the facilities or building of huge dimensions, viewed form a large distance. The example of such illumination is the illumination of the Cathedral in Gniezno (Poland).

The Gniezno Archicathedral Basilica is a sacred building of historic importance and a monument of national culture. Its history is closely connected with the birth of the Polish state and Christianity. It was created as a Roman structure, then it was rebuilt in Gothic style, which is displayed in many details of the Cathedral architecture. Baroque also influenced the shape and particularly the decoration of the Cathedral chapels.

The Gniezno Cathedral is a high structure situated on a natural elevation – Lech Hill, which makes the towers and the roof of the nave visible from different directions and from quite a long distance. The characteristic Cathedral towers silhouetted against the view of Gniezno remind us of the values which this church fosters.

The Cathedral illumination project was developed after making an analysis of visibility of particular facades. It appeared that the front facade and both side facades are seen mainly from a greater distance. Whereas the facades of the presbytery apse are seen in the frame of the street leading from the Cathedral to the Gniezno Market.

This had a crucial impact on the illumination method chosen, because from a greater distance the structure is perceived mostly as a set of solids – the towers, nave and aisles. At close range watchers are impressed by architectural details – figures, bas-reliefs, stained-glass windows, etc. The desired illumination effect has been attained by selecting appropriate levels of illumination of particular parts of the Cathedral, as well as by diversifying light color. In general about 40 projectors with a total power of 15kW have been used. Flood-lights with halogen, sodium and metal-halide sources with daylight, white and warm light color have been used.

It should be stressed that the electrical system has been designed to enable both cost-effective illumination and the desired visual effect.

The illuminated Cathedral from the main vista side is seen in fig. 2.

Figure 2: Illumination of Cathedral in Gniezno.

The external illumination project has been accompanied by a change in the internal lighting. The existing candelabrums with incandescent lamps have been replaced with fittings with discharge light sources (white soda and metal-halide) – fig. 3.

Figure 3: Interior of the Cathedral.

For the facilities or buildings of small dimensions and limited site-seeing or viewing prospective, the artistic effect of the realized in such a way illumination not always meets expectations, in particular when referring to the facilities or buildings viewed form a short distance.

Within the last years, the spot-lighting method of the illumination becomes more frequently applied, with use of a bigger number of the low power luminaires. This type of the illumination allows more sufficiently underlying the significant architecture details and moreover allows concentrating the viewers' attention on details which very often skip the attention in the daylight.

The small dimension light sources give the possibility of obtaining in the luminaires good optical conditions and allow assembling the luminaires directly on the buildings elevations. This method of the illumination realization provides more flexibility in operating the light and shadow proportions.

An example of such realization is the illumination of the Collegium Maius in Poznań – fig. 4.

Figure 4: Illumination of the front side of Collegium Maius.

The photographs show some examples of illumination effect of front side and of individual fragments of the Collegium Maius building. The light that tangently illuminates the façades and their architectural details emphasized the color and the texture of the stone and the abundance of decorative forms. This way, the authentic character of the building has been featured. The lighting effects achieved will make a new, attractive image of the University Building.

The illumination of the Collegium Maius needed in total 122 luminaires with the capacity from 35 W to 150W.

Applying the spot-lighting method in the illumination with using the luminaires assembled on the building elevation, has got certain limitations. Very often the historians of art and conservators of monuments are against this type of the illumination. In their opinion, illuminating the architectonic details from below creates strong shadows above horizontal details – which is opposite to the natural structure of shadows and excessively exhibits the vertical system of the elevation.

So, there results a problem to be solved: how to illuminate the facility or building viewed form a short distance prospective and at the same time reconcile the need of creating the attractive appearance with conservation limits concerning the way of illuminating the architectonical details as well as the method and location of the luminaires assembling.

Distribution of the photosensitive elements of the human eye retina is the reason that the reception of the surrounding us reality relies upon synthesis of the detailed impressions originated from the small, central field of view and upon general impressions originated from the wider peripheral field of view.

Within the vision process of the nature, we watch it not in a continuous and uniform way in every point but by leaps with individual looks which are attracted by interesting details. These places are directed the biggest numbers of looks.

When utilizing this feature of the vision process, it is possible to construct the attractive nocturnal appearance of the illuminated facility or building by the appropriate distribution of the lighting accents on the elevation and creating the specific illumination guide for the vision of the viewer.

The realization of the illumination lighting with utilizing the principle of creating the nocturnal appearance of the facility or building by positioning on its surface the light spots of different luminance represents the compromise between too monotonous flood-lighting and spot-lighting creating diversified and very often too theatrical appearance of the illuminated facility or building.

This way of illuminating simplifies adopting to the conservation requirements and limits and at the same time allows maintaining the possibility of obtaining the required esthetical and emotional effect. For obtaining this purpose it is convenient to apply:

- diversified light sources having relatively small power,
- luminaires of the appropriately selected and directed light distribution.

This way of the realization of the illumination does not require assembling the luminaires on the facility or building. The example of such illumination is the illumination of the church of St. Joseph and Bernardine church in Poznań.

The St. Joseph church, located on St. Wojciech Hill, is the example of the early baroque architecture. The decorative front elevation is characterized by a certain rhythm of pilasters divided by recesses. The system of cornices divides the elevation into three levels. The church is surrounded by high trees and so it is very well visible mainly from the front.

For the illumination lighting of the church front, there have been used the luminaires equipped with the sodium light sources “white soda” type 100W power, assembled in the ground as well as on the ground – fig. 5. The obtained illumination result has been presented on fig. 6.

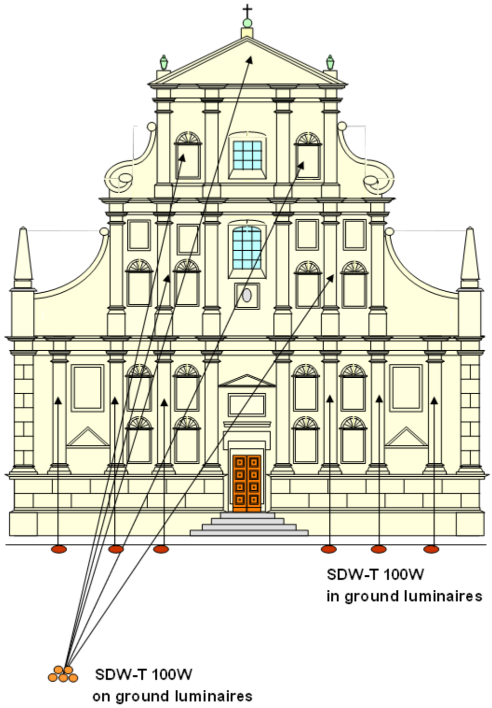

Figure 5: Front elevation of St. Joseph church– the position of luminaires.

Figure 6: Front elevation of St. Joseph church – daily and nocturnal view.

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The church of St. Francisco from Assisi (or Bernardine church) is the example of the baroque architecture. The front elevation is characterized by the rhythm of pilasters divided by recesses. The system of cornices divides the elevation into three levels. The elevations are covered with plaster. Roofs and helmets of high towers are covered with the copper glazed sheet.

The church and in particular its towers are well visible from the more distant prospective. From the shorter prospective of Bernardine Square only the front elevation is visible.

For the illumination lighting of the church front and towers, there have been applied the luminaires equipped with the metal halogen light sources of power from 35 up to 150W, assembled on the existing street lighting pillars. The obtained illumination result has been presented on fig. 7.

Figure 7: Front elevation of St. Francisco church – daily and nocturnal view.

4 Conclusions

The usable lighting is insufficient for creating the appropriate atmosphere and exhibiting the interior decorative elements as well as architecture of the buildings. And it is why there is a need of applying additional, individually designed lighting systems which become the important and valuable element for creating the attractive appearance of the facilities and buildings during the night.

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Section 3
Outdoor lighting

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Digital billboards and road safety

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Abstract

Electroluminescent diodes have become increasingly popular on outdoor billboards for the last few years, all over the world. Digital billboards with electroluminescent diodes are large, have high luminance and display dynamically changing images. Billboards located near streets are a potential threat to traffic safety. The paper presents requirements for such billboards, the results and analysis of measurements of selected billboards located in Poznań, Poland, as well as conclusions and recommendations for large size billboards with light emitting diodes located in the vicinity of roads and intersections.
Keywords: light engineering, digital billboards, road safety.

1 Introduction

With the development of the technology of light emitting diodes (LED), large size billboards with electroluminescent diodes have come to our towns. These billboards are usually large, have high luminance and show dynamically changing images. Car, bus and rail vehicle drivers complain that glaring billboards located in their field of vision are uncomfortable to look at and interfere with normal driving tasks, especially in the evening and at night. Billboards located near streets are a potential threat to traffic safety.

The current Polish standards on outdoor lighting and road lighting specify no explicit requirements for this type of billboards. The currently valid requirements specify maximum luminance and luminous intensity values of signs, including billboards emitting light (or illuminated ones). However, the location of the billboard towards the observer, its angular diameter, distance from the main

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direction of observation and dynamic change of luminance related to displayed images (fig. 1) are not taken into account.

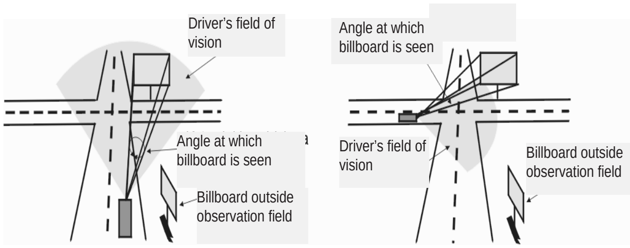

Figure 1: Location of the billboard in relation to the driver's observation direction.

Legal regulations applicable in other countries are far from coherent: from complete prohibition of use across the entire country (Spain), through country specific (Holland, South Africa, Brazil) or local partial restrictions on selected parameters in force in specific states (Queensland, Victoria, New South Wales in Australia, New York, Virginia in USA), through specific cities (San Antonio, Oakdale in USA) and through no legal regulations whatsoever (numerous countries in Asia and Middle East).

The following are examples of requirements applying to such billboards, accepted by local self-governments, states and government bodies in countries which have already acknowledged the problem of outdoor billboards. Also, results of measurements of photometric and geometric parameters of selected billboards located in Poznań, Poland, have been presented, and recommendations for the operation of large size billboards with light emitting diodes have been formulated.

2 Current legal situation in Poland

The Polish lighting standards related to the lighting of work places located outdoors [1] and road lighting [2] do not specify requirements for large size billboards with light emitting diodes as objects impacting road traffic safety. The standard [1] consists of requirements on the limitation of interfering lighting, but they only address the reduction of inconvenience for people, animals and plants. The stipulations of the standard fail to address requirements related to driving (drivers of vehicles present in the road). Only maximum luminance and luminous intensity values of signs, including billboards emitting light (or illuminated ones) are specified. Unfortunately, the location of the billboard towards the observer, its angular diameter, distance from the main direction of observation and dynamic change of luminance (brightness) related to displayed images are not taken into account.

The Polish standard's [2] requirements related to glare limitation only apply to situations where small size light sources (luminaires) are present in the road. The evaluation of glare is carried out on the basis of the increase of the threshold value (TI). Consequently, such requirements may not be used when evaluating glare caused by large size billboards with light emitting diodes.

The currently valid ordinance of the Polish Ministry of Infrastructure [3] (point 79 applying to Art. 293 Para. 6) provides requirements for lighting devices, including billboards located outdoors or in the vicinity of buildings that may be inconvenient for pedestrians and drivers. Still, these requirements are not accurate and are no grounds to evaluate the level of inconvenience caused by billboards, especially for drivers. The ordinance specifies requirements on the illuminance of white light (5 lx) and color light (3 lx), but there is no description of the method of carrying out measurements in relation to both the location and external factors (impact of lighting in the road installation). Although the ordinance talks about drivers, these requirements seem to be applicable only to lighting causing inconvenience to residents.

3 Review of requirements applicable to large size billboard with light emitting diodes

Numerous countries carry out research on the impact of roadside billboards on reduced concentration of drivers. To a large extent, the research applies to traditional advertisement media, but there are in fact several papers on electronic advertisement [7]. Generally speaking, the results of all research projects indicate that billboards distract drivers. Several countries have implemented guidelines for issuing permits for installation of roadside billboards on the basis of results of such research projects, carried out mostly at the request of governmental bodies or road authorities. The following are the most important ones.

3.1 Displaying moving images

The issue of displaying moving images is well covered by world literature [5, 9, 11]. Displaying moving images (animation, video) is explicitly forbidden. Electronic billboards may only display still images.

3.2 Minimum billboard display time

This issue raises disputes between billboard owners and road traffic safety specialists. A billboard owners' agenda is to present as many adverts in a given time unit as possible, provided the display time is long enough for the advert to be read and comprehended. There is no information on research projects aiming at evaluation of the impact of operation of billboards on distracting drivers. Different sources quote different times, but the data is not substantiated with empirical research. OAAA, Outdoor Advertising Association of America, an association of manufacturers of advertising media quotes a time of four seconds [9]. FHWA, the Federal Highway Administration operating in United States recommends a time of eight seconds [5]. Recommendations implemented in 41 states in North America specify a time from four to ten seconds [5]. The necessity to specify the minimum time of displaying adverts comes as a consequence of the so-called Zeigarnik effect occurring in case of sequentially appearing advertising messages, provoking the observer to observe the remaining part of the message, leading to a much worse concentration of the driver. This is to be prevented by a requirement saying that the observer (driver) is not supposed to observe changing images in the billboard, but rather is supposed to see the same still advert in the device [13]. The minimal time t of displaying an advert should therefore be connected with the distance d at which the advert is being observed and the speed limit v introduced for the road in the vicinity of which the billboard is located. The analyzed literature suggests the following recommendation is applied (1):

$$t = \frac{d}{v} \tag{1}$$

where: t – minimum advert display time [s], d – distance from the billboard [m], v – speed limit [m/s].

3.3 Visual effects and interval between consecutive images

Generally, all available publications unanimously claim that there should be no delay between the changing images of consecutive adverts. Also, no visual effects should be used between the changing images. Images must not be dimmed, brightened, overlapping and animated [5].

3.4 Amount of displayed information

The longer the time the driver is forced to read an advert, the higher the threat to traffic safety. Research has proven [4] that drivers start reading advertising texts located at a distance of 250 m if the letters of the text are 45 cm high. Reading speed is assumed at one word per second, which gives a maximum number of 8 words at the speed of 90 km/h, 7 words at 100 km/h and 6 words at 115 km/h. The number of words should be lower in unfavorable conditions (lower letters, reduced contrast). No specific recommendations have been specified with this regard. Still, it is known that the amount of information in the billboard should depend on the speed limit in the area and the distance to the billboard. Billboards should also not display website addresses, phone numbers and text message details.

3.5 Brightness, luminance and illuminance

Brightness is subjective, hence cannot be objectively measured. Electronic billboards seem less bright during the day than at night. Billboards seen at night, in city centers, seem less bright than the same billboards observed in dark, unoccupied surroundings. Electronic billboards made from electroluminescent diodes are original sources emitting light by themselves, hence luminance should be used to describe their properties.

Generally, there is no need to limit the luminance of billboards during the day, but there is no doubt such limits should be imposed for billboards at night. The so-called moth effect, described as unintentional directing of one's eyesight to the brightest objects in the field of view. Consequently, the brighter the surface of the billboard, the higher the danger it poses with regard to distracting the driver and leading their eyesight off the road [14].

The luminance of billboard surfaces may not be specified explicitly, as brightness (a subjective sensation) depends on the area of the billboard and the luminance of the surroundings. In general, all literature sources specify the billboard's luminance as the only value affecting the billboard's brightness. Only OAAA, Outdoor Advertising Association of America, an association of manufacturers of advertising media, specifies requirements for illuminance [11, 12].

A document titled "Technical Memorandum: Evaluation of Billboard Sign Luminances" was drawn up in 2008 by the Lighting Research Center, Rensselaer Polytechnic Institute at the request of the New York State Department of Transportation. The memorandum describes three stages of research: a review of recommendations for luminance calculation (on the basis of the paper by IESNA), measurements of luminance of existing billboards and a computer simulation of an electronic billboard. According to IESNA recommendations, the illuminance in the surface of an electronic billboard should be 1000 lx for bright surroundings, and 500 lx for dark surroundings. Assuming that the billboard surface coefficient of reflection of the light stream is 0.8, this corresponds to luminance of 250 cd/m^2 and 130 cd/m^2. The paper's authors confirm that these assumptions are followed by billboard manufacturers. The authors have also measured existing billboards: six backlit billboards and four electronic billboards. The memorandum authors' own research led them to a conclusion that the luminance of a backlit billboard should not exceed 280 cd/sq m at night.

A document [15] listing requirements for roadside billboards has been developed at the request of the Traffic Engineering and Road Safety section of the Queensland (Australia) Government's Department of Main Roads. The document's characteristic features are several definitions. For example, roadside billboards are divided into four categories depending on their size and placement in relation to the road. Attachment D discusses the billboards' brightness, and quotes a paper [16] on backlit billboards. The paper claims that "the brightness of backlit roadside billboards should be limited under any conditions". The authors emphasize the difference between the concepts of brightness and luminance. Luminance is used for assessing the properties of a billboard as a device for displaying images. Luminance may be different in the billboard's surface (luminance distribution) and depending on the angle of observation. The highest luminance occurs when observing the billboard from straight ahead and is reduced as the angle of observation increases. Brightness is a subjective visual sensation, whose intensity depends on the luminance of the billboard's surface (luminance distribution), the size of the billboard, the contrast (in relation to background luminance), the observer's position and the observer's adaptation. The document presents the maximum permissible, average luminance of the billboard's surface for three areas (tab. 1).

The reduction of the billboard's surface luminance is not required at night only, but also in certain situations during the day. In case of a fog, bright billboard surfaces may hamper the drivers' vision. To ensure luminance is

Table 1: Permissible luminance values of billboards' surfaces according to [15].

Area number	Description	Permissible luminance value
1	Area with high level of lighting, not caused by road lighting system, e.g. city centers.	500 cd/m^2
2	Area with average level of lighting, not caused by road lighting system, e.g. suburban industrial areas, filling stations, parking lots.	350 cd/m^2
3	Area with low level of lighting, not caused by road lighting system, e.g. rural areas, residential areas.	300 cd/m^2

reduced during fog, it may not be enough to equip billboards with photodetection devices reducing their luminance at night. Other dedicated requirements for such situations may have to be implemented.

3.5.1 Permits

Authorities issuing permits should be able to analyze annually the impact of electronic billboards on road traffic safety in a given location. Also, the billboard's properties may alter when its elements or software are changed. Ultimately, new requirements may be accepted (on the basis of newly conducted research), which may lead to the change of, e.g. billboards' luminances. It is recommended [5] to follow the method used by Oakdale, Minnesota, authorities [10]. The billboard's investor (owner, operator) obtains a one-year permit to operate the billboard and is required to renew it annually.

4 Research of large size billboards with light emitting diodes in Poznań

In the summer of 2010, over thirty large size billboards with light emitting diodes have been located in the administrative territory of the town of Poznań.

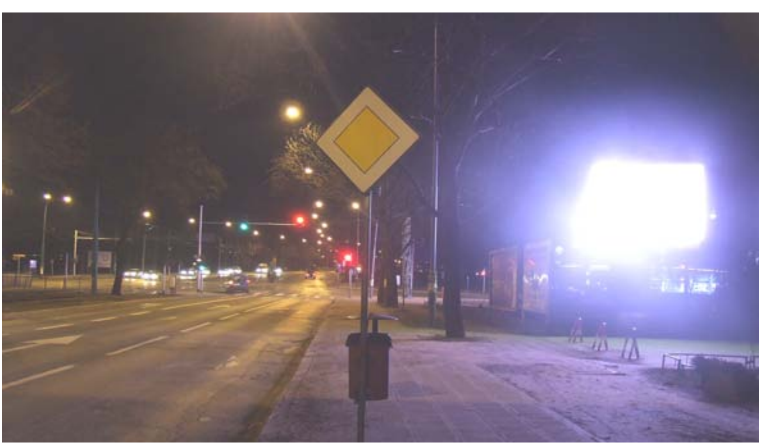

Figure 2: View of a very bright billboard at night.

These billboards are usually large, very bright and show dynamically changing images whose brightness varies greatly (videos, animated images), especially at night. Figure 2 shows an example of a very bright billboard with light emitting diodes.

Billboards with light emitting diodes are usually installed in places where the daily traffic is very high (city centers, high streets, intersections, roundabouts - see fig. 4), and thus significantly impact the drivers' vision conditions, leading to reduced concentration and even glare. Thus, they are a potential threat to road traffic safety. Figure 3 shows an example of location of a billboard near an intersection.

Figure 3: A billboard located in a place where daily traffic is high (as seen during the day and at night).

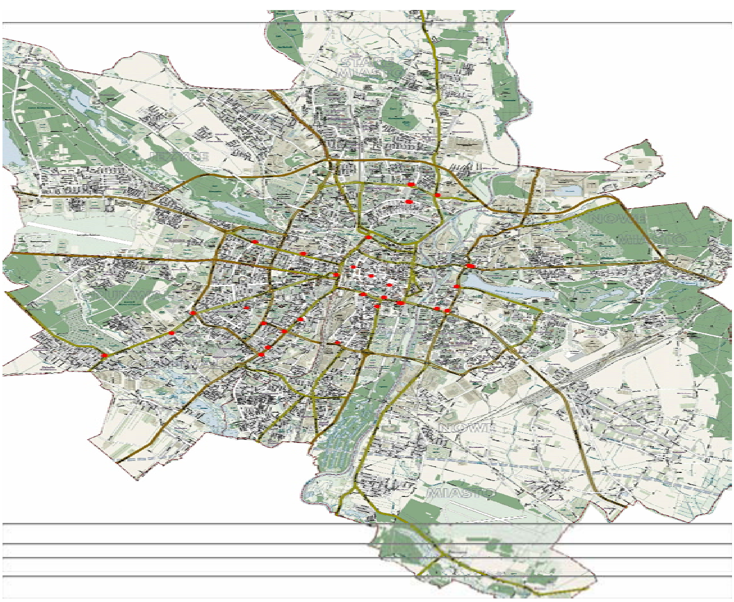

Figure 4: Location of large size billboards with light emitting diodes in Poznań, Poland. Status as of August 2010.

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Figure 4 shows approximate location of billboards in Poznań. Measurements of properties of large size billboards with light emitting diodes have been carried out for 18 billboards located in Poznań. The measurements have been carried out after sunset, as billboards impact drivers' vision the most at night. All examined billboards have been located in the drivers' fields of view, 1.5 m to 13 m above ground. All billboards were large and showed dynamically changing images, except for a single billboard showing still images. The surface of the largest billboard was approximately 30 m^2, and approximately 5 m^2 for the smallest one. Table 2 shows the highest and lowest values of the measured geometric parameters and average values for all billboards.

Table 2: Highest and lowest values of the measured geometric parameters and average values for examined billboards.

Billboard's geometric parameter	Average value for all billboards	Highest of measured values	Lowest of measured values
height [m]	3.1	4.8	1.2
width [m]	4.9	6.3	2.9
surface [m^2]	15.2	30.1	5.4

A site plan showing the location of the measurement point, main observation directions and the location of the billboard in relation to the road has been drawn up during the measurements. The main directions of observation of the surface of the billboard were selected following the analysis of the location of the billboard in relation to the layout of the street and the traffic system (one-way streets, no turn or turn only signs). The location of measurement points was based on the assumed division of angles, for which the billboard's luminance was measured and possibilities of taking practical measurements were assessed. Figure 5 shows examples of site plans of two measurement points.

The measurement of photometric parameters included the measurement of the luminance of the billboard's central point, the luminance of the surface of the road as the adaptive surface for road users and the luminance of the billboard's background. The luminance of the billboard's central point was measured in plane perpendicular to the surface of the billboard's measurement point. The billboard's maximum and minimum luminance in this point was measured. The change of luminance in the billboard's central point depending on four different angles of observation in relation to the plane perpendicular to the surface of the billboard was measured. The road surface average luminance was measured for the lane of traffic moving towards the billboard. The billboard's background luminance was measured for surfaces located in its closest vicinity and for the horizon in the back of the observed billboard.

Table 3 presents the summary of luminance measurements, and a selected distribution of luminance in the billboard's surroundings is shown in fig. 6.

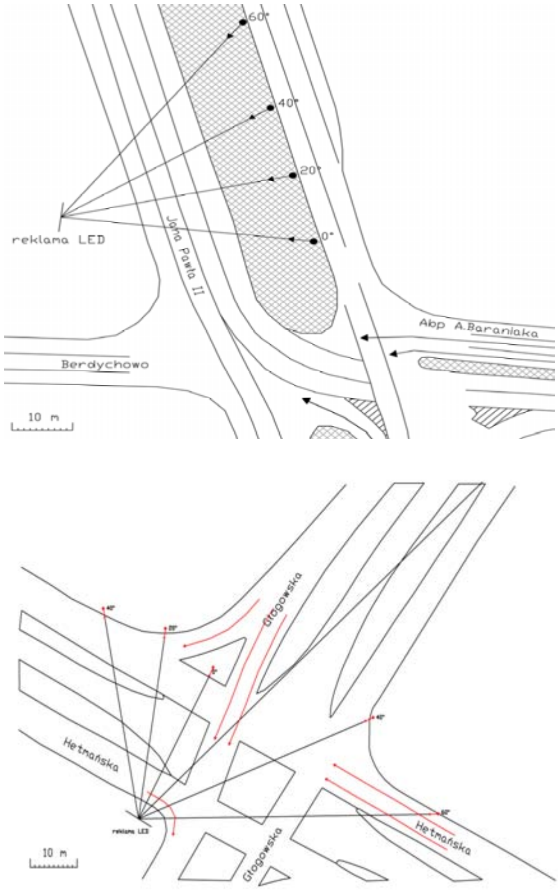

Figure 5: Street layout indicating the examined billboard and locations of measurement points for angles 0°, 20°, 40°, 60° and main directions (marked with arrows in traffic lanes).

Table 3: List of measured luminance values.

Luminance [cd/m^2]	Average value for all billboards	Highest of measured values	Lowest of measured values
maximum for billboard's central point	1983	7953	377
billboard surroundings	9.3	108	0.9
horizon	1.8	6.5	0.2
road surface	3.1	4.6	1.1

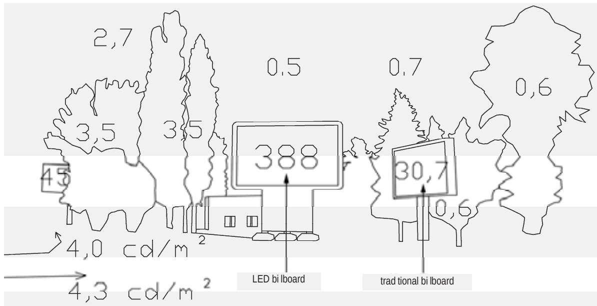

Figure 6: Selected distribution of luminance (cd/m^2) in the vicinity of a billboard with light emitting diodes.

The change of luminance of billboards depending on observation angle was also changed (fig. 7).

5 Analysis of obtained results

The measurements of properties of large size billboards with light emitting diodes confirmed the existence of high values of luminance of billboard surfaces at low values of luminance of the vicinity of the billboards. If a value of 500 cd/m^2 suggested in [15, 16] and presented in tab. 1 is assumed as a criterion of evaluation of permissible values of luminance for high illuminance surfaces, then only 2 out of the examined 18 billboards meet this requirement. The two billboards had maximum luminance of 377 cd/m^2 and 388 cd/m^2. The remaining billboards luminance was from 554 cd/m^2 to 814 cd/m^2 (6 billboards) and over 1000 cd/m^2 – from 1051 cd/m^2 to 7953 cd/m^2 (10 billboards). The average luminance of the surface of all examined billboards was 1983 cd/m^2, given the average background luminance below 10 cd/m^2 and average road surface luminance, namely adaptive luminance, of approximately 3 cd/m^2. Almost all examined billboards featured highly variable parameters and high luminance contrasts of the displayed images. The highest value of luminance contrast, defined as the relation of the luminance of the object to the luminance of the background, was over 4000.

The obtained results show it is necessary to impose limits for billboard luminance values at night.

The measurements of changes of luminance of billboards' central points depending on the angle of observation in relation to perpendicular plane allowed us to distinguish three groups of billboards differing in the dependence of the change of luminance on the change of observation angle. Figure 7 presents average results for these groups.

