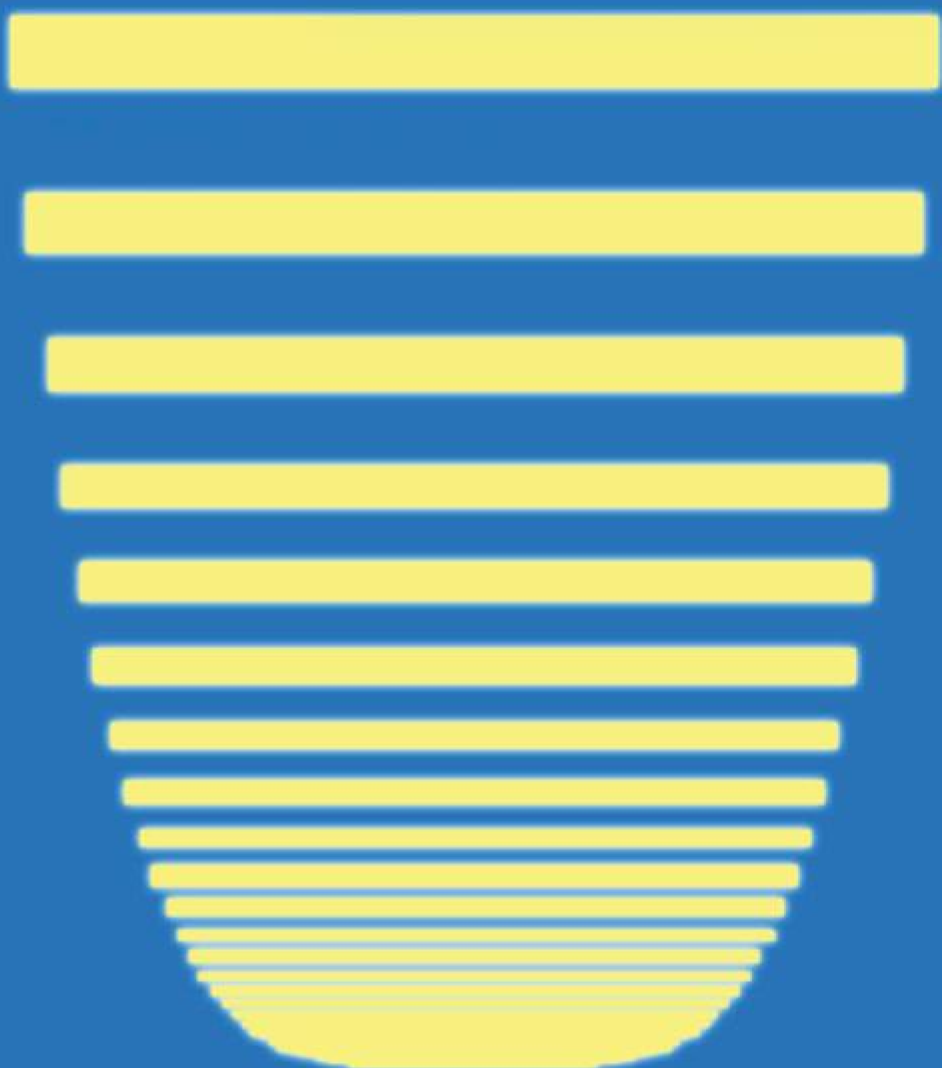
# INGINERIA ILUMINATULUI

JOURNAL OF LIGHTING ENGINEERING



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# INGINERIA ILUMINATULUI
# Journal of Lighting Engineering

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INGINERIA ILUMINATULUI – Journal of Lighting Engineering - is a publishing media for valuable original scientific papers in the field of lighting engineering. The papers proposed for publication are considered based on their originality, meaningfulness and area of interest. In order to be accepted, the papers have to be remarkable in their field. The papers are evaluated by two independent reviewers. The contributions have to conform to the generally accepted practices for writing scientific papers, with respect to paper organization and style of writing.

The journal is published every six month, in June and December. Two issues form a volume. It has its own web page, covering the editorial policy, publishing criteria, information for authors, as well as all papers, available in PDF format, with open access.

The journal is classified by CNCSIS, code 244.

The journal is indexed by Index Copernicus Journal Master List (ID 5747) and DOAJ - Directory of Open Access Journals (index no. 14545837).

The journal was created following the EU program: "Lighting Engineering Centre - LEC - consulting and continuous formation, 1998/99 Tempus-Phare CMS - Compact Measures Project - CME-03551-97", presented on the web site http://users.utcluj.ro/~lec

INGINERIA ILUMINATULUI – Journal of Lighting Engineering - is affiliated to the CNRI – CIE Romanian National Committee on Illumination, member of the CIE – Commission Internationale de l'Eclairage.

INGINERIA ILUMINATULUI - Journal of Lighting Engineering - has a scientific presentation and content, targeted to the continuing education in the lighting field. The objectives of the journal consist of the presentation of results of lighting research activity, dissemination of lighting knowledge, and education of interested people working in public administration, constructions, designers, dealers, engineers, students and others.

Its content is organised in six parts: Editorial, Papers, Theses and Dissertations, Conferences and Symposiums, Information, Anniversary.

### Subscription Information

The 2014 subscription rate is €50, including mail taxes.
Orders and payment should be made by Editorial office.

# Last Issue of INGINERIA ILUMINATULUI - Journal of Lighting Engineering, A Fresh Start for The International Journal of Sustainable Lighting


Dorin BEU, Florin POP

In 1999 the INGINERIA ILUMINATULUI Journal was launched to create a review of Central and East European lighting research. After 2009 the journal was re-centred to Ph.D. students.

Despite the Romanian name of the Journal, all the papers, except the first issues, were written in English, but still it was perceived as a regional journal. It was focussed on lighting engineering and so, some issues like circadian rhythm did not fit well on this framework.

Based on the experience we had so far, we decided that now is the moment for a fresh start. We join forces with Professor Jeong Tai KIM, Kyung Hee University, Korea, following his proposal to launch a new project: **The International Journal of Sustainable Lighting (IJSL),** as the successor of the former INGINERIA ILUMINATULUI - Journal of Lighting Engineering. This is the right moment for a new approach, in a moment when health related issues, lighting pollution, green certifications are becoming mainstream that is why we also consider there is a need for a journal opened to all this aspects. Lighting was always a topic hard to classify, definitely a trans-disciplinary one which need to be addressed. In the upcoming years we will index the journal in the relevant databases, including Thompson-Reuters.

Twenty years ago it was unthinkable to have papers from environment specialists or medical doctors, but this days it is common and the new IJSL will serve this purpose. An important trigger was the participation in the EU Cost LoNNe – Loss of Night Network ES 1204 which made us realise this new change. More details will be presented in the first issue which will be edited in June 2015.

We hope that this new vision will be endorsed by reality, and it is a sign of change among the Editorial Board. The speed of change in the lighting industry plus new discoveries in light related health issues will increase the importance of lighting. So, a new, more dynamic website is essential in our effort to have the research results published as soon as possible.

## 1999-2014

The INGINERIA ILUMINATULUI - Journal of Lighting Engineering started in 1999 and has 33 issues. It was launched through a European Research Program by Professor Florin POP, from Technical University of Cluj-Napoca, with the cooperation of the Universities of Helsinki, Barcelona and Naples.

*["Lighting Engineering Centre - LEC - an excellence center for consultancy and continuing education the lighting field in direct link with the needs of the labour market, 1998/99 Tempus-Phare CMS - Compact Measures Project - CME-03551-97" was dedicated to disseminate lighting knowledge and to promote direct contacts between our students and other interested people - local designers, dealers, engineers - and lighting community with high specialists from Romania and abroad. This project, developed between December 15, 1998 – March 14, 2000, concentrated the efforts of university professors from Cluj-Napoca, Barcelona, Helsinki and Naples.]*

The first four issues were sponsored by EU, the following ones by ELECTRICA Local distribution branch and, later, by sponsors and Lighting Engineering Center/Laboratory UTC-N. The journal started as the only Romanian lighting journal which brought together specialists in lighting community; the objectives of the review consisted of the presentation of the results of the lighting research activity, the dissemination of the lighting knowledge, the education of the interested people working in public administration, constructions, designers, dealers, engineers, students and others.

Initially, it was printed mainly in English, translated to Romanian, and few articles in Romanian with a large English abstract of the papers, to penetrate the Romanian market and to be in the support of Romanian professionals. This policy started with its first issue until the issue no. 11 (Vol. 5, No. 1, June 2003). Afterwards, the published articles were only in English with a large translation to Romanian – issues no. 12-14 (Vol. 5, No. 2, 2003 - Vol. 6, No. 2, 2004). Starting with issue no. 15 (Vol. 7, No. 1, 2005), the journal was printed entirely in English, sometimes with short abstracts of articles in Romanian.

The journal is also presented in a PDF format on the web site, with open access.

Step by step, it was transformed in a European journal with accent on Early Stage Researchers – ESR. The latest lighting developments researches, state of the art designs, PhD thesis and also the past and future lighting events in Europe were all put together.

During 15 years, its pages hosted 228 authors with their research papers, scientific or technical information and celebration of personalities.

High lighting personalities joined the Editorial and Advisory Boards and/or contributed with scientific papers to develop a prestigious lighting journal.

We would like to address our heartiest thanks to all the people involved in the INGINERIA ILUMINATULUI - Journal of Lighting Engineering presence in the lighting word.

# CHALLENGES OF PROVIDING DAYLIGHT IN OPERATING THEATRES LOCATED IN THE TROPICAL REGIONS: AN EVALUATION STUDY OF DAYLIGHT DESIGN OF OPERATING THEATRES OF SUNGAI BULOH HOSPITAL, SELANGOR, MALAYSIA

**Choong-Yew CHANG, Michael PHIRI, Steve FOTIOS**
University of Sheffield, UK

**Abstract:** *The convention of the planning of modern operating theatre (OT) complex worldwide has been based on a deep-plan concept. Majority of the modern OTs were designed in such that the environments resembled specialist equipment rooms, which were usually windowless and thus there was no access to daylight. In contrast to this convention, studies have shown that daylight assists humans in reducing stress and depression, and more daylight is linked to greater job satisfaction of hospital staff. Incorporating daylight in OT can potentially create positive impacts on surgeons since surgical operations require relatively long working hours and intense focus. Research has shown that there are strong associations between patients' satisfaction and surgeons' job satisfaction and working conditions. Therefore daylighting should be an essential consideration in the design of OTs in order to enhance productivity, health and well-being of surgeons and other OT staff. In this paper, we discuss the challenges in daylight design of future OTs in the tropical regions. The empirical study is based on a maternity OT in Sungai Buloh Hospital, Selangor, Malaysia. The aim of the study is to evaluate the potentials of eight different types of windows for the purpose of daylight optimisation in OT. Based on the mapping of OT activities and the two daylighting metrics in the SLL Lighting Guide 2 (Hospital and Health Care Buildings) 2008 – i.e. average daylight factor and uniformity of daylight illumination, it was found that rooflight and roof monitor have the highest daylight performance for OTs.*

**Keywords:** Window Design, Evidence-Based Design, Design Intervention, Surgeons' Working Conditions

## 1. Introduction

Operating theatre (OT) is the "operative" core unit of every surgical hospital and it is one of the most sensitive areas as herein invasive manipulation on the patient takes place (Koneczny, 2009). A large amount of research have been carried out on the visual requirements and artificial lighting of OTs (Hemphälä et al., 2009), but there was no in-depth study on the potential of introducing daylight into OTs. Literature reviews show the positive impacts of daylight on humans, and how daylight affects a person's well-being through the visual system (visual performance, spatial appearance, visual comfort), the non-visual ocular systems (circadian regulation; mood, alertness and cognition), and skin exposure (thermal sensation and ultra-violet radiation) (Ulrich 1984; Beauchemin & Hays 1998; Benedetti et al 2001; Walch et al 2005; Veitch et al.2012). While much has been revealed regarding the healing effect of daylighting on patients in hospital patient rooms (Joarder, 2012), globally there is still a lack of daylighting considerations in the design of healthcare environments, particularly spaces such as OTs, which have traditionally been perceived as specialist equipment rooms in the hospitals.

There is currently no published design guide and regulation in terms of daylight for OTs. BREEAM Healthcare 2008 has no mention of daylight requirement for OTs. The normal practice of creating OTs with no access to daylight has not been challenged by healthcare facility planners, architects, engineers and stakeholders who have given in to demands to install more controllable and manageable artificial lighting. During a hospital inception and planning stages, architects and healthcare planners tend to position the OTs in the deep plan where the sterile corridors and work corridors are placed parallel to each other on both sides of a row of OTs to enhance the efficiency of space circulation and servicing. This planning strategy results in OTs all having internal walls and thus the OTs have no access to daylight, except 'borrowed' daylight through internal windows in some cases.

Many studies of task lighting have evaluated office-related tasks (Veitch 2001). In this case, examination and operation lighting in medicine, surgery and dentistry emerge as special instances of task lighting. While acknowledging that access to natural lighting enhances psychological well-being, studies on task lighting have taken the view that natural light alone is not enough for most tasks because of the wide variation in light intensity that exists even in spaces that have plentiful natural light. The problem is seen not as determining the contribution natural light makes but as establishing the lamp characteristics and specifications (Fotios 2001). Efforts centred on providing the correct lamp for the task lighting has resulted in daylight design for the OT that focuses on and dominated by supply and installation of the lamp over the operating table.

Although useful when considering daylight provision in OTs, studies on the effect of illumination levels on outcomes such as errors in the performance of surgical procedures (Moorthy et al., 2003, Pluyter et al., 2010), prescription- dispensing error rate (Buchanan et al., 1991), medication dispensing errors (Flynn et al., 2002) do not mention the contribution of daylight i.e. the daylight component. When considering the daylight provision in the OTs and evaluating the experience of surgeons, confounding variables are health, age and eyesight of the surgeons. When people do not have adequate light or the 'right' kind of light, they may experience eyestrain, headaches and make more mistakes.

