Natural Light is the Right Light
Daylighting Design and Technology between Architecture, Art and Sustainability

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English Abstract
Within contemporary architecture, the art of daylighting design – despite its many recognized advantages in comparison with electric lighting – still encounters skepticism, primarily because it is usually developed and articulated more intuitively, rather than technically. Innovative daylighting applications have added sparkle and interest to buildings. The sun's rays have been captured to create magnificent plays of forms in light. People perceive daylight as an essential element of life. But architects, lighting designers, and clients alike, often underestimate the importance of daylight for human well-being and energy performance of buildings. It is undisputed that modern architecture requires a creative, but well-planned approach that allows for the integration of many aesthetic, technical, and social or historical factors. If integrative planning is neglected, especially in the early phases of the design process in which the cornerstone for good daylighting design is laid, problems may arise for the building user later on, resulting in reduced occupant comfort, and higher expenses for installation and operation of environmental control or HVAC systems. Architects, lighting designers, engineers and clients are therefore advised to consult with each other at the earliest possible time to explore all potential alternatives for cost- and energy-effective building design. This brief discourse describes some of the fundamental issues for daylighting design and provides tools and ideas for approaching daylighting design with an open mind and an appreciation for basic human needs.

German Abstract
Tageslichttechnik führt in der Architektur trotz Anerkennung ihrer Vorzüge gegenüber elektrischer Beleuchtung noch immer ein gewisses Schattendasein, da sie mehr intuitiv als technisch behandelt wird und ihre Bedeutung für das menschliche Wohlbefinden und den Energiehaushalt eines Gebäudes zum Teil unterschätzt wird. Es ist unbestritten, dass eine an den Benutzer- und Energieanforderungen orientierte Architektur eine ausgereifte und durchdachte Planung erfordert. Dennoch führt die Nichtbeachtung eines integrativen Konzepts, insbesondere in den ersten Phasen des Planungsprozesses, in denen unter anderem auch der Grundstein für eine mögliche Nutzung der Tageslichtenergie gelegt wird, oft zu Problemen für die Nutzer des

Gebäudes, erheblichen Mehrkosten in der technischen Gebäudeausrüstung und zu gesteigertem Energiebedarf. Architekten und beratende Fachingenieure aus den betroffenen Bereichen müssen aus diesem Grund frühzeitig kooperieren, um die bestehenden Möglichkeiten auszuschöpfen. Der vorliegende Beitrag beschreibt einige grundsätzliche Überlegungen zur Thematik der Tageslichtplanung und -technik und versucht Ansätze für das Vorgehen aufzuzeigen.

Planning Concerns for Daylight Utilization

Climate conditions and our work and living practices require us to spend major portions of a typical day inside more or less enclosed buildings. Openings in the building skin are regarded as essential elements of an architecture that responds to human needs. With these openings we associate view connections to our immediate surroundings, daylight for the illumination of our work and living quarters, and air to breathe. But the utilization of window or skylight elements is not without problems, as discomfort from too much or too bright light, unwanted solar heat gains, or winter heat losses, can become critical factors in the performance of buildings.

Besides its influence on perception and visual comfort, the effect of daylighting design on building energy performance and the selection of environmental control or building service systems has gained renewed interest in the building industry. The goal is to utilize daylight energy in such a way that energy consumption for electric lighting can be partially or completely eliminated, and cooling loads associated with the electric lighting system can be reduced. The amount of electricity used for lighting in buildings differs according to the type of buildings. In some buildings, lighting is the biggest single category of electricity use. On average, office buildings use the largest share of their total electricity consumption for lighting. European office buildings use 50% of their electricity for lighting, while the share of electricity for lighting is 20-30 % in hospitals, 15% in factories, 10-15% in schools and 10% in residential buildings. Because the heat generated by the lamps adds to the loads imposed on the mechanical cooling equipment, each unit of electric lighting energy, as a rule-of-thumb, contributes to an additional one-half unit of electricity for space conditioning. Energy savings from lower lighting loads can reduce air-conditioning energy consumption by an additional 10% to 20%.

Ideally, lighting, heating, ventilating, air-conditioning (HVAC), and their communication and control technologies are discussed early in the design process to allow for an integrated building system that fulfills user and energy conservation needs. Such a holistic approach to architectural technology is in the center of the discussion about sustainable and intelligent buildings.