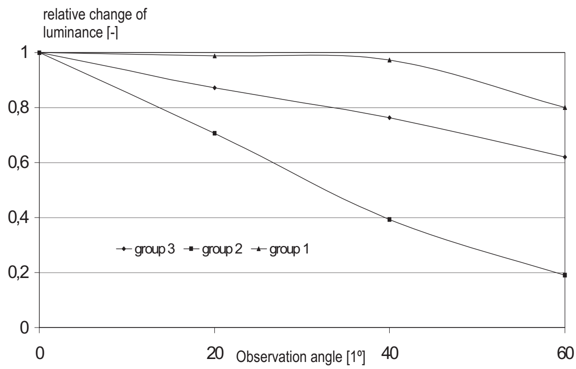

Figure 7: Relative changes of luminance in the billboard's central point depending on the angle of observation in relation to the plane perpendicular to the surface of the billboard.

The calculated characteristics of the change of luminance depending on the angle of observation in relation to the perpendicular plane and the know maximum luminance make it possible to specify a permissible (subject to possibility of glare) location of a billboard with light emitting diodes in relation to observation angles.

6 Conclusions

The completed measurements and their analysis have shown the negative impact of large size billboards with light emitting diodes on drivers' vision conditions, especially at night, and consequently on road traffic safety. Factors resulting in negative impacts of such billboards may be divided into two categories:

- Factors related to photometric parameters of large size billboards and their immediate surroundings influencing the vision process:
  - high luminance of billboards with light emitting diodes at low background luminance - favorable conditions causing glare among drivers,
  - high contrast of displayed images causing glare among drivers,
- Factors related to perception of adverts and the process of seeing the road:
  - dynamically changing images (video, animations, rapidly dimmed or brightened images) that distract drivers,
  - displaying content intended for memorization (addresses, phone numbers, mails),
  - location of billboards where increased concentration is required (intersections, roundabouts, road vicinity),
  - placing billboards at low heights in relation to the ground, making it difficult to spot road traffic signs.

On the basis of research results, experience and the analysis of recommendations discussed in other papers, the researchers suggest that requirements and limits related to large size billboards with light emitting diodes presented in table 4 are introduced. These recommendations are discussed in detail in the report [17].

Table 4: List of recommendations for large size billboards with light emitting diodes.

Name	Recommendation
Maximum luminance of billboard surface	At night 400 cd/m^2 During the day 5000 cd/m^2
Billboard location	Within 90°–180° in relation to road surface border Unacceptable emission of light towards locations with higher risk of road collisions Outside intersections
Displaying moving images	Prohibited
Minimum advert display time	10 seconds
Issuing permits	Temporary, for one year
Visual effects and interval between consecutive images	Prohibited
Type of displayed information	Addresses, websites, emails, phone numbers, text message instructions

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Assessment and measurement of energy demand and efficiency in public lighting networks

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Abstract

Due to technological developments in the last decades and to a long lifetime of installations, public lighting is recognized as one of the fields in lighting with significantly high energy saving potential. Side by side there exist obsolete systems older than 40 years and new modern high-performance systems with discharge lamps and powerful luminaire optics as well as promising LED technologies and sophisticated lighting control systems. To promote energy efficient solutions and to support or speed-up re-constructions of old systems, it is desirable to create tools for decision makers and municipal authorities helping them to distinguish between good and better. Linking thoughts to other lighting fields like EPBD, a numerical indicator expressing the energy efficiency level is to be set up. Works on this task currently run in CEN as a European normalization body as well as world widely recognized CIE.

This paper focuses on analysis of different approaches that are actually discussed. A leading role is played by SLEEC (Lighting Energy Efficiency Criterion), a working name for a new lighting energy indicator proposed for public lighting systems. It is based on effective system comprising of the effective power of lamps, gears and other devices like control units, directly associated to the lighting of the area to be lit. Switching profiles, lighting control and operator's behavior or preferences should be considered as well. Depending on the main user and respective lighting class, different versions of SLEEC are proposed. The paper attempts to generalize the leading approach, branching into different variants and discussing their pros and cons. Methods and schemes for measurement of SLEEC are also proposed.

Keywords: energy efficiency, public lighting, road lighting, SLEEC.

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1 Introduction

The importance of energy efficiency is increasing rapidly. The European Commission has already adopted two eco-design regulations to improve the energy efficiency of household lamps, office, street and industrial lighting products. The two regulations lay down energy efficiency requirements which will save close to 80 TWh by 2020 (roughly the electricity consumption of Belgium) and will lead to a reduction of about 32 million tons of CO_2 emissions per year. It is known that the implemented measures alone are not enough the reach ambitious targets of EU by 2020. Energy savings potential on system levels are at least as high as on product level. That is why the Commission’s focus is on improved measures on products, energy labeling and introducing the Lighting System Legislation (LSL). LSL is an energy conscious way of design, installation and operation of lighting systems:

1. selection of the right criteria for the lighting task
2. design of the right lighting to meet lighting and energy saving criteria
3. verification of the lighting design
4. installation of the lighting system according to the lighting design
5. verification of lighting quality and energy saving criteria of the new installation by metering
6. commissioning, sign-off and hand over to the user of the lighting installation
7. maintenance, service (schedule defined the design) and operation of the installation by the user
8. verification of lighting quality and energy saving criteria of the maintained installation by metering.

The process above for office lighting is backed with a series of directives and standards. In contradiction, highlighted steps for street lighting are not covered by accepted EU standards [1] and verified practice of calculation and measurement. Highlights here do not indicate priorities, just a sign for the lack of legislation.

Those energy saving elements were targeted by the statement from CIE (International Commission on Illumination) during the Session in Beijing 2007, which led to formation of Technical committees. Current works in CEN (European Committee for Standardization) aim to develop a system for assessment of energy efficiency of street lighting systems as a possible framework for energy labeling of these systems. Those missing elements are subjects of the present paper. CIE publications [2] are essential for preparation of EU standards and for lighting practice.

Energy savings in public lighting are studied in many European countries. Comprehensive studies have been performed e.g. in Slovakia and the Czech Republic [3]. As continuously emphasized in CIE, energy savings must not decrease the lighting quality and proper lighting [4] has to remain the framework objective.

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2 Derivation of the Street Lighting Energy Efficiency Criterion (SLEEC)

For expression of energy efficiency level of public lighting (street lighting) systems, a work name *Lighting Energy Efficiency Criterion* (abbreviated as SLEEC) is introduced. However, definition of this criterion (in fact an indicator) is still a subject of vivid discussions. Up to now, several less or more compatible approaches are available. Leading approach can be defined by generalization of various particular formulae for calculation of SLEEC, having common philosophy. Some other approaches are briefly discussed in Section 3. General formula for calculation of SLEEC can be composed as follows:

$$SLEEC = \frac{Power\ Demand}{(Luminous\ Parameter) \times (Relevant\ Area)} \tag{1}$$

2.1 Power demand of a lighting installation

Different approaches may lead to usage of one of the following:

A/ Installed Power P(kW): Total input power of all installed luminaires (including lamps, ballasts and control gears) and other energy consuming devices (e.g. for control or monitoring purposes) installed in electrical compartments (poles, switchboards) within the defined relevant area. Installed power approach is easier for calculation but does not take into account lighting control and its benefits to energy demand of the lighting system. For the sake of simplicity, losses in cables can be neglected in the design stage.

B/ Annual Power Consumption W (kWh): Suitable switching profiles [5], light dimming [6] and other techniques may contribute to optimize energy utilization for public lighting. Due to seasonal changes of daylight availability, at least one-year basis should be used for setting up the parameter. If no dimming is applied, standard annual operation times can be derived for different geographical locations. However, particular local conditions or requirements may be applied as well. If dimming systems are to be installed, lighting levels should correspond to lighting classes linked to the relevant area as per EN 13201-2 [1] or CIE 115 [2], differentiated for normal (full-level) and dimmed operational regimes. Lighting designer has to consider all assumptions and calculations perform with the most probable switching/control diagram (for examples see Fig. 1). The diagram must be attached to calculations as part of the lighting project.

Power consumption approach is more complex than installed power approach though shortcomings can be seen in the ambiguity of results as a consequence of different switching/control profiles used for calculations, depending on particular lighting system. On the other hand, annual consumption principle is used also in other schemes, as such as LENI for assessment of energy performance of lighting in buildings [7].

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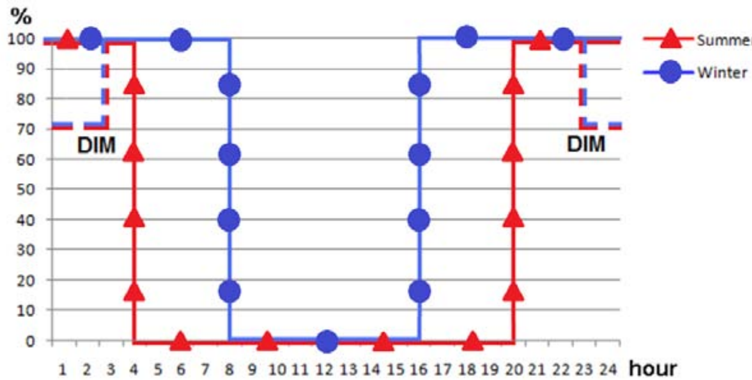

Figure 1: Typical daily switching profile for 50° latitude with and without light dimming.

Installed power can be calculated using the formula as follows:

$$P = \sum_{i=1}^{N} \left(n_i x P_{Li} \right) + P_{Ci} \tag{2}$$

where

P_{Li} - rated input power of a particular luminaire type

n_i - number of installed luminaires of a particular type within the area

i, N - index and number of different luminaire types

P_{Ci} - total input power of all lighting control installed outside of luminaires, exclusively concerning the relevant area

In general, annual power consumption can be expressed as follows:

$$W = \int_{year} P.dt \tag{3}$$

Assuming that in public lighting only limited number of lighting levels is applied, following simplification of the formula (3) can be introduced:

$$W = \sum_{i=1}^{365} \sum_{j=1}^{M} \left(P_{ij} x t_{ij} \right) \tag{4}$$

where

t_{ij} - daily operation time of a particular lighting level

P_{ij} - installed power expressed by formula (2) reduced according to corresponding lighting level (NB: reduction of luminous flux generally do not gain in linear decrease of power)

j, M - index and number of different pre-set lighting levels

If different light levels are applied, segregation of formula (1) to individual levels is needed. More detailed calculations are needed in these cases:

- if more complex profiles are used to control the lighting
- if adaptive lighting systems are used (only estimations can be performed)
- if individual luminaire control is used

2.2 Luminous parameter

Luminous parameter is used to relate the energy demand to lighting level of the illuminated relevant area [8, 9]. More illumination calls for higher consumption, so the mutual ratio of the two parameters help to describe efficacy of lighting systems similarly like luminous efficacy of lamps is defined, though here in reciprocal expression. Luminous parameter is strongly dependant on lighting class of the relevant area. Design criterion is either based upon luminance L (cd.m^{-2}) [10] or illuminance E (lx) what necessarily leads to split of formulae to L- and E-based SLEEC. Besides the said, following approaches can be identified:

A/ Normative parameter: If normative parameter is used, result of calculation will point to overall energy efficiency of analyzed lighting system, when common basis is used to compare different lighting systems under standard conditions. Such assessment can show the quality of designer's effort to fulfill the desired lighting levels with least power demand. Big difference between normative and calculated values of a luminous parameter will lead to worse ranks of the lighting system.

B/ Calculated parameter: In contradiction to the previous approach it may be desired (e.g. by municipalities) to have higher lighting levels than required by standards, e.g. for marketing purposes. Technical standards (EN 13201-2 for instance) require only minimum levels, while range from the upper side is open, in fact. Therefore, if the calculated parameter is used for assessment, the result of the calculation will emphasize energy efficiency of technologies incorporated (lamps, luminaires, accessories), regardless on dimensioning of the system.

<u>Identified problems</u>:

- In some cases, relevant area (e.g. straight road) is required not to be solely illuminated from edge to edge, some part of luminous flux should be used to illuminate the proximate surrounding (requirement set through the „surround ratio" parameter).
- One lighting system quite usually serves to illuminate more than one area, for example road + sidewalks (sometimes separated by grass strips capturing light; such light losses exceeding required surround ratio level cannot be effectively controlled).
- In parks, lighting is not aimed only to illuminate footpaths but to help increase the feeling of safety and to create pleasant lighting atmosphere e.g. by illumination of trees from the bottom. This cannot be considered as unuseful spill light. Similar situation is on places where building facades have to be illuminated to some level.

2.3 Relevant area A (m^2)

Relevant area A (m^2) defines the density of lighting system efficacy (energy demand over luminous parameter). Two main typical situations can be distinguished:

A/ Straight road: This situation (fig. 2) is typical for luminance based systems because application of the luminance concept requires at least a certain straight section of road (calculation area between two consequent poles plus 60 m braking distance before this area). This approach can be with no limitations used for the illuminance approach as well. Though in practice indicators relating installed power or power per lux or cd.m^{-2} to 1 km of a road are sometimes used, the true value of this parameter is only informative. As width of the illuminated road has significant meaning, it cannot be neglected and tabelization of values for different typical road widths seem to be impractical.

B/ Any closed area: This situation (fig. 3) can only be used for illuminance based systems. Transversal profile of roads or lighting system geometry is not critical for this approach. Closed area may include any number of installed luminaires, any number of distribution boxes and any topology of cable routes. Area to be taken into account should be carefully calculated, depending on the illumination task. For example, if in a park the task is only to illuminate footpaths, the total area is summed up from particular sections of these footpaths. If aim is to illuminate the park as a whole, total park area should be taken (intentional dark places should be excluded).

Relevant area for the case of a straight road can be calculated as follows:

$$A = l \; x \; w \tag{5}$$

where
l - length of the relevant section of road
w - width of the road

Some roads are not ideally straight but small differences are negligible. For general case of quasi-straight roads with curvatures, bends and variable widths more detailed calculations are needed, using the following formula:

$$A = \int_{section} l.dw \tag{6}$$

If requirements to accuracy of calculations are not very high, the following simplified formula can be used instead of the previous two:

$$A = n \; x \; s \tag{7}$$

where
n - number of poles installed on the relevant road section
s - typical spacing of poles in a linear (single side) geometry

3 Analysis of efficiency of street lighting systems

Assuming that lighting designer aims to reach required lighting levels with minimum power consumption, optimization of lighting design is needed. In general, results of lighting calculation should always be higher than minimum values prescribed by standards. Designer working with discrete inputs (power of lamps, selection of luminaires and optics, heights depending on available poles, spacing usually taken e.g. in 1 m steps) should seek for minimum difference between his result and normative requirement. The same time, spill of luminous flux to unnecessary area or directions should be limited as much as possible. Overall efficiency of lighting systems can be defined as the ratio of luminous flux necessary to fulfill the lighting function to the total luminous flux of all lamps installed within the relevant area.

Overall efficiency incorporates:

- Luminous efficacy of lamps: depends on lamp type and its power; some lamp types are available in standard and improved versions, the latter having increased luminous flux thus better luminous efficacy. Luminous efficacy of the light source is usually determined in nominal (optimal) circumstances, Nevertheless, light source at the luminaire works far from nominal. In that case, luminous efficacy in real situation will be different (usually smaller) than that for optimal. Typical example is the luminous efficacy of LEDs given at chip temperature of 25°C and nominal current, although chip temperature and actual current will be different in reality. This must be taken into account, when overall efficiency is calculated. For example of LEDs, ‘thermal efficiency’ can be calculated, which indicates the ratio of efficacy at nominal and real situations.
- Luminous efficiency of luminaires: given by quality of optics (e.g. high-reflectance MIRO vs. cheap diffuse reflector) and construction of the luminaire (e.g. deep flat-glass vs. shallow luminaires).
- Maintenance factor: It is multiplied from lumen depreciation of the light source and the maintenance factor of the luminaire. Lumen depreciation is a function of the depreciation curve and designed replacement cycle of the source. The maintenance factor of the luminaire depends on quality of environment, prescription of maintenance, materials and tightness of luminaires.
- Efficiency of ballast: in case of magnetic ballasts, approximately 20% of luminaire’s rated power is consumed by ballast while for electronic ballasts this portion can approach near towards 0.
- Lighting control: A combination of all mentioned parameters result to certain W/L or W/E values (see Eq. (1) above). Direct application of these parameters is an alternative approach how to express and calculate the SLEEC. Problems with this approach may occur, if different technologies are used in the relevant area.

Lighting systems ranking to the highest energy efficiency class should fulfill these criteria:

- Most efficient light sources for the purpose (usually high-pressure sodium lamps)
- Lamp versions with increased luminous flux (e.g. PLUS or SUPER denoted versions)
- Luminaire efficiency better than 0,75

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- Good luminous intensity distribution for the purpose (well-designed and optimized optics, selectable according to the application for some luminaire types)
- Maintenance factor not below 0,80

Note: Cleanliness of the environment has significant influence on energy consumption and efficiency of lighting system through the maintenance factor. Moreover it is an attribute that usually cannot be improved. Thus, ranking of lighting systems will always comprise this property of the installation site.

4 Measurement of SLEEC in public lighting networks

In order to verify calculated values of SLEEC, measurement is an alternative method. For new or renovated lighting systems, SLEEC can be calculated in the designing stage while measurement can support the first inspection of this system, possibly together with electrical tests of the lighting network and/or photometrical measurements.

It is necessary to distinguish between short-term and long-term measurements. Although for calculation method the energy consumption parameter is preferred (see Section 2), its verification requires continuous energy monitoring during minimum one year period what is time demanding. Other complication comes from the fact that it is almost impossible to permanently install measuring instruments in desired points of network or in every pole or luminaire. Sophisticated control systems may provide this option and “smart metering” seems to be a promising technique, this approach is, however, out of the scope of this paper.

For certification purposes, instantaneous measurements based on input power can be used. For a straight road and linear electrical line topology, the measurement scheme is depicted in Fig. 2. In certain points where the network is branched, electrical parameters like voltage, current and power are to be measured. Arrows in Fig. 2 show the flow of energy (from sources to appliances). Positive values of current or power (P, Q, S, PF) are given to all inputs while negative values are linked to outputs. Such a way, remaining difference represents the parameters of the relevant area.

Voltage shall be measured in each point as well because voltage drop along the line impacts the real input power of luminaires. As a consequence, input power will in real differ from rated power and will vary from luminaire to luminaire.

Measurements according to the scheme in Fig. 2 can be performed on terminal blocks installed in foots of poles if the network is looping through. In case of overhead lines, connections are also easily accessible. But if buried cables are not looping via terminal blocks in poles and buried T-connectors are used, the method described above is not usable. For this case there is no practical solution up to now but the problem is identified and solutions are sought.

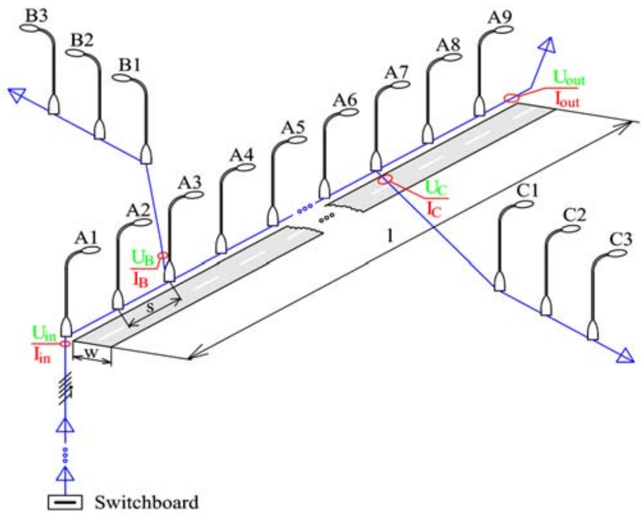

Figure 2: Example of measurement diagram with relevant area as a straight road.

If relevant area has an irregular shape, like in case of parks, places or pedestrian zones, measurements can be performed in a similar way as described above. Situation is depicted in Fig. 3. Here, inputting and outputting lines are

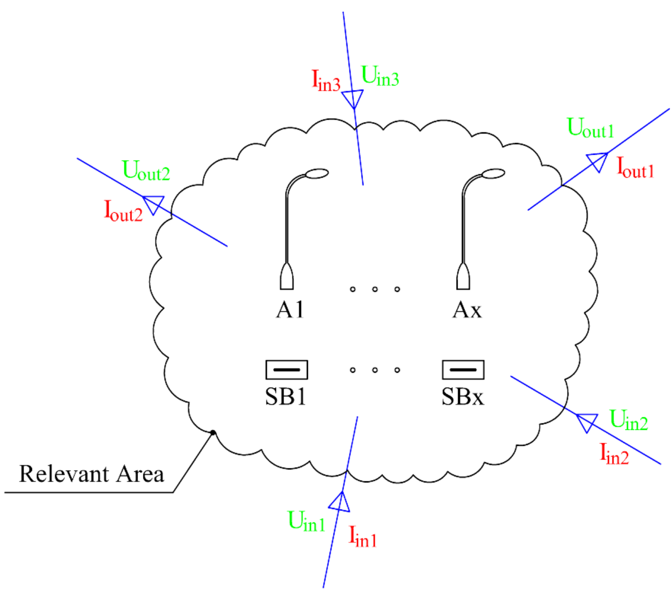

Figure 3: Example of measurement diagram with relevant area of an arbitrary shape.

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also measured in bordering points of the relevant area. Internal sources represented by switchboards SB1 to SBx need to be included as well. In that case measurements have to be performed also on output terminal blocks of these switchboards.

5 Sample calculations and measurements of the SLEEC

In-situ measurements of power quality have been performed in a real lighting network described below in Table 1. Comprehensive measurement of power quality was induced by overvoltage problems [11] arising from switching processes, investigation of harmonic distortion in public lighting networks [12] and related problems. Measurements have been performed in accordance with recommended practice [13, 14]. Purpose of measurements was not primarily focused on SLEEC, but all necessary parameters for SLEEC have been recorded and measurements have been performed in accordance with requirements described in the previous section.

Lighting system is renovated and original lighting project with proper calculations is available. In comparison to measured values, SLEEC is also calculated by means of formulae given in Section 2 with these variations:

- A: Power in W, normative L
- B: Power in W, calculated/measured L
- C: Consumption in kWh, normative/calculated L, 3 900 hours/year (only by calculation)
- D: Consumption in kWh, normative/calculated L, 2 075 hours/year on full level and 1 825 hours/year on reduced 70% level (only by calculation)

Table 1: Identification of the installation site.

Locality (48,1°N/17,7°E)	Galanta
Lamp type	NAV-T 100 W SUPER 4Y
Lamp efficacy	100,0 lm/W
Luminaire type	Schréder Sapphire 12N100PC
Luminaire efficiency	79
Luminaire’s rated power	121 W
Mounting height	8 m
Average spacing of poles	30 m
Width of the road	6 m
Length of the relevant road section	297 m
Lighting class	ME4b
Normative/Calculated/Measured maintained luminance	0,75 $cd.m^{-2}$
Maintenance factor	0,73
Number of poles	9
Total rated power of luminaires	1 089 W
Measured installed power of the installation	882 W

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In the studied case, calculated value was the same as normative and even the measured. In luminance based systems, calculation results are often very close to the normative requirement. Bigger differences may arise only by conscious over dimensioning of the system by lighting designer. As a conclusion, $SLEEC_L$ is normally not dependant on normative or calculated luminous parameter or the difference between them is negligible.

As seen from table 2, SLEEC values are very small, namely for the variations A and B if power is expressed in kW. For this reason, values in Table 2 are shown in W/(cd.m^{-2}.m^{2}). A decision will be needed on how to present SLEEC as practical values.

Table 2: Calculated and measured values of $SLEEC_L$

Variation	Calculated	Measured
A (W/(cd.m^{-2} m^{2})	0,8148	0,6560
B (W/(cd m^{-2} m^{2})	0,8148	0,6512
C (kWh/(cd m^{-2} m^{2})	3,177	–
E (kWh/(cd m^{-2}.m^{2})	2,732	–

Differences between calculated and measured values make 20%. Voltage measured on poles was 215 V (6% voltage drop). Other influences were not identified though measurements have been performed in each pole.

6 Conclusions

Based on proposals and their analyses in this paper we can conclude that:

- Power consumption approach should be preferred against installed power. If no relevant information on lighting switching, control or dimming is available, standard annual operation times can be used.
- Because luminance and illuminance are different design criteria corresponding to different lighting applications, it is not suitable (though it is possible) to unify SLEEC for the two. Therefore, different formulae for $SLEEC_L$ and $SLEEC_E$ have to be defined.
- Both normative and calculated luminous parameters coming to the calculation of SLEEC have their benefits but generally usage of normative parameter can be recommended. The other approach does not provide pressure to decrease overall energy demand of lighting systems, that is the main objective of the mandate to elaborate standard.
- Definition or derivation of SLEEC directly from technical parameters of individual components seems to be logical but practical applications may meet with barriers.
- Metering of SLEEC is important to verify the calculated values or it can be a self standing alternative method that can be used e.g. for commissioning of the lighting system. Metering method is proposed in this paper for instantaneous performance, useful for quick verifications. Long term monitoring is a matter of further works on this topic.

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Performance of LED street lights in hot environments

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Abstract

Solid-state LED street lights present significant benefits to street light operators as well as drivers and pedestrians. Questions remain, however, about their performance in high temperature conditions. This paper explores the performance of LED street light in one of the hottest regions in the world.

Two LED street lights were installed in an actual street in the city of Al Ain, United Arab Emirates. The street was closed to the traffic and illuminance measurements were taken daily every 10 minutes throughout the summer of 2010. Temperature and relative humidity values were also taken inside the two light fixtures as well as outside the fixtures. The summer of 2010 had significantly high temperatures with one week in July reaching maximum ambient temperatures of 53^{o}C.

This paper shows the Lux levels as well as the temperature and relative humidity data acquired in the field. Results show fairly stable light levels throughout the summer. The Lux levels did not change by more than 10% throughout the summer.

Keywords: LED, solid-state lighting, street light, roadway lighting.

1 Introduction

Solid-state (LED) street lights present significant benefits to street light operators as well as to drivers and pedestrians alike. However questions remain on their performance in high temperature conditions. Whereas, many studies have reported the relationship between junction temperature and luminous flux on laboratory conditions, few studies were made on site under real conditions.

In recent decades, numerous papers have analyzed the LED (solid-state lighting) thermal challenge [1, 6]. The LED thermal challenge is a bottleneck

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that limits the stability, reliability, and lifetime of LEDs. While the luminous efficiency and light output of these devices continue to increase, the present day values still require that multiple die be used to produce enough light to replace conventional general illumination sources. With the use of large LED arrays, it is possible to generate a large heat loads at the system level which can cause challenges for overall heat dissipation, especially when passive cooling is used. The large array with passive cooling techniques leads to elevated LED die temperatures, which have been linked to lower quantum efficiencies, shorter lifetimes, emission wavelength shifts and, catastrophic device failure [1–6]. A heat flux from a $900\ \mu m^2$ high brightness LED chip, has already reached approximately $125\ W/cm^2$ [3] which is considered relatively high heat flux and comparable to heat generation in integrated circuits.

In general, nearly 90% or more of the thermal energy is directly dissipated from the LED die through conduction as opposed to radiation as seen in incandescent sources [7]. Hence, the LEDs packaging materials are critical for thermal dissipation since it affects the thermal resistance. At the system level, convection to the surrounding is the main scheme for thermal dissipation which is attained through natural or active means. Therefore in order to increase the luminous flux for compact high power LED arrays, thermal packaging engineer must focus on providing the highest convective heat transfer coefficients (within reasonable energy constraints) while improving the packaging design. In literature, several LEDs thermal management solutions are employed such as flat heat pipes [8], forced air convection, and liquid cooling which is vital to the development of high power compact LED arrays. While much attention is given to maintaining a specific temperature limit, thermo-mechanical effects also play a large role in array reliability and must be investigated as well. The stress in the die can be considerably different when mounted to Copper versus Aluminium heat sinks. It is reported in literature that residual compression is found in GaN die [9]. This is critical for LEDs design since the compressive stresses affect the band gap and the light output from the LED die.

From literature, it is clear that the LEDs package materials must satisfy numerous requirements, including high thermal conductivity, high mechanical strength and stiffness and, high chemical inertness [10].