An important consideration with regard to daylighting provision for OTs is to determine visual preferences for the surgeons and other staff most likely to benefit directly from the presence of natural light or to be affected by symptoms such as eyestrain as a result of depriving them of suitable lighting. Generally, it is widely accepted that people have a strong preference for natural light over artificial light in a room and constant exposure to artificial light is commonly mentioned by nurses as one of the draining aspects of their work.

The current legislation in Malaysia on daylighting requirement is very minimal, governing only the minimum proportion of window. For instance, Section 39 of the Uniform Building By-Laws 1984 states that for hospital patient room, window area shall be at least 15% of the floor area of the room. Presently there are 141 government hospitals in Malaysia. Among the 14 government hospitals located in the Federal Territories of Kuala Lumpur and Putrajaya as well as the State of Selangor, only 4 hospitals have OTs with windows.

The Health Facility Planning Division, Ministry of Health, Malaysia revealed the following: firstly, there is presently no existing guideline on daylight design of OTs in Malaysia. Secondly, daylight and window view benefit the surgeons by providing relaxation of their minds; and younger surgeons tend to prefer the presence of daylight window in OT. Thirdly, most of the local hospitals rejected the idea of providing daylight windows for OT because of three main reasons: problem of discomfort glare and excessive heat gain resulting from daylight penetration; problem of maintenance (because window sills and frames potentially increase dust retention which compromises the sterility in the OT environment); and problem of privacy faced by the patient (because the surgical procedures may be exposed to other parties that view from outside).

The pertinent question now is what type of daylight window has the potential of optimising the daylighting performance of an OT in the tropical region, for the purpose of enhancing the OT staff's productivity, health and well-being?

## 2. Methodology

A multi-method approach was adopted in the study. Quantitative methods were used on numeric description of daylight data and other physical data of the OTs. Qualitative methods were used on validating the accuracy and reliability of findings. Overall the research methods were based on the actual daylight measurement in a case study OT as well as the mapping of parameters – i.e. daylight distribution, staff activities and staff movements in OT. Digital model of the case study OT was constructed to carry out daylight simulation and analysis

The case study OT was one of the two maternity OTs in Sungai Buloh Hospital (SBH), a 620-bed public hospital located in the district of Sungai Buloh, Selangor, Malaysia. The global location of SBH was referred to latitude 3.2191° N and longitude 101.5833° E. The orientation of window in the OT was 203° CW. There were 22 OTs in SBH including 5 windowless OTs. The case study OT was the only OT with external window with an unobstructed view to green landscape.

**Figure 2.1** The case study OT – the Maternity OT No. 1 at Level 2, SBH

The daylighting performance evaluation in the study was based on the two daylighting metrics stated in the SLL Lighting Guide 2 (Hospitals and health care buildings) – i.e. average daylight factor (*ADF*) and uniformity of daylight illumination (*d*). The recommended *ADF* is between 2% and 5%; uniformity of daylight illumination is between 30% and 50%. However the guidelines are for hospital spaces in general and there is no specific mention of daylight requirements or considerations for OTs. Average daylight factor (*ADF*) is the average value of daylight factor, which is the ratio of work-plane illuminance at a given point to the outdoor illuminance on a horizontal plane under the condition of a standard overcast sky. Uniformity of daylight illumination (*d*) of a given plane is calculated as the quotient of the lowest value of illuminance of the plane ($E_{min}$) and the average illuminance of that plane ($E_{av}$). Therefore $d=E_{min}/E_{av}$. In the study, *ADF*, $E_{min}$ and $E_{av}$ were derived from VELUX Daylight Visualizer 2.

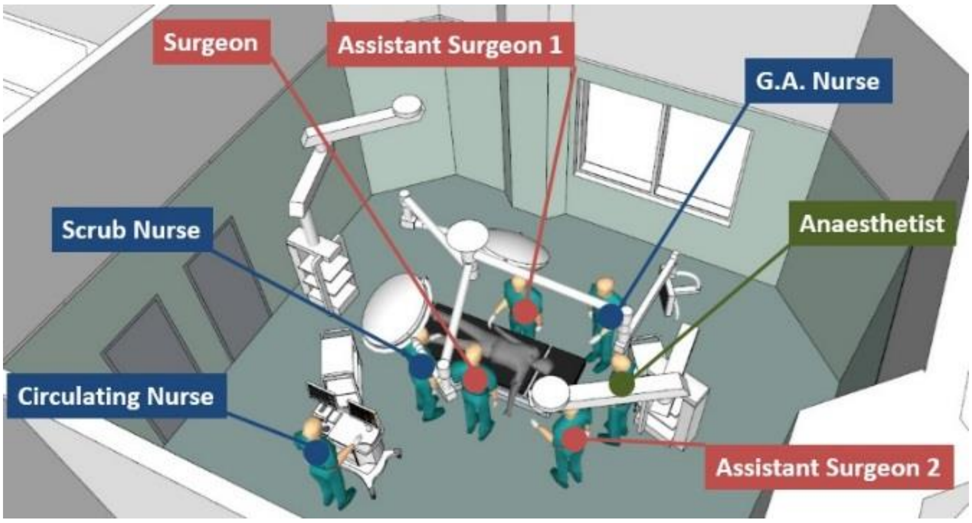



**Figure 2.2** Medical staff and their activities during a surgical procedure in the case study OT

Daylight measurements were taken on a horizontal task plane at the height of 1000 mm in the case study OT using a TES digital illuminance meter (model TES-1330A). The height of task plane was an estimate based on the height of operating table. The OT was divided into a 5 by 5 grids, each measuring 1500 mm by 1500 mm. The grid system was intended to establish three "ring zones" – i.e. the outer ring along the four walls, the intermediate ring, and the centre where the operating table was situated. Illuminance readings in unit lux were taken at the centre point of each grid and then recorded on the layout plan of the OT. The readings were taken in two situations – i.e. when all the lamps in the OT were switched on, and when all lamps were switched off (so that the OT was only lit by daylight entered through the window). Daylight distribution layout was superimposed with the OT staff's activities and movement layout in order to establish a mapping between these parameters. The purpose was to align daylighting analysis with activities taken place in OTs – i.e. the types of work of each of the OT staff, which comprises surgeons, anaesthetist and nursing staff.

## 3. Results

Daylight measurements at the case study OT revealed that light distribution across the room was relatively uniform when all the lamps were switched on. However, when all the lamps were switched off, it was observed that the distribution of daylight has low uniformity as shown in Figure 3.1 below.

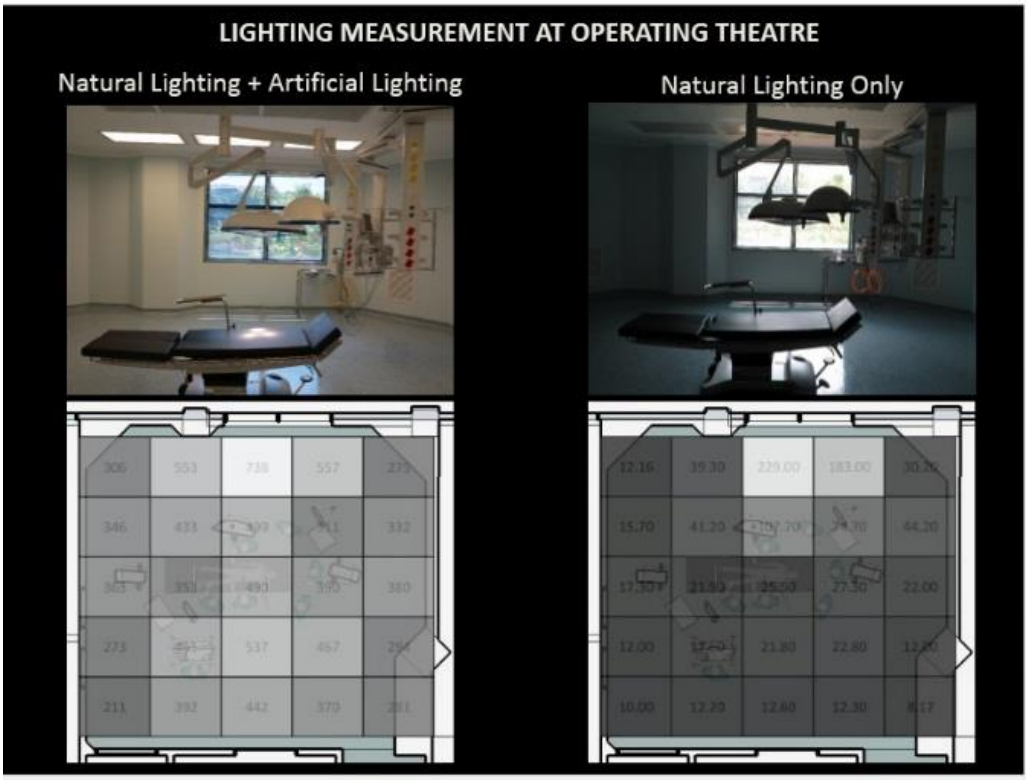



**Figure 3.1** A significant difference in terms of uniformity of illuminance when all artificial lighting was switched on (left) compared to the situation in which the same OT was solely lit by natural lighting (right)

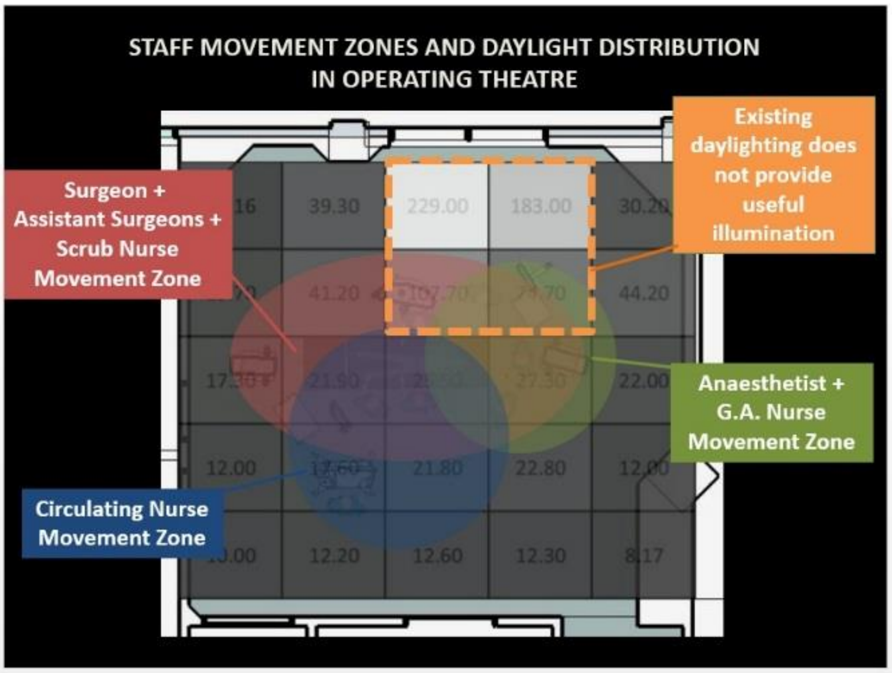



**Figure 3.2** OT staff's activities and movement layout did not match the daylight distribution pattern in the case study OT

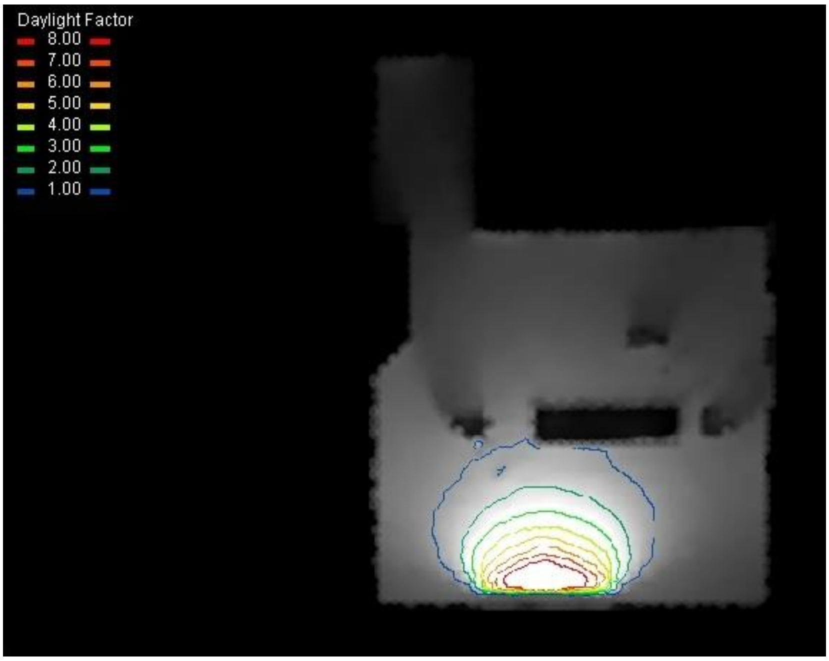



**Figure 3.3** Daylight factor analysis of the case study OT

Based on the daylight analysis using VELUX Daylight Visualizer 2, it was found that at the centre of operating table, the daylight factor was less than 1.0%, which was below the minimum 2% recommended in the SLL Lighting Guide 2. It implied that the distribution of daylight illumination in the case study OT was not useful for any surgery-related task that could take place around the operating table.

The “punched window” approach of daylighting in the case study OT provided a very low uniformity of daylight illumination of 13% with an average daylight factor of 0.8%. This was far below the uniformity of 30% - 50% and average daylight factor of 2% - 5% recommended in the SLL Lighting Guide 2.

A three-dimensional digital model of the case study OT was constructed to explore the daylight distribution based on seven other types of windows – i.e. claustras, clerestory, external reflectors, light duct, light shelf, rooflight and roof monitor. VELUX Daylight Visualizer 2 was used to analyse the daylight performance based on average daylight factor and uniformity of daylight distribution. The results are summarised in Figure 3.4 (a) and (b) below.