Researchers and designers attempt to coordinate all relevant building systems – site layout and design, structural system, building envelope, interior design elements, and environmental control systems – in such a way that all components work in unison to create thermal, acoustic and visual comfort economically and energy-efficiently, while also providing good air quality and safety for the user. Advanced computer systems can be utilized during the design and construction phases of the building and for monitoring of its performance after it has been occupied to assure that problems can be detected as early as possible and eliminated.

The integration of daylighting design in such a process requires particular care, because the potential for daylight utilization depends to a large extent on the earliest design decisions such as site layout, building orientation, building shape and volume, and the placement of openings in the facade. It is very difficult to light a building with natural daylight if there is very little exterior surface area in relation to the building's volume. Similarly, if a building is placed in the shadow of a high-rise structure or in very narrow streets, daylight access will be limited.

Daylight Availability

To make specific design recommendations for lighting a particular building with natural daylight, the designer needs to take several steps. It is important to conduct a detailed site and climate analysis to gather data for solar radiation and daylight levels. Daylight availability varies throughout the day and the seasons. Some days are cloudy, others bright and sunny. Days in the winter are shorter, those in the summer longer. A bright sunny day can produce daylight levels of 100,000 lux or more, but on an extremely dark and rainy day or during dusk and dawn, we may measure only a few hundred lux. Local data may be available from a nearby weather station at an airport, but they will probably have to be adjusted to account for differences in terrain between the airport and the particular building site, which may be affected by surrounding buildings and different topographical features. Reliable information on average daylight levels is required to accurately predict exterior and interior surface illuminance values on a typical day. The (day)lighting designer also needs to know when and how often daylight levels alone cannot meet the recommended lighting levels to determine the need for supplementary electric lighting.

Visual Comfort, Perception and Health

The renewed focus on daylighting applications and increased attention on qualitative aspects of lighting is expanding our understanding of these criteria and is resulting in a fuller appreciation of the effect of lighting on human performance and well-being. A well-designed luminous environment helps us to do what we like or need to do and makes us feel good about doing it. For our perception of the spaces around us, we rely on accurate visual information. We are comfortable when that information is clearly visible and accessible. Visual information should not be distractive or confusing. We focus our attention on elements of our surroundings that guide us in performing our conscious activities. Another important factor on the research agenda is that of photobiology and the lack of access to daylight and sunlight for people such as shift-workers. The fairly recent discovery of a third photoreceptor affecting the human circadian system suggests that there will be more we will have to consider. In any case, natural daylight seems to have a very positive effect on people. Environmental psychology research suggests that surgical patients might recover faster in rooms with windows overlooking a natural scenery and that classrooms without daylight may influence children's ability to concentrate or cooperate and eventually have an impact on body growth and sick leave. Good daylighting design for schools, on the other hand, can have a significant impact on better learning achievements. The relationship between light and health has received much research attention in recent years. Good lighting quality, daylight illumination and visual connections to the exterior surroundings of a building have been found to have a considerable effect on the satisfaction of office workers. Even a small window can go a long way. Additional studies have found that improved visual comfort increases employee productivity and decreases absenteeism, which may lead to considerable savings for employers considering all personnel and administrative costs associated with these factors. Daylight in retail environments has been shown to increase sales over stores without daylight. To provide a satisfactory and pleasant work environment is not always an easy task for architects and interior designers, especially when company executives ask for a building with a basically square-shaped floor plan and a large interior core zone that cannot be daylit because of its distance to the building skin. That particular scenario, however, is very common in some countries like the United States, Canada, Australia and New Zealand. Most European building codes and standards do not permit interior offices without sufficient daylight illumination. The German regulations, for example, require a view window for every workspace that is occupied for more than 3 hours per day and is not used for work activities that preclude daylight, such as darkrooms in photo studios. That window has to fulfill specific requirements for size and daylight provisions. The daylight factor – the ratio of incident daylight illuminance on a horizontal interior surface over the incident daylight illuminance on an unobstructed horizontal exterior surface under overcast sky conditions – or task dependent illuminance levels are generally used as the criterion for quantitative daylight requirements.