Conventionally LEDs are driven in the amplitude mode (AM) by direct current or in the pulse-width-modulation (PWM) mode by pulsating current [11, 12]. Despite the apparent ease of operating the LEDs with direct current, it is challenging to dim the LEDs given the high sensitivity of the forward current to a change in the forward voltage owing to the device’s small dynamic resistance, where a very precise regulation of the forward voltage is required for a stable luminous output. It is also well documented that a direct change of the forward current can alter the emitted wavelength or color of the LEDs at different luminosity levels. In contrast, dimming is conveniently achieved with PWM by controlling the pulse duration, thus avoiding direct adjustments of the current amplitude and consequently high colour stability is attained. However, this is possible at the sacrifice of luminous efficacy, given that the LEDs have to

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operate at larger current amplitude during the pulse duration for the same average current as the AM case. This is due to the tendency of the luminous output of LEDs to saturate at large forward current. In short, the conventional driving techniques are beneficial in some aspects but lacking in others.

PWM dimming operation consists of switching on and off the LED light, making it flicker. If this flickering is performed fast enough, the human eye can only perceive a decrease in the luminous output due to the stroboscopic effect. The human eye does not perceive the flickering if the dimming frequency is at least 50 Hz, but the recommended minimum frequency is 200 Hz so moving objects do not seem to be still. Three main methods for PWM dimming operation were identified by Yuan et al. [12].

Long et al. [13] tested a 50 Watt street light in a street in China, using a 9 LED module with an adaptive driver. The heat sink temperature reached 58^{o}C after 60 minutes of operation. After three months of operation Long et al. did not detect any changes in light levels and the junction temperature was in the range of less than 78^{o}C measured by an IR thermometer.

In this project, two 101 watt LED Street light driven by PWM drivers, were tested in the field in the city of Al Ain, United Arab Emirates during the hot summer season. The city is known for its extreme hot climate. Two lighting units were mounted in relatively low use street which has minimum lighting from the surrounding, in order to isolate the effect of the surrounding lighting systems.

The objective of the experiment is to test the stability of LED street lights under hot environment from an illumination point of view. The experiment described thereof is not about the effect of temperature on the life of the LED.

The manuscript presents two sets of data which were collected in (a) the laboratory and (b) the field. The collected data include internal and external lighting fixture temperature and relative humidity (RH) recorded over a period of time as well as illumination levels.

1.1 Thermal measurements

The temperature and relative humidity (RH) data is collected using data recorder from ACR “Smart Reader Plus 2”.The data were recorded every 10 minutes which allows 10 months period of data collection.

1.2 Laboratory measurements

A test was done in the laboratory at room temperature conditions. The collected data is presented in Figure 1. The temperature data logger was installed in the LED light box and was tested on June 15th at 7 am. A test was conducted from 9:15 am to 4:50 pm which is shown in Figure 1. The results show that the temperature went up from 24.8 to 41^{o}C in less than two hours. The data recorder collected data inside the light box till 4:50 pm where maximum temperature inside the box reached around 42^{o}C.

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1.3 Data collected in the field

Two LED street lights were installed on a 10 meter high pole. Each street light was 101 watt including the LED drivers. There were 84 LEDs in each fixture with each LED rated at 1 watt. The data collected in the field is presented in the next subsections.

Temperature and relative humidity data loggers were programmed to take measurement every 10 minutes and were mounted in the following locations as illustrated in Figure 2:

1. Inside the pole but close to the base (this value is considered the ambient temperature)
2. Inside light fixture number 1 in the LED-driver's compartment
3. Inside light fixture number 2 in the LED-driver's compartment
4. On the side walk.

The ambient temperatures throughout the test period are presented in Figure 3. The maximum temperature during this period was 54^{o}C which occurred on July 17th.

The average and the maximum temperature daily values inside the two light fixtures were compared to the ambient temperature; the results are shown in Figure 4.

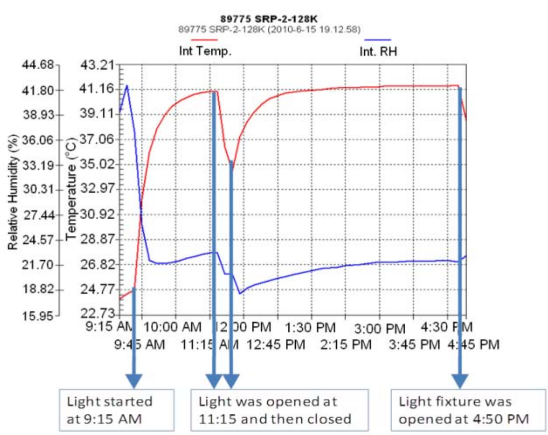

Figure 1: The temperature inside the LED light fixture recorded on June 15th from 9:15 am till 4:50 pm. The fixture was opened at 11:15 am for 10 minutes period. Room temperature conditions.

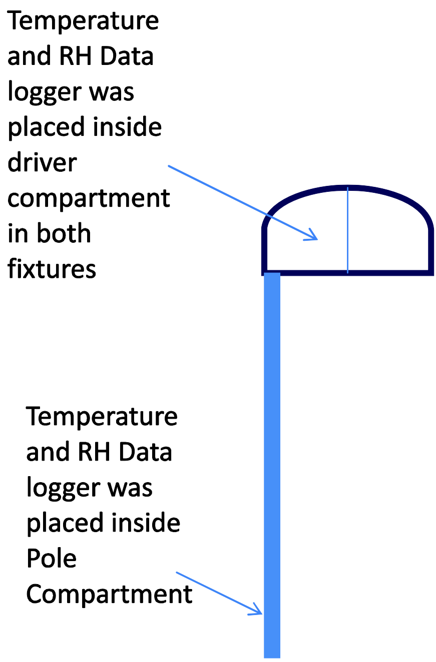

Figure 2: Locations of the temperature and relative humidity data loggers.

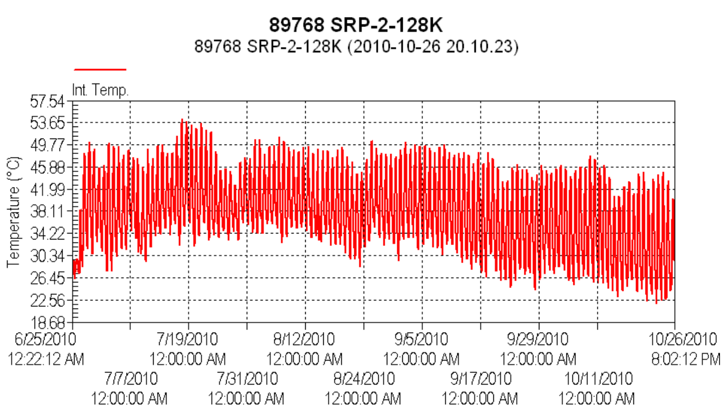

Figure 3: Ambient temperature throughout the summer. Site conditions.

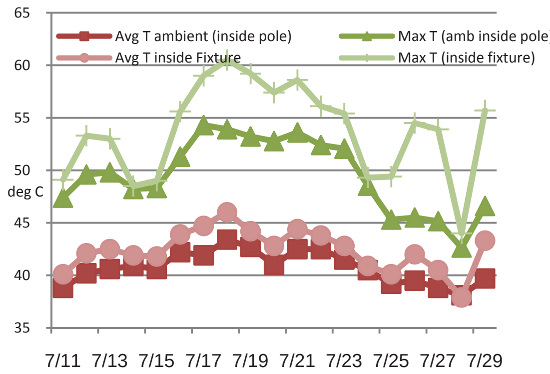

Figure 4: Comparison between ambient temperatures and temperatures inside fixture 1. Using average and maximum daily values.

As far as the temperature inside fixtures 1 and 2 the maximum temperature recorded inside fixture 1 was 60.5°C. This temperature occurred during the daytime of July 18. The maximum temperature during the night was 46°C. On the other hand, the maximum temperature recorded inside fixture 2 was 61.1°C which occurred during the daytime, while the maximum temperature inside fixture 2 during the night was 46°C. The dynamic of temperature variation inside the light fixtures for one day (June 30th) is illustrated in Figure 5. The figure shows how the temperature inside the fixture experiences a sudden rise after the lights are turned on and a sharp drop when the LEDs are turned off.

For most of the day, the temperature inside the fixtures is higher than the ambient temperatures. Temperatures inside the fixtures during the night were in the range of 38-44°C. The minimum and maximum as well as the average temperatures inside fixtures 1 and 2 are shown in Figure 6 through to Figure 8.

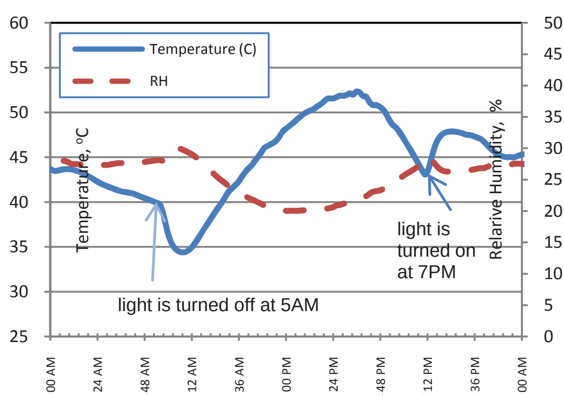

Figure 5: Temperature dynamic inside fixture 2 in one night.

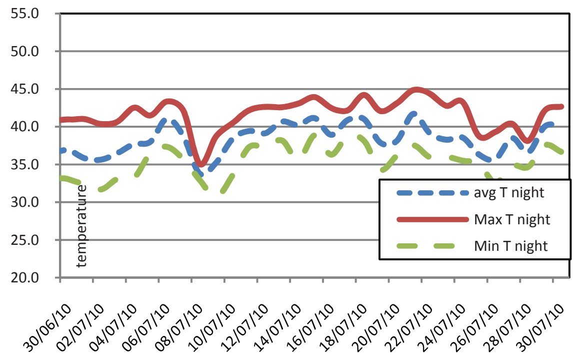

Figure 6: Night temperatures values in degree Celsius inside fixture 1 for the month of July.

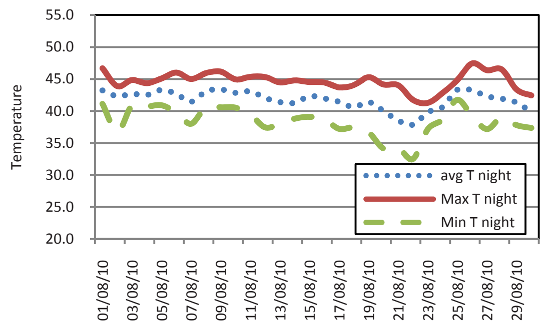

Figure 7: Night temperature values in degree Celsius inside fixture 1 for the month of August.

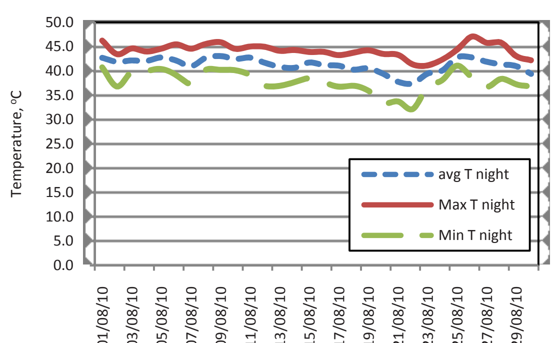

Figure 8: Night temperature in degree Celsius inside fixture 2 during the month of August.

2 Illumination results

An isolated street in one of the university campuses in Al Ain, United Arab Emirates, was used as the test site. The street was closed to traffic. The city has extremely hot and dry conditions during the summer months. Two 10-meter high poles were used with a spacing of 50 meters on this 7.3 meter wide street. Eight illuminance sensors were used; three sensors were along the lateral direction of fixture 2, three more sensors were placed halfway along symmetry lines, while 2 sensors were used for fixture 1. The sensors were dusted off daily using compressed air. The top view of the setup is shown in Figure 9. The lights were turned on at 7pm and off at 5 am. Lux values were collected every 10 minutes including daytime. Daytime Lux levels gave an indication of sky conditions during the day whether cloudy or sunny. The spikes in the light levels indicate the start and the end of daylight. The Lux levels at point 1-1 ranged from 19 to 21 Lux and are shown in Figures 10 and 11. The average Lux levels at point 1-1 and 2-1 were compared to the average temperature inside fixture 2 during the night. The results are shown in Figures 12 and 13, respectively.

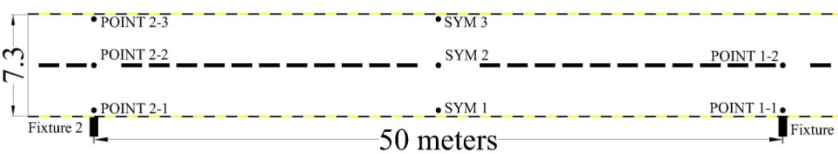

Figure 9: Top view of the street showing location of poles and location of illuminance sensors.

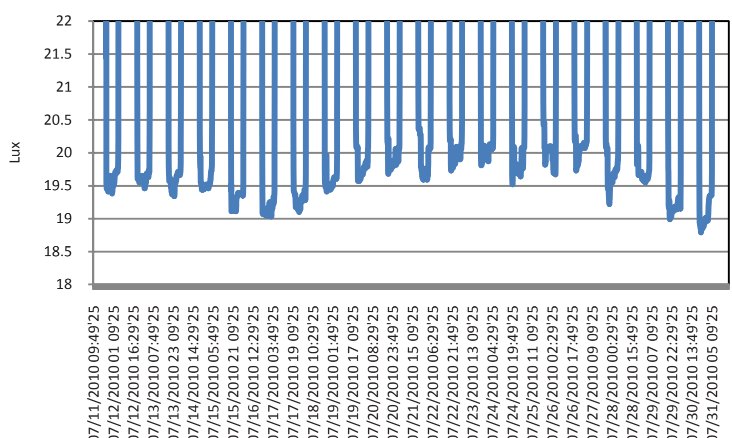

Figure 10: Lux Levels for point 1-1 –July.

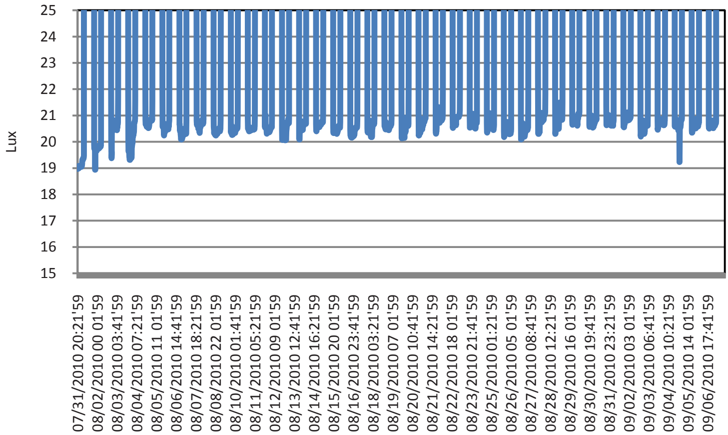

Figure 11: Lux levels for point 1-1 August through to September 7th.

For three weeks in July, the hottest period during the test, the average Lux at point 1-1 was 19.65 with a standard deviation of 1.5%. The maximum Lux level for that point during the month of July was 20 while the minimum level was 19.1 Lux. The summary of temperatures throughout the summer is shown in Table 1.

The average night time illuminance at point 1-1 versus the average night time temperature inside fixture 1 during one night (July 31) was plotted in Figure 14. A regression fit can be obtained and the drop in light levels with increase in temperature inside the driver compartment is clear. This drop is, however, very small.

The luminance map of the street was taken using a CCD imaging camera. The result shows an average luminance of 1.1 cd/m^2 with an average to minimum uniformity ratio of 1.6.

We were able to monitor the voltage and current for a limited number of days for 1 LED from 1 light fixture. The on-site recorded duty cycle of the PWM signals are in line with the value measured in the lab for full intensity (without dimming); thus we can easily conclude that no dimming has occurred during all these measurements. This is an important observation to conclude that any drop in Lux levels is caused by increase in temperature and not due to the dimming of LED by the driver.

Table 1: Average daily temperature values for the summer from 14th June through Oct 26th.

	Maximum	Mean	Minimum	Range	Std deviation
Ambient	54.30	37.13	21.02	33.29	6.80
Inside fixture 2	61.09	41.27	22.71	38.39	6.43
Inside fixture 1	60.53	41.17	22.97	37.56	6.47

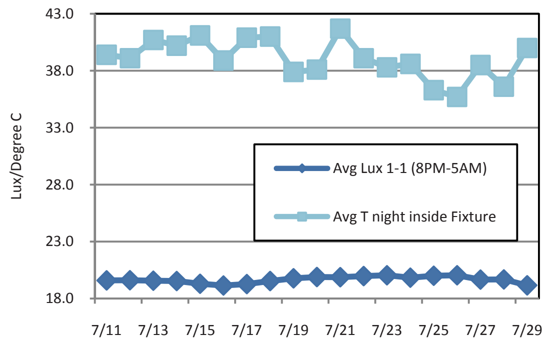

Figure 12: Lux levels for point 1-1 and temperatures inside fixture 1.

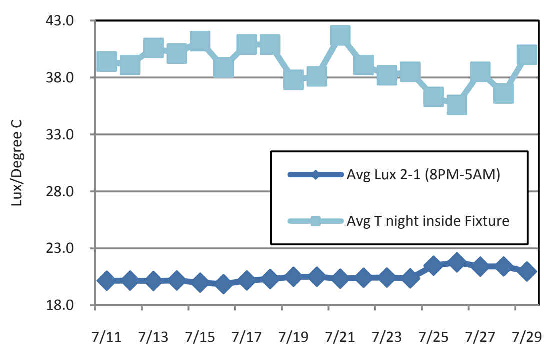

Figure 13: Average daily Lux levels at point 2-1 relative to the night temperature inside fixture 2.

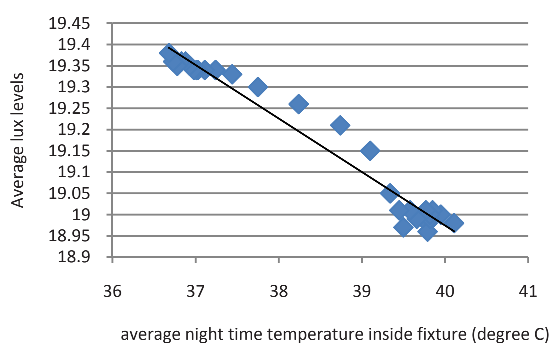

Figure 14: Average night time Illuminance at point 1-1 versus average night temperature inside fixture- night of July 31.

3 Conclusion

The following conclusions can be made:

- The LED light levels of the LED street light were fairly stable throughout the hot days of the summer.
- For fixture 1 and 2 the average nightly temperature inside the fixture ranged from 35-43^{o}C. The average temperature inside the fixtures for the month of August was around 41^{o}C.
- Lux levels did not change by more than 10%during the test period.
- The average Luminance of the street was 1.1 cd/m^2,with a uniformity ratio (average Luminance over minimum Luminance) of 1.6.
- No electrical dimming has occurred in all on-site measurements.

Further studies need to be made to test the Lux levels at cold days and, the Lux levels over several years to test lumen depreciation. Given the fact that the heat sinks of different street light from different manufacturers have different designs, caution must be taken not to extend the conclusion of this test into all LED street lighting products.

Acknowledgement

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Visibility concept in road lighting

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Abstract

A major purpose of road lighting is to increase the visibility for drivers and other roadway users. The visibility of a target depends on observer age and visual characteristics, observer duration, size of target, luminance of the target, luminance of the background, contrast polarity, exposure time, magnitude of the disability glare, and adaptation. A visibility formula was described by Adrian in 1989 and applied with Visibility Levels in North America as a quality criterion. According to procedures described in ANSI/IESNA RP-8-00: American National Standard Practice for Roadway Lighting the visibility of the target can be calculated when the target luminance, background luminance and veiling luminance in calculation methods are given. In European countries this criterion is still investigated as a new concept.
Keywords: road lighting, visibility level, small target visibility, road lighting standards.

1 Introduction

Road lighting has significant impact on road traffic comfort and safety. All participants of the traffic, vehicle drivers, cyclists and pedestrians alike, should benefit from vision conditions that facilitate the completion of visual tasks. The entire road along with its background should be well visible at all times. Cyclists and pedestrians alike should see all obstacles in their way and should be able to correctly identify the intentions of other traffic participants. The visual reliability of drivers should be suitably high to allow them to spot, quickly enough, pedestrians, cyclists and any obstacles present in their traffic lane, as well as road signs and information boards in its immediate background, in order to reduce the likelihood of dangerous situations or traffic accidents. Even though the attempts to identify direct relation between quantitative and quality parameters of road

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lighting, such as road luminance (illuminance), longitudinal uniformity, surround ratio, glare limit and road accident ratio have failed so far, numerous research projects have confirmed a significantly lower number of accidents on illuminated roads in relation to conditions where there is no fixed road illumination, the illumination is off or its design is faulty. Studies have shown that the accident rate is 1.5 to 2 times higher during the night-time than in daylight. In the case of the fatal accidents the rate is three times higher in darkness as in daylight. In general, construction of road lighting is found to reduce night-time accidents by 20–40%. Based on several studies, the mean accident reducing effect in darkness is found to be about 30% for all injury accidents, 60% for all fatal accidents, 45% for pedestrian accidents, 35% for injury accidents at rural junctions, and 50% for injury accidents on motorways [5]. A great deal of investment and operating costs of road lighting equipment translate to savings to the society, as many accidents are effectively prevented.

2 Visibility of targets in illuminated roads

A driver can spot an object in the road or in its background only if the contrast the object creates with the background (the road or its background) is above the threshold value of the contrast. If the object's luminance is higher than the luminance of the background the contrast is positive, otherwise the contrast is negative – which is most often the case with road lighting.

The difficulty of spotting obstacles in the road depends on the following factors:

- the contrast between the luminance of the object and its immediate visual background,
- the general level of adaptation of that portion of the retina of the eye concerned with the object,
- observer duration on road,
- the size, shape of the object,
- disability glare - the amount of veiling luminance entering the eye,
- transient adaptation - the difference in eye adaptation between successive eye movements,
- the background complexity and the dynamics of traffic,
- visual capability of drivers.

Numerous research projects of the past 70 years aimed to identify the criterion for evaluation of visibility of obstacles in the road. On the basis of Blackwell's laboratory research, the International Commission on Illumination (CIE) introduced in 1972 the Visibility Level (VL) (eqn (1)) defined as the relation of current contrast of a reference object (a disc of angular diameter of 4 minutes) to background, to the object's threshold contrast in threshold conditions, with the same background luminance [4].

$$VL = \frac{C}{C_{th}} = \frac{\Delta L}{\Delta L_{th}} \tag{1}$$

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where: C is the actual contrast and C_{th} is threshold contrast and ΔL is the actual luminance difference in cd/m^2, ΔL_{th} is threshold luminance difference in cd/m^2.

Still, the direct application of formula (1) to calculate the Visibility Level in the road proved virtually impossible, as the driver's visual task differed from the relative task recommended by CIE [4] either in terms of the size and shape of objects used in the experiment, or in terms of criteria used for measuring the task's performance. Adrian's [1] research at the end of 1970's finally led to a calculation model of Visibility Level in the road. Currently, Adrian's formula is the basis for Small Target Visibility (STV) criterion. Apart from illuminance and luminance, STV is the third criterion employed when designing road lighting in USA. In Europe countries Small Target Visibility criterion is still investigated as a new concept.

3 Night-time visibility assessment

3.1 Adrian's calculation model

The visibility calculation model presented by Adrian [1] draws from laboratory research by Blackwell [3] and Aulthorn [2]. The calculation of threshold luminance difference (ΔL_{th}) of the object and background was based on two laws: Ricc's and Weber's. Adrian introduced two auxiliary functions: the luminous flux function determines perception, characteristic for the Ricco-process, and luminance function L, reflecting Weber's law [1]:

$$\Delta L_{th} = 2.6 \cdot \left(\frac{\Phi^{\frac{1}{2}}}{\alpha} + L^{\frac{1}{2}} \right)^2 \tag{2}$$

where: α - is the angular size of target in minutes of arc.

Moreover, the basic formula (eqn (2)) was extended by Adrian with factors that take into account the impact of the observer's age - AF, object observation time - TF and contract polarization F_{CP} on the visibility of targets in an illuminated road (eqn (3), (4), (5)):

$$AF = \frac{(Age - A_a)}{A_b} + A_c \tag{3}$$

where: A_a, A_b, A_c – constants dependent on the age and presented in [1],

$$TF = \frac{a(\alpha, L_b) + t}{t} \tag{4}$$

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where: t - observation time, a(α, L_b) –function of target size and luminance of background,
\

$$F_{CP} = \frac{\Delta L_{neg}}{\Delta L_{pos}} \tag{5}$$

where: ΔL_{neg}, ΔL_{pos} - luminance difference threshold for negative positive contrasts.

The presence of glare sources in the visual field of drivers impair their vision and results in a necessary increase in ΔL_{th} to keep targets visible. The impact of glare hindering the driver's vision is taken into account by means of veiling luminance (L_V) calculated on the basis of the classic Stiles–Holladay formula [9]:

$$L_v = k \cdot \sum_{i=1}^{n} \frac{E_{glare_i}}{\Theta_i^2} \tag{6}$$

where: k - constant dependent on the age, E_{glare} - illuminance at the eye due to the glare light in lux, Θ - the angel between the direction of glare source and the direction of the target in degrees.

In the case of glare the adaptation luminance (L_a) around location of the target on the retina is consequently composed of the background luminance (L_b) and veiling luminance (L_V),

$$L_a = L_b + L_v \tag{7}$$

The threshold value of the difference of luminance of the object and background calculated with the above dependences and the current difference of luminance of the object and the background are components of the Visibility Level (VL) as identified by CIE (see eqn (1)).

3.2 Small target visibility (STV)

The American Standard Practice [10] includes three criteria for designing continuous lighting systems for roadways. These are illuminance, luminance, and Small Target Visibility. Illuminance (STV) based design is a simple design approach, which has been historically used in roadway lighting. It calculates the amount of light on the roadway surface. Luminance based design calculates the amount of light directed toward the driver and predicts the luminance of the roadway. Small Target Visibility is a visibility metric, which is used to determine the visibility of an array of targets on the roadway. STV includes the calculation following factors:

- the luminance of the targets,
- the luminance of the immediate background,

- the adaptation level of the adjacent surroundings,
- the disability glare.

Target luminance (L_t) is calculated for point at the centre of Lambertian Target and veiling luminance is calculated on the basis of the classic Stiles–Holladay formula (eqn (6)).

Background luminance (L_b) is determined as the arithmetic average value of two background luminance (L_{b1}) and (L_{b2}). Background luminance (L_{b1}) is calculated at a point on the pavement adjacent to the centre of the bottom of the target, that is, the target's position on the roadway. L_{b2} is calculated at a point on the pavement 11.77 meters beyond the target, at a point on a line projected from the observer's point of view through the point at the centre of the top of the target (fig. 1).

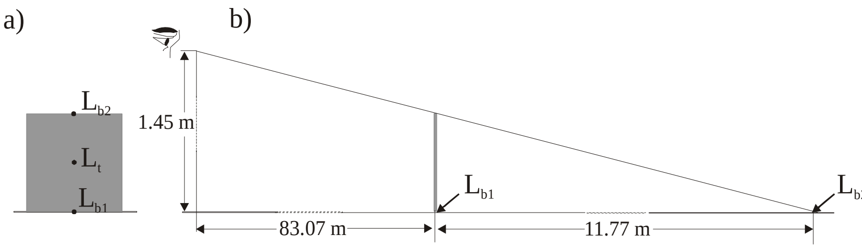

Figure 1: Luminance of target and background location on the pavement: a) front seeing, b) side seeing (not in scale).

The Visibility Level (VL) is calculated step-by-step basis on background luminance (L_b) target luminance (L_t) and several intermediate functions using the adaptation luminance (L_a) and angular size of object (A = const= 7.45 minutes) (eqn: (8)–(32)).

Step 1: Determination of the sensitivity of the visual system as a function of adaptation luminance – functions F and L. This is done by using one of three equations depending on the value of adaptation luminance.