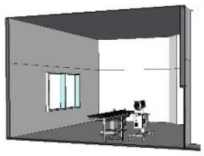
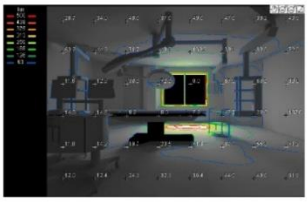
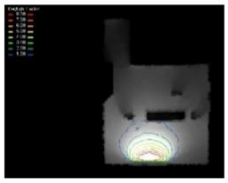
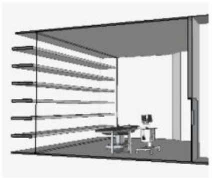
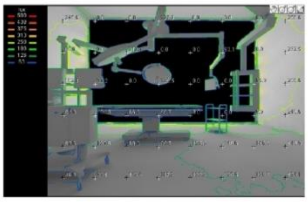
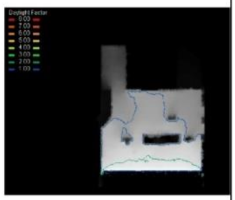
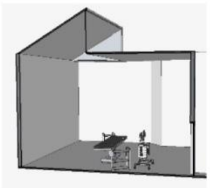
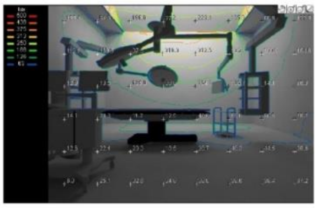
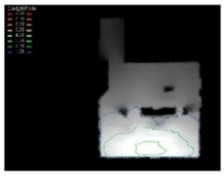
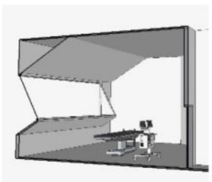
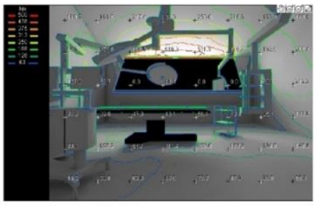
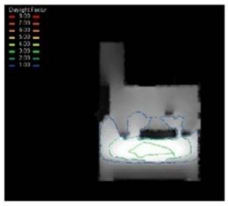
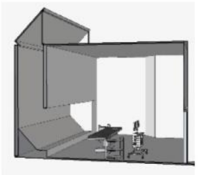
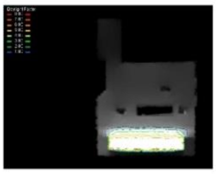
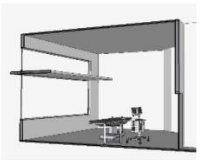
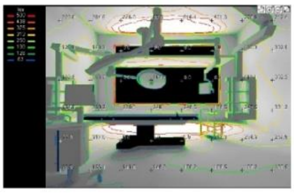
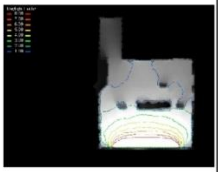
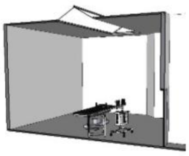
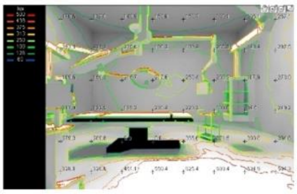
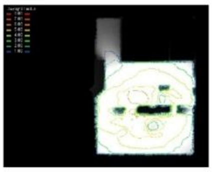
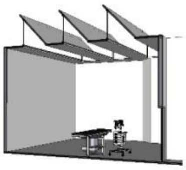
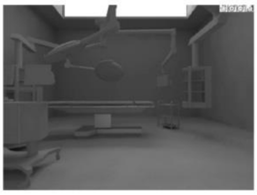
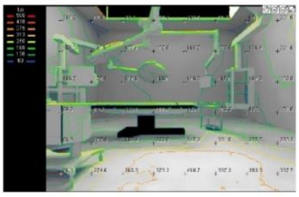
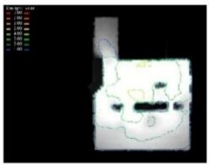
| Types of Daylight Windows | Daylighting Visualisation & Analysis (Tool: VELUX Daylight Visualizer 2) | | |
|---|---|---|---|
| | **Luminance** | **Illuminance** | **Daylight Factor** |
|  **Punched Window** |  |  |  Average DF = 0.8% Uniformity = 13% |
|  **Claustras** |  |  |  Average DF = 1.2% Uniformity = 43% |
|  **Clerestory** |  |  |  Average DF = 1.1% Uniformity = 23% |
|  **External Reflectors** |  |  |  Average DF = 1.0% Uniformity = 22% |

**Figure 3.4 (a)** Daylighting visualization and analysis based on various parametric daylight windows

| **Types of Daylight Windows** | **Daylighting Visualisation & Analysis** (Tool: VELUX Daylight Visualizer 2) | | |
|---|---|---|---|
| | **Luminance** | **Illuminance** | **Daylight Factor** |
|  **Light Duct** |  |  |  Average DF = 1.1%<br>Uniformity = 8% |
|  **Light Shelf** |  |  |  Average DF = 2.5%<br>Uniformity = 25% |
|  **Rooflight** |  |  |  Average DF = 3.7%<br>Uniformity = 42% |
|  **Roof Monitor** |  |  |  Average DF = 2.3%<br>Uniformity = 39% |

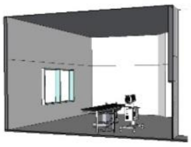
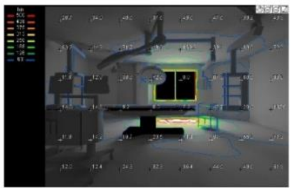
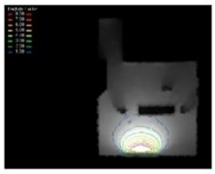
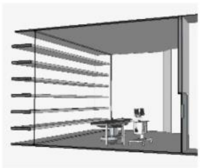
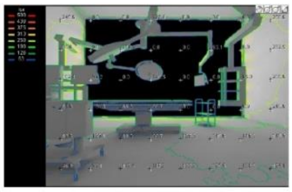
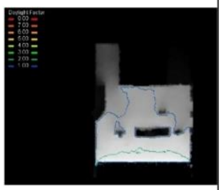
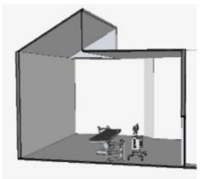
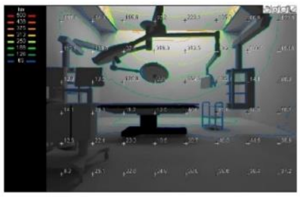
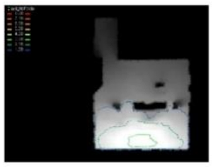
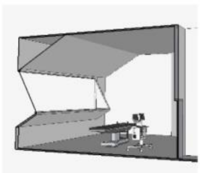
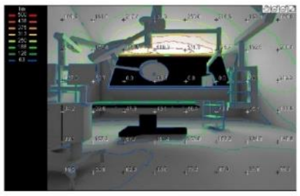
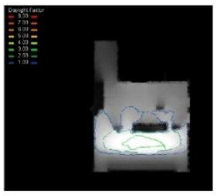
| **Types of Daylight Windows** | **Daylighting Visualisation & Analysis** (Tool: VELUX Daylight Visualizer 2) | | |
|---|---|---|---|
| | **Luminance** | **Illuminance** | **Daylight Factor** |
|  **Punched Window** |  |  |  Average DF = 0.8% Uniformity = 13% |
|  **Claustras** |  |  |  Average DF = 1.2% Uniformity = 43% |
|  **Clerestory** |  |  |  Average DF = 1.1% Uniformity = 23% |
|  **External Reflectors** |  |  |  Average DF = 1.0% Uniformity = 22% |

**Figure 3.4 (b)** Daylighting visualization and analysis based on various parametric daylight windows

From the analysis, it is clear that only rooflight and roof monitor meet the recommended level of uniformity of daylight distribution and average daylight factor, as shown in Figure 3.5 below:

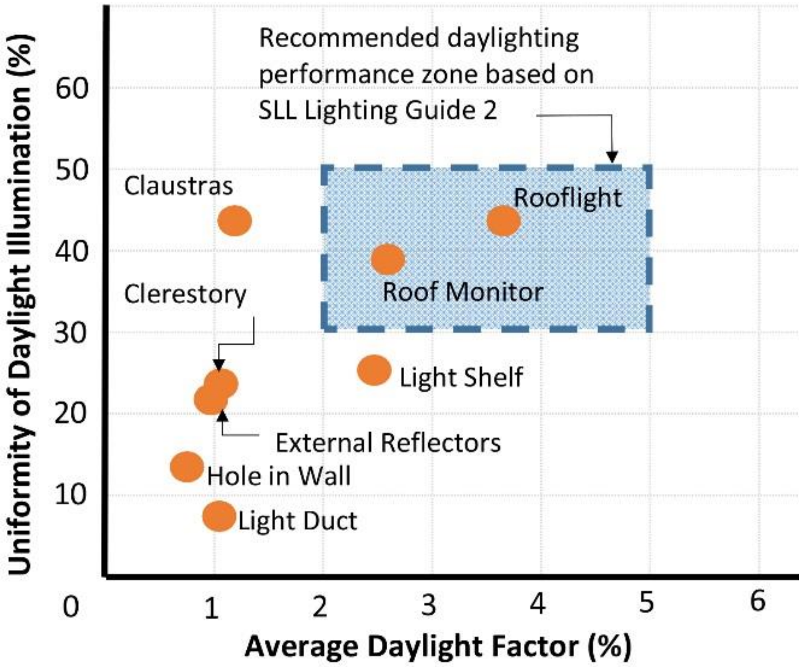



**Figure 3.5** Daylighting performance of OT according to eight types of parametric daylight windows

Despite the highest performance of rooflight and roof monitor in terms of average daylight factor and uniformity of daylight distribution, solar heat gain of each type of the daylight windows above deserve further studies to ascertain the its suitability for OT environment.

## 4. Discussion

Based on the study above, it is evident that the issues related to daylighting of OT is more than just the provision of typical windows for the OT; daylight performance should be optimised.

In order to optimise the daylight performance of OT, the following parameters need to be taken into consideration:

1. Window design: Size of window opening, shape of window, position of window, orientation of window, proportion of window size to room area, transmission of glazing;
2. Shading devices: external shading devices such as louvred screen; internal shading device such as roller blinds;
3. OT layout: room depth, ceiling height, shape & size of room, position of

operating table & instrument, positions of access to scrub room etc.;
4. Colour and texture of surfaces in OT (wall, floor, ceiling etc.);
5. Integration of artificial light – the window designs need to integrate with the artificial lighting layout and types of lamps (both ambient light and task light).

The daylight experienced by surgeons when carrying out the medical procedures in the OT is essentially what should be investigated. The challenge is then that of measuring the amount of daylight experienced by the surgeons but also establishing the extent to which varying levels of daylight impact on the performance of surgery tasks.

## 5. Conclusions

The present study shows the problems associated with daylight provision in OTs within the tropical region. There are lots of challenges with few options of addressing. The pilot study of OTs in Sungai Buloh Hospital (SBH), Malaysia shows the need to change attitudes and nature of provision dominated by artificial lighting, as well as the approaches in designing daylight windows.

There were surgeons who specifically requested for windows to be incorporated into OT design. However, surveys have yet to be carried out to estimate the proportion of surgeons who have preference for daylight windows. And also to find out if their request was because of daylight illumination, or view outside, or both.

Daylight availability through the window or via skylights has to be modelled to determine how it best serve activities in the operating theatres. Further studies will adopt a multi-method approach which will be used to collect data for analysis supported by measurements of daylight to establish the nature and characteristics of daylight provision. Staff productivity and satisfaction of work will be evaluated based on hospital records and other healthcare information systems, for example medical errors and staff retention. Surveys of clinical staff will be conducted to understand the level of work satisfaction in OTs with daylight and OTs without daylight. Computer simulated models of OTs will be used to examine different daylight design interventions. Results from the study will develop a suitable daylight design tool and guidance for OTs.

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# FROM MARVEL TO POLLUTION. EXCESSES OF OUTDOOR ARTIFICIAL LIGHT THROUGH THE AGES

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**Abstract:** *Excesses of outdoor artificial light were recorded since ancient times in the many forms. In Antiquity, only very few cities, all of them in the South-Eastern part of the Mediterranean world, had their main streets illuminated. The first successful attempts to illuminate every night at least the most central parts of a city are all to be inscribed in the golden age of the Islamic expansion. At those times, Europe sunk in complete night darkness, cities like Paris being "supplied" with a single public candle at the main city gate. Soon, for the first time in History, "lighting excesses" did not concern only the Mediterranean area, the richest in good oils for lamps as well as in waxes. Then, historians could draw exactly the nature of the celebration, thanks to diverse sources, from a rare precision for these times. We realize that for the "homo religious" of the Medieval times, so many lamps were the "sun" he offered to the divine and the flame of divine blessing him. The emergence of light pollution was based on the higher capacity of adaptation of the man in comparison with most animals. The "moonlight towers" episode, which could have been used as a milestone in the fight against lighting pollution, is now largely forgotten by specialists.*

**Keywords**: lighting pollution factor, moonlight towers, lighting strategy

## 1. Introduction

"*At the tenth hour, which they call here licinicon, or as we say lucernalis, all the people assemble at the Anastasis in the same manner, and all the candles and tapers are lit, making an infinite light*" (Etheria, The Pilgrimage, 2:24; VIth century AD travel diary)

Most of us have forgotten that public lighting is, from a historical point of view, a relatively "new" concept.