Despite of these fairly specific requirements, it is not a simple task for architects to assure that the lighting design scheme meets the user needs. To achieve a pleasant work and living atmosphere it is not enough to just satisfy quantitative descriptors. Occupant comfort depends to a large extent on lighting quality (color, contrast, etc.), and quality has to be treated with at least equal weight to avoid glare and visibility problems. Veiling reflections occur when bright reflected light, such as luminaire reflections in a computer screen, washes out part or all of a task that we are attending to and makes task performance difficult or impossible. Glare problems are associated with exceedingly large luminance contrasts within the visual field of an observer. A worker who is adapted to a specific light level will experience glare when light sources of a much higher brightness are introduced into the visual field. Possible glare sources include direct sunlight and highly reflective glazing elements of opposing buildings that redirect sunlight into a worker's eyes. Discomfort and disability glare from daylight, however, can be avoided with careful placement of window openings and solar shading devices, and appropriate material and color selections for interior walls, ceilings, and work surfaces. While some progress has been made in recent years, reliable prediction methods still elude us and additional research is needed to understand the fundamental mechanisms involved in the perception of glare discomfort.

High quality daylighting can perhaps be best described as the type of daylighting which is sufficient for visual task performance, visually comfortable and glare free, visually pleasing and appropriate for the architectural and social context, well-distributed across the space, and supportive of human health and well-being.

Known descriptors for daylight quality include:

- Luminance (adaptation, ratios, contrast, distribution)
- Volumetric brightness (perceived effect of overall brightness of all room surfaces – analogous to mean radiant temperature in thermal comfort assessment)
- Illuminance (ocular, vertical, horizontal, work plane, scalar, cylindrical) and its uniformity
- Daylight factor (average, minimum)
- Correlated color temperature and spectrum of light source
- Directed and diffuse lighting contributions

Unfortunately, even established designers frequently apply these terms or descriptors incorrectly and without a clear understanding of the underlying concepts. Further education is obviously needed.

In addition, all of the above are still descriptors of measurable quantities, rather than quality. On the other hand, quality needs to be based on the relationships between these and other not yet known quantities for such quality to be consistently and accurately assessable. Unfortunately, the exact relationships between the various factors are not yet known and will likely vary from situation to situation. A study of potential trade-offs in the interaction between individual descriptors would therefore be useful to arrive at acceptable solutions for situations that do not allow for the resolution of all factors with equal weighting. Perhaps, there is a need for establishing qualitative terms which can be illustrated graphically to facilitate a common understanding of their meaning. This could serve as a starting point. Otherwise, it is likely that the quantity versus quality debate will continue without actually being resolved.

Goals for Daylighting Design

For the purpose of daylighting design, we often differentiate between daylight (diffuse solar radiation) and sunlight (direct solar beam radiation). Daylight is wanted, but direct sunlight needs to be carefully controlled. Evans outlines the following primary goals for good daylighting design, but these are not the only factors to be considered.

1. Get as much daylight as possible as deep as possible into a building interior. The more light there is deep inside the building, the better people can see and the less electric lighting energy will be needed.

2. Control the brightness of surfaces in the visual field, both inside and outside the building, to reduce excessive contrast which diminishes visibility and visual comfort.

3. Avoid creating conditions within the building that may allow disabling veiling reflections to occur where there may be critical tasks.

Not all tasks are of critical nature. There are many tasks in our environment which will not require a high degree of visibility. In areas where such tasks are performed, direct sunlight may be appropriate to add visual interest to the space.

Guidelines for Good Daylighting

Evans also suggests six recommendations for approaching a daylighting design concept.

1. *Avoid direct sunlight and sunshine on critical tasks.* The easiest way to get plenty of daylight into a space is to use very large openings – clear glass windows, clerestories, or skylights – with a minimum of controls. But direct sunshine in the vicinity of critical task areas and a direct view of the sky from these areas might expose occupants to excessive brightness contrasts that will result in poor visibility and discomfort.

2. *Use direct sunlight and sunshine sparingly in non-critical task areas.* Direct sunshine can add excitement to architecture. It provides opportunity for changing patterns of light and shadow on interior surfaces. It can give building occupants a sense of well-being, time and orientation. However, it must be used with care or it is likely to produce adverse visual conditions or adds unwanted heat to the space.