If La ≥ 0.6

$$F = \left[\log_{10}\left(4.2841 \cdot L_a^{0.1556}\right) + \left(0.1684 \cdot L_a^{0.5867}\right)\right]^2 \tag{8}$$

$$L = \left(0.05946 \cdot L_a^{0.466}\right)^2 \tag{9}$$

If La ≥ 0.00418 and La < 0.6

$$F = 10^{\left\{2\cdot\left[\left(0.0866\cdot\left(\log_{10}(L_a)\right)^2 + \left(0,3372\cdot\log_{10}(L_a)\right) - 0.072\right)\right]\right\}} \tag{10}$$

$$L = 10^{\left[2\cdot\left(0.319\cdot\log_{10}(L_a) - 1.256\right)\right]} \tag{11}$$

If La < 0.00418

$$F = 10^{(0.346 \cdot (\log_{10}(L_a) + 0.056))} \tag{12}$$

$$L = 10^{\left[0.0454 \cdot (\log_{10}(L_a))^2 + 1.055 \cdot \log_{10}(L_a) - 1.782\right]} \tag{13}$$

Step 2: Calculate intermediate functions: B, C, AA, AL, AZ, DL_1.

$$B = \log_{10}(A) + 0.523 \tag{14}$$

$$C = \log_{10}(L_a) + 6 \tag{15}$$

$$AA = 0.360 - \frac{0.0972 \cdot B^2}{B^2 - (2.513 \cdot B) + 2.789} \tag{16}$$

$$AL = 0.355 - \frac{0.1217 \cdot C^2}{C^2 - 10.40 \cdot C + 52.28} \tag{17}$$

$$AZ = \sqrt{\frac{(AA)^2 + (AL)^2}{2.1}} \tag{18}$$

$$DL_1 = 2.6\left[\frac{\sqrt{F}}{A} + \sqrt{L}\right]^2 \tag{19}$$

Step 3: Calculate negative contrast factor (FCP) based on intermediate functions: M and TGB.

If -2.4 < $\log_{10}$(La) < -1

$$M = 10^{-10^{-\left[0.075 \cdot (\log_{10}(L_a) + 1)^2 + 0.0245\right]}} \tag{20}$$

If $\log_{10}$(La) ≥ -1

$$M = 10^{-10^{-[0.125 \cdot (\log_{10}(L_a) + 1)^2 + 0.0245]}} \tag{21}$$

$$TGB = -0.6 \cdot (L_a)^{-0.1488} \tag{22}$$

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$$FCP = 1 - \left[\frac{(M)\cdot(A)^{TGB}}{1.2\cdot(DL_1)(AZ+2)} \right] \tag{23}$$

If $\log_{10}(La)$ < or = -2.4 then FCP =0.5.

Step 4: Adjust DL_1 in accordance with the observation time (t), which in [10] is a constant - 0.2 seconds.

$$DL_2 = DL_1 \cdot \frac{AZ+t}{t} \tag{24}$$

Step 5: Calculated the adjustment (FA) for the age of observer (TA), which in [10] is a constant - 60 years. For the age less than 64 years:

$$FA = \left[\frac{(TA-19^2)}{2160} \right] + 0.99 \tag{25}$$

$$DL_3 = DL_2 \cdot FA \tag{26}$$

Step 6: Calculate the adjustment if the target is darker then background.

$$DL_4 = DL_3 \cdot FCP \tag{27}$$

If $L_b < L_t$ then $DL_4 = DL_3$.

Step 7: Calculate Visibility Level (VL).

$$VL = \frac{L_t - L_b}{DL_4} \tag{28}$$

Step 8: Visibility Level is calculated for all grid points (n) and then there is determined Relative Weighted VL (RWVL) and Average RWVL (ARWVL)

$$RWVL = 10^{\{-0.1\cdot|VL|\}} \tag{29}$$

$$ARWVL = \frac{\sum_{i=1}^{n} RWVL_i}{n} \tag{30}$$

Finally, STV is calculated.

$$\text{STV=Weighted Average VL= -10 } \log_{10}(\text{ARWVL}) \tag{31}$$

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4 Simplifications and assumptions employed in Adrian's formula and in STV

The Small Target Visibility criterion, based to a large extent on Adrian's [1] model, introduces far-reaching simplifications for the calculation of the Visibility Level, despite its clear method of evaluation. The road section considered during the calculation is free from other traffic participants and vehicles approach from the opposite direction, hence no glare caused by headlights of these vehicles. The driver's visual task is simple and consists in spotting an object in a specified location, aligned directly with the driver's eyesight. Under real conditions, the complexity and dynamics, combined with other traffic participants, significantly limit the visibility of obstacles in the road. Several question come to mind when analyzing the visibility criterion, concerning the calculation of background luminance and the driver's adaptation conditions:

- What makes up the background luminance of the object in the road? Is it arithmetic average from luminance on road surface where the object is located and luminance at the distance of 11.77 m behind the object, or is its average luminance for a specific road surface in the vicinity of the obstacle (see fig. 1)?
- What elements in the driver's field of vision specify its adaptation? Is it only the point's background luminance and veiling luminance generated by the source of glare (see eqn (7))? Undoubtedly, the driver's field of vision is much wider than the traffic lane itself. Apart from the road, it consists of its background on the left and right, visible landscape and a part of the sky.
- Would it not be necessary, for purposes of calculating road visibility, especially for roads located in centers of towns, to take into account transient adaptation taking place when shifting eyesight from the road to its immediate background? After all, the driver's eyesight may be shifted from road surface to surfaces of billboards, shop display windows etc. whose luminance is much higher.

It is a difficult task to find answers to these questions and numerous scientific experiments are still required, but they will surely allow us to assess Visibility Levels matching real road conditions with much higher accuracy.

5 Limits when applying the STV criterion for purposes of designing road lighting according to European standards and recommendations

The method of calculating STV as described in the American National Standard Practice for Roadway Lighting [10] makes it possible to assess visibility in a relatively simple, step-by-step method. This method, however, has been created for design purposes based on American standards. The visibility criterion is not used for design purposes in Europe. The research to establish the European concept of visibility is still under way, as the direct takeover of STV as employed in USA for European requirements and recommendations is a difficult task. There are several differences between the American [10] and European [8, 11] design requirements and recommendations.

The following are some of the more important differences:

- Reflectance and the size of the critical obstacle. The American [10] standard used for calculations identifies the critical obstacle as a flat object with diffuse reflection and reflectance ρ = 50% and size 18 cm by 18 cm. The CIE [4] recommended critical obstacle is also a flat object with diffuse reflection, but with reflectance of ρ = 20%, and slightly larger: 20 cm by 20 cm.
- Computational grid. According to [10], the calculation field is limited by placing two consecutive luminaires in the same row. The location of calculation points in longitudinal direction is equal to 1/10 of the distance between luminaires, but no more than 5 m. The lines of the first and last calculation points in longitudinal direction to the road are located halfway between points in this direction. Crosswise, the points are located on each traffic lane, at a quarter of the width of the lane from each border of the traffic lane. According to [8, 11] the computational field is also limited to two consecutive luminaires in one line, and the location of calculation points in longitudinal direction is equal to 1/10 of the distance between luminaires, but no more than 3 m. The first and the last calculation points in longitudinal direction to the road are located halfway between points in this direction. Crosswise, the distance between calculation points is a third of the width of the roadway. The external calculation points are located in the distance of a sixth of the width of the roadway from the edge of the traffic lane.
- Observer's position. American standards assume the altitude of observation at 1.45 m above the road surface, 83.07 m before the critical object. The observer are located on each traffic lane, at a quarter of the width of the lane from each border of the traffic lane. The observer's location is subject to change, along with the location of the obstacle in the computational grid. This geometrical array will always generate a single degree observation angle and a fixed angular diameter of the observed critical obstacle of 7.45 minutes. European standards assume the altitude of observation at 1.5 m above the road surface, 60 m before the calculation field. The position of the observer in relation to the calculation field is fixed. The observer are located on centre each traffic lane.
- Observer's age. The currently accepted American standard assumes the observer to be 60 years old. For design calculations according to European standards, the observer is usually assumed to be 23 years old.
- Lighting classes and standard requirements with regard to photometric parameters in the road. The lighting requirements specified in American standards are lower in relation to standard values of photometric parameters and refer to a simple classification of roads: class A, freeway class B, expressway, major, collector, local and the possible occurrence of conflict areas with pedestrians. In case of European recommendations, lighting requirements refer to specific lighting classes established on the basis of

parameters such as: the type of major traffic participants, their typical speed, daily stream of vehicles, complexity of the field of vision, road background luminance.

- Minimal required values of VL. According to [10] the final result of specifying visibility in the road on the basis of STV is the calculation of the weighted average of VL values from all calculation points and its comparison against standard values. Despite the fact that the visibility criterion is not taken into account in Europe for road design, the International Commission on Illumination's publication no. 115 dated 1996 [6] presented suggested values for Visibility Level (VL) for illumination classes from M1 to M5. However, the publication fails to state whether this is a value for a single, specified position of the critical obstacle, or for the assumed computational grid. The publication fails to state whether these are average arithmetic values, weighted average values or perhaps the lowest value of all values calculated for all grid points. The standard minimal STV values and recommended VL values according to [6] are presented in tables 1 and 2.

Table 1: Lighting requirements based on small target visibility [10].

Road and Pedestrian Conflict Area		STV Criteria	Luminance Criteria		
Road	Pedestrian Conflict Area	Weighting Average VL	L_{avg} [cd/m^2] Median <7.3m	L_{avg} [cd/m^2] Median ≥7.3m	Uniformity Ratio L_{max}/L_{min} (Maximum Allowed)
Freeway "A"	-	3.2	0.5	0.4	6.0
Freeway "B"	-	2.6	0.4	0.3	6.0
Expressway	-	3.8	0.5	0.4	6.0
Major	High	4.9	1.0	0.8	6.0
	Medium	4.0	0.8	0.7	6.0
	Low	3.2	0.6	0.6	6.0
Collector	High	3.8	0.6	0.5	6.0
	Medium	3.2	0.5	0.4	6.0
	Low	2.7	0.4	0.4	6.0
Local	High	2.7	0.5	0.4	10.0
	Medium	2.2	0.4	0.3	10.0
	Low	1.6	0.3	0.3	10.0

In the next publication, no. 115 dated 2010 [7], CIE stopped giving VL values until the completion of works of the Technical Committee 4-36.

Table 2: CIE lighting requirements based on visibility concept [6].

LIGHTING CLASS	VISIBILITY LEVEL Minimum Maintained	L_{avg} [cd/m^2] Minimum Maintained	L_{min}/L_{max} Minimum Maintained	TI [%] Initial
M1	7.5	1.0	0.2	10
M2	7.0	1.0	0.2	10
M3	6.0	0.7	0.2	10
M4	5.5	0.5	0.2	10
M5	5.0	0.5	0.2	10

The differences in assumptions and approach to designing road lighting presented above make it impossible to directly use STV for designing road lighting according to requirements and recommendations in Europe. Naturally, such barriers can be generally overcome with different variables, such as the object's angular diameter or age factor, but it is required to specify appropriate Visibility Level as evaluation criteria, taking into account the differences present between the used standards.

More serious concerns when evaluating the Visibility Level are raised by simplifications assumed for STV, as presented in point 4.

6 Summary

The driver's main visual task is to spot objects in the traffic lane or in its background. Road traffic comfort and safety are increased if obstacles are spotted quickly and easily. All over the world, research projects on road visibility are under way. Attempts are made to find answers and clarify doubts, and the results of such research will make it possible to formulate a criterion to evaluate visibility when taking into account conditions which do, in fact, reflect lighting situations and road visibility conditions for drivers.

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Section 4
Indoor lighting design and applications

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A critical analysis of the methodology for calculation of the Lighting Energy Numerical Indicator (LENI)

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Abstract

Energy certification and labelling of buildings according to the Commission's Energy Performance of Buildings Directive concerns four main energy consuming systems with lighting as one of them. Previously there was neither practice nor experience with certification of lightings systems. First practical experience brought a series of questions and problems to be solved on methodological level. Main goal of the paper is to treatise on identified problems with evidence shown on practical case studies. Imperfections in the light of stressed necessity to run the certification process evolved a big amount of research works performed in order to improve the methodology and to investigate energy saving potential in buildings with new approaches. For each individual problem a solution is developed, which is now already implemented to the legislation on national level and put in practice. It is expected that these solutions may help to improve the current methodology by revision of the standard and this way to become a broader acceptance. Practical experience will help to support this effort. Solutions are introduced in this paper.

In final part of the paper, a software tool developed for calculation of LENI is presented. Important feature of the software named EHB LiteCalc is that all steps of calculation can be separately inspected, also giving the user possibility to enter the calculation process by inputting manually forced values. This special option can serve for experimental purposes.

Keywords: energy efficiency, energy performance of buildings, lighting energy, LENI.

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1 Introduction

With the rapid increase of human population resulting in higher energy demands day by day, critical level of greenhouse gas emissions (particularly CO_2) has already been reached. Thus, many studies, actions and implementation plans have intensively been realized for more than ten years. Since it is a global threat, the Kyoto Protocol which is a protocol of the United Nations Framework Convention on Climate Change (UNFCCC), was adopted in 1997 and entered into force in 2005 with the goal of achieving stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system [1, 2].

In the EU political and economical area, several directives referring to the Kyoto protocol aiming to the reduction of greenhouse gases have already been published. European Parliament and the Council adopted the Directive on Energy Performance of Buildings (EPBD) 2002/91/EC [3] on December 16, 2002. Main goal of the directive is to improve the energy efficiency of buildings. Four main areas have been identified, where lighting systems play an important role – as in lighting there is huge energy saving potential expected due to very fast technological development.

EU member countries were obliged to implement this important directive into national legislation not later than January 4, 2006. National Parliament of the Slovak Republic fulfilled its obligation by release of the Act No. 555/2005 [4], prepared by the Ministry of Construction and Regional Development under tight collaboration with experts responsible for individual energy systems concerned. Requirements for lighting and issues relevant to lighting have been prepared with participation of authors of this paper. Basic methodological principles, having force of legislation, are today given by the Ordinance No. 311/2009 [5]. By this ordinance, practical experience and identified problems and difficulties with certification, described in this paper, have been reflected by relevant solutions. Technical details of the methodology for lighting are covered by EN 15 193:2007 [6]. Although there are many considerations on lighting systems and building properties related to lighting in this standard, some problems occurred during implementation process are necessary to be solved in order to make its best implementation in practice and to achieve accurate and comparable results. Slovak Republic developed his own national methodology [7] introducing new approaches to some of the relevant problems. Turkey also prepared his national methodology, which came in force by December 5th, 2009. Bringing the EPBD and EN 15193 in particular into practice is the subject of a joint effort within the European CENSE project [8].

2 Theoretical background

The European standard EN 15 193 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 used for certification purposes. It also provides guidance on the establishment of notional limits for lighting energy derived from reference schemes.

The standard can be used for existing buildings and for the design of new or renovated buildings. It also provides reference schemes to base the targets for energy allocated for lighting usage and also provides a methodology for the calculation of instantaneous lighting energy use for the estimation of the total energy performance of the building.

Energy consumption related to building area is defined as a *Lighting Energy Numeric Indicator* (LENI) in kWh/(m^2.year), which can be established using the following equation:

$$LENI = \frac{W_L + W_P}{A} \tag{1}$$

where

W_L - lighting energy for illumination (kWh/year)
W_P - parasitic energy (kWh/year)
A - total useful floor area of the building (m^2)

Lighting energy required for fulfilling the illumination function and purpose in building shall be established using the following equation:

$$W_L = P_n F_C F_O \left(t_D F_D + t_N\right) \tag{2}$$

where

P_n - installed power of the lighting system (kW)
F_D - daylight dependency factor (-)
F_O - occupancy dependency factor (-)
F_C - constant illuminance factor (-)
t_D - daylight time usage (h)
t_N - non-daylight time usage (h)

Parasitic energy is estimated using equation that incorporates total installed parasitic power for standby energy of the controls and charging power of the emergency luminaries regarding the charging time of emergency luminaries. Details can be found in the norm [6].

3 Identified problems and recommended solutions

3.1 Insufficient lighting levels

Having the correct lighting standard in buildings has utmost importance and the convention and procedures assume that the designed and installed lighting scheme conforms to good lighting practice. For new installations withindoor work places the design should be with respect to EN 12464-1 [9]. Thus, in order to compare buildings between each other, estimated energy consumption of lighting systems should be determined in all buildings that are assumed to fulfill the lighting criteria particularly the average illumination level. If this cannot be satisfied, then required energy demand for lighting will be considerably lower.

This situation may mislead the certification process into inconvenient situation that will prevent the comparison possibilities between buildings. Therefore within certification it is necessary to check illumination levels according to relevant technical standards.

As a common approach, the energy consumption values can be normalized to values that can provide required illumination levels. One of the proposed approaches how to avoid invalidity of assessments is based on an additional *Maintained Illuminance Factor* F_{em} which is introduced to the Eq. (2) aside other factors. Now the Eq. (3) becomes a new form as follows:

$$F_{Em} = \frac{E_r}{E_m} \tag{3}$$

where:
E_r - required illuminance level (lx)
E_m - measured illuminance level (lx)

Note, that the maintained illuminance factor is more than one for buildings (or rooms) with insufficient lighting. If measured illuminance is higher than required, the maintained illuminance factor is set to $F_{Em} = 1 =$ const. F_{Em} is to be determined by proper measurements of selected rooms with emphasize on illumination of workplaces. The following rules shall apply:

- If possible, calculations should cover all rooms of a building. Then F_{Em} values and W_L shall be calculated for each room separately.
- Otherwise rooms shall be sorted descending according to installed power.
- Rooms shall be selected for verification until representing at least 50% of the total installed power.
- Rooms shall be selected for verification considering the usage time; rarely used rooms should be ignored.
- If there is enormous number of rooms in a building, similar rooms shall be taken as duplications. In addition, 20% of rooms can be considered as a sufficient sample for validation of lighting criteria.
- Average F_{Em} values shall be calculated for the selected and measured rooms and used to multiply W_L for the building as a whole.

Certainly, there can be several approaches to reduce the number of measurements bringing a selective modality to assign the rooms to be measured. Since installed power is mentioned as a selective parameter together with usage time, third bullet of the list above applies. If there are several rooms with lower areas, it can still be unpractical to achieve the 50% level and therefore the 20% sample under the fifth bullet shall be preferred. Note that proposed ratios are draft values and should be determined by experimental and statistical approach on national level.

A different kind of approach is to introduce a punitive factor similar to F_{Em}, with a constant value. This approach is implemented in the Slovak National Methodology [7] where a factor of three is used. This number comes from practical experience with hygienic measurements of illumination of workplaces (a legislative requirement for successful commissioning of buildings) and auditing of older buildings. Statistical evaluation of numerous measurement results showed that, in average, illuminance is only about one third of the current normative requirement. Sounds to be suspiciously low, but this is an everyday reality for both of old existing buildings as well as new constructions. As results of small survey performed in last year showed, lighting designers almost do not exist here and their job is taken by designers of electrical installations who are not skilled for the task, then they mainly draw from what they can see in older buildings, also what the illumination levels concerns. The least efficient solutions with rectangular modular 4x18 W fluorescent lamps are most popular even for the most demanding and representative interiors. Hence the factor of three.

This approach has been implemented in time when the mentioned problem was just identified and quick solution was needed. Approach with F_{Em}corrections took place in later stage. However, a punitive approach needs not to be deemed as too rough. To fulfill light quality criteria is a normative obligation with corresponding responsibility. If measurements in arbitrary selected rooms give evidence of violation of these requirements, it is not the task of certificant to evaluate as accurate as possible correction factor in order to come closer to generally acceptable results. Thus, lighting system may obtain good ranks if incorporating energy efficient solutions although do not duly fulfill its lighting task. Punitive approach will always point to bad systems and force investor or building proprietor to make improvements, followed by new certification process. This is in scope of the Directive.

Let us have now a closer look to the punitive approach and its procedural aspects, as these have been fully elaborated by authors of this paper. Verification method should be undoubtedly based on measurements; visual inspection can lead to excessive subjective errors. For the purpose, simplified measurement methods may take place. If e.g. for the commissioning of buildings protocols of (much more precise) measurements are available, these can be fully regarded. Otherwise certificant should select 10% of the total number of rooms for measurement as a minimum. Details are not prescribed; it is assumed that certificant is a high-skilled expert who is able to make a good choice. It is necessary to mention that the method has been proposed as a legislative tool for certificant helping him to avoid ranking high those lighting systems that are under dimensioned. Illuminance levels should be checked in sufficient number of measurement points and on critical places, points need not to be arranged to a grid. 10% of all measured rooms may still fail to fulfill the criteria.

Having in mind pros and cons of F_{Em} approach vs. punitive approach, it is expected that the first will substitute the latter in Slovak national method by its next revision. Further research works are still needed here.

3.2 Quick method usability

The quick method is intended for lighting design. Its simplification versus the comprehensive method naturally leads to higher values of energy consumption, what is also mentioned in the European standard EN 15193. As a consequence of the quick method philosophy, calculations need not to be performed room by room but for building as a whole what is a significant simplification. Thus, total installed power of lighting systems in a building is taken as a single number.

Lighting installation usage times t_D and t_N for daylight and non-daylight operation hours have critical influence to the resulting value (of consumption and thus for LENI as well) but the norm do not provide any standardized method how to calculate them (further explanation can be found in Section 3.3). Instead, for the quick method standard tabelized values are provided. Their relevance is discussed in Section 3.4.

Factors F_D, F_O and F_C help to reduce the energy consumption for lighting assuming that if there is available daylight or if rooms are not occupied, eventually if a system compensating the MF is installed; lighting is not working on 100% in the whole building and during the whole operation time. It can be expected that influence of these factors is very critical. Using the comprehensive method, these factors are to be obtained by calculation. For the quick method, benchmark values are provided, though, both F_D and F_O are not too far from 1 and manually operated systems have these factors always equal to 1. As a results, energy consumption W_L and/or LENI are then much higher than by using the comprehensive method. As in Slovak Republic the energy efficiency classes are defined separately also for lighting (and all other sub-systems as well), usage of the quick method leads to a difference of three or even more classes in comparison to the comprehensive method while we can desire the maximum one class difference.

It can be concluded that using the normative benchmark values makes the quick method unusable. Therefore, in Slovakia national standard values of F_D, F_O and F_C factors have been established (see Tables 1 and 2), derived from statistical evaluation of buildings assessed by the comprehensive method, i.e. averaging the factors from room-per-room values. It is evident that considering full operation of lighting with manual control is an overestimation. In any building, besides main rooms with workplaces, there is a significant portion of auxiliary rooms like toilets, washrooms, corridors, stairs and a lot of storage rooms where almost nobody enters during all the day. It is not smart to take full-time operation of such rooms even if manually controlled. The same is for daylight availability. Even if no light sensor is installed and lighting is controlled manually, at sufficient daylight occupants do not switch-on their lighting. Automated systems undoubtedly help to reduce power but manual control must not be underrated.

Parasitic power is another question for consideration. The quick method offers, where the parasitic energy consumed is not known explicitly, standard values consisting of 1 kWh/(m^2.year) for emergency lighting plus 5 kWh/(m^2.year) for automatic lighting controls if used. As it was shown in practice, the mentioned figures are much overestimated and undesirably contribute to high consumptions. First, if there is no any emergency lighting or lighting control in a building, W_P should be taken as zero. Else it needs to be either calculated like the installed power or to use nationally derived standard values. In Slovakia, standard value based on practical experience has been set to 0,5.

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Table 1: Lighting control strategies.

Lighting control	Group
Manual: ON/OFF without sensors	R1
Manual: ON/OFF with sweeping signal	R2
Motion detector: auto ON + dimming	R3
Motion detector: auto ON + auto OFF	R4
Motion detector: manual ON + dimming	R5
Motion detector: manual ON + auto OFF	R6
Photo sensor: manual ON + constant illuminance dimming	R7
Photo sensor: daylight control switching or dimming	R8
Central control	R9

Table 2: Slovak national values of daylight factor F_D and occupancy factor F_O for the quick method.

Factor	F_D			F_O			
Building category	R1 – R7	R8	R9	R1 – R2	R3 – R6	R7 – R8	R9
Office buildings	0,92	0,85	0,92	0,7	0,5	0,7	0,6
Schools and edu buildings	0,92	0,85	0,92	0,5	0,4	0,5	0,5
Hospitals	0,92	0,90	0,92	0,9	0,9	0,9	0,9
Hotels	0,92	0,92	0,92	0,8	0,7	0,8	0,8
Restaurants	0,98	0,98	0,98	1,0	1,0	1,0	1,0
Sport facilities	1,00	1,00	1,00	1,0	1,0	1,0	1,0
Wholesales and shops	1,00	1,00	1,00	1,0	1,0	1,0	1,0

3.3 Calculation of daylight time and non-daylight time usage

Comprehensive method requires determination of annual daylight and non-daylight time usage for calculation of the estimated energy demand of a building. There had been defined a methodology integrated in the first draft of the standard EN 15193, but composed equations were nonfunctional, hence excluded from the final version of this standard. As a result, there is no guideline for authorized certificants how to determine the daylight time and non-daylight time usage.

The proposed method is inspired by original procedure of the draft version of EN 15193 and Slovak studies utilizing experience in the field of solar energy engineering, involving various approximation formulae. This method is standardized within the Slovak National Methodology and with slight modifications adopted also for Turkish conditions. The calculations are proposed on a monthly basis.

Annual daylight time usage t_D (h/year) and non-daylight time usage t_N(h/year) is calculated by summing up the respective monthly values $t_{D,I}$ and $t_{N,i}$:

$$t_D = \sum_{i=1}^{12} t_{D,i} \quad t_N = \sum_{i=1}^{12} t_{N,i} \tag{4}$$

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Daylight time usage $t_{D,i}$ (h/month) and non-daylight time usage $t_{N,i}$(h/month) for a given month "i" can be calculated as follows:

$$t_{D,i} = N_i C_{we} \left[\left(t_{end} - t_{start} \right) - \left(t_{bs,i} + t_{as,i} \right) \right] \quad (5)$$

$$t_{N,i} = N_i C_{we} \left[\left(t_{bs,i} + t_{as,i} \right) \right] \quad (6)$$

where:

N_i - number of days for a given month (monthly basis)

C_{we} - correction factor for weekends (-)

t_{start} - starting operation time of a building (FROM)

t_{end} - ending operation time of a building (TO)

$t_{bs,i}$ - operation time before sunrise (h/day)

$t_{as,i}$ - operation time after sunset (h/day)

Note that starting and ending operation times are now standardized in Slovakia, tailored for each building category (see Table 3). Number of days for a given month "i" (1 to 12) is taken from this set:
N_i = {31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31}

Weekend regime is regarded by means of the weekend correction factor C_{we} which is a ratio of working days to full week's 7 days. Time of sunrise and sunset are calculated by means of these equations:

$$t_{sunrise,i} = 12 - \frac{\omega_i}{15°} - \eta \left(\frac{J_i}{60} \right) \quad (7)$$

$$t_{sunset,i} = 12 + \frac{\omega_i}{15°} - \eta \left(\frac{J_i}{60} \right) \quad (8)$$

where:

J_i - order number for 15^{th} day of a given month "i"

ω_i - hour angle(°)

η_i - time equation (°)

Order number for 15^{th} day of a given month "i" (1 to 12) is taken from this set: J_i = {15, 46, 74, 105, 135, 166, 196, 227, 258, 288, 319, 349}.Time equation η_i can be calculated by means of the formula as follows:

$$\eta(J) = 0{,}0066 + 7{,}3525 \cos(J'+85{,}9°) + 9{,}9359 \cos(2J'+108{,}9) + 0{,}3387 \cos(3J'+105{,}2) \quad (9)$$

where:

J' = J.360°/365 isdate angle(°) (10)

For calculation of hour angle ω_i, the following equation is available:

$$\omega_i = \arccos\left[-\frac{\sin\varphi \sin\left(J'_i\right)}{\cos\varphi sos(\delta J_i)} \right] \quad (11)$$

where:
δ_i - solar declination(°)
φ - geographical latitude of a building(°)

Declination δ_i can be calculated as follows:

$$\begin{aligned}&\delta(J) - 0{,}3948 - 23{,}2559\cos(J'+9{,}1°) - 0{,}3915\cos(2J'+5{,}4°)\\&+ 0{,}1764\cos(3J'+26{,}0°)\end{aligned} \tag{12}$$

Procedures given above are algorithmized and standardized in the Slovak National Methodology. The idea was to keep the philosophy of the first proposal of EN 15193, which finally has not been published, and to make corrections in order to satisfy the functionality and to obtain valid results. To ensure standardization, starting and ending time of building operation have been set constant in dependence on building category, but unfortunately C_{we} was omitted from this standardization. Certificants now experience confusedness in practice, using different weekend correction factor with a significant influence to results.

