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DAYLIGHTING AND DAYLIGHT SIMULATION

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Abstract- Daylighting is often accosted as one of the best win-win strategies for "high performance" or "sustainable" buildings. It provides the highly dominant benefits of an architecturally beautiful and memorably lit space, and one that is potentially low preservation and low energy while also enhancing the comfort and well-being of the inhabitants. However, there is also often a supposition that because daylighting is "natural" it should also be very simple. We are all familiar with older buildings that provide beautifully daylight spaces, suggesting that good daylighting design can be very low-tech, even sensational. However, such a hypothesis belies the centuries of building experience that went into developing those traditional buildings. Now, with many new sophisticated fenestration technologies available, and vastly more commands on the performance of our buildings, especially for dramatically reducing energy performance while maintaining human health and comfort, we need advanced metrics and analysis methods by simulation software to help us optimize daylighting design under these new conditions. It is clear that the development of new performance metrics for daylighting must be an iterative process between understanding needs and tool development. Understanding organizational needs of all likely users helps to define the functional requirements for simulation tools, but the current abilities of simulation tools define the limits of what metrics can be debated.

Keywords: Daylighting Challenges, Daylight Factor, Daylight Simulation, Daylighting Quality, Daylight Availability.

I. INTRODUCTION

It is well understood that energy savings and electric demand moderation potential of daylighting is fundamental. However, accurately predicting daylighting at an hourly time-step, for a yearly simulation is not a simple task. This was the task at hand for the Daylight Metrics Project , a research project to develop a set of simulation based metrics to describe daylighting in architectural spaces. An important component of green building construction is the efficient use of natural light. Innovative methods are used in the design to draw more natural light into a building, improving the structure's visual environment.

The more natural light brought in, the less reliant inhabitants will be on artificial lighting. To complete this goal, daylight must be accepted and distributed throughout the space as deeply and as evenly as possible. Natural light must be controlled so that the sun's rays do not perforate into areas where they will cause discomfort or glare. The natural light must also be integrated with the electric lighting system.

Daylighting is a notoriously difficult building performance strategy to evaluate. What is good daylighting? Research careers have been invested in answering this question. One of the difficulties of determining good daylighting may be that different professions concentrate on different aspects of daylighting (Table 1).

Table 1. Five sample definitions for daylighting [1]

Architectural definition: the interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment.
Lighting Energy Savings definition: the replacement of indoor electric illumination needs by daylight, resulting in reduced annual energy consumption for lighting.
Building Energy Consumption definition: the use of fenestration systems and responsive electric lighting controls to reduce overall building energy requirements (heating, cooling, lighting)
Load Management definition: dynamic control of fenestration and lighting to manage and control building peak electric demand and load shape.
Cost definition: the use of daylighting strategies to minimize operating costs and maximize output, sales, or productivity.

Table 1 presents a sample list of definitions for daylighting that were presented to participants in a recent survey on the use of daylighting in sustainable building design. Figure 1 shows how a group of over 120 mostly North American and Australian building design professionals, who participated in the survey, rated which definition in Table 1 was most relevant to their work. Participants were grouped by their self-reported profession. Architects, lighting and interior designers are marked in black. Engineers are marked in gray. The architectural and building energy consumption definitions received highest ratings, with designers mostly voting for the architectural definition and engineers focusing on energy and costs. Note that over 80 percent of survey participants were either LEED accredited, on their way to being accredited, or regularly use the rating system as a design tool.

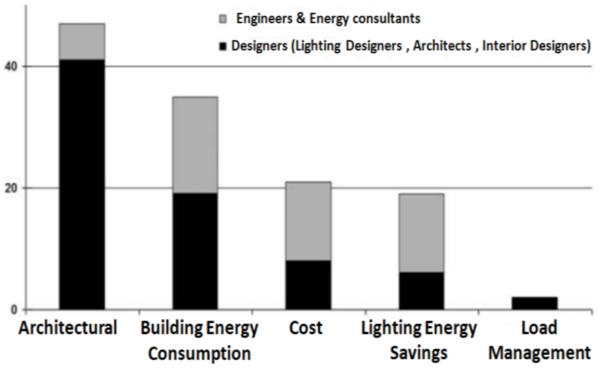

Figure 1. Results of a recent survey on the role of daylighting [1]

II. DAYLIGHTING CHALLENGES

The following points outline the fundamental challenges in daylighting design. Future sections provide strategies to deal with each of these challenges.

- Integration of daylighting design into all design stages. Special endeavors need to be taken by the design leader to certify that the design specialties that influence, or are influenced by daylighting design, subscribe to the design and construction process.
- Difficulty in achieving daylight perforation into deep building spaces.
- Shading by obstructions. Obstructions can have a crucial effect on the daylighting potential of a site. For low-to mid-rise projects, obstructions usually arise from buildings, land or trees. For larger buildings the obstructions are usually other large buildings.
- Thermal comfort. Heat loss from windows and resulting lack of comfort near windows on cold days. Overheating in summer, primarily with the desire for panoramic views achieved by large window walls.
- Glare and control of contrast are problems in all seasons, especially for tasks requiring computer use. When there is too great a difference between the light entering and the lighting on an object, contrast is a problem. Daylighting is most effective in areas that can tolerate high mutability in lighting conditions.