3. *Bounce daylight off surrounding surfaces.* Daylight that reaches our task, although originating from the sun, comes from nearly all surfaces and objects around us by way of reflections. Each time, daylight is reflected by a surface, it is spread and softened. Light that is spread over large areas and reflected is partially absorbed and thus reduced in intensity, but the process spreads and evens the general brightness patterns, increasing visibility and seeing comfort.

4. *Bring the daylight in high.* The higher the light opening is placed the deeper daylight will penetrate the interior space and the less likely the opening will allow excessive exterior brightness into the field of view. In addition, the light that comes in high is more likely to be softened and spread by surfaces and objects before it gets to the task level. It is important, however, to also allow for a view connection to the outside from the task location.

5. *Filter the daylight.* The harshness of direct skylight and direct sun can be filtered for additional softness and more uniform distribution. Trees, shrubs, vines, curtains, light shelves, and louvers are effective tools for filtering daylight as it enters building interiors.

6. *Integrate daylight with other environmental concerns.* Design for daylight should be integrated with other environmental concerns. Views, thermal comfort, natural air movement, acoustics, and electric lighting are all elements to be considered. A change in building or component design in response to one element of the environment is likely

to affect the response to other elements – an operable window to allow daylight and natural air flow will also allow noise to enter the space. Therefore, all environmental factors must be considered simultaneously.

Daylighting Strategies

Classical daylighting strategies include toplighting and sidelighting. Toplighting predominates in warehouses, factories, markets and other public or single-story buildings, primarily because the buildings are usually deep. Sidelighting is found in offices, homes, apartment buildings, and multi-story buildings. An atrium combines both forms as it initially admits daylight through a horizontal or near-horizontal opening in the plane of the building roof and later allows the light to penetrate through vertical openings into the spaces surrounding the atrium.

Early architects understood that the depth of a room away from a window is limited by the need for natural light. The height of the window sill, the overall height and width of the window are all critical dimensions. Similarly, the overall width of a building is limited by the depth of two rooms and a hallway between them: thus, buildings tend to have typical footprints. A variety of floor plans can commonly be found, roughly resembling the letters I, L, F, E, H, U and O. In some spaces, it may be possible to have sidelighting from more than one side of the building. However, one needs to consider that differences in orientation will affect the amount of daylight available to actually enter the space. The reflectance of room surfaces is another important factor. The higher the reflectance, the more light is available at the rear of the room and the more even is its distribution.

In many early buildings, particularly churches, clerestories were used. Clerestories are sidelighting openings usually placed high in the wall and parallel to the primary axis of a space. Combined with the structural order in the building, they can produce dramatic lighting effects.

An innovative light distribution strategy is a horizontal fin above eye level but below the ceiling, often protruding both inside and/or outside of the glazing. Such fins are referred to as light shelves and they may have different glazing above and below the shelf. Their effectiveness depends on orientation, generally performing better on facades facing the sun. If properly designed, they can create a more even light distribution by decreasing the illumination level at the front without significantly decreasing the level at the rear of the room. Good light shelf design provides for improved visual comfort.

Toplighting strategies include sawtooth roofs, roof monitors and skylights. A sawtooth roof uses a series of single exposure clerestories. This design is typical of industrial buildings of all sizes in Europe dating from the turn of the 19th to the 20th century. The openings usually face away from the sun to utilize the diffused skylight, rather than direct sunlight for illuminating the building interior. If facing the sun, sawtooth roof openings require effective shading devices to prevent glare problems. Roof monitors are a version of a stepped roof which may allow light to enter simultaneously from two or more directions. With a proper overhang on the facade facing the sun and a stepped roof, the light distribution inside the building can be very uniform. Skylights are horizontal or sloped openings in the ceiling or roof surface, which bring in a large amount of light with a minimum amount of glazing area. The drawback is the possible higher summer heat gain since summer sun angles are higher.

Prismatic or holographic glazing panels, mirror panels and core daylighting systems (such as light guides or light pipes and Fresnel lenses combined with fiber-optics) are more recent developments aimed at improving daylighting access for spaces deep within a building. They can be very effective, but require careful design and analysis.

