Guest editorial: Daylighting – light, form, and people

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Guest Editorial
Daylighting – Light, Form, and People

This special issue on 'Daylighting Buildings' presents a collection of original research papers related to the lighting of building interiors with daylight, offering an international overview of many current developments in the field. Some of the papers are directly related to energy use in buildings, the traditional focus of this journal. Other papers review the impact of light on human health, report on work plane illuminances measured in office buildings, or develop a method of how to model complex fenestration systems. By presenting such a range of daylighting-related topics in a single publication, we hope to sensitize the reader to the unique challenges of daylighting, and to assist those who are seeking design solutions that deliver reliable performance to owners and occupants. It is important to realize that daylighting is not 'only' an energy-efficiency technology but also an architectural discipline, and a major factor in occupants' perception and acceptance of workspaces in buildings. The dynamic interplay of building form, light, and people is what makes daylighting design so challenging and so rewarding. Practitioners and researchers should always be aware of these interactions because successful energy savings from daylighting can only be realized when the building and systems design support broader occupant needs for comfortable and healthy indoor environments.

While most of the papers in this issue were written within the context of the International Energy Agency's Solar Heating and Cooling Programme, *Task 31: Daylighting Buildings in the 21st Century*, selected contributions were invited in order to present a more complete image of ongoing research. Other research activities led by Task 31 members were still underway when this special issue went to press, e.g. the development of a new daylighting design guide. An overview of all Task 31 activities is provided by Ruck following this editorial.

Where are daylighting practice and research heading today? One might wonder what kind of new ideas to expect from a field as old as buildings themselves. The importance of daylighting to building design has fluctuated throughout history. It started out as the primary light source and a significant architectural formgiver before the first part of the 20th century, and was then largely ignored in the post-war era as fluorescent light, air conditioning and cheap energy drove building design. Daylighting attracted renewed interest as a result of the oil crises of the 1970s, and suffered again from declining interest in the 1980s and 1990s as energy concerns lessened. Nowadays, the quest to light buildings with daylight and sunlight is enjoying increasing interest from building owners and architects alike. The source of this interest often lies beyond the energy-efficiency concerns of the past decades. Instead, a 'new', emerging school of daylighting design has become more occupant-centered, concerning itself with questions such as how can one design a building that satisfies occupant needs for comfort and health, and, in a commercial setting, positively influences the productivity of the organization it hosts? Within that school of thought energy savings remain important but the real challenge is to find design solutions that simultaneously serve both goals.

Three major developments are contributing to this recent surge in interest: recent discoveries of the impact of light on human health, the growing influence of 'green building rating schemes', particularly in North America, and progress on lower-cost, reliable, integrated control technologies to provide the responsiveness needed for comfort and energy savings. We will introduce these developments below, and highlight the papers in this issue that address them.

In 2002, *retinal ganglion cells* were identified to be a previously unknown direct connection between the eye and the suprachiasmatic nucleus (SCN), the circadian pacemaker within the mammalian brain that drives daily wake-sleep cycles as well as certain hormonal levels [1]. Subsequent studies investigated the spectral composition and intensity of light required to send signals to the SCN. Though in its infancy, this emerging research field could establish new requirements for lighting buildings that are based on non-visual effects of light on humans. Such requirements might at times be higher than the minimum visual requirements that are currently stipulated in norms. Satisfying these new needs could become both an environmental burden, if met through electric lighting, or an opportunity, if satisfied through an increased use of daylight.

The first paper by Webb presents an accessible overview of recent research findings on non-visual effects of light on humans. This invited paper aims to frame the ongoing debate among designers, lighting manufacturers, and other stakeholders within the design community of how future lighting requirements could or should be accommodated.

Webb's paper is complemented by Galasiu and Veitch's literature review on occupant preferences and satisfaction with the luminous environment in daylit offices. The paper identifies knowledge gaps in our understanding of daylighting and its interaction with occupants, and recommends potential future research activities to narrow these gaps.

The two literature reviews set the stage for two laboratory and three field studies. Glare from fenestration can be a fundamental limitation on acceptance of daylighting solutions. The lack of criteria and tools to identify and assess glare conditions remains critical. Wienold and Christoffersen investigated the relationship between luminance distributions in over seventy subjects' field of view and their self-reported perception of glare. The outcome of this study is a new glare prediction model called 'Daylight Glare Probability' that has been implemented into a RADIANCE-based evaluation tool.