In Antiquity, only very few cities, all of them in the South-Eastern part of the Mediterranean world, had their main streets illuminated. Among them, we can quote the examples of Ephesos, Antioch or Edessa[1]. Even in the mighty Rome, peaking with more than a million inhabitants in its golden imperial period, wealthy people had to have a slave (the *lanternarius*) preceding them with a lantern to light their way in the dark streets of the capital.

## 2. The emergence of outdoor artificial light

The first successful attempts to illuminate every night at least the most central parts of a city are all to be inscribed in the golden age of the Islamic expansion: Baghdad, Cairo, Jerusalem and, of course, the prestigious Mozarab Cordoba, the best known example of a city renewal of both hydraulic conducts and street lighting, to be dated 850 AD. At those times, Europe sunk in complete night darkness, cities like Paris being “supplied” with a single public candle at the main city gate.

Real studies and implementations of systematic planning to light properly the central part of a city are all to be seen much later, during the late 17th century[2] (Paris in 1667[3], Amsterdam in 1669[4], Berlin in 1682[5], London in 1684[6] a.s.o.) and, even most of the lighting plans were carefully made, the lighting power of the street-lamps was still very modest, all of them still using simple candles or natural oil lamps.

In this context, several Mediterranean civilizations developed, in their wealthiest periods, exuberant light festivals, the only occasions when some cities were lit “*a giorno*” for one or more nights.

Herodotus and many others make extraordinary reports of the events they witnessed in Egypt, which had since the Pharaonic period a long tradition of “*festivals of lamps*”: “*At Sais, when the assembly takes place for the sacrifices, there is one night on which the inhabitants all burn a multitude of lights in the open air round their houses. They use lamps in the shape of flat saucers filled with a mixture of oil and salt, on the top of which the wick floats. These burn the whole night, and give to the festival the name of the Feast of Lamps. The Egyptians who are absent from the festival observe the night of the sacrifice, no less than the rest, by a general lighting of lamps; so that the illumination is not confined to the city of Sais, but extends over the whole of Egypt. And there is a religious reason assigned for the special honour paid to this night, as well as for the illumination which accompanies it*.” (Herodotus, II, 50)

The most important of such celebrations was doubtless the five-days and five-nights celebration of the birthday of Isis[7]. As far as we know, each believer had to bear a lightened lamp to the temples, and light as many as he could at home. Initially confined to Egypt, the Isiac feast found its way, during Roman times, through all the main cities of the Empire, as the Graeco-Egyptian cults seduced a large number of Romans.

**Figure 1** Roman clay lamp of the Ist c. AD, boat-shaped, with representation of Sarapis and the Dioscures, used for Isiac celebrations

But Isiac celebrations, as well as some other Greek and then Roman sacred feasts, were certainly much closer to what happens nowadays in India[8] during the Diwali (Birthday of the Goddess Lakshmi and Indian new year)[9] or in Tibet during the ChötrulDüchen (butter lamps day in honor of Buddha)[10]. People used to light infinitely much more lamps than in usual days, but the largest concentration of flames had to be found near the temples, meaning the conditions of a "*lit city*" were still not fulfilled.

In Figure 1 is presented special lamps for holy celebrations.

**Figure 2** An Indian craftswoman painting lamps to be used for the Diwali

**Figure 3** An Indian woman lights dozens of lamps in the street at Diwali

**Figure 4** Tibetan monks lighting butter lamps at ChötrulDüchen.

We have to wait for the rise of Christianity to witness real massive lighting excesses, even if we must be cautious as most of the sources tend to be too emphatic when they describe holy celebrations.

Besides Easter, but also the daily vespers in some holy cities like Jerusalem as witnessed by Etheria, the most incredible moments are linked to the death of a powerful ruler or clergyman[11]. The first of those events to be mentioned are doubtlessly the night processions in honor of Constantine the Great himself and of one of the Fathers of the Church, John Chrisostomos, whose funerals impressed the chronicles, both lighting the Bosphorus as it would have been daylight.

Soon, for the first time in History, this kind of "*lighting excesses*" did not concern only the Mediterranean area, the richest in good oils for lamps as well as in waxes. French chronicles describe the mourning of Bishop Saint Germain, in 447, when the city of Auxerre shined by night as if it was daylight.

But all these texts, even if very suggestive, do not provide us with exact quantities of lighting devices lit and hence do allow us to measure what our ancestors praised as "*a copy of the sun*".

One of the first events we can really measure and analyze in technical terms is the inauguration of the Cathedral of Segovia on August 14th, 1558[12]. As a matter of fact, hundreds of small clay lamps, with their cotton wick, remains of their fuel - a mixture of pine resin - and their wooden supports have been discovered in the crypt of the cathedral, letting us understand which kind of devices were praised in the texts with the generic word "lamps".

Then, historians could draw exactly the nature of the celebration, thanks to diverse sources, from a rare precision for these times. The archives of the cathedral preserve, for the date of August 22nd, 1558 - eight days after the great celebration - the bill paid by the Bishop services to Sir Luis de Mendoça: 23,050 Maravedis for all the lamps, which had been placed inside and outside the Church for its inauguration.

In a precise account made for the town hall, published shortly after the event, we can read: "the city appeared to merge from the light, the believers in procession carrying any sorts of lights. All the towers of churches, and of course of the cathedral, were decorated up to their summit by thousands of lit lamps". Much more interesting are the following pages, through which we know that the municipal government took itself at its own expenses the two thousand lamps placed in the niches of the big bridge of the city, while the Bishop and the believers paid for the rest of the lamps, which exceeded twenty thousand units.

**Figure 5** Holy procession with candles at Lourdes: a modern image of how the ancient "rivers of light" should look like © Sanctuaire Notre Dame de Lourdes

We hence understand that for a medieval Spaniard, 22,000 lamps lit meant a sort of "sunlight", as no such quantity of light by night had been seen from generations. Judging by the fuel used, resin, which has a very high concentration of turpentine, we can estimate that a lamp emitted a light power of ca 1 candlepower (0.981 candela).

**Figure 6** The Cathedral of Segovia and some of the lamps with their wooden support discovered in the crypt, now preserved in the Archaeological Museum

**Figure 7** The Cathedral of Segovia and some of the lamps with their wooden support discovered in the crypt, now preserved in the Archaeological Museum

We realize that for the "*homo religiosus*" of the Medieval times, so many lamps were the "sun" he offered to the divine and the flame of divine blessing him. It is certainly an *''excess''* of lamps, but we are still far from the contemporary reality of "*lighting pollution*"[13].

In this field, we have to wait for the 1800's to witness the first man-made lamps, which really had a strong and negative impact on health. This time, it is no more to honor a heavenly god, but to praise another deity: the Progress.

With the invention of the arc lamp, Europeans and Americans dreamed to have lighthouses for their cities, gigantic monuments that could light a whole town[14].

In Europe, projects submitted by engineers were mainly unrealizable by their disproportions, so that almost none of them had ever been implemented. Among the most utopic ones, let us remember the project published in 1885 by the famous architect Jules Bourdais and the light engineer AmédéeSébillot: a single tower of some 80 m height equipped with a single, so powerful, arc lamp that it was designed to light, alone, the hole French capital[15]. An interesting anecdote is the fact that Gustave Eiffel proposed his project of tower, also designed to be topped by very powerful arc lamps, in the same session of the French Civil Engineers Society, and had the chance to draw quick conclusions of the very negative reactions he witnessed when Bourdais' concurrent project was debated.

As a matter of fact, arc lighting was so powerful that it was unsuitable for an indoor use and could blind a man if too close. In France, it met strong oppositions since its first applications.

The Revue des DeuxMondes, in its edition of March the 15th, 1878, is maybe the first to quote the scientists, who dared to underline the health damages the new lighting technique can cause to the humans: "*Quand vous regardez la lumière électrique, disent-ils, vous voyez tout autour comme les rayons divergents d'une auréole céleste; puis, après la contemplation de ce point lumineux, il reste dans la vue des taches de toutes couleurs qui semblent se promener dans l'espace; on n'yéchappe point en fermant les yeux, c'est une véritable cécité, momentanée sans doute, maisil n'est pas sans exemple qu'elle ne devienne éternelle. L'un des plus éminent sphysiciens de la Belgique, M. Plateau, a payé par la perte totale de la vue des observations qu'il a trop long temps continuées* (...)".

Even before the 1880's, the French daily press starts to attack mercilessly the first arc lightings implemented in Paris, at the Opera square and on the Champs Elysées: "*Au lendemain de cette épreuve, si nous en jugeons par notre vue, réputée bonne, compromise pour plusieurs jours, nous tenonsqu'il y a péril à rechercherce spectacle d'un nouveau genre (...) Pour le moment, mettonsnos lunettes de couleur, nosvisièresvertes, et craignonsquecette application de l'électricité, tout en ne nous rendant pas plus clairvoyants, ne devienneune occasion de triomphe pour les oculistes*" (La Presse, 17th of June 1879).

No wonder then that Bourdais' project was refused and that the Eiffel Tower, after years of debates, was accepted only at the condition the light it would emit would be only artistic and not designed to lighten the city. In Europe, light towers were hence confined to industrial areas such as railways maintenance stations, areas where they increased productivity and did not disturb inhabitants.

In the USA, the debate was very different. Many town halls were searching a way to illuminate the dark streets of their cities without having to face the impressive expenses and public works that a gas lantern network presupposed.

It was the birth of the "*moonlight towers*". Soon, many cities launched the construction of grids of tall metallic towers designed to light the whole urban area.

The first tower has been built in San José (California) in 1881, bearing six lamps, representing a total power of 24,000 candles, i.e., one single tower producing as much light as all the lamps lighted in Segovia for the abovementioned cathedral inauguration festival more than 300 years before.

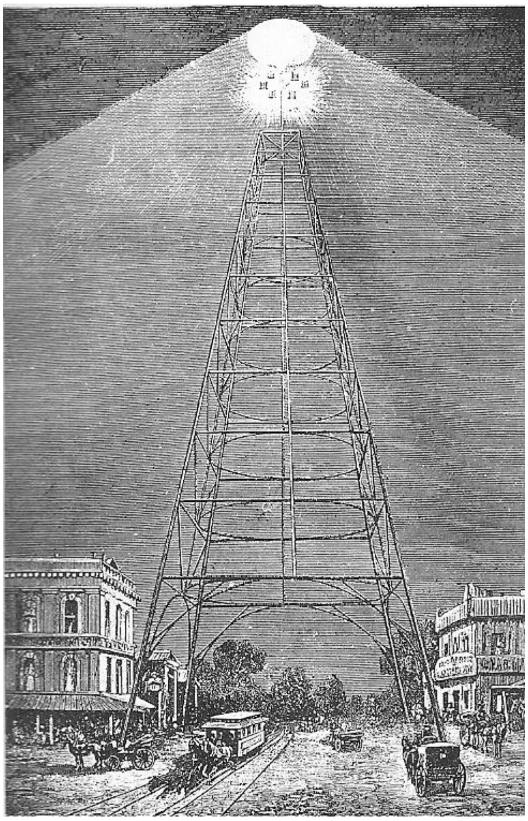

**Figure 8** Engraving showing San Jose's first moonlight tower, 1881

Many small cities followed, but the only large metropolis to develop this system was Detroit, as it is witnessed by Fred H. Wipple in his handbook "*Municipal Lighting*"[16]:

"*There are 122 towers of 153 feet each. Detroit has about 230,000 inhabitants, and has a dense business section of about one*

**Figure 9** Detroit City Hall (Campus Martius square) with its moonlight tower, ca. 1900

*square mile. This section has about 20 towers, which average 1,000 to 1,200 feet apart. The belt immediately contiguous, embracing the closely-built and densely shaded residence section has its towers about 2,000 feet apart. Beyond this the spaces widen to 2,500 feet apart, and in the suburbs they are spaced about 2,500 to 3,000 feet apart*."

"*The press of the country has uniformly conceded Detroit to be the best-lighted city in the world. All its streets, yards, backyards and grounds are illuminated as effectually as by the full moon at the zenith. The blending of light from the mass of towers serves to prevent dense shadows*."

But this emphatic text hides a different reality. First, the lighting power of the towers was not stable, and then, it created an alternation of over-lighted zones with total dark zones, as every obstacle in the way of the artificial light (from a simple tree to a large building) generated a deep shadow zone. Security problems, at the heart of the Detroit town-hall decision of implementing "moonlight towers" were far from being solved.

If Detroit has been praised in the newspapers when launching its tower grid, several other cities' decision-makers were not entirely satisfied by the system, such as G. Hodges, the Secretary of the Committee in charge of the lighting of Utica (New York), who conclude that towers had to be "*used mainly in the outskirts and thinly settled districts. There they are a perfect success. In the heart of the city they are a failure*"[17].

Soon, other reports began to be extremely negative, as the notice given by the City Recorder of Ogden (Utah), who wrote that "The tower system of electric lighting was tried here several years ago, and discarded as being a complete failure. It is a bad system of street lighting, being impossible to erect a tower high enough to throw the light into the streets uniformly. One side of the street will be shaded by the buildings, which produces an intense darkness (when contrasted by the light on the opposite side), which is very disagreeable. Our city is now lighted by electric lamps placed in the center of the street"[18].

Moreover, in semi-urban areas, the lighting pollution factor generated by the moonlight towers is finally recognized, studied and analyzed, as their impact on domestic animals was catastrophic: "*the lights also brought unanticipated complications along with their steady illumination. Animals, for one thing, were unaccustomed to the newly extended daytime. Chickens and geese, unable to sleep in this new state of omnipresent light, began to die of exhaustion*"[19].


**Figure 10** One of Austin's Moonlight towers, 1890's

Even the introduction of the incandescent lamp did not help to solve the problems raised by the moonlight towers. In the 1910's, almost all of them towers were dismantled throughout the USA. Today, only Austin, once nicknamed "*the city of perpetual moonlight*" has a plan to preserve the 16 towers, which survived until nowadays, from the original grid made by 31 such "monuments"[20].