The strategies considered in any design application must always be evaluated with an overall perspective. It is not just a question of illumination available on a horizontal surface, but of the interactions between daylight availability, lighting quality, climate, building function and orientation, as well as building materials and equipment for overall energy use, and especially occupant comfort.

Integration with Electric Lighting

Careful consideration needs to be given to the selection of an appropriate overall lighting installation comprising both daylight and electric light sources. Because daylight level and distribution vary throughout the day and seasons, electric lighting configurations need to provide flexibility in their control. While luminaires close to the window opening may be dimmed down or turned off completely, luminaires deeper in the space may need higher light output to balance the overall appearance of the space. It also appears worthwhile to further study the effects of spectral distributions in integrated lighting systems. As daylight varies its spectral characteristics, exhibiting lower color temperatures in early morning and late afternoon than during the middle of the day, building occupants may benefit from electric lighting systems having similar characteristics, although the use of electric light sources of different color temperatures at the same time should probably be avoided. With the ban of some incandescent light sources, other light source technologies need to be further developed to achieve good color rendering across the entire spectrum.

The differentiation in lighting installations between ambient (general), task and accent lighting is another critical aspect for lighting design. Daylight (diffuse component) and sunlight (direct component) can be used effectively to achieve a suitable balance. While it is undesirable to allow direct sunlight to provide general or task lighting, it certainly has a role in creating accents in non-critical areas of a space, a function which may also be provided by electric accent lighting at nighttime. Additionally, attention needs to be given to the distribution of light on horizontal and vertical surfaces as daylighting and electric lighting systems can differ widely in this respect, depending on where the electric light sources and daylight openings are located.

Solar Heat Gains

As already mentioned above, it is generally recommended to prevent uncontrolled direct solar radiation from entering a building through window or skylight openings as it can lead to overheating problems in work spaces during much of the year, but especially in summer and early fall. Excess heat in a building is referred to as a cooling load that has to be removed from buildings by refrigeration and air-conditioning equipment. This is especially true for larger or tall office buildings, where windows often cannot be opened for natural ventilation purposes because this might disturb the operation of mechanical cooling equipment or create unwanted drafts from high exterior air velocities. Appropriate shading devices can be optimized for daylighting and solar control through computer analysis or physical model tests to significantly reduce overheating and glare problems associated with direct sunlight.

For architectural applications, solar shading devices are classified in two categories: fixed (overhangs, fins, egg-crates, horizontal and vertical louvers, light shelves) and movable (adjustable awnings, Venetian blinds, shutters, curtains). Both types are capable of controlling direct sun penetration but allow for diffuse or scattered daylight to enter the building. Fixed devices require compromises to balance the needs for daylight utilization, solar shading, glare protection, and view as they cannot be adjusted or completely removed when weather conditions and sun positions change. Exterior shading devices are more effective in reducing the impact of solar radiation on unwanted heat gain in buildings, as they prevent the greenhouse effect. Architectural aesthetics or maintenance concerns may, however, preclude the use of exterior sun control and may suggest the use of shading devices between two glazing elements or on the interior side of the window. Adjustable Venetian blinds that are placed between two or more glass panes, in particular, are not exposed to dust and other dirt particles, but can effectively control solar radiation while still allowing for daylight to enter the space. Similar devices include fixed reflector elements, honeycomb-like fiberglass tubes, or aerogel sheets between glass panes. Aerogel, despite its excellent insulating capabilities, is a translucent, rather than transparent material and is therefore limited in its application to windows or skylights that do not require view connections to the outdoors. Spectrally selective window coatings are capable of filtering out selected wavelengths such as the infrared portion of the solar spectrum to contribute to a more controlled heat transmission through the glass. Photo-, thermo- and electrochromic glazing materials also offer performance improvements. These glazing types utilize light-based, thermal or electric impulses to switch between transparent and translucent states, depending on whether direct sunlight is desired inside the space or not.

Heat Losses

Windows are often a weak point in the insulation of a building and can lead to significant heat losses and condensation on the glazing surfaces. Winter heat losses are an important contributor to overall energy consumption of buildings and require more attention. Researchers in North America, Europe and Japan have spent considerable effort on advancing window components to improve overall window insulating values to match those of wall elements, especially also in developing improved thermal breaks in window and door frames. Other components in common use in Europe are rolling shutters that are lowered over the windows at night to increase the insulating value of the window and provide added security to the building occupants. These shutters are usually opaque and have to be removed during the daytime to allow sufficient daylight to enter the room.