In a second laboratory study, Clear, Inkarojrit, and Lee observed the experiences of forty-three subjects who worked for several hours in a full scale test room equipped with switchable, electrochromic windows (visible transmittance range from 3 to 60%) and venetian blinds. The test rooms employed integrated controls designed to maximize daylight energy savings while minimizing glare. Measurements of physical conditions within the space as well as subjects' responses established that net energy savings potentials are intimately linked to tradeoffs around providing glare control and daylight admittance. Optical switching strategies that optimize glare will often switch the smart glass to its lowest light transmittance, increasing electric lighting use. New studies split the façade into an upper daylight window and a lower vision window, thus providing comfort and higher lighting energy savings.

Sutter, Dumortier, and Fontoynont monitored the use of remotely controlled black venetian blinds and standard manually controlled fabric blinds in fifteen offices over thirty weeks. Their findings echo previous work that occupants' use of their shading devices is consistent, but that usage also varies widely between individuals. Access to a remote control seemed to increase the use of blinds. The authors' findings further indicate that brighter VDU screens lead to office workers tolerating higher daylighting levels on the screen, thus allowing more daylight in a space for ambient lighting.

Lindelöf and Morel analyzed the way manual light switches were operated in fourteen single- and two-person offices in Switzerland for over two years. Based on the collected data they derived an 'intermediate switch–on' probability function for electric lighting. The function correlates the illuminance near an already occupied work place to the probability that an occupant switches on the electric light. The function is complementary to Hunt's switch-on probability function upon arrival [2].

While the previous two field studies monitored long-term switching behavior for electric lighting and blinds every couple of minutes in a relatively small number of offices, Nicol, Wilson, and Chiancarella monitored occupants in 26 European office buildings on a monthly basis. They collected indoor environmental conditions as well as occupants' subjective evaluations of their work places and how they operated their blinds and electric lighting. In accordance with previous findings, occupants chose to work under widely ranging lighting conditions and used their lighting and blinds to 'adapt' to their environment.

The results from all of these human subject studies are encouraging. They reveal that while our understanding of office workers' use of personal controls remains limited, findings from earlier studies were independently confirmed in different buildings and countries. This result is important since human subject studies are expensive. The results further reiterate the usefulness of international collaboration.

One way to make the findings of human subject studies directly useful to a design practitioner is to combine them into a coherent 'user behavior model'. Earlier within Task 31 a model called 'Lightswitch' was proposed that describes occupant use of lighting and shading devices in offices. The model was implemented into two daylight simulation programs to help practitioners quantify energy and cost benefits of automated controls (occupancy sensors and photosensors) over manual control. Bourgeois, Reinhart, and Macdonald took the concept one step further, introducing occupant behavior modeling into the whole-building simulation program ESP-r. Example simulations of the enhanced ESP-r version demonstrate that, depending on the occupant behavior model chosen, primary energy use for heating, lighting, and cooling in a sidelit office can vary by more 40%.

'Green' Buildings are *en vogue* and promoters of green building rating systems such as LEED [3] and EPBD have experienced an unprecedented wave of interest in this design approach. In Europe, the 'European Energy Performance Building Directive' (EPBD), which includes lighting, has already triggered strong national efforts and is expected to have a significant impact on lighting and daylighting design as well as energy efficient lighting techniques. This positive trend is accompanied by a mounting demand for more rigorous performance metrics and assessment tools, as a whole industry begins to make more design decisions based on these rating systems. Since daylighting is a declared feature of most sustainable green buildings, interest in daylighting strategies is rising, thus generating renewed interest in better daylight simulation tools and performance metrics. A series of seven papers demonstrates progress in the development of design tools, design data, and daylight performance metrics.

Reinhart and Fitz provide a snapshot of the current use of daylight simulations during building design based on an online survey of 185 individuals from 27 countries. The paper confirms the existence of a growing group of designers, engineers, and consultants who routinely use daylight simulations during building design. It further provides an overview of which tools these individuals use, how they use them, and why.

Over the past decade a series of validation studies has shown that simulation engines such as the backward raytracer RADIANCE can simulate lighting conditions in daylit buildings featuring standard facade elements such as glazings, lightshelves, and diffusing blinds. On the other hand, modeling more advanced, light re-directing complex fenestration systems (CFS), such as laser cut panels or specular blinds, remains a challenge even for the most sophisticated tools. Bidirectional Transmittance/Reflectance Distribution functions (BTDF/BRDF) are a useful concept to describe the interaction of incoming light with a CFS. Andersen and de Boer present an overview of existing and planned experimental and numerical tools to determine the BTDF and/or BRDF of a variety of CFSs. Their paper discusses the benefits and shortcoming of the different setups and describes already-existing BTDF/BRDF databases.