For Turkish conditions, Slovak National Methodology has been used as a basement. Modifications to some of the formulae like (7), (8) and (11) have been made. Improvements incorporate also the daylight saving time. As a next step, further development of the Slovak National Methodology is under preparation. According to new proposals, calculation of declination and time equation are based on approximation formulae by Dogniaux in Kittler and Mikler [10]. Daily calculation basis is preferred now against the monthly basis. Average monthly values can be still used for the sake of simplicity but now calculated by new formulae. Previous philosophy of the draft EN 15193 is released. It is expected that new procedures will increase the accuracy of calculations and will be tailored to the European conditions.

What concerns the C_{we} factor, new approach is studied. Before, this correction factor only adjusted the weekly operating time by ratio of the number of working days over 7 days of the week. This approach seems to be too rough. Operation during Saturday and Sunday much differs from operation behavior during normal working weekdays. While most of the buildings (administrative, educational) have reduced weekend operation (if any) while other building types may have emphasize right on weekends – like some sport facilities or shopping malls. Thus, a different approach is needed here.

3.4 Determination of building operating hours

As mentioned before in Section 3.2, operation hours are closely linked to the energy consumption. The standard EN 15193 encourages us to use real operating hours of buildings in calculations. Turning attention to objectives of the Directive, such approach cannot be accepted. Aim of the efforts is to compare buildings of similar functionality between each other what concerns their energy demand. Only and only technical properties of buildings shall to be considered, in no case the behavior of their occupants.

An example can explain how serious this problem is. Let us have two buildings of the same functional usage, of the same construction and dimensions, with the same type of lighting system etc. The only difference will be in operating time. While first of the buildings will be operated e.g. since 7 am to 16 pm, the other one will have non-stop all-day-round operation. This situation was noticed amongst first certificates made in Slovakia, 24h-operation was in a dispatcher centre of a natural gas provider. Of course, as expected, the energy consumption for lighting in non-stop regime was three times the consumption in the other building, therefore with very bad ranking (G class). But properties of buildings are to be labelled, not if the building is used part of day or whole day. For this reason, operation times have to be standardized regardless on real usage times. May be such a way energy consumption will not be a precise realistic value, what is not the aim indeed, rather it will be a value comparable to other similar buildings calculated the same way and under the same standard conditions.

To give a solution, operation times have been standardized. For the quick method, annual operation times have been provided. For the comprehensive method, standard operation times are given in a FROM – TO format, necessary for daily and monthly based calculations (Table 3).

Table 3: Default annual operating hours for the quick and comprehensive method.

Method	Quick			Comprehensive	
Building category	t_D	t_N	t_O	FROM	TO
Office buildings	2250	250	2500	7:00	16:30
Schools and educational buildings	1800	200	2000	7:00	14:30
Hospitals	3000	2000	5000	7:00	21.00
Hotels	3000	2000	5000	7:00	22:00
Restaurants	1250	1250	2500	7:00	22:00
Sport facilities	2000	2000	4000	7:00	20:00
Wholesale and shops	3000	2000	5000	7:00	20:00

4 Development of software tools to aid calculations

Complicatedness of methodology does not allow calculation other than by means of computeral tools as all the procedures must be performed for each individual room. Due to differences between national conditions, mainly country specific software is being created. Philosophy is based on the idea of normative methodological core and adjustment of national databases and conditions.

Another question is if there should be common software for all sub-systems or three-four independent programs for experts active in their field. It seems, and first experience give a clear evidence, that independently acting experts have just a little chance to meet using one tool, what is unpractical and time consuming. Independent software are therefore prepared instead. In Slovak Republic the state of the art follows this philosophy and it is supposed to possibly tie these programs together in future via generally agreed data exchange format (some R&D work is still needed here).

Authorisation of software is also a matter of discussions. The question is, if there should be a body responsible for verification of commercially manufactured software or there will be no guarantee for the software usage. Current decisions made in Slovakia follow the principle of liberal market without authorisation. It means, in fact, that software must be assumed as a tool for certificants, while certificants are fully responsible for their results. It practically means just one – certificants must be provided for all the interim results, they need to have an option to watch, check, inspect and modify every single result throughout the calculation procedure. And software has to allow this.

EHB LiteCalc (comprehensive method) and EHB QuickCalc (quick method) [11], developed by Typhoon, are examples of software supportive tools having these features. EHB LiteCalc (actually in version 3) is based upon well known and highly accepted excel format what makes it very easy to use. The newest version is available with improvements of calculation procedures and user environment. It should ease the work of certificants and to provide new options. Currently the software has implementation of Slovak and Turkish methodology, Czech version is under preparation and there is possibility to extend this software to any other national conditions. For general usage there is English version available with basic normative methodology (free of national modifications).

5 Conclusions

Energy certification of buildings is still an unmatured process. Most of work is still up to come as problems and imperfections arise from current practical experience with certification. This creates a big amount of research works to be performed, in order to improve the methodology and to investigate energy saving potential in buildings, to find out new approaches – all this is a challenge for all who want to add a value to the process leading towards such important aims like limitation of greenhouse effects and climate change.

Insufficient lighting is one of the most important problems that mislead the certification process and need to be considered in every adoption process. Quick method is found as unusable with normative benchmark values. As the standard excludes procedure for determination of daylight and non-daylight usage time of buildings, national methodology should be offered as a guideline which is a need for majority of certificants.

Slovak National Methodology is a pioneering document drawing from conscious approach to the practical implementation of the Directive. It is a very positive fact that the field of lighting was let to lighting experts, unlike in series of other countries where all fields are covered by civil engineers with lacking knowledge of lighting. What concerns the methodology itself, experts from other countries may learn from the experience though national adjustment of criteria may be needed. And vice versa, there are still a lot of questions to be solved and even current solutions are still open to further improvements.

Turkey recently developed his national methodology as well. It incorporates many improvements of previously available methods that have been studied in the preparatory phase. First certificates and audits will confirm if national conditions have been correctly set. There is also big potential for further improvements and for significant contribution to the continuous development of the European methodology.

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A lighting study for air traffic control towers

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Abstract

The purpose of this work was to determine the characteristics of glass and natural and artificial lighting systems capable of achieving, within the operating rooms of the air traffic control towers, the optimal conditions in terms of visual performance and comfort, within a framework established by law, from energy conservation, the availability of materials, ease of maintenance, security. The solutions identified, although the result of a compromise between different environmental and functional requirements often conflict with each other, were still subject to the need to ensure the proper and safe view of the external environment by air traffic controllers.

The methodology, given the complexity of the problems arising from the interaction between various parameters, is based on different and successive levels of detail, each of which is in preparation of the next. In particular, starting from a lumped parameter-analysis that considers only the global aspects of the problem and identifies the main characteristics of materials and systems used, is followed by a study of distributed parameter to analyze in detail the visual aspects and solutions possible, before arriving in the creation of design specifications whose validity has been verified by studying a case type. The different levels of analysis can be summarized as follows:

1. Lumped parameter analysis
2. Distributed parameter analysis: visual environment
3. Distributed parameter analysis: case study

Keywords: air traffic control towers, control room, natural lighting, artificial, lighting, glass, curtains, dimming, visual comfort.

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1 Introduction

The purpose of this work was to determine the characteristics of glass and natural and artificial lighting systems capable of achieving, within the operating rooms of the air traffic control towers, the optimal conditions in terms of visual performance and comfort, within a framework established by CIE (Commission Internationale de l'Eclairage) Standards [1–4], from energy conservation, the availability of materials, ease of maintenance, security. The solutions identified, although the result of a compromise between different environmental and functional requirements often conflict with each other, were still subject to the need to ensure the proper and safe view of the external environment by air traffic controllers.

The methodology, given the complexity of the problems arising from the interaction between various parameters, is based on different and successive levels of detail, each of which is in preparation of the next. In particular, starting from a lumped parameter-analysis that considers only the global aspects of the problem and identifies the main characteristics of materials and systems used, is followed by a study of distributed parameter to analyze in detail the visual aspects and solutions possible, before arriving in the creation of design specifications whose validity has been verified by studying a case type. The different levels of analysis can be summarized as follows:

- Lumped parameter analysis

The purpose of this first level is the identification of the main characteristics of the materials, particularly glass surfaces, to ensure both a low-energy and visual comfort (integrated analysis). The instrument used for this purpose is a kind of lumped-numerical simulation.

- Distributed parameter analysis: visual environment

The purpose of this second level is the identification of the main characteristics required to artificial lighting and natural in terms of performance and materials in order to obtain specific environmental and functional tower operations rooms in accordance with the regulations and based on information obtained from interviews, site inspections and measurements made in control towers of different importance and different sizes.

- Distributed parameter analysis: case study

The purpose of this third level is to evaluate in detail, on a real case, the results obtained on the basis of lighting design choices resulting from the first two levels, using commercial components. The type of material is further defined and specified, developed in the analysis than in lumped one. Different distributed parameter simulation packages were used, in order to reach the purpose applied to the geometry of the control room of a major Italian airport.

2 Lumped parameter analysis

The purpose of this section is to identify the optimal value which the following parameters must have:

- Transparency and inclination of the glass surfaces
- Accommodation and transparency of internal screening components
- Type of lighting control system

The range of variability of these parameters within which to move to carry out the optimization, it appears to be rather limited as determined by common and established practice systems and some general rules related to the basic mode of operation of control rooms and on CIE Standards [5–7]. In particular, to reduce dazzle and reduce heat loss, the glasses are normally used transparencies in the visible range between 35% and 50% and shall be put in place with inclinations between 5° and 30°, mainly to limit fouling, while the thermal transmittance range between 1.3 and 2 [W/m^2 K] and are always accessible with the use of double glazing, and possibly with low-emissivity layer. Internal screening components consist of motorized blinds, controlled manually, which has transparency between 20% and 50%. As for artificial lighting, the limit is represented by the European Standard EN 12464-1 [8], which provides an average illuminance of 500 lx dimmable; in particular, by an analysis of existing towers, reducing the flow of light is normally manually operated and this specific control is referred to the illumination of the working field, operated locally by each controller, while general lighting is centralized. The optimization is performed by using a numerical package, able to integrate aspects of thermal, natural and artificial lighting, the occupants' interaction with the systems of internal screening and control of the flux emitted by the lamps. The optimization parameter, once the visual and thermal requirements are guaranteed, is the total energy consumption.

The data used for the calculation are:

- latitude and external climatic conditions
- illumination of interior design
- design of the indoor temperature and humidity conditions.

The need to obtain results in terms of lighting and energy comparable with each other for the different Italian climatic conditions, imposed to pre-establishing the size of the analyzed system, in order that all calculations refer to the same geometry.

2.1 Methodological approach

An analysis software, for the simulations, has been developed: it's a both of thermal and lighting energy integrated, consisting of a central thermal analysis interacting with sub modules that perform lighting calculations, simulations of control strategies and people interact with systems control. The program is based on the method of heat transfer functions TFM (Transfer Function Method), SATF (Air Space Transfer Function) in order to calculate the heat extracted and environmental temperatures. The module uses the lighting calculation program "Superlite" [9], which interacts with the program using its thermal calculations of solar radiation, solar elevation and azimuth.

The meteorological data used as input of the simulations are the TMY (Typical Meteorological Year). The TMY hourly climate data are sequences most likely derived from calculations based on measurements made over two decades in major Italian cities using data from the stations of the Italian Air Force Weather Service; they report hourly data outside temperature, radiation direct sunlight and diffused in the horizontal plane, speed and wind direction, relative humidity, and were obtained by combining sequences of actual months. The simulations were performed for the city of Rome (latitude 42°N), Milan (latitude 45°N), Catania (latitude 38°N).The change in the slope of the glass structure was planned in three steps, 0° (angle of reference), 15° (slope of the proposal) and 30°.The room is operational at any time throughout the day, with conditions of temperature in the range 20÷26°C depending on external environmental conditions. Interior heat load consists of the people, machines and lighting.

We considered two different commercial glazing systems:

- A double glazing which represents the average solution found during the inspections carried out in various Italian airports Control Towers. This system, shown in the simulations and diagrams with code EN1 is colored green/blue with a transmittance coefficient of 0.35 in the visible and thermal transmittance of 1.7 W/(m^2 K).
- A double glazing with outer pane constituted by a low emissivity and non-reflective deposit on surface 2: it has a “solar filter” behavior too. This system, shown in the simulations and diagrams with code EN2 is colored green, with a transmittance coefficient equal to 0.42 in the visible and thermal transmittance of 1.6 W/(m^2 K).

The control of natural light is obtained by closing motorized curtains operated directly by the operators. The management of the curtains has been suggested to be of linear type with adjustable phasing as a function of dazzle on the basis of site inspections carried out, the type of activity, the types of curtains used which severely limit or even prevent the external vision. In order to have best results, we analyzed the case in which the curtain is closed in the presence of dazzle (on/off) and the case in which the curtain is completely open; the second situation, based on studies carried out in offices, appears to be more likely in case of very light curtains, which allow both of the outside view and dazzle, produced by light scattered by the sky, protection. The same issues of simulation of human behavior occur in the management of the dimming of the lighting. In this case, since the actions are strongly influenced by the air traffic, we analyzed two opposite behaviors: completely off or turn on the light (on/off) dimming and on one or more areas.

2.2 Energy and lighting analysis

The results that have been reached are presented first to the analysis efficiency, and then in terms of lighting performance. The abbreviations used generally cover glasses (EN1, EN2, to indicate the two different types of glass referred to), the slope of the structure, which is explicitly mentioned in the angle of

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inclination to the vertical (0°, 15°, 30°), the type of regulation imposed on the system of artificial lighting (3d, 2d, 1d, 0d denote the setting or "dimming" to 3, 2, 1 zone, or on/off), the adjustment of curtains (or index on/off, or to fully open or fully closed, L shows a linear setting), the type of curtain (as described above, tA, tB, tC). The analysis of the results was conducted in steps, for each parameter, in order to reach some general conclusions, involving the variability of many parameters of interest for the study.

In order to evaluate the effect of different types of curtains, the use of glass EN2 was analyzed: since it's lighter than all'EN1, EN2 requires a more frequent use of the system of internal shading, and has a greater influence on energy demand. From this preliminary analysis, (Figure 1), it's possible to show that the choice of curtains is on average negligible in terms of energy, because it has a maximum variation of less than 4.5% in the worst case corresponding to the use a vertical glass and a light management of the on/off. The three curtains, substantially, lead to the same result as the energy behavior: so the different parameters will always refer to the curtain tA.

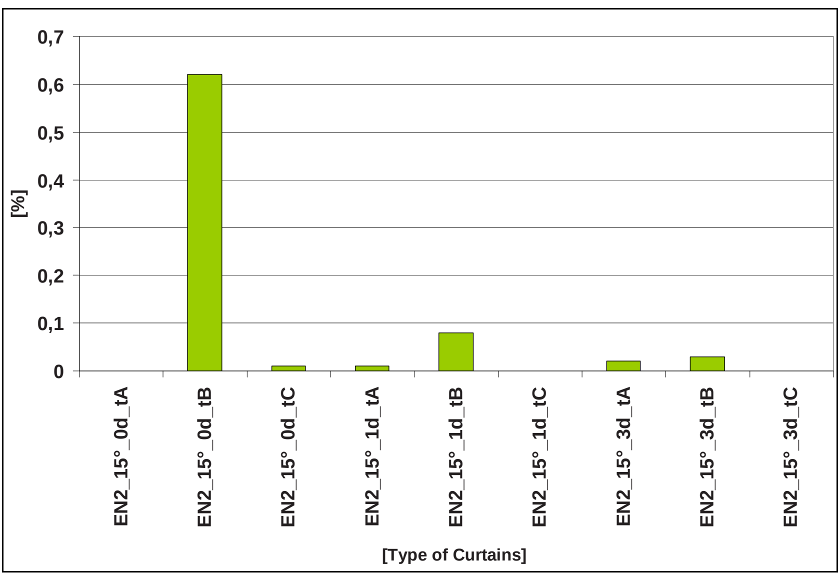

Figure 1: Rome case study: percentage change in consumption: glass EN2, linear adjustment of the curtains, structure with 15° inclination and dimming 0, 1 and 3.

The influence of the inclination of the windows and the dimming are shown in Figure 2 for the glass EN1 and EN2.

From the results, it is clear that the use of more complex control of artificial lighting may be unnecessary, since the percentage differences in consumption are significantly small.

Moreover, the use of a tilted transparent solution is on average, more efficient, if its slope is not excessive. The optimal solution is indeed to be angled 15° from the vertical, as more fully shown in Figure 3 and Figure 4, respectively, with the glass and EN1 EN2. In particular, we can see that a simple increase from 15° to 30° can lead to increased consumption of up to 7.0-7.5% for glass EN2 and up to almost 8.0% for glass EN1. The influence of different types of dimming is very sensitive to the corner assembly, tending to fall in step vertical to the inclination of 30 degrees; in particular, we found maximum variations of 20% in the case of glass EN1 passing the case on/off dimming up to three zones.

The results obtained for the different energy behavior of the two windows considered, show that the structural solution at 15° tilt is the best, regardless of the type of glass used. In this case, the glass EN2 is much better than the glass EN1 in terms of energy, especially if applied on a moderately sloped structure; moreover, the increase in complexity of the control system of artificial light from 1 to 3 dimming zones has little importance, since the improvement is around 0.8%.

The overall representation of the various cases studied is shown in Figure 5, and defines the guidelines for purely energy choice of the best solutions for designing Control Tower environments in the climate of Rome.

The same type of analysis, developed for other latitudes, although with small percentage changes in consumption values obtained in different cases, confirms all that we reported for the climate of Rome.

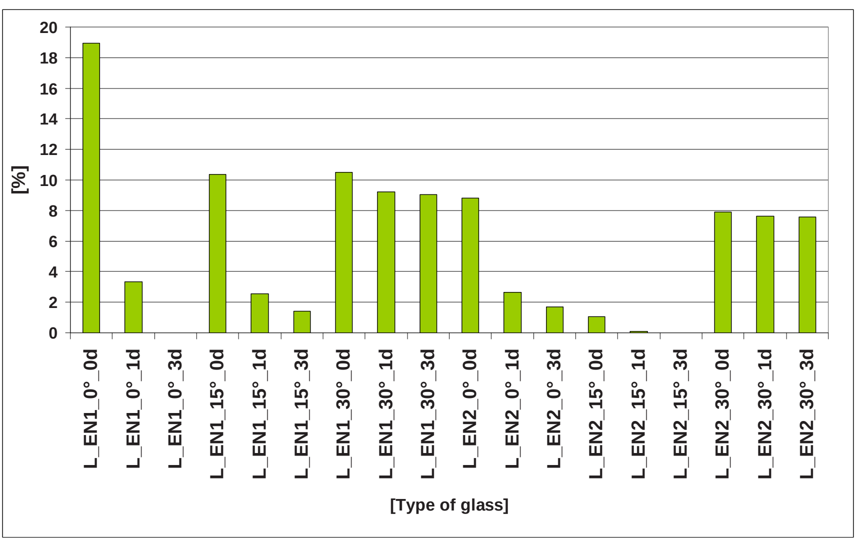

Figure 2: Rome case study: percentage change in consumption as a function of the control strategy of the lamps and the glasses (EN2 and EN1) linear adjustment of curtains.

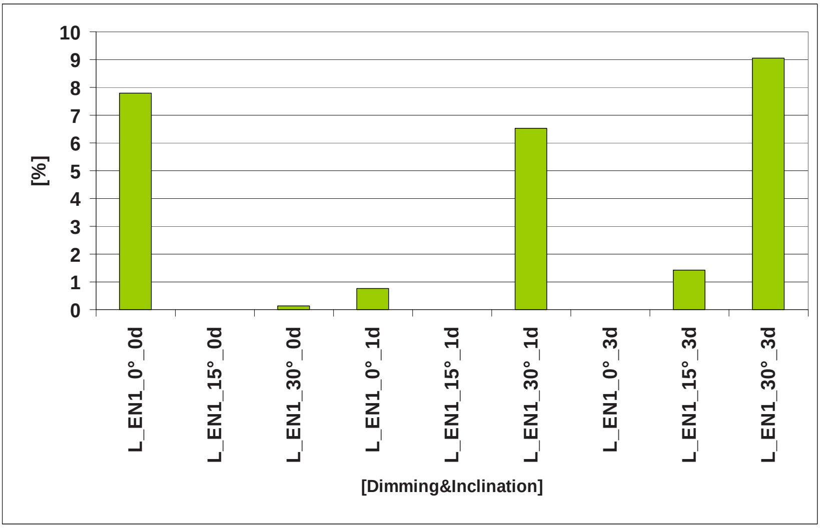

Figure 3: Rome case study: percentage change in consumption as a function of inclination and dimming; glass EN1.

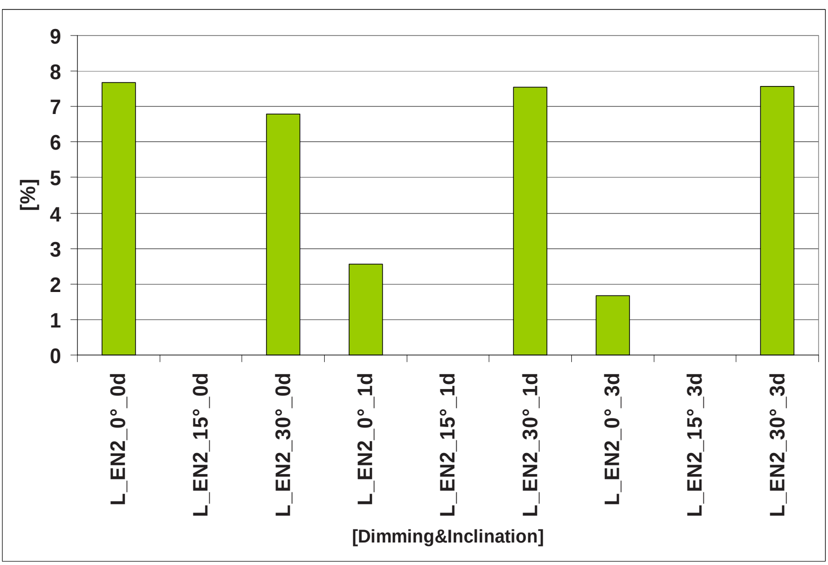

Figure 4: Rome case study: percentage change in consumption as a function of inclination and dimming; glass EN2.

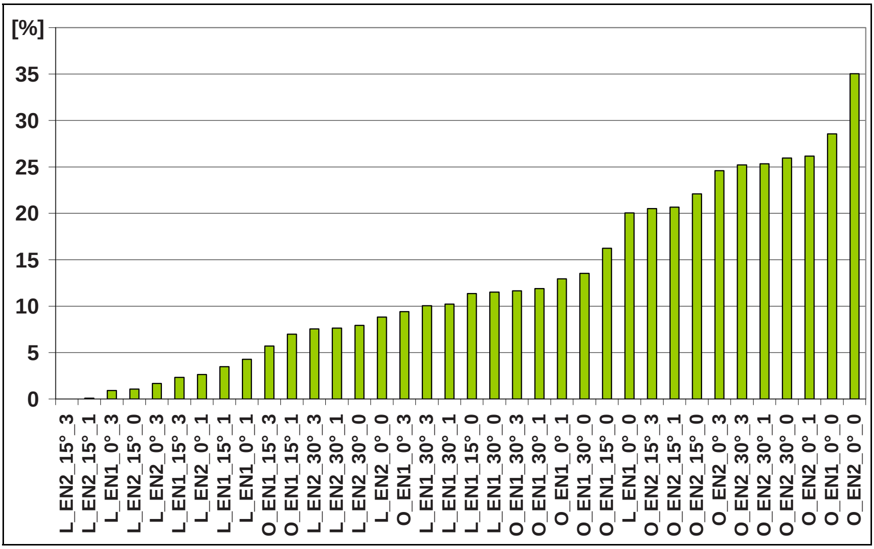

Figure 5: Rome case study: percentage change in consumption, overall analysis, and screen type tA.

2.2.1 Lighting results

This analysis deals primarily with natural light illumination; the annual distribution of illumination in the most disadvantaged point, generally and at the center of the room, has been studied for different control strategies and glass systems. In Figure 6, referring to the case of Rome, the annual cumulative distribution of natural light is shown; in other words it's the percentage of working hours in the period during which natural light is greater than a given value in the less illuminated environment. In Figure 14 we can observe that all control systems have an acceptable behavior, since they ensure a minimum of 500 lx for 30% of working hours throughout the day, including even the night. Various curtains have essentially the same behavior in terms of cumulative distribution, even if they differ in terms of protection from dazzle. The system EN1 shows a cumulative distribution percentage of 27% at 500 lx, with a structure 30° tilted, 35.5% for inclination of 15°, and 38% with a vertical structure; instead for the system EN2 these values become respectively about 30%, 37% and 41%. Due to its higher transmittance, glass EN2 shows increasing values of cumulative distribution than the glass EN1, and it's preferable both in terms of lighting and energy, because it reduces the number of hours that may become necessary for the use of artificial lighting to ensure the required value of lighting design. The inclination is very important in terms of lighting, and even in this case the inclination of 15° is much more preferable than a higher one, with differences of small percentage, which in this case are be very significant.

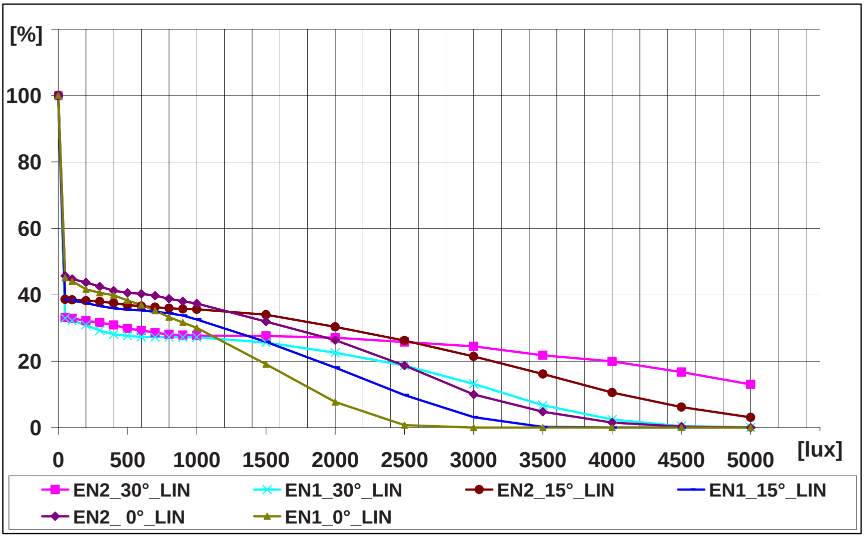

Figure 6: Rome case study: cumulative annual distribution of natural lighting: overall results, adjustment linear strategy of the curtains and screen tA.

Another interesting aspect is related to the internal behavior of the curtain: EN2, with greater visual transmittance, is characterized by a minor number of hours with light on, but also, for the same reason, the maximum number of hours with curtains closed, resulting in continuous shielding from the external environment and risk of exclusion from the outside for occupants.

2.3 Lumped Parameter Analysis: conclusions

The lighting and energy analysis were carried out independently, to show the characteristics of the different alternatives simulated. So it is clear that the best solutions are those with the most efficient in both performance testing. Based on the analysis carried out we can observe that:

- The glazing system must have a light transmittance greater than 35%, a low solar transmittance, less than 30%, and a low reflection coefficient (less than 11%);
- The glazing system must have an inclination between 12° and 15° from the vertical;
- the internal screen must have filtering capabilities to reduce dazzle and reduce energy consumption, against the direct and diffuse radiation; in particular the latter two functions may be delegated to two different curtains: the first, in face of the environment, which allows the vision of external objects, must have control function of the dazzle from diffused light, and the second one for direct light;

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- the installation of artificial lighting must be divided into zones and/or into dimming system that, depending on the activities, should be devoted to:
    - general lighting
    - lighting directed on the work area (task area)
    - transit lighting.

3 Distributed parameter analysis

The purpose of this part of the work is an accurate and detailed characterization of the issues related to natural and artificial lighting, in order to achieve a detailed definition of the performance requirements for systems and equipment. The tools at the base of the reached solutions are the use of the results obtained by the interviews with operators, the legislation and the technical and commercial aspects of the available materials. In particular, the goals of this analysis are:

- ensuring occupants an environment where the vision is efficient, accurate and precise as suggested by the specific regulations;
- ensuring occupants an environment where the vision is easy and comfortable; this means that the efficient realization of a vision should not cause discomfort, ensuring an appropriate degree of visual comfort;
- ensuring the proper integration of environmental impact of artificial lighting, which is optimal in terms of visual comfort and energy savings, by an appropriate choice of elements and strategies of regulation and control;
- safety, flexibility, durability, low cost of the system.