**Figure 11** One of Austin's Moonlight towers, today

## Conclusion

We can only underline that, unfortunately, man has a much higher capacity of adaptation in comparison with most animals. The "*moonlight towers*" episode, which could have been used as a milestone in the fight against lighting pollution, is now largely forgotten by specialists.

Moreover, doctors, biologists, zoologists, neurologists a.s.o., are constantly demanded to bring new evidences of the lighting pollution damages on human and animal health[21] to convince decision-makers to change their city lighting strategy.

Sadly, from a unique and punctual gift of man to deities, light excess became normality in most of the developed countries. Should man be a bird, and die in the atrocious way described by the famous American poet Henry Wadsworth Longfellow, the world leaders would probably think more seriously about the impact of lighting on our lives?

*The sea-bird wheeling round it, with the din*
*Of wings and winds and solitary cries,*
*Blinded and maddened by the light within,*
*Dashes him self against the glare, and dies.*

Henry Wadsworth Longfellow,
*The Lighthouse, 1848, verses 45-48*

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# AIMING TO ACHIEVE NET ZERO ENERGY LIGHTING IN BUILDINGS

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**Abstract:** *Energy consumption for interior lighting is rapidly increasing and takes up 17.5% of the total global electricity consumption on average. With European office buildings using 50% of their total electricity consumption for lighting alone, and other shares of electricity of 20-30% in hospitals, 15% in factories, 10-15% in schools and 10% in residential buildings, there is significant potential to reduce energy consumption for lighting. By implementing a combination of key measures, such as minimisation of lighting power density; use of highly-efficient lighting technologies based on renewable energy sources; use of appropriate lighting control systems; and maximisation of daylight use, energy saving targets can be pushed forward to aim at achieving net zero energy lighting in buildings. This paper presents findings from Building Research Establishment projects for public and private buildings to reduce lighting energy consumption whilst improving the quality of the internal luminous environment.*

**Keywords:** energy performance, interior lighting, daylight, efficient lighting, lighting controls.

## 1. Current background

Lighting is a large and rapidly increasing source of energy demand in buildings. In 2005 grid-based electricity consumption for lighting was 2650 TWh worldwide, or around 19% of the total global electricity consumption, whilst the electricity consumption for interior lighting alone was estimated at 2438 TWh worldwide, or about 17.5% of the total global electricity consumption (Halonen, Tetri and Bhusal, 2010). Interior lighting accounts for a significant part of the electricity consumption in buildings. According to International Energy Agency (IEA) research, heating is the leading energy consumer in EU commercial buildings, followed by lighting (Figure 1).

The electricity consumption for interior lighting varies with the type of building. In some buildings, lighting is the largest single category of electricity consumption; office buildings, on average, use the largest share of their total electricity consumption in lighting. 50% of total electricity consumption in European office buildings is used for lighting, 20-30% in hospitals, 15% in factories, 10-15% in schools and 10% in residential buildings (EC, 2011).

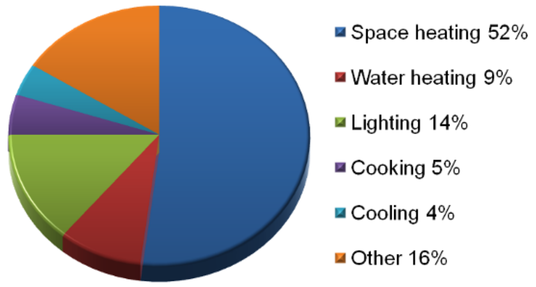


**Figure 1** Energy consumption by end use in EU commercial buildings (source: IEA)

The heat generated by lighting represents a significant fraction of the cooling load in many internal spaces, and contributes to further consumption of electricity.

Figure 2 illustrates findings of BRE and Carbon Trust analysis on carbon emissions from different building types and end uses (Carbon Trust, 2011). Carbon emissions from lighting are shown in orange. Whilst more than 50% of all lamps installed in Europe are still not classed as energy efficient, the potential for improvements and energy savings is significant. Increases in energy price can also act as a driver towards efficiency, and encourage energy-efficient lighting solutions. The EU is aiming for a 20% cut in Europe's annual primary energy consumption by 2020. In order to increase energy efficiency, the Commission has implemented EU Ecodesign regulations (EC, 2009a; EC, 2009b; EU, 2012a) to gradually remove from the market inefficient products like tungsten lamps, less efficient tungsten halogen, compact fluorescent,

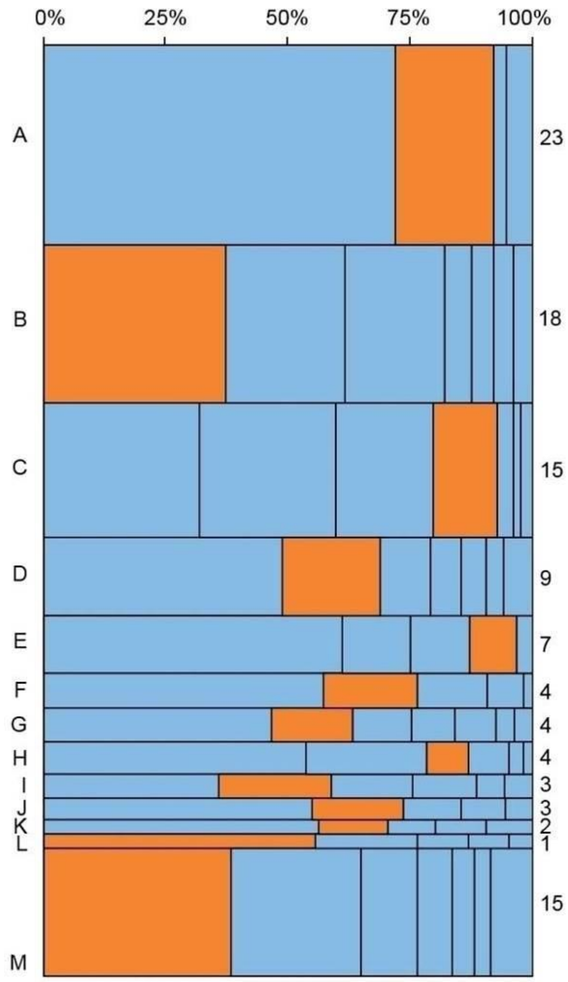


**Figure 2** Emissions by building type and end use (source: Carbon Trust).
Figures on the right indicate carbon emissions in $MtCO_2$; letters on the left indicate building types:
A – industrial; B – retail; C – hotels & restaurants; D – commercial offices; E – schools;
F – healthcare; G – government estate; H – further & higher education; I – sports; J – heritage & entertainment; K – public offices; L – transport/ communications; M – miscellaneous.

and metal halide reflector lamps, all high pressure mercury lamps, less efficient sodium and metal halide lamps, the least efficient LED lamps and magnetic ballasts.

The Commission has also implemented Green Public Procurement (GPP) criteria to increase resource and energy efficiency within the public sector (EC, 2012). The GPP criteria also include lighting in buildings covering lamp efficacy and overall power consumption of the whole system. Other Commission measures refer to the use of smart meters that encourage consumers to manage their energy use better, and to the labelling of energy-using products (EU, 2012b).

The Energy Performance of Buildings Directive (EU, 2010) strengthens the requirements for building energy performance by requiring each Member State to establish minimum energy performance requirements for new and existing buildings, and to implement energy certification schemes. The Directive also requires that all new buildings are nearly zero-energy by 2021, with new buildings occupied and owned by public authorities nearly zero-energy by 2019. An approved methodology is employed to determine energy performance which also includes impacts from daylighting and built-in lighting systems.

In the UK, the updated Part L of the Building Regulations (DCLG, 2014) requires that new lighting in office, industrial and storage spaces should have an average luminaire efficacy (the amount of light emitted from the luminaire divided by its circuit wattage) of at least 60 lm/W. Lower efficacy values apply if some types of automatic lighting control are used in some types of space. An alternative, more complex approach uses the Lighting Energy Numeric Indicator (LENI), which is a measure of the energy used for lighting per square metre over the whole year. For lighting in other non-domestic spaces, an average lamp efficacy (the amount of light from the lamps divided by the circuit wattage) of 60 lm/W is required. For display lighting the average lamp efficacy should be at least 22 lm/W. In new dwellings three out of every four light fittings should be low energy, with a lamp efficacy of at least 45 lm/W.

Other energy efficiency initiatives include schemes like BREEAM and the UK Enhanced Capital Allowance (ECA). BREEAM assesses the environmental performance of new and existing buildings, with BREEAM International addressing buildings outside the UK (BREEAM, 2014). Although it is a voluntary scheme, it is often required by client specifiers. Lighting related credits refer to minimum floor areas being adequately daylit, suitable shading, the right quality of light according to relevant codes and standards, appropriate lighting system zoning and control, separate sub-metering of energy use including lighting, and energy efficient external lighting. The ECA scheme (DECC, 2014) gives tax incentives for companies to install energy-efficient equipment including lighting, by writing off capital costs against Corporation Tax in the first year after installation.

Despite the various measures to increase the efficiency of electric lighting, there is still substantial potential to reduce further the energy consumption for lighting and the associated carbon emissions. Whilst there is a trend in the international community to reduce the electricity consumption for lighting with new technology to below 10 kWh/m$^2$ (EC, 2011), the arrival of advanced, optimised daylighting technologies and of state-of-the-art electric lighting technologies using renewable energy sources can help push forward the target by aiming to achieve net zero energy lighting in buildings.

## 2. Methods to achieve net zero energy lighting

Modern lighting techniques and equipment, and more efficient light sources, provide opportunities for significant reductions in the use of energy, while achieving a greatly enhanced level of illumination and improved visual appeal. Cutting wasted energy for lighting can also reduce overheating, and therefore cut the high cost of air conditioning.

Although lighting products are becoming more efficient, longer occupancy hours and higher light levels have increased the energy used for lighting in buildings. Also, inappropriate control strategies and improper choice of light sources result in energy being wasted.

Key areas for minimising lighting energy consumption in buildings include: minimisation of lighting power density through optimisation of lighting strategies and levels of illuminance; use of highly-efficient lighting technologies; use of appropriate lighting control systems; and maximisation of daylight use. Quality should not be neglected when implementing measures to increase lighting efficiency, and therefore attention should always be given both to the effectiveness and the quantity and quality of lighting.

### 2.1 Minimising lighting loads

The general illuminance level in a space has a substantial influence on the energy consumption for lighting. Reducing the general illuminance has a direct impact on energy consumption, as the power consumed is roughly proportional to illuminance.

Recent research and consultancy projects carried out by BRE for public and private clients have revealed that illuminance levels in various types of internal space are higher than those recommended by current relevant standards and guidelines. For example, opportunities to decrease illuminance levels and therefore the lighting energy use have been noted in case of retail buildings. A survey carried out by BRE revealed that the average lighting power density in retail spaces was 36 W/m$^2$, compared to 10–12 W/m$^2$ in a modern office space with efficient lighting (Ticleanu, Littlefair and Howlett, 2013). Significant energy savings can be achieved by changing the lighting design philosophy so that instead of aiming for an overall level of illuminance the focus falls on the lit effect of the scheme, and hence on delivering lighting to where it is required. Two main techniques are proposed for retail buildings: using the right proportions of task and ambient lighting, so that low illuminance levels are achieved in the bulk of the store, whilst using accent lighting on displays to guide shoppers to key focal areas; and lighting the perimeter of the space to make the whole space look better lit by making the walls brighter. Another possibility is to use daylight to provide some or most of the ambient light levels.

A good practice example is shown in Figure 3, which illustrates a store that reduced its energy use by 30% and its carbon emissions by 23% by implementing measures that included lower ambient light levels of 300 lx and higher illuminances only on vertical surfaces of the merchandise. In combination with highly-efficient LED lighting, this led to a reduced lighting load of 7 W/m$^2$ (Ticleanu, Littlefair and Howlett, 2013).


**Figure 3** Lower ambient light levels leading to lower energy consumption (source: Philips Lighting)

These techniques can be employed in a similar manner in other types of space or building, in accordance with standard recommendations. Reducing illuminance levels to the values recommended by relevant standards and codes, and optimising lighting strategies typically lead to significant reduction of lighting power densities (in W/m$^2$) and normalised lighting power densities (in W/(m$^2$.100 lx)), with direct consequences for the energy use for lighting.

## 2.2 Using highly-efficient lighting technologies

Fluorescent lamps are by far the most popular lamps for lighting non-domestic buildings, although metal halide lamps and even tungsten halogen lamps are widely used in various applications that include accent or display lighting. Metal halide lamps are also a typical choice for high bay internal spaces. LED technologies are increasingly used following their significant advances in the last years. Various types of luminaires are used for indoor lighting, depending on the type of building.

Given the phase out of inefficient technologies brought about by EU legislation, new alternatives have been developed, with higher luminous efficacy and reduced environmental impacts. New types of lamp include LEDs, highly efficient fluorescent lamps and improved tungsten halogen lamps. Highly efficient compact fluorescent lamps use up to 80% less energy than conventional tungsten lamps, while improved tungsten lamps incorporating halogen technology use 20% to 45% less energy for the same light output than conventional tungsten lamps. The latest developments in compact fluorescent technology include lamps with higher luminous efficacy and lower mercury contents. Recent developments of the metal halide lamp type include ceramic metal halide lamps driven by electronic ballasts that are highly energy efficient. Having the array of wattages expanded to lower values of 20-22 W, ceramic metal halide lamps driven by electronic ballasts last up to 20,000 hours and can reach lamp efficacies of up to 104 lm/W.