In a closely related paper, de Boer describes a new method of how to combine BTDF data from an arbitrary CFS with external sky conditions in order to determine indoor illuminance conditions. The method is based on Fourier optics and has been implemented in a new simulation tool that also features a BTDF database.

Maamari, Fontoynont, and Adra present a series of test cases that have been developed by IEA-Task 31 and CIE Technical Committee 3.33 to assess the accuracy of lighting computer programs. The test cases differ in type, ranging from simple analytical scenarios to more detailed experimental protocols. The paper applies the test cases to two existing lighting computer programs, Lightscape 3.2 and Relux Professional 2004.

Maamari, Andersen, de Boer, Carroll, Dumortier, and Greenup compare the ability of four simulation programs to reproduce indoor illuminances through a CFS measured in a test box, illuminated under either real overcast sky conditions or an artificial sky. The CFSs investigated are a laser cut panel and a crenellated plastic panel. The investigated programs generally modeled indoor illuminances with an accuracy of around 20% under overcast sky conditions. This number is comparable to earlier RADIANCE validation studies that involved standard double glazings.

Reinhart and Andersen carried out a validation study for a translucent panel. The optical properties of the panel were determined via goniophotometer and integrating sphere measurements and were converted into a RADIANCE material model. A comparison of measurements under varying sky conditions in a full-scale mockup that featured the translucent panel and RADIANCE simulations revealed that RADIANCE could reproduce the measured indoor illuminances with an accuracy of 20%. The paper further demonstrates that this type of simulation error is sufficient for practical design applications such as daylight factor and daylight autonomy calculations, or predictions of annual electric lighting use.

Simulation accuracy, and the ability to model a range of relevant materials, are basic requirements for the wider use of daylight simulations. Of equal importance is *what* one should calculate and how this information can impact design decisions. The limitations of the static daylight factor metric, a metric based on a single overcast sky condition, have been widely discussed before: it is independent of climate, building orientation, and building use. Dynamic daylight simulations, i.e. time-series of indoor daylight levels over a whole year, are becoming an attractive alternative to daylight factor calculations. The important remaining question is how does one interpret these time series and boil them down into accessible performance metrics? Nabil and Mardaljevic compare daylight factor simulations with two dynamic metrics, daylight autonomy and useful daylight index (UDI). UDI is an interesting new metric that provides a measure of both whether minimum illuminance levels are maintained in a space through daylight, as well as how often daylighting levels might be too high.

Most of the previously discussed papers are concerned with occupant preferences and behavior in daylit spaces, or emerging assessment methods for daylit buildings and complex fenestration systems. The results from these papers can help a design team to (a) initially justify a daylit design, (b) balance incoming daylight and solar gains, and (c) decide which type of lighting and shading control strategy to use. Once the decision to use automated controls has been made, the design team faces a new series of challenges: deciding which system to purchase, and making sure the system is properly commissioned, affordable, and programmed in a manner that will provide occupant satisfaction and save energy. While automated, integrated controls have been commercially available for some time, market penetration is still low, particularly in North America, due to high cost and performance uncertainties. The last paper in this issue by Lee and Selkowitz reports measured energy saving and system performance of several different automated roller shades and daylighting control systems that were monitored over a nine-month period in a 401m^2 unoccupied, furnished daylighting mockup. A unique dimension of the project was that the mockup was a test-bed for a new 110,000 m^2 commercial building in New York, in which *The New York Times* will be the major tenant. After they had been commissioned properly, new control algorithms and set points were developed for the commercially-available daylighting control systems, which demonstrated reliable performance and significant lighting energy savings. Equally important, the results from this study led to very detailed bidding specifications for the lighting controls and automated shading controls in the building, which in turn resulted in competitive bids with ballast system costs reduced to about half the originally estimated price range.

In closing, we would like to sincerely thank all of the collaborators in IEA Task 31 for the shared knowledge, debates, building visits and challenging discussions during the term of the Task, and we particularly thank the authors and reviewers for their contributions to this special issue. With evidence for the benefits of daylighting mounting and system costs falling, we are confident that there will be more collaborative research to report (and daylit buildings built!) in the years to come.

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