3.1 Visual environment

In the study of the visual environment, two different phases, having different objectives, can be identified.

The first phase, whose purpose is to provide the most detailed knowledge of the features of the control room lighting, is based on the survey and measurement of the main lighting and photometric characteristics of the situation in the different air traffic control tower.

The second phase takes into account the fact that the feelings more or less positive that you can try “living” environment, however, depend on the impressions of physical, physiological and psychological environment that creates in users. For this purpose a questionnaire was constructed as a way of investigation to better know the expectations of the users, air traffic controllers, and to evaluate the level of satisfaction of individual needs. This instrument, even if delicate and of difficult interpretation, allows to face the problem of vision globally. The environment of air traffic control tower, although in some aspects can be compared to an office for the presence of computers, has its own peculiar needs of visual contact with the external environment by the use of glass walls exclusively.

3.1.1 TWR control room lighting

Most of the information, in tower control rooms, is visual and affects primarily reading, handwriting and/or by computer, work with display screen and a visual check of the aircraft. So for a good vision it's important to have:

- suitable light source;
- uniformity of illumination;
- limitation of direct dazzle produced by light sources within the field of vision, and dazzle caused by the specular reflection of one or more objects that receive light from sources inside or outside;
- optimal color rendering;
- static and dynamic balance of luminance;
- control of the shadows;
- integration of natural and artificial light.

The EN 12464-1 provides an environment specifically for control towers, a value of average illuminance on the work plane of 500 lx, with reference to the average value of exercise guaranteed by the installation of artificial lighting, and that is the average state degradation of the system; the CIE (Commission Internationale de l'Eclairage) values are in agreement with these proposed regulations. The regulations also require that artificial lighting is adjustable, that the quality class for dazzle reduction is high, that the environment is considered as the type of environment with the visual task very difficult (for the standard EN 12464-1 UGR $\leq$ 16), that the color rendering index is Ra $\geq$ 80,that natural light dazzle is avoided, that duplication of reflections on windows and displays, especially in night time are avoided and that the reflected dazzle on the monitor is limited with luminance of furniture and reflex areas less than 200 cd/m^2. The investigations in the field have shown that operators use mainly during the night table lamps, with average illumination of 300 lx to avoid excessive contrast between interior and exterior environment. Regard to the illuminance values in the daytime period, the mostly transparent structure ensures values high enough and the assistance or intervention of artificial light is not required, except in periods of transition or, in special cases, to balance luminance contrasts. The situation is quite different for the problems relating to natural light, where there are no regulation advices, if not aimed at maximizing its use, clearly for reasons of energy conservation, while limiting the situations of discomfort caused by direct illumination and reflection caused by the same natural light. Another important aspect is the proper distribution of luminance in the field of view, taking into account the fact that operator activity is not conducted exclusively in a static way, that the operator doesn't focus on a particular plane and his activity takes place under dynamic conditions. The luminance values in the environment must be balanced as far as possible, in order to not have excessive contrasts in the direction of normal observation of the operators. To get a good visual performance, it is important to create a just and balanced distribution of luminance, but is not necessary the actual uniformity of the same. The human eye is able to adapt to an intermediate level between the luminance of the visual task and the surrounding areas, as a function of luminance, size, and position on the various areas within the visual field; as the greater the difference between these luminances, the more difficult the eye will be able to adapt to the environment, creating situations that can come to lead, in extreme cases, uncomforted situations. Everything is still valid and effective until it considers an artificial lighting system; it's a different matter when analyzing the problem from the natural light point of view, which inevitably creates differences difficult to manage, and is affected by unpredictable variations. Dazzle is mainly caused by excessive luminance values and luminance contrasts too high. For air traffic control tower it's quite difficult to eliminate the cause of dazzle produced by excessive natural luminance and luminance contrast, because the need to maintain a constant visual check with the outside prevents an appropriate and effective screening of the glass surfaces. Anyway it's possible to take lower transparency of transparent surfaces, compatibly with the energy introduced by this solution, and the shielding efficiency, possibly perforated, to allow effective screening and the ability to ensure the vision. In such work environment that we suggest a shade of neutral and warm light, as proposed by the regulations.

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Section 5
Light and human health

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Optimizing lighting design for hospital wards by defining user zones

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Abstract

When studying standards and recommendations for lighting in hospital environments, they often suggest a uniform light distribution to facilitate the needs of the staff. At the same time, the standards recommend a lighting design which supports the patients' feeling of a homely and pleasant atmosphere, however, they also point out that the light should not disrupt the patients' wellbeing. These two approaches are not necessarily consistent because the right quality and quantity of light in wards is highly dependent on the functionality of the space and the desired and expected lighting atmosphere of the space as well as a comparison of lighting design in private and public settings which are often not similar. The purpose of this article is therefore to present an approach dividing the hospital ward in 3 user zones for patients, staff and visitors. The main user of the zone should be in control of the light scenario. Thereby leading to a refining of the lighting design, so it has the ability to support the different users' activities and behavior on the ward.

By using RFID tracking and manual observations, we have analyzed and evaluated the ward functionality as well as the working environment for the staff. The method creates a better understanding of the ward by mapping the flow of the staff and related work situations, which thereby makes is possible to create zones within the space. These zones can be used as guidelines for lighting design with the staff assignments in mind.

Keywords: hospital lighting design, behavior mapping tools and methods, RFID tracking, manual observations, zoning of space.

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1 Introduction

Lighting plays an important role in the perception of space and atmosphere (Böhme [1], Jörgensen *et al.* [2]). Light quality is therefore a key element in creating pleasurable and inspiring environments for living, working and recreation.

Hospital design challenges many aspects of architecture and lighting due to the complexity of the space (Loe [3]). The ward has, unlike many other forms of spaces, very different user preferences and needs for light. It is therefore difficult to define pleasurable lighting conditions in this kind of multifunctional space (Ulrich and Zimring [4], McClughan *et al.* [5], Knez and Enmarker [6], Stidsen *et al.* [7]). The aim of this article is therefore to investigate how the space of the ward is used and how it can be defined as zones focusing on the different users' needs and preferences.

The tools and methods, which can be used for analysis and evaluation of the ward as a space of high functionality with different users, is going to be the main focus in this paper and the analysis will especially be looking at the staff as a case. The evaluation is based on the theory of Stidsen *et al.* [8] and Ulrich and Zimring [4].

The main focus of the paper is the staffs' working area, and their use of space and need for light. It discusses the possibilities of dividing the space into zones with different light settings according to the use of space. The results of this paper will be a part of the pre-studies used in the design process of a light installation at a hospital ward at the Department of Orthopedic Surgery at Odense University Hospital, Denmark. The studies will evaluate the presented zoning introduced in this paper and the method used to define zones through tracking and observation of staff.

2 Lighting in hospital design

The hospital ward is a 24-hour, seven days a week, working environment with different working conditions and patterns. In Denmark, the daylight conditions available in a room are changing throughout the year and depending on seasons. Almost all year round, the length of a working day is extended by supporting the daylight with artificial light, which thereby becomes a central element of everyday life at the hospital (Forster [9]).

Standards of light installations at hospitals are defined to ensure lighting that satisfies the need for visual assignments of the space. The guidelines do not give specific advice about placement of light but talk about the patients' and staffs' preferences of light. "*Patients have few visual tasks, but need lighting design that makes as pleasing surroundings as possible. The staff must have adequate lighting to perform their visually demanding work*" (Dansk Standard 703 [10]).

Attempts to save energy by underlighting are therefore a false economy, as without sufficient light, errors and mistakes increases, whereas overlighting creates a higher energy use than necessary (Ulrich [4]).

Previous research has revealed that the use of artificial lighting occurs to a much greater extent in the hospital environment than in normal commercial and industrial premises. The inconsistency of natural light often results in electric lighting being left switched on also when the light is not needed (Forster [9]).

Therefore, the understanding of the functions of the wards, the users' needs and expectations for lighting is crucial and important in achieving a pleasurable light atmosphere (Stidsen *et al*. [11]).

2.1 The design approach

The theories of the design approach are based on a model presented by Stidsen (Stidsen [8]). The model clarifies the parameters which are interplaying in the experience of light atmosphere in wards. "*The purpose of the model is to display the parameters influencing the judgments of the lighting design and form the basis parameters of a pleasant hospitalization*" (Stidsen [8, p.9]). The model introduces different elements that influence the atmosphere, the main elements being;

- Users
- Time
- Space
- Light source

The light source can be divided into daylight and artificial light. Daylight is mostly affected by the architectural layout of the space and the placement of windows, whereas artificial lighting, on the other hand, is meant to support the daylight. Time is affecting the daylight but time of day and season of year also influence the perception of light and thereby, also affects the need for light. The users can be divided into different groups as the patients, the staff (doctors, nurses, cleaning staff), and the visitors (family, friends), which all make the model specific for hospital wards.

The light atmosphere of the ward is crucial for the patients' experience of wellbeing, but there is a huge different in the requirements and expectations for light because of the different user groups [12]. The staff has to perform high demanding visual task such as examination and communication with the patients whereas the ward for the patients is not a work space but a space for rehabilitation and recuperation. The visitors are only using the space for shorter time periods where the patient is in focus (Stidsen [8]). This problematic is also described in Dansk standart 703 "*The requirements for lighting in hospitals are quite complicated because two different needs must be met, being both patients and staff*" (Dansk Standard [10]).

It is our experience that most ward lighting is satisfying or focusing on the staffs' needs for light, because of the uniform light distribution mounted to the ceiling. By zoning the ward and thereby defining "staff zone", "patient zone" and "visitor zone" it gives the lighting designers the opportunity to create a light scenario designed for needs, preferences and expectations for all users of the ward [13]. This article presents the study of the definition of the staff zone and

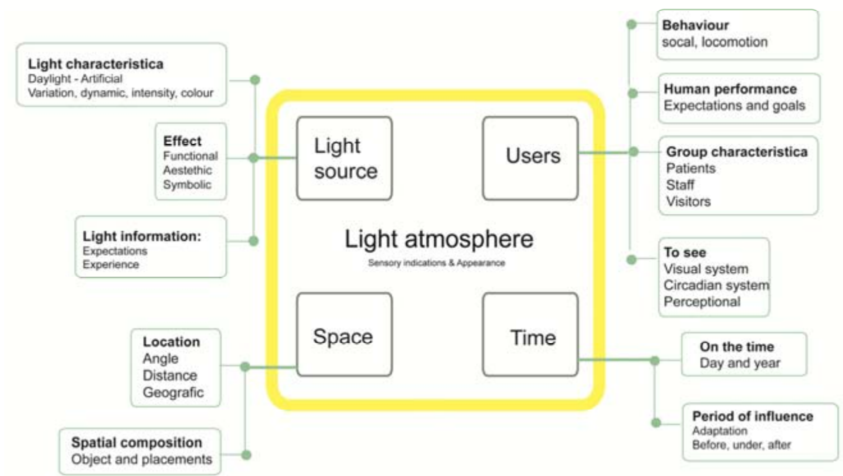

Figure 1: The model of parameters in light atmosphere in wards.

their need for light, thereby not saying that the other users play a less important role in creating a good lighting atmosphere. The focus is concentrated on the staff to clarify a part of the parameters that play an important role in creating a good lighting atmosphere in wards for all users.

2.2 Methods of analyzing space

How the artificial lighting could support the functionality of the ward and the functions of the ward is important and it needs to be defined exactly even though the ward is a small space. There are many different ways to gather information concerning behavior flow of work situations (Suenson *et al.* [14], Millonig and Gartner [15] and Hillier and Hanson [16]). The selection of tools has to be well-grounded to give the right results. Unobtrusive observations avoid participants feeling under observation which can change the way they act which thereby can blur the results. Unobtrusive observations are therefore preferred because it avoids the risk of such "observer effects" (Millonig and Gartner [15]).

One of the methods to clarify the use of spaces is questionnaire surveys. Questionnaire surveys can provide comparatively large samples, and allow the collection and analysis of data within a short amount of time. But the human behavior can hardly be mapped and can only be interpreted by verbal structures.

Another category of surveys is direct observation, such as mapping or tracking. These surveys can be done in many different ways, the simplest one being manual observations that are recorded by notes and drawings. Monitoring by video is another way to analyze and interpret human behavior (Millonig and

Gartner [15]). The limitations by using video are the view of space for observation which can be limited. This limitation is not present because the ward is a small space, but observations by video cannot be used in wards because of the privacy of the patients that need to be respected.

A new developed tool to gather information about human behavior is the digitally based localization technologies. An example of this could be satellite based technology such as GPS (Global Positioning System) which can gather data within a very large study area. For indoor observations, the GPS system is insufficient as data basis because of the lack of signal between receivers and satellites (Millonig and Schechtner [17] and Suenson *et al*. [14]).

An alternative to the GPS system is the RFID (Radio Frequency Identification) technology. The RFID system use radio waves to identify people and objects instead of satellites, which makes it possible to be used indoor and which is not possible with GPS. RFID is still a new developed tool for tracking indoor behavior and therefore, the data collected by this technology can be more complicated to gather and interpret than GPS at the point of writing Millonig and Gartner [15] and Suenson *et al*. [14]).

The study of functions and use of space can be improved by combining different techniques. The combinations of manual observation and digital tracking with RFID clarify both the flow in space and the functions related to the space. The combinations of the tools are therefore picked for further studies of the staff behavior in the space.

The staffs' use of the ward space is investigated by RFID–technology of tracking and visual observations. This method is chosen because of its possibilities to make digital recordings indoor, combined with manual observation where the work situations are recorded.

3 Analyzing the work flow of the ward

The selected study case is a ward at the orthopedically department at Odense University Hospital, Denmark made in October 2010. It is a type of ward where the staff are often summoned to help patients in and out of the bed or in other ways supervising the patients. The interior design of the ward is fixed and cannot be changed and the layout of the ward can be seen in figure 2.

The RFID-technology is based on receivers (lommys) and senders (tags). A signal is sent out every 30 seconds from the tag and when the lommy is within the radius of the signal a registration is made. When the lommy is without the radius of the tag, it is also registered. The radius of the Tags can be calibrated to fit different setups (Simonsen [18]). An experimental setup of the tags and radius of signal is made as illustrated in figure 3. All the members of the staff, having contact to the patients inside the ward, are given a lommy from nr. 1 to 5.

The setup indicates the time when the staff is entering or leaving the ward and if they are situated near bed 1 or 2. The investigation thereby indicates the staffs work situation at the wards length and if the staff is situated near the hospital beds. The tracking is supplemented by visual observations for a whole day together with a day of hospitalization as a patient, where the different work related assignments are recorded. The time scope of the investigation with RFID is from 10.30 to 18.00.

The study shows that the staff has a high frequency of short periods of time inside the ward, whereas the frequency of longer periods situated inside the ward is smaller. The results can be seen in table 1. The observations indicated that the staff in the long periods is dealing with mobilization and training of the patient while short periods in the ward mainly are concentrated around calls from the patients and food serving. In the period of the investigation, five different members of the staff were entering the ward.

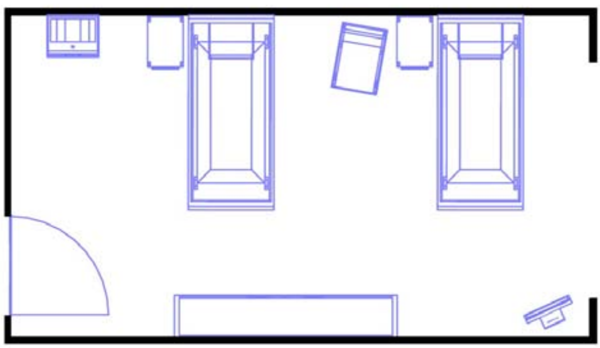

Figure 2: Layout of the ward.

Table 1: Table showing the result of the RFID-tracking of the staff.

Lommy nr.	Entering ward	Time at bed nr. 1	Time at bed nr. 2	Leaving ward	Time inside ward
nr. 1	11.00	3 min		11.03	3 min
nr. 1	11.04	1 min		11.05	1 min
nr. 2	12.08	2 min		12.10	2 min
nr. 3	12.10		2 min	12.12	2 min
nr. 3	12.24	1 min	1 min	12.26	2 min
nr. 2	14.38		3 min	14.41	3 min
nr. 1	14.38		2 min	14.40	2 min
nr. 4	16.36		5 min	16.41	5 min
nr. 5	16.47	8 min	14 min	17.09	22 min
nr. 5	17.39		2 min	17.41	2 min

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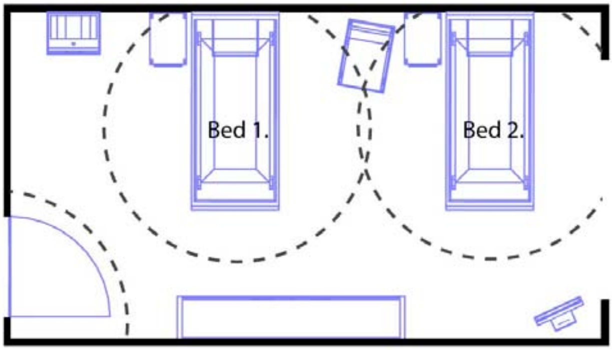

Figure 3: The placement of tags in the ward and their radius.

4 Zoning of space

Dividing the ward in zones can be done to visualize the functional differences of the space to benefit the different users' needs and preferences. The zoning makes it possible to design adiversity in the light setting and still fulfill the requirements concerning light and visual tasks for all users. The zones can therefore be used as guidelines in the following design of the lighting (Malkin [19]).

Figure 4: The different work and visitor related zones inside the ward.

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The combination of tracking and observation makes it possible to divide the ward into different zones. The zones are defined from an understanding of the space, which makes it possible to modify the light sources according to the functionality. The zones are a simplification of the complexity of the ward, and there will therefore be work situations that do not fit these categories. The zones are illustrated in figure 4.

The high frequencies of short stays strengthen the problems of lighting being left turned on of the staff when leaving the room again. This problem can lead to overlighting of the ward, and at worst be uncomfortable for the patients. The problem is also based in the immobility of the patients, which makes them unable to turn off the light themselves. Fagerhults [20]

Greater divisions of lighting control are therefore important for energy savings, the work of the staff and for the wellbeing of the patients. A division of light control can be a solution to this problem but need further examination. For further information about studies in this area see the article “Patients light preferences in hospital wards – related to light atmosphere in Danish homes” by L. Stidsen, H. S. Bjerrum, N. Thuesen, P. H. Kirkegaard, A. M. Fisker.

4.1 Lighting of the ward in zones

The division of zones illustrates that the lighting do not need to be uniform but can vary according to the quantity and quality of light preferred or needed in each zone. It indicates that the high demanding visual tasks are situated near the beds or in the perimeter of the beds. Difficult visual task demands high intensity of light depending on the task and the guidelines for treatments and examinations of patients states a minimum of 300 lux (Lang [21] and Danish Standards [10]) states a need for at least 500 lux.

The high intensity of light should therefore be concentrated in the nursing zone and at the perimeter of the bed. In the rehabilitation zone, lighting between 200 and 300 lux is estimated as sufficient to solve the visual task for the staff and patients.

The passage zone does not need the same amount of lux seen from the functionality of the staff point of view. The stated efficiency of lighting in such areas is recommended to be around 50 to 100 lux as the area does not contain any high demanding visual tasks (Lang [21]). In situations where cleaning of the whole ward is necessary, a minimum quantity of light on 200 lux is required and it is therefore also important that it can be achieved. “…. *in addition to a standard illumination of 50 lux, it is possible to achieve an illumination of 200 lux for cleaning, ward rounds, etc., if conditions require it*” (Dansk Standard [10]).

The divisions of zones are made in the horizontal plan, but a dividing of zones should also be done in vertical plan to fully unfold the potential of zoning. A vertical division of zones could be done by investigating the level in which functions are executed.

The distribution of lighting in terms of lux levels are placed according to the zones as can be seen in figure 5.

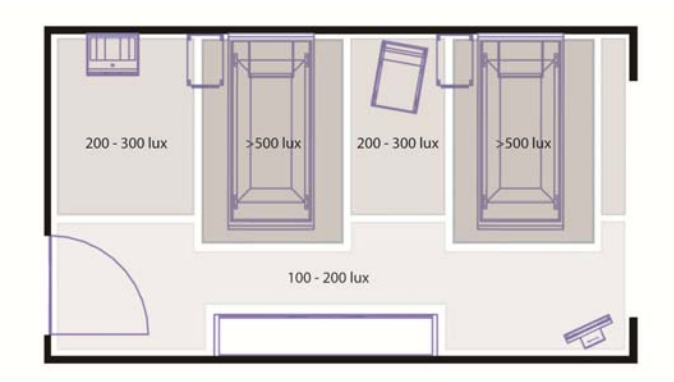

Figure 5: The lux levels needed according to the use of the space.

5 Conclusion

The goal of this paper was to investigate methods to analyze space with the aim of zoning the ward and thereby creating guidelines about lighting of the ward. The studies indicate that RFID tracking of staff combined with observations of the staffs work and time at the ward clarify the working functionality of the space, and thereby illustrates that from the staffs' point of view, the ward can be divided into different zones. From zoning the ward, lighting can be more specified and thereby improve preferences, needs and furthermore reduce energy use on lighting because it becomes possible to illustrate areas of high and low visual assignments. The highest demand for light is in the areas at the hospital bed and in the perimeter next to the bed, and the lowest in the passage zones in front of the door.

The studies in this paper are focusing on the method and design parameters for lighting. The tools used for analyzing the space produce quantitative data for interpretation and because of the small time scope, the data is only giving an indication on how the ward is used. For more reliable results, tracking and observations need to be made for a longer period of time with a higher level of setup. Further studies should therefore be done in the future to strengthen the results emphasized in the investigations.

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Patients' light preferences in hospital wards: related to light atmosphere in Danish homes

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Abstract

When designing Danish hospitals in the future, patients, staff and guests are in focus and it is especially important to design an environment with knowledge of users sensory and functionally needs. Likewise, focus should be on how hospital wards can support patients' experiences or maybe even how it can have a positive influence on the recovery process. The present paper introduces the human perspective and the Danish cultural approach in illuminating homes and how it can contribute to innovative lighting design at hospitals. The importance of having a holistic approach to lighting design is introduced based on the theory by Gernot Böhmes i.e. "concept of atmosphere" dealing with the effect of experiencing atmosphere. The aim of this study for design of a lighting concept for wards is to get qualified information on patients light preferences for light atmosphere by studying the everyday use of light in homes.

This explorative study displays the preferred light atmosphere in Danish homes in the age group of 60–85 years old people. With an anthropologically approach to the subject using semi structured interviews, the goal is to explore preferences for light atmosphere when the user are in the control of the light and get inspiration on how they create a private sphere. The purpose is also through this analyse to display cultural trends of illuminating homes, therefore, the paper will introduce the design lighting concept for wards based on different everyday situation activities from a hospital ward.

Keywords: lighting design, hospital ward, light atmosphere, private sphere, cultural factors, patients light preferences, lighting Danish homes.

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1 Introduction

Design parameters for creating a pleasurable light atmosphere in hospital wards are a complex field to study. Researchers have investigated the topic and display some of the important factors in Evidence Based Design (Ulrich and Zimring [1]), Healing Architecture (Frandsen *et al.* [2] and Dalke *et al.* [3]) elaborated on the field by studying the importance of colour and light in hospital design. The users of hospital wards are diverse and they have all special needs and preferences for light depending on their activity and purpose of using the ward.

Foqué *et al.* [4] point out that light is an important factor in experiencing ward atmosphere. The philosopher Böhme [5] presents the concept of atmosphere and highlights the bodily presence in the evaluation of atmosphere as important. Madsen [6] studies the effect of light zones, Millet [7] claims that light reveals architecture and Malnar and Vodvarka [8] present light as one of the important factors in sensory design. All in all, the environmental factors, the ward atmosphere, and light must support the staff's working conditions, the patient's private atmosphere and the visitors' experiences of being guests (Jörgensen *et al.* [9], Knez and Enmarker [10], Mc Clughan *et al.* [11], Stidsen *et al.* [12]).

Studying theoretical instructions for lighting design (Leslie and Conway [13], Loe and Rowlands [14], Cuttle [15], Bean [16]) it is interesting to study how the light is integrated in an architectural context. A practical study of e.g. Frank Lloyd Wright (Heinz [17]) presents a holistic approach to architectural experiences including lighting design. But there seem to be a gap between the theoretical information of Gernot Böhmes and best practice of lighting design, which does not account for the cultural differences as well as the geographical difference preferences of artificial light. The cultural issue is important for the experience of a space and our hypothesis is that artificial light is used by the way we experiencing daylight (Bille and Sørensen [18], Stidsen *et al.* [19]).

These diverse needs and preferences require different light scenarios at the ward and it seems to be incompatible issues regarding lighting design. By rethinking ward lighting and by creating activity based light scenarios, the different user of the ward should be able to achieve a pleasurable light atmosphere. In the process of rethinking lighting design for hospital wards, parallel studies have been made. These studies display lighting problems of existing wards and are collecting inspiration from comparative places to the ward.

The aim of this study is to collect information of light preferences and light atmosphere in private settings and to clarify how light is used in Danish homes and use it as inspiration to lighting design for patient zones in hospital wards. Therefore, this paper presents a Danish approach to illuminate our private sphere and display some of the cultural issues important for using artificial light in a Danish design context. Lastly, we present a proposal for how the gained information can be translated to a lighting concept for hospital wards.

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2 Methods

Present Evidence Based Design is an important agenda and in addition Malkin *et al.* [20] has produced a visual guide of the important design issues presented in an American hospital context. The research through design and the knowledge of design professionalism can contribute to the existing knowledge with innovation because the designers have the ability to turn everything upside down and rethink, refine and combine existing knowledge in new innovative ways.

To find interesting results in a Danish design context and to explore new approaches in lighting design in hospital wards, we prefer using qualitative methods rather than more scientific approaches. Seeberg [21] describes the difference in the subject field to distinguish between the stable versus the reflexive object. Regarding the reflective objects, it is appropriate to use methods where the understanding of the contextual and constructed is embedded in the method. Qualitative methods are thus particularly suited for scientific studies dealing with strength and depth in exploring new ways of looking at themes. In this context, anthropological methods are particularly interesting with the emic approach to the study. As Hastrup [22] writes: "The empirical claim implies that anthropology deals with (specific, known and named) people's actions and the perception of their own lives and activities (...)".

The approach of using Anthropological methods focuses on the informant's own world and experience. Therefore, the method is interesting in connection to user-centred design. Here is the opportunity to examine the user group's preferences for light, their way of illuminate in their private sphere.

2.1 Framework for the interview guide

To establish the framework of the interview and to form a usable interview guide, we studied different approaches in experiencing wards and the daily life at a hospital. Beyond the theoretical and practical design studies, we interviewed 2 nurses at Odense University Hospital, Department of Orthopedically surgery (hereafter O3) to clarify their needs for light and their understanding of patient comfort.

Inspired by Bohme's ideas of bodily presence in experiencing atmosphere and in order to understand the patient's experience of a hospitalization, we were allowed to observe the daily rhythm at the ward seen from the bedside for one day and night. That way we were having a bodily experience of the situation of being hospitalized. The purpose was to collect information gained through inter-subjective discussions and studies of everyday situations for patients. This is not to say that we have the knowledge of what it is like being a patient and what patients' needs are, but the study contributes with important and interesting issues, which are specified in the interviews guide.

Through this study, we also found some critical issues about the existing illumination of the ward and got new ideas of improvements. To clarify the staffs' needs and preferences for light, Thuesen [23] studied the workflow at the ward and the effect of zoning the ward in staff area, patient area and visitor area.

By interviewing and observing the staff and having a personal experience of everyday activities at a hospital ward, we made the framework of the interview. Through the interview process, the informants added important viewpoints to the categories and they refined and elaborated concepts as “Dining”, “Watching TV”, “Going to bed”, “Sedentary Activities” as reading, knitting, sewing, solving crossword, “Upstanding Activities” as walking, playing music instruments, cooking, etc. and at last “Communication/social interaction” as having guests, having conversations with staff etc.