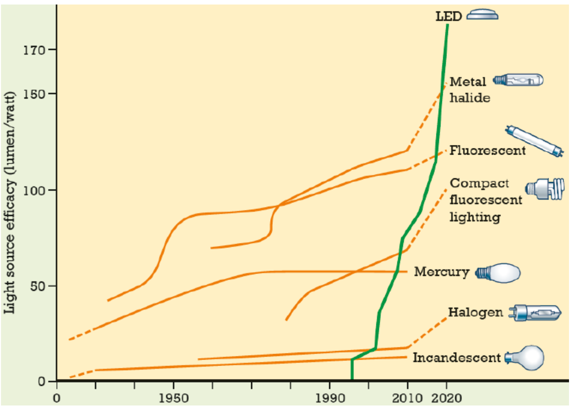


**Figure 4** Accelerated increase in LED lamp efficacy (source: IET).

The most significant technical developments have been made by LED technology, which is increasingly being used for various lighting applications and lasts longer than other light sources. Not only has the variety of LED fittings increased, but the luminous efficacy of LEDs is improving year on year and is now comparable with that of fluorescent lamps. Whilst state-of-the-art white LED lamps have already reached efficacies of 100-150 lm/W, LED lamp efficacy is growing fast and, as shown in Figure 4, further improvement is expected over the next 5-10 years (IET, 2013). Osram is already claiming a lamp efficacy of 215 lm/W for a T8 replacement LED tube that will be launched in 2015 in both warm white and cool white appearance (Osram, 2014). With a 95% efficiency driver, the claimed system efficacy is 205 lm/W.

Other technical developments in lighting include high-efficiency optics for luminaires with increased light output ratio, and optimized lamp-ballast systems consuming less energy and providing longer lamp life.

In order to reduce the energy consumption for lighting, the overall

**Figure 5** LED luminaire rated at 100 lm/W luminaire efficacy (source: Philips Lighting)

efficiency of the lighting system should be addressed. There is no sense in placing an efficient lamp in an inefficient luminaire, so the most efficient luminaires should also be used.

## 2.3 Employing adequate lighting controls

The control strategy for lighting in building is usually set according to the type and complexity of the building and application. It can include various controls ranging from localised manual switching to daylight-based photoelectric dimming and complex management systems.

The choice of lighting controls from simple manual switches and dimming switches to presence detectors and light-level sensors has a large impact on total lighting energy use. However, currently most lighting control systems are under-specified, and electric light is often delivered to spaces where no one is present, or for which there is already adequate daylight. Most spaces are typically lit fully on during occupancy hours and this leads to substantial energy consumption even when sufficient illuminance levels can be provided by incoming daylight. Using photoelectric control linked to daylight sensors in daylit areas leads to significant energy savings depending on the characteristics of the interior space and the existing lighting systems.


**Figure 6** Examples of user interfaces for lighting controls (source: Helvar).

For example, the illuminance measured at various points inside a car showroom display area was in the range 860-5100 lx, which was generated mostly by daylight. However, all electric lighting was maintained fully on continuously during the day and there were neither daylight-linked, nor dimming controls. A multi-gang switch was used to manually control the lighting both in the showroom and other open-space areas. Implementing daylight-based controls of the electric lighting in the car showroom can save 25 MWh of electricity each year, or around 8% of the total electricity used (including all consumers e.g. cooling, small and large power), and 13 tonnes of carbon each year, or around 6% of the total carbon emissions of the showroom.

Research shows that simply providing users with the capacity to control lighting levels in the space they occupy can significantly lower lighting energy use. Effective lighting controls can save 40-60% of the building's lighting energy use (Littlefair, 2014). Energy can be saved after working hours and when work stations are unoccupied, and when daylight is sufficient. Even a short switch off (5 minutes or more) can save energy and money. If dimming is provided, additional savings can be made by dimming lamps early in the maintenance cycle when their output is high. This can typically save around 10% of lighting energy use even in a non-daylit space. With LED lighting the savings can be higher (15% or more) and the lifetime of the LEDs can be increased due to dimming (Littlefair, 2014).

A wide variety of control types are now available (Figure 6), with new forms of manual control including wireless and smart phone controls. Occupancy sensing is especially valuable for infrequently used spaces. Photoelectric controls switch or dim the lamps in response to daylight. Time switching is appropriate for buildings with set hours of occupancy. Sophisticated lighting management systems are available which can control the lighting in an entire building, combining all these different control types if required. It is important to take into account the type of space, how it is used and the amount of daylight available.

## 2.4 Maximising the use of daylight

Daylight has physiological and psychological benefits for building occupants and can improve performance and wellbeing. At the same time it is a freely available light source that can provide high quality lighting to internal spaces at zero costs and with no carbon emissions. However, using daylight successfully requires careful planning and design to avoid associated problems such as glare from direct sunlight or solar heat gains.

Sidelighting can provide a view out that may be appreciated by building occupants and can be integrated in multi-storey buildings. However, the amount of daylight that penetrates into the space depends on the building orientation and the absence of obstructions, and there is a higher risk of glare from direct and reflected sunlight.

The distribution of daylight in the space from sidelighting is uneven, with higher daylight levels in areas nearer to windows and decreasing amounts further away into the space. For this reason, sidelighting is not effective for internal spaces with a deep layout. Advanced sidelighting strategies (Figure 7) can improve daylight penetration into the depth of the building by redirecting it onto a reflective ceiling. Light shelves, sun-directing glass or anidolic collectors can be installed in the upper part of windows to redirect daylight deeper into the buildings (Littlefair, 1996).

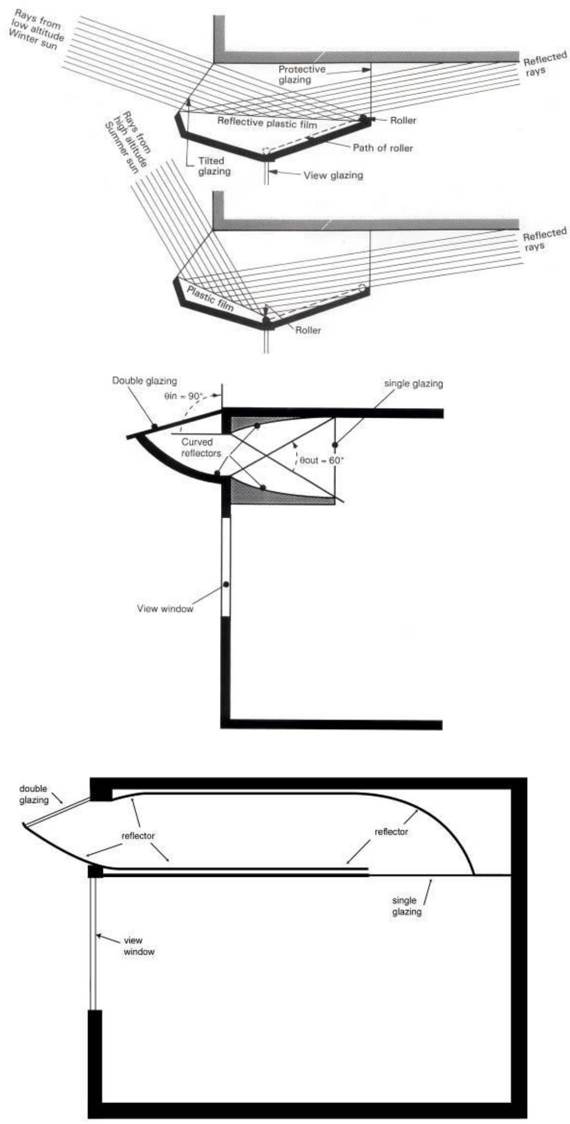


**Figure 7** Sidelighting techniques. From top to bottom: variable-area, light-reflecting assembly; anidolic reflector system; anidolic ceiling arrangement.

Toplighting strategies (Figure 8) use openings in the roof to allow daylight penetration into a space: hence their application is limited to single-storey buildings, or to the top floor of multi-storey buildings. However, daylight uniformity is significantly improved throughout the whole space, and there is less impact from obstructions, with maximum available daylight at all times.

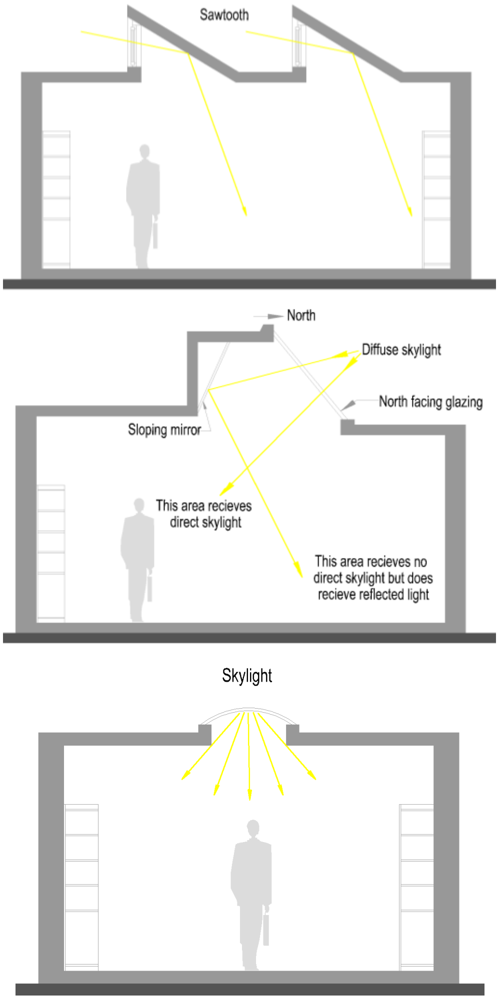


**Figure 8** Toplighting techniques. From top to bottom: northlight; sawtooth; rooflight.

There is a limited view out, but toplighting strategies in atria and courtyards allow occupants to experience connection to the outside at all times of the day. Because of higher and longer exposure to sunlight, irrespective of orientation, toplighting strategies – other than northlights – typically incur a higher risk of overheating than sidelighting. Soft-coat, low-emissivity glazing with low solar transmittance (g-value) but higher daylight transmittance should be considered for such strategies.

Typically roof apertures over 8%–10% of the whole roof area can be sufficient to keep electric lighting turned off during a significant part of the daytime. Substantial savings can be made by capitalising on the availability of natural light, while creating a pleasant, airy atmosphere that is favoured by occupants.

Optical systems are able to redirect or harvest daylight by means of tubular light-guiding systems, fibre optics, or arrays of mirrors and lenses. Daylight-guiding systems (Figure 9) can lead daylight collected at roof level into internal spaces via highly reflective, mirrored tubes, and are more effective under clear sky conditions, although some of them can deal quite effectively with diffuse skylight. This helps reduce the need for electric lighting during the day.

**Figure 9** Daylight guidance systems using light-pipes (source: Monodraught).

Fibre optic systems rely mainly on direct sunlight, as they are typically integrated within complex arrangements using sun-tracking collectors. Sophisticated arrangements of mirrors and lenses can be used to direct daylight (mainly direct sunlight) into specific internal areas of interest.

Using daylight as a primary light source can potentially save energy by reducing the need for electric lighting. However, over-glazing can lead to high solar heat gains. The aim should be to provide generous levels of daylight with reasonably low associated solar heat gains to avoid using extra energy for cooling. Daylight into internal spaces needs to be controlled, and lighting controls are required to adjust the electric lighting to match daylight variability. Significant energy savings can be achieved by correct zoning of the electric lighting that establishes the groups of luminaires that should be controlled simultaneously, based on different factors that include daylight availability. The electric lighting system needs to be controlled separately in the daylit and non-daylit areas to maximise energy savings while providing the required light levels. Typically, luminaires should be grouped together in each zone that receives a similar amount of daylight.

### 2.5 Using renewable energy sources

Recent developments in renewable energy technologies, such as photovoltaic panels and wind turbines, have made it realistic to conceive nearly-zero or even zero energy lighting systems, particularly if highly-efficient lighting technologies and adequate controls are used. However, solar or wind powered lighting systems are still not commonly used in buildings due to a number of technical and financial challenges. Although government schemes support the uptake of such technologies by practising attractive feed-in tariffs, payback is typically long (particularly for smaller systems) and electricity generation is strongly affected by climatic conditions. Additional equipment is also required, such as inverters or batteries, and this requires supplementary storage and power optimisation.

Nevertheless, by nature, LED lighting systems are most commonly DC devices, operating from a low voltage of direct current. This makes it easier to integrate them with renewable energy based technologies, whilst achieving a higher system efficiency that allows for net zero energy.

## 3. Case studies

A number of projects have already been completed or are being assessed in order to reduce the energy consumption for lighting whilst improving the quality of the internal luminous environment.

### 3.1 Clothes store

Illustrated in Figure 10, the LED-only scheme delivers an average light level of around 500 lx on the walkways and a light level on specific focal areas of the merchandise of around 900-1000 lx. By using LEDs rated 16 W and 50 lm/W, which deliver warm white light of 3000 K colour temperature and colour rendering index CRI of 90, the installed lighting load is 17 W/m$^2$ (Ticleanu, Littlefair and Howlett, 2013).

**Figure 10** Fully LED-lit clothes store (source: Reggiani).

**Figure 11** Daylight-based, dimmable T5 fluorescent fittings with adjustable reflectors and louvres producing the right light output at the level of the merchandise (source: Whitecroft Lighting)

### 3.2 Superstore

The use of pre-wired, daylight-based, dimmable 2×73 W T5 Eco fluorescent fittings, with adjustable reflector and louvre for precise direction to the point of sale, as shown in Figure 11, provided a 28% energy saving, 30% reduction in the number of lamps required, and 25% reduction in installation time compared with the previous lighting scheme (Ticleanu, Littlefair and Howlett, 2013).

### 3.3 Supermarket

The sales area is lit by a combination of ceiling-recessed square modules and round spotlights using LEDs with a colour temperature of 4000 K, while chiller cabinets are lit by 4200 K CRI 80 LED tubes concealed from the shoppers' view and aimed at the merchandise (Figure 12). This delivered a well-lit solution at less than 9 W/m$^2$ and achieved an energy reduction of approximately 40% (Ticleanu, Littlefair and Howlett, 2013).