Daylighting Design Tools

The above examples show how important architectural design decisions and the detailing of building systems and components are for building energy performance and the well-being of its occupants. Nevertheless, for many architects and designers formal and aesthetic aspects are still the focal point of attention, and building energy conservation, despite the generally heightened awareness, is often not an integral part of the design process, but rather an add-on that is unable to really provide the benefits that could be achieved with the currently available technology. Building and energy research institutes all over the world are working on providing user-friendly, but effective and comprehensive design tools which allow architects and engineers to get quick feedback on the impact of design decisions on daylighting and energy performance, as well as occupant comfort at any point in the process.

Physical architectural models are often completed for study during the design process and demonstration purposes during meetings with clients and building officials. These models can be adapted and scaled in such a way that they can be utilized for predicting interior daylight levels and their spatial distribution with acceptable accuracy. This is possible because the behavior of light does not change with the scale of the environment. Daylight factors – the ratio of incident daylight illuminance on a horizontal interior surface over the incident daylight illuminance on an unobstructed horizontal exterior surface under overcast sky conditions – describe measured illuminance values for various points inside the room as a percentage of the available daylight outside. Daylight factor measurements can easily be performed on an unobstructed horizontal outdoor surface under stable overcast sky conditions. An array of small light sensors connected to a readout instrument or a data logger is all that is needed. As the daylight factor is independent of absolute lighting levels and depends only on the geometry of the space and its components, it is a very convenient measure of daylighting performance. It is the goal to optimize daylight distribution in interior spaces to achieve appropriate light levels throughout the space. The same scale models can also be used to study sunlight penetration and the effectiveness of shading devices using a heliodon sun simulator. A heliodon is a simple table that can be rotated and tilted to simulate the effects of different latitudes and seasonal or diurnal changes on the sun position and its subsequent impact on building performance.

To be able to simulate various sun positions and sky distributions at any given time of the year, research institutes have built sky simulators that allow designers to test building projects with a larger degree of accuracy and without having to tilt the model. That permits architects to build more flexible models that could incorporate removable parts for the testing of alternative design schemes. Fairly elaborate sky simulators are available in the lighting laboratories of some universities. Simpler, so-called mirror-box sky simulators, that can predict daylight levels for overcast sky conditions, are available in many architecture and engineering schools. Some schools also provide more sophisticated sun simulators to test solar shading devices and evaluate solar obstructions resulting from surrounding buildings.

With the integration of more advanced technical equipment into daylight simulators or actual buildings, such as CCD cameras which have been calibrated for luminance measurements, building scientists and architects are able to analyze fundamental questions of visual comfort, particularly glare. These issues have so far been treated rather intuitively as calculation procedures have been very time consuming or were only possible with high-end computer equipment. Various research institutions around the world are currently working on further improving such systems.

Researchers also continue to explore and develop computer simulation algorithms for application in integrated building energy design and analysis tools. These design tools will eventually include evaluation and operation tools for every step in the design process, from early design sketches to the specification of building system components, construction and bidding documents, and the operation and monitoring of the building after occupancy. Computer systems will at some point perhaps be able to communicate fundamental as well as detailed knowledge and case studies for every aspect of design through interactive text, images and motion pictures.

Future Outlook

In recent architectural history daylighting design has not been developed to its full potential. Misguided government policies reduced the awareness and funding for energy research. Architects and lighting designers cite time or resource constraints for insufficient treatment of daylighting issues. But there is hope that the rising awareness of the effects of climate changes will change how building professionals think and open new possibilities for increased utilization of daylight energy. The awareness of daylighting and passive solar design as tools for energy conservation, and the desire to create an architecture that makes occupant comfort a high priority, are growing again. Fostering such a growth requires the cooperation of researchers, architects, consulting engineers, and technicians in the building industry. It calls for a team effort that begins with a solid foundation in architectural and engineering education and continues with an open mind towards new forms of communication between the building industry and the community it serves.