2.2 Semi structured interviews

The typical method for an anthropological study is to conduct fieldwork and participant observation combined with formal and informal interviews. The observation of participants has primarily the object as common area, and in this study we have chosen the theme of lighting. Simultaneously, the group we want to study (patients and potential patients) is not a naturally cohesive group. “The community” is formed on a common experience through the admission; however, it is short and usually crucial for the patient’s identity. Hence, we have chosen semi-structured interviews as the main method for this study. A method that is ideal for what Rubow [24] calls “multi-site field work”

It is a challenge to work in a multi-sited field as the informants’ homes. Many people have trouble describing their own perception of light; maybe it is because light is primarily phenomenon that we relate intuitively and experientially to. Therefore, we have combined our interviews with a visual approach to fieldwork using photo albums Winther [25]. Both album and interview guide focuses on keeping the interview concretely and descriptively. As Kvale [26] writes: The interview itself should be the main issues of descriptive character “What happened and how did it happen? How did you feel then? What was your experience?”

2.3 Photo documentation

The specificity of this study is verbalizing something that very few have articulated. There is a tendency to see illumination in our daily life as something that relates to an instinctive non-reflective level. As Böhme claims, we just note whether we like being in a space, or if it is “nice”, “cosy” or “safe”, but we rarely get to behave in a more conscious way.

The generation of knowledge in qualitative methodology is an interaction between informant and researcher. This means that there may be a bias in interactions when the researcher appears as an expert in the area that the informant has previously reflected upon tacitly rather than explicitly. In such a case, the researcher may have a disproportionately large influence on the informant’s statements. To minimize this effect, we have chosen to let the informants start working alone by giving them a disposable camera and a few instructions. We wanted to get as close a description of their everyday use of light as possible. Therefore, the method was given the following form: Firstly, the informants took pictures of their use of light in everyday life. Then we developed pictures and made a photo album. Afterwards we interviewed informants in their homes and used the photo album as structure for the interview. Lastly, we transcripted and analysed the interview.

Deductively we asked specifically into selected categories during the interview. The categories were chosen over known activities taking place at a hospital, but as reflected in every situation in homes. The categories were as follows: “Dining”, “Watch TV”, “Go to bed”, “Sedentary Activities” as reading, knitting, sewing, solving crossword mm, “Upstanding Activities” as walking, playing music instruments, cooking, etc., and the last category were “Communication/social interaction” as having guests etc.

To optimize the method of the study, we undertook a pilot study. This was primarily to ensure that the participant’s tasks of working alone were easy to understand and to test the idea of structuring the interview over albums. We wanted to be sure of the participant’s feeling on top of the interview and experts of their way of using light.

2.4 Selection of informants

Basically the goal was to select informants among patients at O3. By choosing informants from the department, we wanted to interview the patients at home before the admission and later during hospitalization. We wanted to achieve a random selection of informants, the possibility of having a re-interview and be able to get informants themselves to match their daily use of light with their experiences of ward lighting. Therefore, we started out trying to recruit participants at the Joint Care meetings at O3 two to three weeks before the operation. Here the nurses helped us distributing project information and the coming patients were supposed to convene the project. This method did not succeed. Maybe because patients had too many concerns about the coming operation or maybe it was too scary to share pictures of the private sphere with strangers.

Consequently, we changed the recruitment approach and found it comparable to find participants from a reference group similar to the group of patients at the hospital. We distributed a mail with project information to 44 persons in our network and asked them being ambassadors for the project and help us finding informant in the age group of 60–85 years old. This method succeeded and we got 12 informants, 8 couples and 4 singles in the age of 61–86 years old. Geographically located in five different cities in Jutland, Denmark both from the countryside and from the centre of the main capital of Jutland.

Now the method using proposed re-interview was not applicable for this study. Patient relation to ward lighting was no longer a central question in the interview, but some informants told voluntarily about experiences from hospitals. It was often related to questions about good or bad experiences of light outside the home, or in their questions to the goal of the study. This information is included in this study.

Data were collected during the period ultimo November 2010 to beginning of January 2011. That time of the year where the Danes have a lighting tradition using candle lights and having Christmas décor in their homes. This season is not representative for our light preferences through the year, but the seasonally changes in using light is mentioned in all interviews. The group of informants ranging from those who have a special interest in light and have chosen their house because of its location and daylight distribution, to informants who have not noticed the light as important for their living.

2.5 Field work and validity

Wadel [27] claims that Fieldwork as participation observation entails at least three types of challenges and skills the field worker must possess. Firstly, the ability to obtain access to the participators observations and the other skill is to be able to possess a repertoire of roles in the progress of fieldwork. Thirdly, it is important to be “a sociologist on oneself”. In this way, Wadel initiates his reflections on the anthropologist’s task of fieldwork in own culture. The field worker’s challenge is to find a role that can provide access to a field. The role must simultaneously make it possible to collect data, where communication can take place in culturally accepted and understandable terms. The researcher should not insist on just being a scientist.

Caused temporal and access reasons in the study, we chose not to work with prolonged participant observation. However, this dilemma was considered. In connection with the recruitment of informers, it was important that they understood in which context the data would be used. Therefore, the participants have been aware that it is a research project and the interviewer’s role as a researcher. The generation we are working with in this study is typically informants with a lot of respect for authority and knowledge holders. Wadel suggests that it could be beneficial for the field worker to take the role as apprentice or trainee because it is a known role in many contexts. In this study, it has not been possible for us to establish such a relationship in the interview situation. Instead we have, as described, sought to minimize the influence on the informants’ first reflections of illumination through photo documentation.

Simultaneously, it was important for us to be “a sociologist on oneself” in the interview situation where the interviewer was often met with great respect. Informants were concerned about whether they had taken the right pictures, whether they were good enough and whether they knew anything about lighting. Because the interviewer also possessed “the researcher role”, we spent time before the interview appreciating the informant’s work and worked on a more equal relationship in the interview. It was an advantage for the interview situation that it took place in informants’ homes. This meant that the interviewer simultaneously got the role as a guest and it gave the hosts the possibility to define rules for interaction.

One of the major advantages of photo-documentation method was that the photo album created a natural and familiar situation. An interview may sound unfamiliar and promoted as something of “experts”. To show visitors pictures is another matter. It is a familiar situation, making it easier for informants to relax in the interaction. At the same time the pictures helped to keep the interview practical and user-oriented. In that way we prevented the problem that Bernard [28] describes as finding good informants who are experts on the questions. He claims that an important question for ethnography is the following: “Are a few informants really capable of providing adequate information about a culture?” And his answer is that it depends on two things: choosing good informants and asking them things they know about.

When informants were sitting with their own pictures in their own house, it was obvious that they were experts in their own lives and they felt able to talk about the illumination. The disadvantage of this method was that it might have contributed to filter out some informants because the user group may have felt it prohibitively and confusing even to take pictures. In 4 cases, the informants agreed to participate but they needed help to take the pictures. Through the process, the informers chose to be interview individual or together with their partner.

A great advantage of the anthropological methods using fieldwork is that the participant observation complements the conversations and interviews. It is a so-called method triangulation (Selmer [29]). In other words, the study illustrates both the informants’ conceptions of themselves and their practices. Not using prolonged participant observation, the approach using photo albums as interview guide and visiting the participant’s homes has the function of method triangulation. The fact that the interview took place in the home gave the interviewer the opportunity to compare the pictures with the reality and have an experience about the type of environment for the illumination.

3 Analyse: light preferences in Danish homes

The collected data were transcribed in real time method, where the transcripter writes along the tape that is running nonstop. The data was sorted by the previously mentioned categories and analysed. Information included in this analysis is, as well as the earlier presented studies, background for a proposal of lighting concept in hospital wards. The gained knowledge of collected information is going to be translated to a concept for lighting hospital wards.

3.1 Dining

The activity of having dinner can be divided into two different situations. The every day dinner at home for residents was eaten in the kitchen or maybe in the same form in the dining room. At weekends, the dinner experience should be different, so if they had a dining room or a living room with a dining table the meal was served there. Almost all informants, across aesthetic choices of interior design and placement of dining table, chose an illumination where a pendant would be hanging down over the table creating a light zone containing table and chairs. The pendant hanging over the table was often flexible and could be moved up or down and from side to side. Another situation was if they had guests for dinner. Then the informants turn on more light in the room. Many illuminated the table with candlelight or maybe a dimmed light in the pendant. To compliment the desired atmosphere, most of the informants preferred having a light zone at the other end of the room emphasizing the character of the room.

3.2 Watching TV

When it comes to the activity of watching TV, the light atmosphere was very important. The most important thing to avoid in the illumination was light reflections on the TV screen. Therefore, most of the luminaires were located beside or behind the TV or somewhere away from the observer location.

3.3 Going to bed

In general, the lighting design of bedrooms was not a focus area for the informants. Many were apologizing for the illumination of this room; and it seemed to be illuminated by chance arranged with the “left over” luminaires. The analysis showed that the activity of “going to bed” or “having a rest” could be split into two different categories i.e. those who are reading lying in the bed and those who do not read in bed.

Most of the informants had a ceiling mounted luminaire placed centrally in their bedroom. The luminaires were usually “switched on” when entering the room, and then “switched off” as soon as possible when they had turned on the bedside lamps. The informants who read sitting or lying in the bed knew exactly how the light should be distributed from above the head and how to avoid conflicts between couples if only one was enjoying the reading from bedside.

In some cases, the informants had trouble seeing the contents of the closet and desired to have direct light placed there.

3.4 Sedentary activities

Analysing the sedentary activity as reading, knitting, sewing, solving crossword etc. produce several interesting answers of light preferences. The informants were focused on the subject and had a pronounced opinion about the light atmosphere for this activity. The usability of the lamps was important and many informants had floor lamps or lamps mounted to the wall right above and behind the chair or sofa to create the perfect light. Almost all informants were in this situation using a primary luminaire for visual task lighting and then secondary luminaires for light in the peripheral vision creating light atmosphere. Almost all of the participants were conscious about the fact that they need more light now than when they were young.

3.5 Upstanding activities

When it comes to upstanding activities such as walking in the hallway, using the bathroom or cooking, it seems to be important to have a general illumination supported by specific task lighting if necessary.

The general light preferences for standing activities were to have a uniform light distribution so every part of a room appears bright and an illumination coming from the ceiling supported with specific task lighting right where it is needed. For work related light, it seems to be important to see the space around you in a uniform way. If the space is used as a walking area as in a hallway or when entering the bedroom, the light should just distribute enough light to see where you are walking, and prevent accidents.

3.6 Communication / social interaction (having guests, conversations)

The situations where the informants are having social interactions as having guests in their home, they presented their homes in the best light. They turned on almost every luminaire in the “guest area” as a gesture of welcoming visitors. Almost every informant mentioned that they light more candles and that they illuminate their living room with many luminaires, so the room is filled with a warm light atmosphere and myriads of light zones. The luminaires were mostly located near the walls in varying heights often supplemented by luminaires highlighting the tables. All luminaires were placed so they emphasized the room appearance in different light settings. When the communication was in connection to work situation it was different. Then the informers preferred a more uniform light atmosphere. One informant, working in a workshop for capacity weak people, had a problem using pendants and having dark areas in a classroom because it could prevent contact with users. She preferred a light distribution with fluorescent light tubes. Here she felt a good connection with the workshop users, and pointed out that it was very necessary to have good light.

This analysis of the everyday use of light in Danish homes among people in the age group of 60–85 years old established a clear picture of this user group’s preference for everyday illumination. The interviews contributed with new subjects important to the informants.

“Daylight” was important for almost everyone and they were generally conscious about location and orientation of the house in relation to the sun. Many mentioned also the importance of getting enough light at wintertime. The number of “Light zones” and luminaires in the room were also an issue in the illumination of their homes. We counted up to 14 luminaires in a living room and it was important that the light could be varied and flexible of use. The “Placement of luminaires” seemed to be near the walls illuminating the corners and creating a dark zone in the middle of the room. The consumption of “Candle lights” is enormous and it seemed to be synonymous with the Danish saying “hygge” (translated to “cosiness”) in Danish homes. The informant had an impression of “hospitals environment” being cool and too white, and it was mentioned that at night the light was often disturbing the sleep. Many of the informants claimed that the illumination of southern Europe housing was unsympathetic and unpleasant. They were not able to find it comfortable or cosy to be in a light atmosphere using fluorescent light tube or light bulb mounted to the centre of the ceiling in a room where they were suppose to relax and feel at home. Lastly, they all had a favourite place in their living room. They had different ways of creating a private sphere around the place or ways of illuminating the area, but they all had there “own” place where they liked to relax.

The explorative study contributed with new approaches for the lighting design of hospital wards. As we experience lighting in hospital wards today, it seems to be a lighting concept having a uniform light distribution supplemented by a

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private illumination at bedside. The patient can control this private luminaire as well as it is used as specific task lighting by the staff. The uniform light distribution is suitable for general task lighting for the staff. This lighting concept is typically for illumination public area and there is a huge difference to familiar illumination of the private sphere. The Danish homes we generally prefer many luminaires, and a varied light distribution and intensity. The flexibility as well as the control of the light is important factors in feeling a pleasurable light atmosphere and the light is used as a gesture welcoming guests.

It is not possible to illuminate a ward with candlelight, but the opportunity illuminate a room in a flexible way placing luminaires around the ward seem to have a positive impact on experiencing a pleasurable light atmosphere for the different users. When it comes to creating the perfect light setting when reading or watching TV, the illumination and light atmosphere should please the patients comfort and prevent light reflections in the TV screen. Dividing the ward in user zones as well as vertical grid locates the luminaires near the walls. In a horizontal grid in three zones, “High”, “middle” and “low” most of the luminaires are placed in the middle zone. The light distributions are modulated into the room through lampshades supplied with downlights/spots distributed to the place where it is needed. The luminaires can be divided into “primary luminaire” or “secondary luminaire”. The purpose of the “Primary luminaires” is to distribute light for visual tasks as reading, solving crosswords, or as the pendant hanging over the table so we can se what we are eating. “Secondary luminaires” have the purpose of creating atmosphere. It can be small luminaires in the other part room illuminating in a way that it defines the architectural space; it can be candlelight’s in the windows or shelf light etc.

4 Conclusions

As mentioned the purpose of this study collecting data from the private sphere is to get information and inspiration for the development of ward lighting for patients at Odense University Hospital, Department of orthopedically surgery (O3). The explorative study contributed with information on familiar light experiences and it innovate the process of creating a private sphere with pleasurable light atmosphere at the ward.

The information from the interviews supported our hypothesis of having a Danish light culture using several luminaires in our environment, and thus various light zones and different types of light distributions in our private sphere. With the aim of creating an innovative design and having the focus on designing a pleasurable light atmosphere in hospital wards, it seem to both useful and successful to study the every day use of light for diverse activities in private homes.

Therefore, we recommend a lighting design containing the possibility to change light according to user needs and user preferences focused on everyday activities at the ward. The concept of illuminating should contain several luminaires located around the ward and mostly near the walls in the vertical plan and in the middle zone of the horizontal plan. If the recommendations of light distribution are complied, the patients should have the opportunity to achieve a pleasant light atmosphere at the ward.

The lighting concept is going to be installed and tested at OUH department O3. The evaluation will be on the patient's needs and preferences for light and their experiences of light atmosphere. The concept of ward lighting and practically examples will be presented at the conference Light 2011.

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Examples of the application of light-tissue interaction to biomedical engineering

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Abstract

The subject of this paper relates to the measurable effects of light behavior in biological materials. The problems considered include some current topics concerning the achievements and still ongoing development in the selected fields of light-tissue interaction to be used in biomedical measurements. Measurable effects of interaction between light and tissues may be utilized in biomedicine with emission, reflection or transmission modes, respectively. The latter is especially considered in this paper: transillumination as the method of examination by the passage of light through tissues or a body cavity is a diagnostic technique in the course of intensive development at the moment. Red light and near-infrared radiation emitted by high-efficient LEDs can be non-invasively transmitted through the blood-supplied tissues. Some representative examples of the medical applications of non-invasive effects of light-tissue interaction are discussed. Under the transillumination and illumination from underneath, it is possible to diagnose and monitor the parameters of tissues and organs examined. This paper includes discussion of selected issues related to the biophysical and optical phenomena used and examples of practical applications of tissue transillumination techniques. The authors briefly report the current state-in-the-art and also present their own results. Among other things, the presented examples include: optoelectronic techniques used in monitoring of living tissue vitality, and promising results obtained during preliminary experiments with transillumination scanning applied to fingers of the human hand.
Keywords: biomedical optics, light-tissue interaction, optoelectronic sensors, noninvasive biomeasurements, medical imaging.

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1 Introduction

The different parts of the electromagnetic spectrum have very different effects upon interaction with biological objects. Radiation energy may be transmitted, reflected, absorbed and scattered by living tissues but light is first of all absorbed strongly. The optical part of the whole spectrum offers a wide range of measurement possibilities. The role of optical techniques in current medical measurements and imaging is especially significant [1–5]. Using optoelectronic sensing allows us to convert sophisticated effects of light-biological object interaction to electrical signals, which may be convenient to process and measure. The-state-of-the-art, taken here into account as the background, refers to the reported optical parameters of tissues when exposed to light of wavelengths included in the optical window in tissue spectrum [1, 6].

When a biological object is exposed to illumination, we can receive the selective optical response to particular wavelengths. Information about optical parameters of the medium is included in this response, however, other physical parameters of a given object also influence its output signal. The surface conditions, internal structure and size in the direction of light action are of great importance.

In the paper, discussion is focused on the selected methods which apply the effects of light-tissue interaction to be used in noninvasive biomedical engineering. The examples presented by the authors include: optoelectronic techniques used in monitoring of the living tissues vitality, and promising results obtained during preliminary experiments with transillumination scanning applied to human hand fingers. Previous own authors' experience in one-dimensional modeling for transmission pulse oximetry [7, 8] has been adapted.

2 Interdisciplinary aspects of biomedical engineering

The discipline of biomedical engineering is a diverse field that includes such areas as e.g. bioinstrumentation, biomaterials, medical imaging, biosensors, biotechnology, and tissue engineering [1]. This interdisciplinary field based in both engineering and the life sciences relates to physiological as well as electrical, optical, mechanical, chemical, and other principles to be applied in diagnostics and therapy. Over the last years, the development of new and different medical equipment is impressive.

Advances in medical and biological technology are due to the increasing interaction and collaboration between medial and engineering scientists. There is also necessity to work well in a well-integrated interdisciplinary team. Efficient and safe application of light-tissue interactions to biomedical engineering must meet the various human and technical needs such as: medical practice, ethics, clinical care of patients, instrumentation reliability, material biocompatibility.

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3 Specificity of interaction between light and living tissues

Among the applied methods of tissue parameters measurement, a tendency to develop methods based on detection and analysis of natural and forced bio-optical phenomena is significant. Bio-signals can be acquired in a variety of ways. Bio-optical signals are generated by the optical attributes of biological systems. There is a specific window extending from 600 nm to 1200 nm in which optical radiation can penetrate into human tissue set and propagate through it. However, due to strong scattering of the light, the practical implementation of optical transillumination for medical imaging is a difficult task. Measurements are very rich in artefacts, noises and disturbances which affect processing and can cause the decrease in useful output signals.

Tissues are optically turbid media that are highly scattering. A typical scattering coefficient for visible light in human tissues is 100 cm^{-1} in comparison with 0.2 cm^{-1} for X rays used in medical diagnostics.

The interactions occurring between the light and the tissues result in scattering, absorption and fluorescence, providing information on the structure, physiology, biochemistry and molecular functions. Optical imaging is used for description of surface and volume structures.

Reports in the literature often give the particular information about parameters, e.g., percentage transmission or reflection of light measured at the particular wavelength penetrating a particular human or animal organ [1, 2, 6]. Many reports refer to data collected *in vitro* or *in vivo*, but always invasively. Inhomogeneities in the living complex structures must lead to a spread in measured values when compared to those obtained for the selected homogeneous samples. A particular tissue composition very depends on blood and water contents what results in differences between values of optical parameters if to determine them at several compositions of various kinds and size. There are several sources of optical inhomogeneity of a biological object, which can be described mainly as structural imperfections and optical anisotropy. Depending on the locality and diameter of the light beam passing through the object the effects of light-tissue interaction can differ very much. The specific human blood feature is that hemoglobin which is carrying oxygen (oxyhemoglobin HbO_2) absorbs light in the IR region of the spectrum; hemoglobin that isn't carrying oxygen (reduced hemoglobin Hb) absorbs visible red light [2].

3.1 Optoelectronic sensors

By definition, an optoelectronic sensor is a device that produces an electrical signal proportional to the amount of light incident on its active area [3, 4]. These sensors still become more efficient, portable and smaller.

Measurable effects of interaction between light and tissues may be used in biomedical engineering with emission, reflection or transmission mode, respectively. The methods used in positioning objects in relation to the sources and optical radiation sources are presented in fig. 1.

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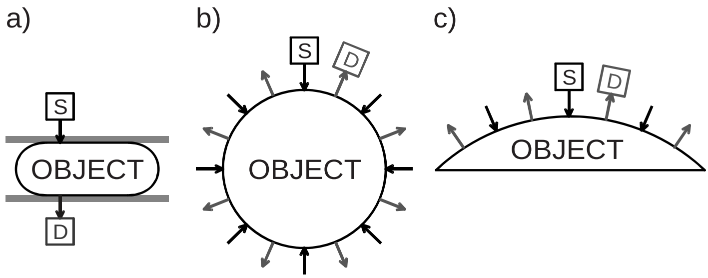

Figure 1: Examples of the variants of the investigated object position in relation to optoelectronic sensors containing the photoemitters (light sources S) and photodetectors D [9].

Optoelectronic sensors usually combine a set of LEDs emitting the incident light (600 nm to 1000 nm) as the photoemitter with a broadband photodiodes (350 nm to 1100 nm) as the photodetector of transmitted or reflected light. Modern high-efficient LEDs are very useful as moderately narrowband photoemitters with an approximately Gaussian spectral shape. The silicon PIN photodiodes may be used in practice as photodetectors. These small and lightweight elements are very sensitive, have low noise levels, and convert the light into electronic signal linearly, in the whole measuring window and over a large dynamic range.

A current driving LEDs intensity makes the sensor to be 'smart' by means to control levels of the transmitted light and provide incident light which might be transmitted through various real objects, as being more or less thick and pigmented. Evidently, a way the photoemitter is driving by current impulses as well as the selective photocurrent is converted, amplified and conditioned, are also critical [4, 5].

The sensor types include: light-to-voltage converters, light-to-frequency converters, ambient light sensors, linear sensor arrays, colour sensors, reflective light sensors [3]. The transmission variants of light-tissue interaction (fig. 1a) that is accomplished with the object transillumination can be often more convenient and sensitive than the reflection variants.

3.2 Advantages of transillumination

Transillumination is understood as the phenomenon of transmitting optical radiation with defined parameters by a given object, which becomes the carrier of information about the characteristics of this object.

Continuous monitoring of light transmitted in the penetrated region could offer a control about the changes inside the objects, and become important in predicting the light action outcome. Representative examples of transillumination may include:

- detection of body fluids components (spectrophotometry, oximetry in vivo),
- localization of veins, cysts, and neoplasms from underneath,

- transillumination with white light (instead of X-rays),
- imaging and monitoring of pulse wave (photoplethysmography),
- transmission variant of pulse oximetry,
- optical tomography.

Optical properties of transilluminated or illuminated tissues or organs depends on strong light absorption and scattering – numerous issues related to the result interpretation still remain unsolved. A given set of living tissues consists of many components, which create the determined spatial configuration. Light transmitted through tissues is classified into three categories: ballistic light, quasi-ballistic light, and diffuse light. Depending on the locality and diameter of the light beam passing through the object the effects of light-tissue interaction can differ very much. Optical radiation that is to play the role of an effective information carrier should be sufficiently coherent and, due to the high optical density of the object, should also have possibly high intensity. However, for higher power density quantities, some destructive photothermal effects can occur. Wavelength and power of radiation selected improperly may not only act ineffectively, but may cause damage or destruction of the object.

4 Monitoring of arterial pulse wave and oxygen saturation

The most common example of transillumination is the observation of arterial blood pulsation allowing for measuring the blood pulse and blood oxygenation [2, 10]. Measurements of arterial blood gases and pH provide information about the adequacy of blood oxygenation and CO_2 elimination. Knowing what percentage of the hemoglobin is saturated with oxygen is important when administering anesthesia as well as for helping diagnose various diseases.

All traditional *in vitro* measurements of blood oxygen content need to draw blood samples are risky, rich in complications and very time consuming. Early evaluations of blood oxygenation with noninvasive, transcutaneous techniques based on light-tissue interaction were unacceptable in practice; however, the progress which has been made in this area is excellent. Credit for the great present interest in these measurements belongs to anesthesiologist William New who with engineer Jack Lloyd founded in USA Nellcor Incorporated [11] where first commercial device called pulse oximeter was fabricated in 1985. Today, various models are manufactured and used in a lot of countries in the world. However, up to now, the method employed is a subject of continuous development and improvement.

4.1 Photoplethysmography and pulse oximetry

The modulations of biooptical signals, induced in tissues by the arterial blood pulsations, are the basis of very important optical blood-less diagnostic methods: photoplethysmography (PPG) and pulse oximetry [2, 8] which make possible to monitor noninvasively the living tissues vitality. The analysis of PPG with the simultaneous monitoring of ECG makes possible to decrease influence of artifacts, and produce accurate results in patients with often poor peripheral circulation. Pulse oximetry which is currently known as one of the most significant advance made in patient monitoring, bases on noninvasive use of two phenomena: natural arterial pulsations and differences in optical properties of blood and other tissues. This technique smartly joins rules of both *in vivo* spectrophotometry and photoplethysmography to monitor the arterial blood oxygen saturation $SaO_2 = HbO_2/(Hb+HbO_2)$ (fig. 2). What is unique in pulse oximetry that it is possible to sense the global oxygen saturation of human body arterial blood by noninvasive transillumination of only a peripheral tissue set which allows us to see a ”representative” arterial blood in other tissue components. The principle is simple as based on spectrophotometry rules, referring to idealized blood consisting of only two absorbers to be detected.

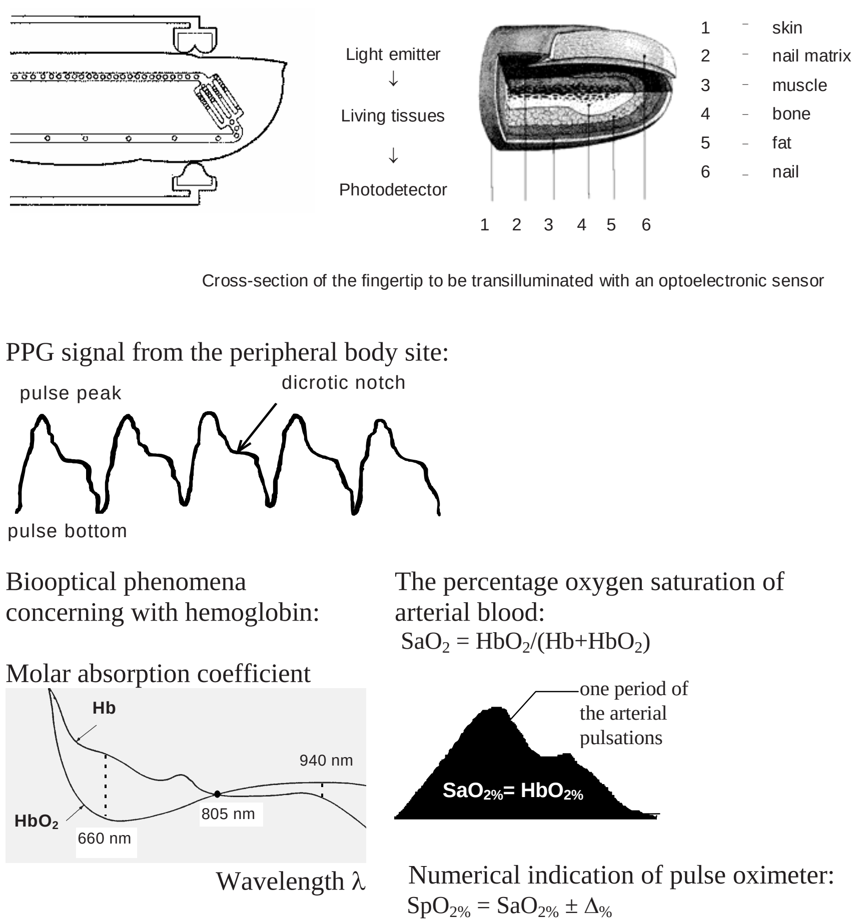

Figure 2: Illustration of PPG and pulse oximetry measurement signals and arrangement of a transmission noninvasive optoelectronic sensor placed on the fingertip – a pulse oximeter indication $SpO_{2\%}$ estimates the true value $SaO_{2\%}$ with the uncertainty $\Delta_{\%}$.