**Figure 12** LEDs used for general and display lighting

### 3.4 Fashion store

It is proposed to upgrade the lighting in the 2-storey store shown in Figure 13 from conventional fluorescent and metal halide technologies to warm white LED lighting. The design philosophy is tackled to provide the right amount of light to each type of area (e.g. 300 lx ambient illuminance and a minimum of 500 lx accent illuminance in sales areas) and to minimise the number of luminaires by choosing optimum positions and tilt angles. In so doing, 51% electricity savings and carbon reduction would be achieved, and lighting power density would decrease by 46% to 18 W/m$^2$ in sales areas and by 70% to 6 W/m$^2$ in fitting rooms. Around 83% of the energy used by the new LED lighting system could be supplied by 100 monocrystalline PV panels rated at 320 W$_p$ and 19.6% efficiency covering 163 m$^2$ of the total roof area available (Topriska, 2012).

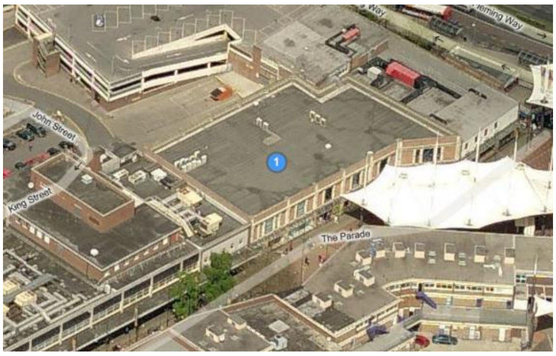


**Figure 13** Fashion store to incorporate LED lighting supplied with electricity from roof-mounted PV panels

### 3.5 Office building

The office building illustrated in Figure 14 has been assessed in order to increase its energy efficiency and substantially reduce its carbon footprint. The current lighting system consists of fluorescent fittings using electromagnetic ballasts and is controlled via wall-mounted switches in offices and presence detection in circulation and other communal areas. No daylight-linked controls are used. The total lighting load currently installed is 14.3 kW, with an estimated energy consumption of 36,190 kWh/year, whilst the average lighting power density is around 14.7 W/m$^2$ throughout the building.

**Figure 14** Glazed façade office building proposed to be lit by a net zero energy lighting system

The aim is to develop a net zero energy lighting system using highly-efficient LED lighting, adequate lighting controls and roof-mounted PV panels. A change in layout is also considered, as the current cellular offices will be converted into larger open-plan office areas. By using the latest LED lighting systems, the total lighting energy consumption can be reduced by 54% to 16,560 kWh/year, at an estimated normalised lighting power density of 1.5 W/(m$^2$.100 lx) on average in office areas and 2.5 W/(m$^2$.100 lx) on average in other areas.

Large glazed areas are present on west, south and east façades. By adding daylight-based dimming controls to reduce the light output of electric lighting when sufficient daylight is available to achieve the maintained illuminances during work hours (9.00 to 17.30), the energy consumption for lighting can be further reduced by an additional 29% to 5,740 kWh/year.

Net zero energy lighting can be further achieved by adding an array of grid-connected monocrystalline PV panels rated at 235 $W_p$ and 14% efficiency, with a total estimated electricity production of 5,800 kWh/year (Park, 2013). The PV panes would require 50 $m^2$ of roof area for the installation, and a simple payback period would be 10.5 years.

## 4. Conclusions

Lighting is a rapidly increasing source of energy demand and takes a significant part of the electricity consumption in buildings. More than half of all lamp technologies installed in Europe are still not classed as energy efficient, and continuous increases in energy prices are expected for the coming years. The EU is aiming for a 20% cut in Europe's annual primary energy consumption by 2020, and the Commission has implemented a number of measures to increase energy efficiency. These are supplemented by various schemes, standards and codes to reduce carbon footprint and energy use.

In this context, where various drivers towards energy efficiency exist, the potential for improvements and energy savings in lighting of buildings is substantial.

Although there is a trend in the international community to reduce the electricity consumption for lighting with new technology to below 10 kWh/$m^2$, recently developed daylighting technologies and state-of-the-art electric lighting technologies using renewable energy sources can give the potential for net zero energy lighting in buildings. This can be possible if such technologies are integrated into optimised design strategies such as minimising lighting power density through optimising lighting strategies and levels of illuminance; use of highly-efficient lighting technologies; use of appropriate lighting control systems; and maximising daylight use.

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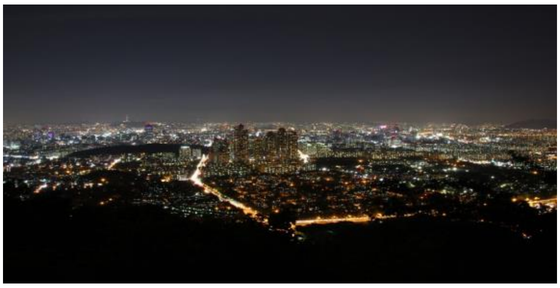
# International Conference on **Sustainable Lighting and Light Pollution SLLP 2014**
## 5-7 November 2014, Seoul, Republic of Korea



**Organized by**
Korea Society of Lighting and Visual Environment
Graduate School of Public Health, Korea University
Center for Sustainable Healthy Buildings, Kyung Hee University
International Dark-Sky Association of Korea

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National Research Foundation Korea

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SLLP 2014 will provide a platform for exchange of knowledge, current status of the research, development, engineering experiences as well as views and predictions on the future R&D needs regarding sustainable lighting and light pollution. The conference is will compass the process of professional lighting research and development in areas of design, science, engineering and education and practice. The conference is ideal for scientific, social science and engineering legal academics, as well as regulators and lighting professionals.

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Façade and Street lighting
Commercial and Media lighting
Design trends and Practices in lighting
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Solid-state lighting and LED applications
Emerging products and Markets
Efficacies and Costs
Challenges and Benefits
**Lighting and Sustainability**
Façade design and Daylighting
Daylighting availability and Modelling
Glare and Controls
Materials, Photometry and Cost
Lighting and Energy legislation
**Lighting and Health**
Perception and Visual acuity
Human-centric lighting and Exposure modeling
Human Psychology/Physiology/Biology
Circadian rhythm, Chronobiology and Melatonin
Illness related to lighting case studies
**Lighting and Pollution**
Visual comfort and Conflicts
Lighting standards and Legislation
The Biological and Ecological effects of light
Measurements and Assessment

Outdoor lighting governance and Policy
Preservation and Ecology
Solution and Practices
Sensing and Monitoring

**Abstract and Paper Submission**

The papers must report original, previously unpublished findings. Abstract of no more than 300 words will include the following information:

Issues and Objectives
Methodology and Validation
Findings and Conclusions
Suggestions and Discussion

Abstract and manuscript submissions will be made directly through the online abstract and paper submission website.

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**Important Dates**

Abstract Submission: 30 August 2014
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**Publication**

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*Presentation selected from the Conference official flyer - see website*

# High-Performance Ray Tracing on Modern Parallel Processors

**Attila T. ÁFRA,** Babeș-Bolyai University, Cluj-Napoca

*The Thesis Advisor: Dr. Horia F. POP, professor, Babeș-Bolyai University, Cluj-Napoca. The Ph.D. thesis was defended in public meeting at the Babeș-Bolyai University, Cluj-Napoca, Romania, on 22 November 2013. The author obtained the scientific degree of Ph.D. in Computer Science.*

## 1. Introduction

One of the most fundamental problems in computer graphics is to generate realistic or stylized images of three-dimensional virtual scenes. This process is called rendering or image synthesis. Rendering has numerous important applications in a wide variety of domains. For example, in computer-aided design (CAD) it enables engineers to create, modify, and analyse models interactively in 3D. Virtual prototypes of products like vehicles and buildings can be presented to clients using arbitrary materials and lighting. The visualization of volumetric medical data, such as CT or PET scans, helps diagnosing and curing diseases. In feature films and games, complex fictional worlds can be portrayed with striking realism, which would not be otherwise achievable.

In many cases, the rendered images must be as high-quality and as photorealistic as possible. This is a particularly difficult problem as it requires the accurate modelling of complex optical phenomena like reflection, refraction, scattering, multiple light bounces, depth of field, and motion blur. Ray tracing [SM03] is a powerful and elegant rendering algorithm that achieves this by simulating the interactions of light rays with the objects in the scene (see Figure 1 for an example image). Its primary drawback is that it is computationally expensive because a very large numbers of rays must be traced to obtain high-quality results.

**Figure 1** Example of a photorealistic image rendered with ray tracing (using NVIDIA Iray). Source: Delta Tracing.

Ray tracing is an inherently parallel task as the rays of light can be traced independently from each other. This is a very useful property since processors are becoming more and more parallel, but fully exploiting the available parallelism is a challenging problem. Monte Carlo ray tracing algorithms [Szi08] typically have highly divergent control flow and incoherent memory accesses, which are not handled efficiently by current parallel architectures. Another major issue is the amount of required memory to render an image. Because of the random memory accesses, the entire geometry and all textures must be kept in high-bandwidth memory. In addition to the raw geometry, ray tracing usually requires an acceleration structure as well, which further increases the memory requirements and the pre-processing time.

In this thesis, we present a collection of novel high-performance ray tracing algorithms that address the problems mentioned above. These algorithms improve the computational efficiency and reduce the memory requirements of advanced ray tracing based methods on modern parallel processor architectures. The ultimate goal of our research is to enhance the speed or visual quality of physically based rendering systems within the same resource budget.

Ray tracing generates images by constructing light transport paths that connect pixels of the image plane with light sources in the virtual scene (see Figure 2).

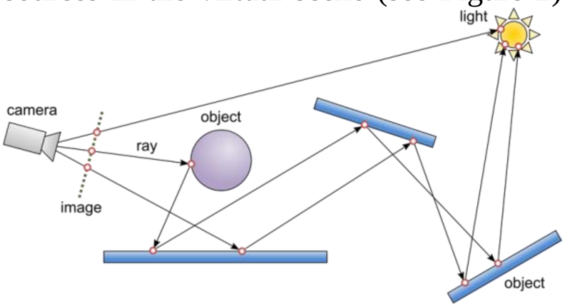


**Figure 2** Image synthesis through ray tracing. Most ray tracing methods trace rays backward from the camera.

The basis of physically based image synthesis is the rendering equation [Kaj86]. Solving the rendering equation is commonly done with Monte Carlo ray tracing methods. A fundamental operation in ray tracing is ray shooting, the objective of which is to find the closest intersection of a ray with the scene. The efficiency of ray shooting is one of the key factors that determine the overall performance of a ray tracing renderer. Thus, we have chosen ray shooting as the central topic of our research.

Most modern processor architectures are highly parallel and are able to exploit application parallelism at multiple levels. In this thesis, we focus on three novel processor architectures: Intel Sandy/Ivy Bridge [Int12] (CPU), Intel Knights Corner [Int13] (MIC), and NVIDIA Kepler GK110 [Nvi12] (GPU).

In the following sections, we summarize the main contributions of the thesis.

## 2. Coherent and Incoherent Ray Traversal Using the AVX Instruction Set

The AVX instruction set introduced with Intel Sandy Bridge has doubled the peak floating point processing power of x86 CPUs. However, efficiently utilizing the 8-wide SIMD units for ray tracing is a difficult problem.

We propose AVX-optimized ray traversal algorithms for both coherent and incoherent rays that provide higher performance than state-of-the-art SSE-based approaches. We use binary and 8-way branching BVHs as acceleration structures. We have measured improvements of up to 74% for coherent rays and up to 25% for incoherent rays. [Áfr11, Áfr13]

## 3. Stackless Multi-BVH Traversal for CPU, MIC, and GPU

Extracting hidden coherence from random ray distributions requires the processing of very large ray batches

[PKGH97]. Most hierarchical ray traversal algorithms maintain a stack, which prohibitively increases the memory requirements of tracing many rays in parallel. Consequently, the size of the ray batches must be relatively small, which leads to suboptimal coherence, and thus performance. The solution is to use stackless approaches instead, but for some efficient acceleration structures like the multi bounding volume hierarchy (Multi-BVH or MBVH), no such algorithms have been proposed so far.

We present a stackless traversal algorithm for 4-way and binary MBVHs, which replaces the regular traversal stack with a small bitstack. The bitstack encodes the per-level traversal state using skip codes. This reduces the total traversal state size by about 22—51x. We demonstrate that our approach has low computational overhead (9-31%) on the latest CPU, MIC, and GPU architectures. [ÁS14]

**4. Interactive Ray Tracing of Large Models**

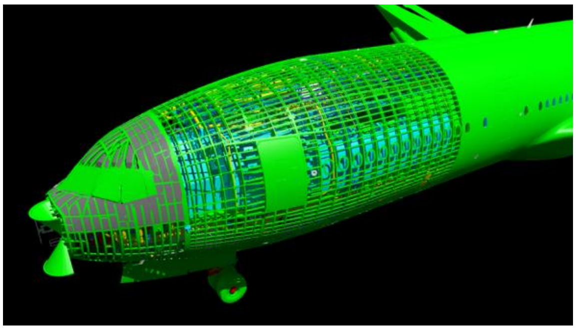

**Figure 3** The BOEING 777 model (337M triangles, 31.4 GB) rendered interactively with shadows and one-bounce indirect illumination using our proposed method. System configuration: Intel Core i7-2600, 8 GB RAM, NVIDIA GeForce GTX 560 Ti.

Rendering massive models consisting of hundreds of millions or even billions of primitives has many challenges. Such scenes usually exceed the size of the available memory, in which case special out-of-core rendering methods must be used. Unfortunately, those usually have severe limitations in interactivity, visual quality, and shading complexity.