Designers want to know how to set design goals for daylight quality and how these goals can be approached. Good examples are an essential part of this process in order for designers to appreciate the real value of daylighting design and approach daylighting design from a positive perspective, rather than from what to avoid. Designers want to know what works and how the outcome was achieved in order to develop confidence in their design ability regarding daylight. How are measurements and recommended lighting values translated first into useful design data and then into design actions? Design tools appropriate for the complexity of the decision making process at each step along the way are also critical. Simple tools (e.g. rules-of-thumb) are often sufficient early on. Later, more complex design tools allowing spatial (3-dimensional) and temporal (time) representation will be required to make appropriate decisions. Designers are also concerned about the extra time needed to incorporate these processes into the overall time and financial framework. And they are concerned about how they will know whether their design decisions will ultimately achieve the desired outcome, especially as they understand that different people occupying a space can have widely varying responses to its characteristics.

From lighting specialists employed by scientific and academic institutions, designers expect more design-oriented outcomes from the research conducted. Currently much research, including some presented during this symposium, appears to be inaccessible for many designers. Designers acknowledge that the research is necessary, but that it needs to be packaged differently if it is to reach the intended audience. Designers argue that research results are often too complex, but based on design scenarios which are over-simplified in comparison with the realities designers face on a daily basis. The discussion in Budapest suggests that research needs to be conducted in complex architectural settings and nevertheless provide simple answers which can be translated into high quality design outcomes. This is a significant challenge for researchers.

In general, both designers and researchers might need to “think more with their eyes” than with their light meters. Indeed, the studies of leading lighting researchers suggest that quality in lighting design should be approached predominantly through luminance-based, not illuminance-based recommendations. Luminance, an absolute measure of surface or light source brightness, is the only visually perceptible unit of measurement. Currently, the most common recommendations for lighting design are based on illuminance values (the amount of light received on a surface from all directions) and well established. The advantage is that they are easy to measure and assess. However, they do not relate to the visual experience of an observer. Luminance ratios, on the other hand, are not nearly as well understood, although some ratios have been proposed many years ago and can be found in many publications on lighting design. In reality, these ratios are frequently ignored and research has shown that occupants of daylit spaces quite happily accept significantly greater luminance differences than the guidelines suggest – in exchange for a view to the outside.

To provide effective guidance to designers, it would be useful to create an international daylighting database on the basis of user assessment studies. For such a database researchers and designers would be recording lighting quality, visual comfort and ergonomics parameters for recently occupied or refurbished “real” spaces in buildings considered visually comfortable, ergonomic, and aesthetically pleasing. The designers of obviously successful buildings could perhaps share their experience designing them with those accessing the database, although some might be reluctant to disclose their skills and methods for fear of loosing the competitive edge in the building market.

Such a database could then also be used to establish updated ranges of acceptable and preferred values for quality indicators in today’s lighting environments, as well as for providing designers with best practice information, including the selection of appropriate technology and equipment. This information could serve to highlight the positive contributions, rather than the prevention of negative effects. An international daylighting database could also be used to support the establishment of new mathematical models to predict and assess which lighting design solutions might provide the best conditions for occupants of daylit spaces as well as for energy conservation efforts.

There are obviously many steps that could be taken to advance our knowledge about daylight quality in buildings. An important task for those active in the field of lighting research and design will be to prioritize needs and assess the feasibility of the proposed actions.

User assessment studies and the suggested compendium of quality or visual comfort descriptors and their prediction and measurement might well provide a significant benefit to the advancement of quality lighting applications and our understanding of human responses to different lighting conditions. Effective design tools which allow the designer to make appropriate design decisions at each step along the design process would likely be welcomed by the designers. But they have to be created with the designer's perspective in mind to really address the identified needs.

However, despite all that additional assistance, designers will still have to rely on their professional judgment as to which factors and value ranges of the quality descriptors would be important and appropriate for their specific architectural design problem. Designers of daylighting systems will hopefully become better informed and able to respond to the requirements of their clients. It is anticipated that the professional recognition of skilled, scientifically and technically well-educated and creative designers will increase as a result, for only they will be able to solve contemporary design problems and achieve high quality daylighting installations. Daylighting design has to be about solving complex problems creatively and sustainably. After all, daylighting design is an art that requires sensitivity and an appreciation for the natural environment.

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