III. THE BENEFITS OF DAYLIGHTING

Daylighting should be considered an integral part of sustainable building subjects. Before electric lighting, daylight was the primary illumination source for all building types. Designers now tend to rely on electric lighting, especially in plans with deep floor plates. However, even northern window orientations provide useful daylight because of diffuse sky radiation. All buildings receive daylight. A daylight building, however, is specifically designed to efficiently use daylight through adapted components and control strategies. The goal of daylighting design is to minimize energy use and maximize human comfort. The benefits of daylighting are far reaching, as the following schematic illustrates in Figure 2.

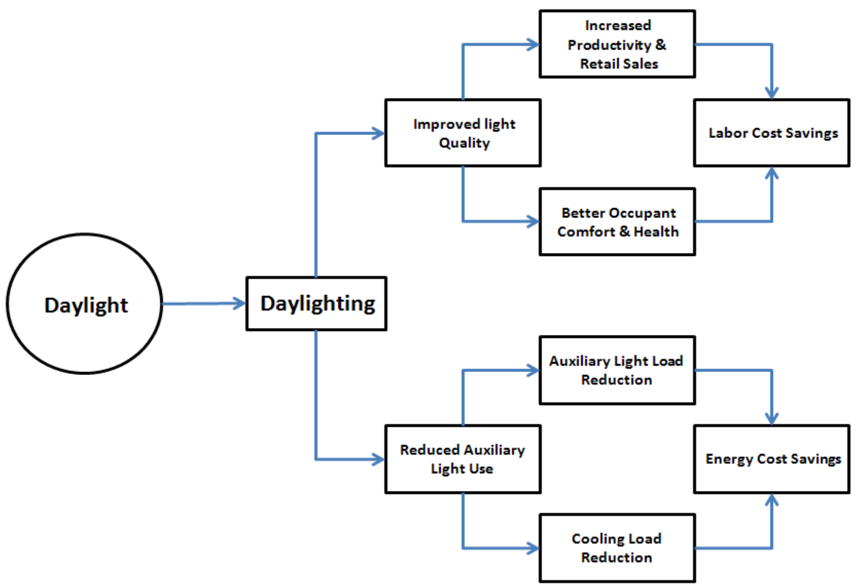

Figure 2. The benefits of daylighting [2]

IV. DAYLIGHTING QUALITY

Until the late 1990s, lighting recommendations were based primarily on lighting needs for vision. In the recent years, the lighting community has adopted a comprehensive definition of lighting quality including human needs, architectural integration, and economic constraints, as illustrated on Figure 3.

A good daylighting design will deliver high amounts of light without glare. Whereas a poor daylighting design will deliver either insufficient amounts of light so that electric lighting has to be used frequently, or high amounts of light together with glare. Daylighting should be designed to provide adequate light levels in the room and on the work plane so that daylight is the main/or only source of light (autonomous) during daytime.

Requirements for daylighting are still missing in terms of specific illuminance levels, but there is enough evidence in literature to demonstrate that illuminances in the range of 100 to 2500 lux are likely to result in significant reduction of electrical lighting usage.

The light variation within your field of view can influence visual comfort and performance. For good visibility, some degree of uniformity of light is desirable. Poor visibility and visual discomfort,such as glare, may occur if the eye is forced to adapt too quickly to a wide range of light levels.

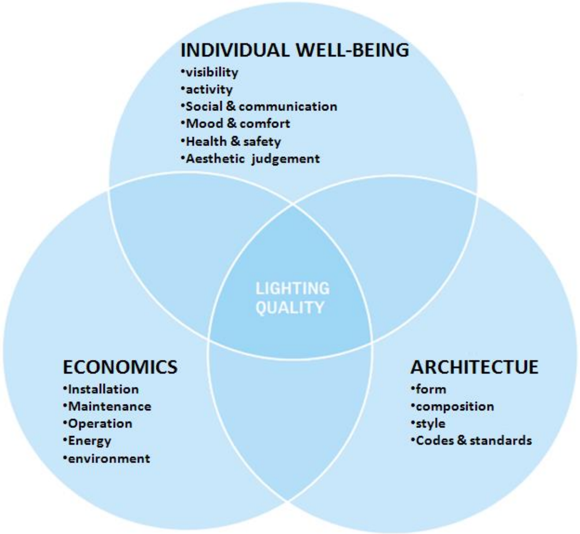

Figure 3. Daylighting quality [3]

V. DAYLIGHT FACTOR AND DAYLIGHT AVAILABILITY

Daylight factor is the ratio between indoor illuminance and outdoor illuminance. It can be measured for a specific point or for an average of a space. The following formula shows how to calculate daylight factor from illuminance levels.