In practice, the measurements are accomplished with optoelectronic sensors placed on “living cuvettes” such as, e.g., finger-tips, ear-lobes, nasal bridges. The finger-tips are the especially useful sites to place the sensors which are applied directly and very often in prolonged duration. During laboratory studies, the authors of this paper use the modern devices shown in fig. 3.

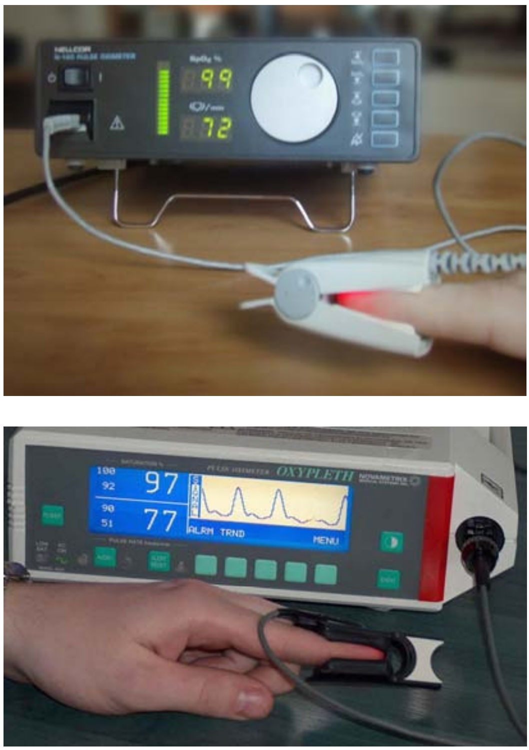

Figure 3: Examples of the measurement results obtained by the authors during their studies with two models of pulse oximeters: Nellcor-180 (top), and Oxypleth Novametrix (bottom). The latter is equipped with a PPG waveform monitoring system.

The majority of the manufactured commercial pulse oximeters, which are portable models or of pocket size units, display the values of oxygen saturation and pulse rate, while the other can display pulse strength, present the trend from a past period of time, and to display specific waveforms. The models which are only slightly larger than most the reusable finger sensors, have been designed especially for evacuation situations. The alarms mean the critical functions in a pulse oximeter, alerting of a potentially dangerous situations that usually include: high oxygen saturation, low oxygen saturation, high pulse rate, and low pulse rate.

The thickness of the object varies with each pulse, changing the light path length which effects are eliminated in estimating the oxygen saturation. The difference in shape and stability of the peripheral photoplethysmographic waveform can be used as an indication of possible motion artifacts or low perfusion conditions (fig. 4). Similarly, if the patient's heart rate displayed by the pulse oximeter differs considerably from the actual heart rate, the displayed saturation value should be questioned.

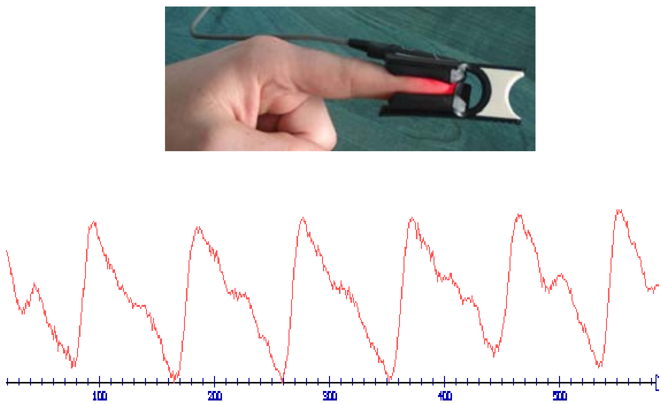

Figure 4: Example of a raw pulse wave acquired from the finger sensor.

4.2 Novel expanded use of the transmission variant of pulse oximetry concept

A modified approach to the transmission variant of pulse oximetry that was used by the authors in their own studies [12] depends on controlling tendency to changes in the selective components of light transmitted by an examined body site. The components of two raw pulsatile optical signals from the object (fig. 5),

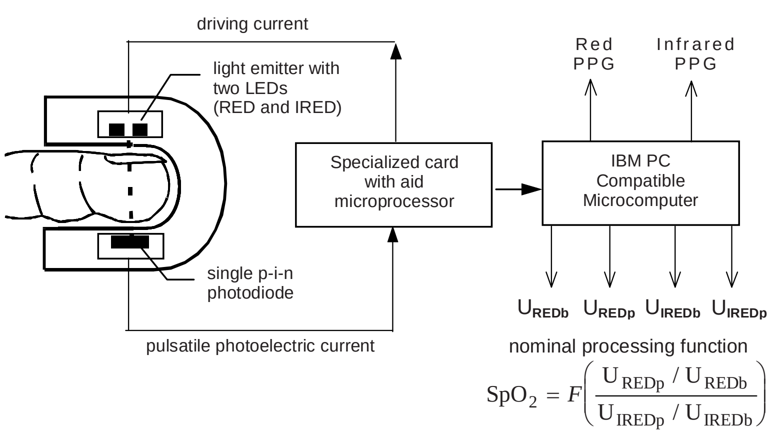

Figure 5: Scheme of the testing device based on a novel use of the pulse oximetry concept.

to be obtained at each of both wavelengths (i.e. U_{RED} and U_{IRED}), can be processed to four values of voltage which correspond to a reference bottom (U_{REDb}, U_{IREDb}), and a peak difference of the arterial pulse wave (U_{REDp}, U_{IREDp}) in each heart beat. Output signals from the sensor are held in the desirable range of values by assignment of current pulses which control the photoemitter. The real relationship between a ratio: (U_{REDp}/U_{REDb})/(U_{IREDp}/U_{IREDb}) and SpO_2 which values estimate SaO_2, has been established experimentally.

A novelty is continuous tracing the components of optical signals acquired from the transilluminated object. Indicating pulse waveforms and changes in the raw PPG signals at both measuring wavelengths allow the end-user to assess in real time the quality and reliability of the measurements. Firstly, the shape and stability of the photoplethysmographic curve can be used as an indication of possible influences. Secondly, by controlling a tendency to changes in raw values of quantities involved in the known nominal processing function, falsely true readings have potential to be detected and corrected.

On the one hand, studying the relationships between either pathological changes in a circulatory rhythm or measurement disturbances and corresponding to them changes in the frequency spectrum of the photoplethysmogram detected from a peripheral body site may be useful in practice. On the other hand, computer creation and analysis of virtual pulse waveforms can be useful to simulate real signals occurring in pathological situations when measurements are impossible because of either ethical or technical limitations. The obtained results may be useful in computer-aided generation of reference data for evaluation of light-tissue spatial transillumination. Computer models in particular have been increasingly successful in simulating bio-optical phenomena.

5 Optical imaging of hand fingers

In 1895 Wilhelm Conrad Roentgen made the first radiogram of a palm, starting the development of noninvasive image diagnostics methods. Currently, different imaging methods are able to detect different properties of investigated tissues through a variety of phenomena to be utilized. The role of optical techniques in current tendency to developing combined medical imaging is especially significant in such a field as, e.g., the modern videoendoscopy [5].

Light scattering and absorption can complicate the transillumination image. The optical image resolution can be lower than that of X-ray images, however, it enables to provide information on the functional conditions unavailable in the RTG technique.

The experimental transillumination of hand and foot fingers is possible in a quite simple as well as quite efficient transmitting-receiving system presented in fig. 6 [13]. The mechanical structure of this system was constructed in the form of letter C fixed to the robot's arm. A LED diode and photodiode were fit at the structure ends in optical channels of 3 mm diameter and about 20 mm length.

The robot arm assembly is flexible and contains the motorization, brakes, motion transmission mechanisms, cable bundle, pneumatic and electrical circuits for the user. A scanning system has been joined with the robot arm. The object's scanning is made in a rectangular *x*-*y* coordinates system. The hand examined is laid on a transparent plate stabilizing its position. A tissue volume is represented by its thickness in the direction of the incident light action. Various high power LEDs were used in the tests. The optical part of the transmitting-receiving system is LED diode placed opposite the PIN photodiode PD. Several wavelengths were used for the tests. The results presented herein have been obtained for an ELJ-880-228B emitting light at the wavelength $\lambda = 880$ nm. This LED was driven with current impulses of parameters as follows: $I_m = 7$ A, $T_i = 1$ µs, $T_{rep} = 1$ ms. The PIN BPW24R photodiode was used as the sensitive photodetector.

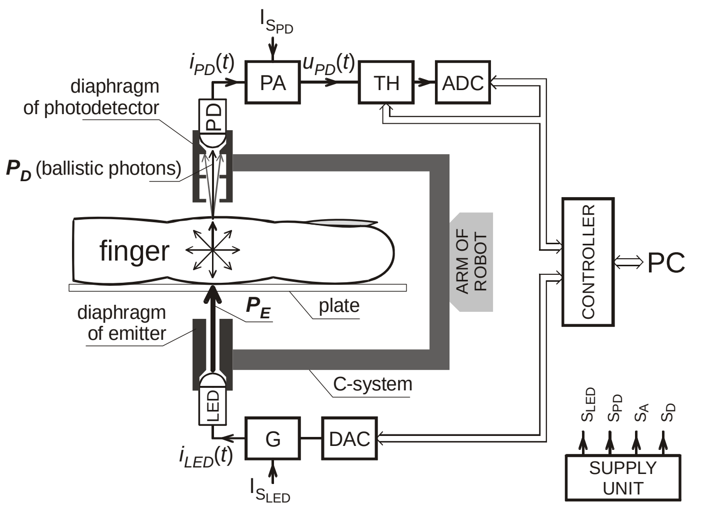

Figure 6: System performed for the impulse transillumination of a finger: PD – photodiode (as photodetector), PA – amplifier and converter of photocurrent $i_{PD}(t)$, TH – trace and hold converter, ADC – analog-to-digital converter, LED – photoemitter, G – source of current pulses $i_{LED}(t)$, DAC – digital-to-analog converter, P_E – radiation illuminating the object, P_D – radiation detected by photodiode PD.

The current signal $i_{PD}(t)$ was converted to the corresponding voltage signals and amplified. The voltage $u_{PD}(t)$ appearing during generation of an optical impulse is then subject to analog-to-digital conversion. Reciprocal of the obtained values, marked as U_M, were collected for particular positions of the scanning system. The relationship occurring between values of U_M and levels of P_D signal power shows differences in light attenuation connected with absorption and scattering of the transilluminated object. High values of U_M prove low levels of P_D signal power – in other words such relation shows strong attenuation for a given position. Figure 7 presents the standardized values of the converted output signal from the photodiode for several *x* values.

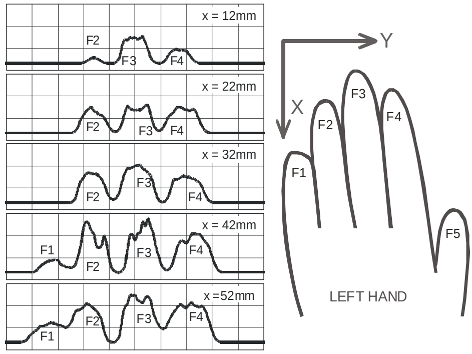

Figure 7: Specification of the output signal dependency on the *y* location for selected cross-sections with *x* coordinate.

The results obtained as preliminary transillumination images are shown in fig. 8. The grayness intensity is represented by the output signal values of the fingers examined (F1, F2, F3, F4). The specific isolines illustrate transmission properties of fingers at the used optical radiation. Despite the measuring system simplicity the imaging obtained was as anticipated. For example, differences between the amplitude variability for fingers without and with joint degenerations were observed. To transilluminate some optically thicker body parts it is necessary to increase the system's sensitivity, better concentration of the optical bundle and possibility to select the detectable photons. The scanner is being built to achieve this goal.

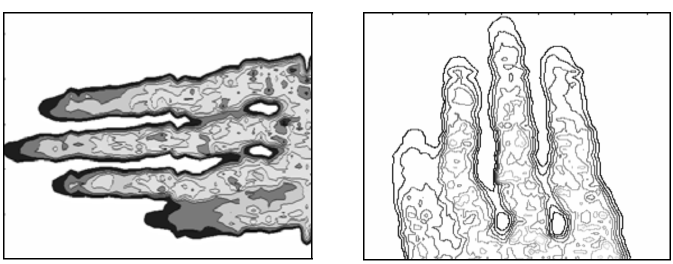

Figure 8: Examples of transillumination images obtained for hand fingers.

6 Conclusion

All traditional *in vitro* biomeasurements that need to draw blood or other tissue samples are risky, rich in complications and very time consuming. From this point of view, the role of noninvasive optical techniques in current medical diagnostics is significant, however, numerous issues related to the result interpretation still need to be solved.

The authors of the paper concentrate their current research on mastering efficient transillumination of thick layers of tissues and building efficient and

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stable algorithms representing the anatomic and functional properties. Transillumination as the method of examination by the passage of light through tissues or a body cavity is a diagnostic technique in the course of intensive development at the moment. From the combined imaging point of view, the optical imaging may provide information on the functional condition unavailable in X-ray and other techniques. Of course progressive development of noninvasive optical imaging and measurements always depends very much on the clinical acceptance of the advanced biomedical technology and engineering.

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Section 6
Special paper

Capturing the light

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Turin, Italy

Abstract

The aim of this paper is to show how beautiful, artistic images can be created by capturing the light around us. Light allows us to see the reality of the world and can make even very ordinary things wonderful. After some thought about photography from the artistic point of view, daylight, moonlight and artificial lights are considered. Then the interaction of light with water and glass is examined, particularly focussing on its ability to generate surreal and oneiric views. Finally some examples of ways of capturing the light are given.
Keywords: photography, art, daylight, moonlight, surreal views, images in water, images in glass, frames.

1 Introduction

Since pre-historic times man has felt the need to represent anything he saw in some way, both as a way of remembering and depicting its beauty and as a means of communication. First in drawings, then in painting and frescoes, in which the light constitutes the even more conscious basis and the structure of the work. Rubens in Holland, Caravaggio in Italy, Turner in England are just examples of the great painters who have made light the essence of their oeuvre.

For little more than a century technology has enabled us to represent everything around us on paper with the help of a camera which can catch light and fix images on paper. Thus a new path of creativity was traced and photography became another way of recording and representing the world, alongside drawing and painting, using different techniques but with analogous content and purpose.

Taking photographs means first and foremost looking around, observing, seeing what people often or almost always fail to see and fixing it on some surface, so as to be able to communicate it to the others. Hence photography becomes a language used between men and women capable of expressing

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concepts and transmitting beauty in efficacious and specific ways, alternative or complementary to spoken languages.

Figure 1 is an example of this. This image shows part of a skyscraper lit up by the sun: every window reflects the same image of a detail of the skyscraper opposite but distorts it in a different way, thus expressing concepts which would take many words to express in verbal language. In short, each of us filters the reality in which he is immersed in his own way, everything is subjective. Perhaps the "truth" lies in the sunlight, but nothing can be made out there anymore, and so man is not allowed to reach it, everyone is prisoner of his own individual truth. Pirandello wrote many works to get these concepts into focus.

Figure 2 represents another example of the expression and communication of concepts. There are two different types of geometrical pattern in this image, the one, Euclidean and sail-like, and the other, fractal and clouds-like: Euclid and Mandelbrot, separated by about 2000 years, in the same image.

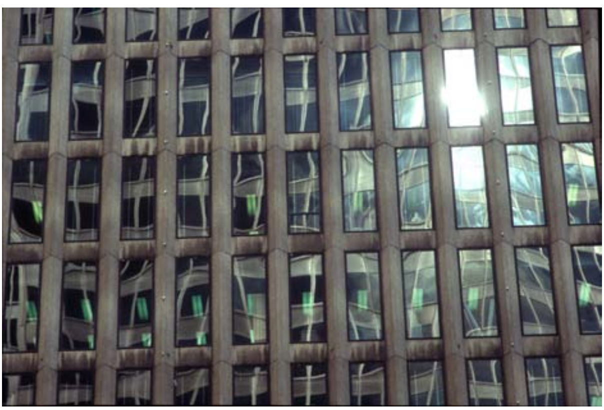

Figure 1: "Pirandello".

Figure 2: Sailing.

However as we look at these photographs we also notice that the essential "element" that gives form and life to the images is light. Light creates the world we perceive around us and, according to how he captures it, the photographer can make something beautiful, a work of art, or a commonplace, unmeaningful image. Playing with light, choosing the best moment to take the shot, choosing the frame that enhances the subject, bringing out its hidden geometric structures, exploiting the contrasts between light and dark areas: in photography it all depends on learning to capture light.

So let us begin with the main sources of light and then observe the images that the light forms, particularly those that it creates by interacting with elements that are interesting and stimulating for the photographer, such as water and glass.

2 Sources of light

The sun and the stars are the main sources of light which shines on our world. So the wish to represent them in images arises spontaneously. Almost everyone must have tried to take a photograph of the sun, especially at dawn or sunset, when it is low on the horizon and easier to look at. Its light creates intense, romantic effects, the play of oblique light and shadow gives depth and fullness to the scene framed. But the photographer can also play at picking out strange, unusual situations like the one in figure 3, where the sun is captured at dawn, just above the chimney of a house, composing something like an enormous “lampshade”.

Figure 3: The “lampshade”, Turin, Superga, Italy.

The stars, too, can create fascinating images. As he attempts to represent them, the photographer can even capture things not visible to the human eye, which yet give a sense of the magic of the night sky. By directing the camera northwards and leaving the shutter open for a long time, you obtain an image with circles described by the stars as a result of the earth’s rotation. They are circles of various colours concentric with the Northern star. In the case of figure 4 the time of exposure was almost one hour.

By choosing a suitable exposure time, after trial and error, the landscape framed can also be lit up while leaving the impression of a night sky. The exposure time in figure 5, as can be seen from the length of the arcs, was about three hours.

The moon sends us a reflected light, but perhaps precisely because of this it is very fascinating and mysterious (Fig. 6). The exposure time is much shorter and the circles of the stars become small segments.

Figure 4: The sky by night, Gran San Bernardo pass, from Italy to Switzerland.

Figure 5: The sky by night.

Figure 6: Moonlight.

3 Nocturnal impressions

There are some especially interesting kinds of light that only last for a moment; in those few minutes, when the day is done but the night has not yet taken over, the artificial lighting has already been turned on but the natural light persists, though faintly. At such moments, the photographer can create especially evocative images (Fig. 7), with a different atmosphere from those taken at dead of night (Fig. 8).

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Figure 7: La Maddalena, Italy.

Figure 8: Padua, Italy.

4 Light and water

Light, interacting with water, sometimes creates dream-like surreal images, generally in puddles, which produce very interesting and complex effects. The photographer can play not only with the images reflected in the water, but, for example, with the ground under the water, objects that may be floating on it, and with its fanciful geometric shapes. Therefore the photographer has to take into consideration light, reflected images, transparencies and geometry all at the same time.

Sometime puddles can break up reflections creating geometrical harmonies and fascinating atmospheres (Figs. 9, 10). In other cases almost surreal situations can be caught by including non-reflected zones in the frame (Fig. 11).

Figure 9: Rome, Italy

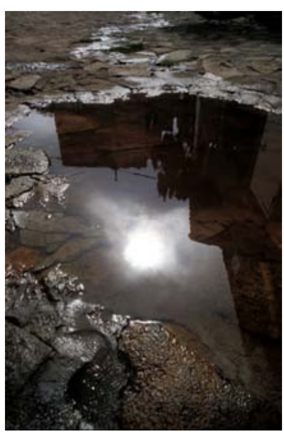

Figure 10: Giglio, Italy

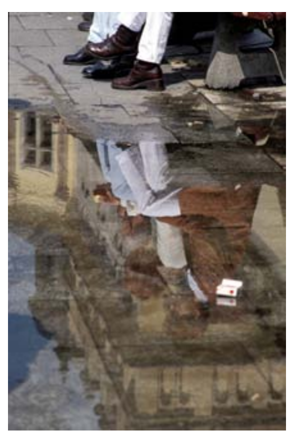

Figure 11: Krakow, Poland

Often it is interesting to turn images upside down [1], obtaining new unusual fascinating effects (Fig. 12).

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Figure 12: Pieve di Teco, Italy.

5 Light and glass

Through glass perhaps more than through water light can create wonderful, incredible but real images. Light passes through the glass, which reflects it and breaks it up into two superimposed images which the observer does not generally look at together. Yet if we try to observe the resulting image, in the streets of a town for example, where there is glass almost everywhere, we get a new townscape and discover images that generally escape most people and which can be caught directly and easily by the camera, without any further elaboration.

Anyone strolling along the streets of a town or a village can watch and enjoy the lights, the shapes and the colours forming wonderful images. Although at

Figure 13: Coburg, Germany.

first sight they may appear fictitious and obtained through complex techniques, these surreal and sometimes dream-like compositions, almost an abstract play on shapes and colours, are in fact simple images of reality captured through the lens of a camera, single shots taken while observing, maybe with a touch of irony, the urban landscape surrounding us. As we look at these images we realize that reality can be more fanciful and unpredictable than any type of imagination.

Let us consider some examples:

Reflected houses and objects on show in the shop-window, framed very accurately, give a single harmonious image both in form and shade of colour (Fig. 13).

Sometimes you get funny situations, for instance [2] suitcases on the roofs of buildings (Fig. 14) or a ghost-tram which appears and disappears in a split second (Fig. 15), or a bedroom where surely privacy is at a minimum (Fig. 16). Whereas in the picture in figure 17, by choosing carefully the point from which the frame is taken, the gradual passage from the book structure to the architectural building structure can be brought out.

Figure 14: Turin, Italy.

Figure 15: Turin, Italy.

Finally, by using a fish-eye lens, the whole shop-window can be included in the image, so that the overlapping vision seems like that of a TV set (Fig. 18). With a touch of irony even a "meta-TV" could be found (Fig. 19).

6 Some examples of how to catch light and water

So far we have considered light as the means of catching images and seen how the photographer can interpret reality artistically, by catching features and situations and creating images which show what people do not usually notice or observe.

There is also another level, perhaps a little more technical, at which light can be captured. At this level artistic images can be created by playing on details, which ultimately constitute the experience the photographer has gathered over the years.

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Figure 16: Turin, Italy.

Figure 17: Turin, Italy.

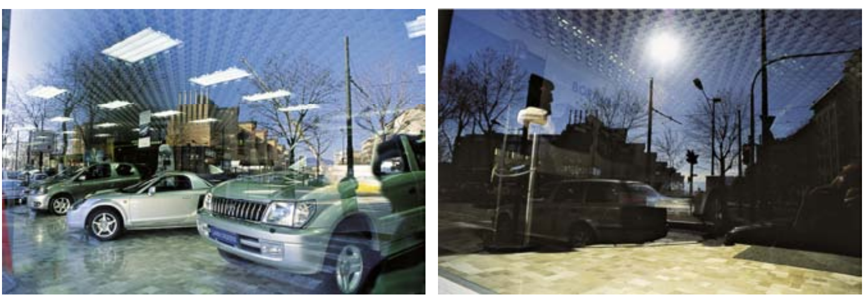
Figure 18: Turin, Italy.

Figure 19: Turin, Italy.

At times one only has to change the frame very slightly to find very different lighting. For example, to include or exclude direct sunlight may lead to the creation of very different images, even though they are taken in the same place at the same time (Figs. 20(a), (b)–21(a), (b)).

(a) (b)

Figure 20: Oropa mountains, Italy.



(a) (b)

Figure 21: Turin, Italy.

It may be very important to observe a scene and wait for the right moment to take the photograph. In figure 22, for example, it was crucial to wait for a car lit up by the sun to give the picture an extra plane.

The photograph in figure 23 provides another example. The curtains inside the shop are gradually transformed into the buildings reflected and a face printed on a poster stuck on the shop-window appears. At the time the photo was taken the sun was appearing and disappearing behind the clouds and the photographer had to wait for it to light up the scene to give life and meaning to the whole image.

At other times, light models the subject for a fleeting moment: to catch it gives meaning to an otherwise commonplace image. The profile of the horse [3] is outlined by a very fine thread of light (Fig. 24).

Figure 22: Turin, Italy.

Figure 23: Coburg, Germany.

Figure 24: The New Forest, UK.

7 Conclusion

If he is able to capture light the photographer can fix on paper images meaningful in content and aesthetic value which can acquaint us with reality very far from what we are accustomed to seeing. Thus photography becomes a figurative art, an instrument for the communication of beauty and knowledge.

In all its forms of expression art is always a means of communication, and hence involves not only those who create the work of art, but those who observe it as well. In the case of photography, it can be said that anyone looking at an artistic image will be able to take part in the creative process entailed in all forms of art.

Because of the character and the nature of the artistic images, those who look at them can do so through whatever "interpretation" they wish to give them, and will be able to grasp aspects and situations that are present in them but that the photographer himself may have not noticed while he was taking the pictures.

We can draw a useful comparison with Music: a composer writes a piece of music following his bent and developing some idea, but then, once it is on paper, that same piece of music can be interpreted in countless ways by different performers in later historical periods. Some of these interpretations the composer had never thought and could have not thought of, but were nonetheless present, hidden in the sheet of music he had written, were potentially there, right from the start. J.S. Bach could hardly have imagined, for instance, all the improvisations famous jazz players would perform centuries later on the basis of his compositions. In the same way photographs can be interpreted in many different ways, because they do not aim at being as-accurate-as-possible copies of what we all normally and absent-mindedly consider "reality", but rather at grasping and representing the "fantastic" yet true aspects of reality, which we much too often fail to see. Capturing the light is the way to do that.

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Traditional Architecture of the Arabian Gulf

Building on Desert Tides

R. HAWKER, *Zayed University, Dubai*

"This volume, which fills a void in the study of traditional Arabian Gulf architecture, will be a crucial reference for further study of particular buildings, regions, and domestic or public structures."

CHOICE

This book chronicles the florescence of architecture in the Arabian Gulf after the expulsion of the Portuguese in the early 1600s. It demonstrates how the power vacuum created by the collapse of Portuguese control over the trade routes in the Indian Ocean encouraged a growth in fortified architecture, especially in Oman, that radiated out to the surrounding region. It also shows how that architecture was slowly replaced by new patterns in domestic and public architecture and town planning throughout the Gulf as trade lines were secured and individual states moved towards new forms of governance.

The book documents the building and crafts of this era and analyses them within the framework of the political, economic, and social information available through primary sources from the period in a way that is both intelligent and accessible. It considers the settlements as part of a larger-connected network of cities, towns and villages and focuses both on how the buildings provided innovative solutions to the demanding climate and yet incorporated new decorative and functional ideas.

Topics are illustrated with photographs of the buildings as they are now, historic photographs from archival and museum collections, line drawings and computer-generated constructions. The book is therefore attractive to a number of different audiences such as people interested in architectural history, including those who live in or travel to the Gulf, as well as people with an interest in Arab and Islamic design, culture and society, vernacular architecture, and post-colonial approaches to colonial history.

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Eco-Architecture III

Harmonisation between Architecture and Nature

Edited by: ***S. HERNÁNDEZ,*** *University of A Coruña, Spain,* ***C.A. BREBBIA****, Wessex Institute of Technology, UK and* ***W.P. De WILDE,*** *Vrije Universiteit Brussel, Belgium*

Architecture ought to be in harmony with nature, including its immediate environs. Decisions have to be taken on ecological grounds concerning locations, siting and orientation, as well as the well-informed choice of materials.

Eco-Architecture makes every effort to minimise the use of energy at each stage of a building's life cycle, including that embodied in the extraction and transportation of materials, their fabrication, their assembly into the building and ultimately the ease and value of their recycling when the building's life is over. The design may also take into consideration the use of energy in building maintenance and changes in its use, not to mention its lighting, heating and cooling, particularly where the energy consumed involves the emission of greenhouse gases. Substantial savings can be achieved by the choice of materials appropriate for passive energy systems, especially natural ventilation, summer shading and winter solar heat gain. Solar and wind energy can provide heating and electric power.

Papers presented are in the following topics: Ecological and Cultural Sensitivity; Design with Nature; Building Technologies; Design by Passive Systems; Life Cycle Assessment; Quantifying Sustainability in Architecture; Case Studies; Resources and Rehabilitation; Issues from Education, Research

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