We propose a new ray tracing based out-of-core rendering method, which supports accurate shadows and indirect illumination, and runs at interactive speeds on multi-core CPUs (see Figure 3). Its key components are: an out-of-core hierarchical model representation that stores triangles and level-of-detail (LOD) voxels, an efficient memory management method with asynchronous I/O, and a LOD-based kd-tree traversal algorithm. Our renderer has a unique set of features, combining the advantages of previous state-of-the-art approaches. [Áfr12b]

**5. Incoherent Ray Tracing without Acceleration Structures**

Standard ray tracing methods build an acceleration structure for the scene to render, which must be updated or rebuilt every time the geometry changes. This makes rendering dynamic scenes with ray tracing much more difficult than with rasterization. A recently introduced approach called divide-and-conquer (DAC) ray tracing [KW11] eliminates the need to maintain an acceleration structure while providing competitive performance.

However, very little research has been done on the implementation of this approach on parallel architectures. Another unexplored area is taking advantage of the actual ray distribution to perform more efficient primitive partitioning, which is not possible with prebuilt acceleration structures.

We introduce an efficient DAC ray traversal algorithm optimized for incoherent rays and SIMD processing (using SSE and AVX instructions). In addition to these optimizations, we propose adaptive partitioning based on the active ray/ primitive ratio, which reduces the partitioning overhead. We demonstrate that our approach outperforms the previous state of the art by up to 2.2x. [Áfr12a]

## 6. Conclusion

In this thesis, we investigate high-performance ray tracing on modern parallel processor architectures. Specifically, we propose methods that better exploit the available parallelism and memory of latest-generation hardware, and enable superior image quality and interactivity than previous approaches. We provide efficient solutions for both offline and real-time rendering.

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# LIGHTING IN THE NEW WORLD

**Cristian ŞUVĂGĂU**
BC Hydro, Vancouver

## Adapting Streetlights Procurement to the LED World

If there could be one “bright” example of a lighting application type in North America that is irreversibly “anchored” in the future, that would be the street and roadway lighting; and the future is all about Solid State Lighting.

The awareness of limited resources as well as the increasing political interest in energy-efficiency, demands that we look beyond buildings for lighting upgrades. A typical North American municipality spends about 20-30% of its electricity bill on street lighting. While for example the Canadian province of British Columbia (BC) alone has about 350,000 streetlights there are approximately 4.5 million street lights in operation in Canada and about 70 million street lights in North America. If one considers an average 30% reduction in energy consumption due to more efficient emerging technologies, particularly LEDs, British Columbia could save approximately 100 GWh annually, and savings in North America could exceed 5,000 GW and 23 TWh. This would be enough to power 800,000 houses (a large city like Toronto). Additionally, greenhouse gas emissions could be reduced by over 7,000 thousand metric tons. Considering that there are over 250 million street lights worldwide, the potential benefits are staggering.

In the last 5-6 years many cities across North America have implemented pilot LED street lighting projects (or even large implementations). In general, these projects successfully demonstrated several benefits and issues with LED street lighting in real-world environments:

***Key benefits***:

- Improved lighting uniformity over existing street lighting technology (HPS).
- Energy savings can be significant (varies from manufacturer to manufacturer).
- Adaptive street lighting has significant potential for even more energy savings. However, light levels from dimming must still meet IES RP-8-00 minimum illuminance/ luminance levels.
- Public response is generally positive favoring LED street lighting due to reduced backlight and/or light trespass and preferable color quality versus HPS.

**Key issues**:

- Manufacturer claims are not always being demonstrated from measurements.
- LED street lighting luminaires have different distribution patterns than conventional HID systems.

*Ingineria Iluminatului* 2014; **16**, 1: 51-54

• The setting of low, extra conservative calculations values for the Light Loss Factor by users could be detrimental leading to an oversized LED wattage selection.

• Initial cost often dominates any energy or maintenance savings. Long paybacks are presently challenging the technology adaption process.

• Adaptive street lighting technology is limited to very few systems. There is a need of a common back-haul (from the streetlights receivers to the console control) communication protocol to allow cities to use controls from multiple vendors.

• Since LED technologies are a moving target, users need to continuously update the technology and performance specifications for the products they purchase.

• While using LEDs with higher CCT (i.e. 5000 K-6500 K) results in greater energy savings and efficiency they are perceived as uncomfortable too “blue”, people seem to prefer as optimal the warmer CCT (4000 K) however less efficacious (there is a reduction of 25% in energy savings between 6000 K and 4000 K). In a major trial in Seattle customer complaints had dropped to zero when fixtures with a CCT of 4100 K (vs 6000 K) were installed.

After numerous pilot projects, many cities—both large and small—have initiated plans for rapid and widespread adoption of LED street lighting (Los Angeles – 130,000 lights, Seattle – 70,000, Las Vegas – 40,000, etc). However, even if currently there are numerous choices for good LED products (DOE reported in 2013 that over 13% of LED luminaires offered in USA were for street and roadway applications) municipalities have to overcome two major barriers: appropriate technical specifications and costs. This opens a vicious cycle: while larger cities seem to be advantaged (skilled, in-house engineers and ability to drive costs lower due to larger volume purchase), the small cities struggle for-ever waiting for the “next” brighter and cheaper LED generation and ultimately discourage even the larger cities for mass LED implementation.

• *Specifications* - upgrading to energy saving street lights through new technologies, particularly LED, requires careful selection of fixtures appropriate to the specific roadway under consideration. The US Department of Energy- SSL Municipal Consortium and pioneer cities like Los Angeles have developed Model Specifications for LED streetlights and adaptive dimming controls that define clear, physical, photometric and measurement criteria, allowing municipalities to draw their own particular specifications. While improved light distribution is often a significant driver of energy savings, conventional lighting design practices are limited in their ability to easily analyze a large quantity of fixtures.

• *Costs* - it is becoming evident that traditional purchasing needs an innovative approach to overcome these roadblocks. While some manufacturers are planning to offer leasing agreements to cities, other vendors seal governmental commitments by opening local assembly factories (thus contributing to job creation - a serious political motivator). Some large cities that own their own electrical utilities have found funding exactly in the huge dollar savings that LEDs bring.

To overcome the barriers for the adoption of LED streets lights in BC, the LED Street Lighting Across British Columbia consortium of partners - a working group that includes the provincial Government, BC Hydro (the province-owned electrical utility), local municipal governments, LightSavers Canada (mandated by the federal Natural Resources Canada), NGOs, and consultants - is working to develop and implement a pre-qualification process that will be used (*http://www2.gov.bc.ca/gov/topic.page?id=1D50F1AB00E441A3989E05049E829D25*) to screen and procure LED streetlights The provincial program is aimed at the conversion of upwards of 130,000 streetlights to LED technology in BC within the next 3 to 5 years.

The provincial program is planning to:

• provide assistance to BC municipalities to understand the technical, financial and administrative aspects of LED technology. A Financial Analysis tool was specially created to build a compelling business case template for use by municipalities.

• consolidate results of the various LED streetlight trials already performed in BC, reporting their performance attributes, and provide technical recommendations. More workshops and international seminars were offered to municipalities' representatives in 2013 and 2014.

• create an advanced technical specification template for BC provincial and municipal LED roadway projects. The owners of the projects can use this template completely or "cherry pick" to create their own specification document.

• develop a provincial pre-qualification process that aims to simplify and accelerate joint procurement of LED streetlight luminaires in BC by using two fast evaluation tools (see below) to identify the most energy efficient LED luminaires that meet minimum LED technical standards while complying with IES RP8 streetlight lighting standards.

• develop a joint provincial procurement program to facilitate municipalities' acquisition of quality and affordable LED street lighting products. A pre-qualified pool of LED families of luminaires from tender-selected manufacturers will allow municipalities to benefit of lower costs while enabling smaller municipalities to group in order to attract price discount for large volumes.

• help with provincial capital funding (BC Hydro incentives) to municipalities that will demonstrate energy savings by upgrading to LED streetlights.

Here is a quick look at the two fast evaluation tools:

***DLC Qualified Listing***

The DesignLights Consortium® (DLC) is a non-profit US project to accelerate energy efficiency in the building sector through public policy, program strategies and education. Since 2010, the DLC has administered the Qualified Products List (QPL), a leading resource that distinguishes (http://www.designlights.org/QPL) quality, high efficiency LED products for the commercial sector. A majority of the products listed are outdoor LED luminaires. Manufacturers must submit documentation such as IES LM-79 and LM-80 laboratory reports that verify the performance of products seeking to be on the list.

Streetlight luminaires must meet seven major criteria to be listed: minimum lumen output, zonal requirement, minimum efficacy, CCT, CRI, lumen maintenance, minimum warranty.

**SEAD Streetlight Evaluation Tool**

The Super-efficient Equipment and Appliance Deployment (SEAD) Initiative of the Clean Energy Ministry is a voluntary multinational collaboration, spearheaded by the US Department of Energy and Natural Resources Canada, whose primary objective is to advance global market transformation for energy efficient products. With SEAD, participating governments (the tool is used a lot in developing countries like India) have access to the resources and technical expertise.

The SEAD Street Lighting Tool is a free, easy-to-use spreadsheet calculator for fast evaluation of equipment performance and costs in street lighting upgrades and retrofits. The tool makes it faster and easier to verify manufacturer performance claims, evaluate light quality (based on IES files), energy use (analyzes multiple fixtures simultaneously to determine if fixtures meet lighting targets for a specified roadway), and costs for the most common road layouts.

(http://www.superefficient.org/SLtool). The Tool's simple step-by-step approach makes the evaluation process less expensive and easier for first time users. By analyzing many fixtures at once it can improve upon manual life cycle cost evaluation methods and better identify the fixtures that are able to save the most energy (produces a short list of candidate fixtures for a specific upgrade). The tool has great potential to accelerate the pre-qualification process in procurement of streetlight luminaires.

The BC Provincial Procurement received numerous vendor applications. After a careful evaluation of how well manufactures have responded to the technical specification for proposed multiple average road scenarios, a thorough checking of the DLC listing and a fast SEAD analysis only five manufacturers have been selected. These will be in place for 3-year term with two, 1 year options to extend and an annual refreshment to allow for new products or cost decrease. A demonstration site (with CCTs of 4000 K and 5000 K per each fixture) is set to allow cities to self-evaluate qualified vendors.

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# Honorary Professor Axel STOCKMAR - the time of anniversary

Honorary Professor Axel STOCKMAR at the retirement time is a non-sense. Axel is still very active at a highest professional level, in service of Light & Lighting.

His background and activity may be described in a few words, but his life dedicated for lighting is much more than that:

Graduated Electrical Engineering (high voltage, power station and lighting engineering, Technical University Berlin), independent lighting consultant, founder of LCI Light Consult International, a company which has specialised in the development of methods and computer programmes for lighting calculations and designs, honorary professor of the Hanover University of Applied Science and Arts, member of many German (DIN, chairman of the exterior lighting committee), European (CEN, member of JWG road lighting) and International Committees on interior, exterior, sports, road, and tunnel lighting, member of the LUX EUROPA Council, President of the German National Committee (2000-2011) and Vice-President (since 2011) of the International Commission on Illumination (CIE).

On September 22, 2008, Dipl.-Eng. Axel STOCKMAR appointed Honorary Professor of Fachhochschule Hannover.

"*FHH honors with the awarding of honorary professor Stockmar's diverse accomplishments and extraordinary commitment to the university. Since 1985 Axel STOCKMAR is at the FHH as a lecturer for the subject 'light engineering' in the degree program interior design works. His reputation is internationally very large and therefore we are delighted that we can make him this honor to participate*." (Web page Hochschule Hannover, University of Applied Sciences and Arts)

Some achievements: Definition = of EULUMDAT luminaire data file format (en.wikipedia.org/wiki/EULUMDAT), = of calculation/measurement grid size (CIE X005:1992, EN 12193, EN 12464-1, EN 124642-2), Elaboration = of European utilization factor method (EN 13201-2), = of procedure for the selection of road lighting classes (EU project e-street, CIE 115:2010), = of energy efficiency measures for road lighting (EU project ESOLi), authoring more than 100 published articles and more than 150 presentations at publicly accessible conferences, co-author of 20 CIE Reports and other books, adviser of e.g. local authorities, law courts, the German Federation of the Blind and Partially Sighted (DIN 32975), and the German Rail (DB AG) working group 'lighting'.

Axel STOCKMAR is a discrete but strong personality, performing his research activity in the silence of his small LCI office but, also, around the world, from Kuala Lumpur to London or Berlin.

I first met Axel at Lux Europa 1993, Edinburgh. I discovered a warm person, an open character. Later, I had the honour and happiness to be accepted among his friends and to cooperate at specific activities, research programs and lighting conferences. He supported me during my professional visit granted with the DAAD to some German lighting units - the first of them being his LCI office - Celle, June 1994. Then, I knew him as a warm husband and father, dedicated to the family and best education of his children. Axel has always enjoyed very much to join all ILUMINAT conferences 2001, 2003, 2005, 2007, 2009 organised under my coordination in the Technical University of Cluj-Napoca. I have met his personality at international lighting conferences and events during years 1993-2009 (when I retired from the professional university and lighting activity). Throughout his visits to our ILUMINAT conferences, we both, together with our wives, Dorothea and Liana, had the great pleasure to discover the beauty of Romanian country - painted monasteries in Bucovina, happy cemetery in Săpânta and wood churches in Maramures, towns of Sibiu and Sighisoara, fortified evangelical church in Biertan.

In September 2013, my son Horia and myself were honoured to join the 125th birthday celebration of Dorothea and Axel.

Axel is a warm and kind friend, closed to the Romanian Lighting community. He offered me and my family a long lasting friendship which dates back even to the last millennium.

*Happy many returns to you and a long and fruitful retirement life!*

Florin POP

## Information for Authors (revised 1st January 2014)

The journal **INGINERIA ILUMINATULUI - Journal of Lighting Engineering** has a scientific presentation and content, targeted to the continuing education in the lighting field, without commercial advertisings inside of its pages. The objectives of the journal consist of the presentation of the results of the lighting research activity, the dissemination of the lighting knowledge, the education of the interested people working in public administration, constructions, designers, dealers, engineers, students and others.

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