$DF = 100 \times E_{in} / E_{ext}$, where E_{in} is indoor illuminance level and E_{ext} is outdoor illuminance level.

By definition, daylight factor should be calculated only under the CIE overcast sky condition. This is critical for the understanding of the final simulation results. An overcast sky does not take into account the direct light entering a space, so rotating a building to face different directions (for example, north, south, east, west) will not considerably change the calculations.

Daylight availability is similar to daylight factor, in that it is the ratio between indoor and outdoor illuminance levels. However, daylight availability is calculated under the actual sky conditions, which also includes clear and intermediate skies. Thus, it is assumed to represent better for sunny climate conditions such as Los Angeles. Although the sky is changing every minute of a day, typically intermediate sky conditions are used for daylighting calculations. Different models of virtual skies have been developed by the CIE and others. CIE has mathematically developed 15 different sky conditions, two of which are shown in Figure 4. Among these sky conditions, overcast and clear skies have been widely used in daylighting simulations all over the world.

- CIE overcast sky:

With completely cloudy sky (100% covered), this sky model has been widely used to calculate daylight factor. Many designers and users have used this model to calculate the worst case scenario. Ecotect software uses this sky model as a default.

- CIE clear sky:

CIE clear sky is defined by having less than 30% of clouds covering the sky or no clouds . In either case, the sky is brighter towards the location of the sun, and the sun is visible. Direct sunlight can be considered and calculated inside a building. This model is useful when visual glare and thermal discomfort studies are performed.

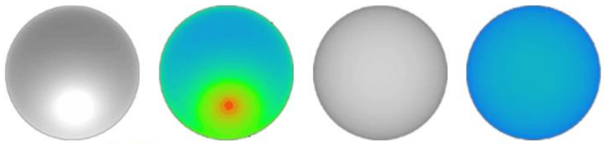

Figure 4. CIE sky conditions [4]

VI. DAYLIGHT SIMULATION

Simulation is determined with speeding up the design process, increasing efficiency, and allowing the comparison of a broader range of design variants. Simulation provides a better understanding of the results of design settlement, which increases the success of the engineering design process as a whole. For more than a quarter of a century, building performance simulation programs have been expanded to manage non-trivial building analysis and appraisements. In general these programs deal only with a small sub- set of the general problem. However, advanced architectural developments require an integrated approach to design.

It is commonly known that many indoor environment and sustainable energy related problems happen in buildings. There is fundamental record that one of the major causes is the traditional engineering approach which can be characterized as mono-disciplinary and primarily focused on static design span conditions while using simplified analytic solution methods. However we now also have computer simulation tools which can be characterized as multi-disciplinary, able to analyze all operating conditions throughout the year and which are based on numerical methods.

The main difference between traditional tools and computer simulation tools is related to the complication of the underlying models. Traditional models have in the order of 10 variables and aim to generate an exact solution of a very simplified model of reality. Simulation models may include more than 10,000 variables. Computer simulation involves performing experiences with an implicit model of reality. There is a connection with experiments on physical models which are used for confirmation, establishment and scaling.

A computer-based, mathematical model of some aspect of building performance based on fundamental physical principles and engineering models.

A computer-based calculation of the amount of daylight available inside or outside of a building under one or several sky conditions. Simulation outputs may be discrete numbers (illuminances and luminances) under selected sensor points within a scene or visualizations of a scene. The principal goal of day lighting analysis is the reliable evaluation of the potential of a design to provide useful levels of natural illumination. Daylighting analysis can take many forms. The schema of Figure 5 describes the Elements needed for a daylight Simulation.

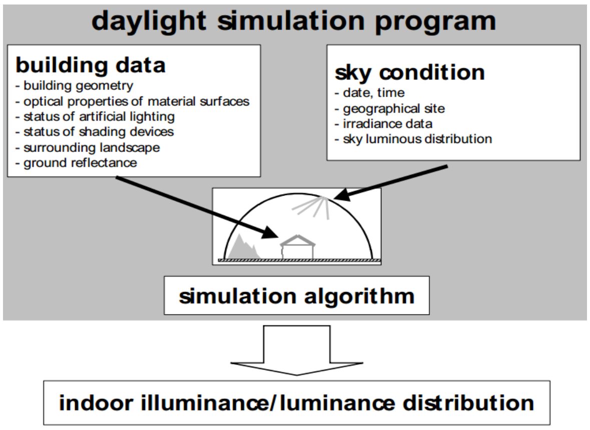

Figure 5. The elements needed for a daylight simulation [5]

The two most common rendering techniques used by most programs are ray tracing and radiosity. The ray tracing technique tracks the path of a light ray as it bounces off or is refracted through the surface. The technique known as backward ray tracing starts off with a ray from the eye towards the light source. This technique is best suited for surfaces having specular reflections and refractions (Figure 6).

Radiosity is a much more accurate and process-intensive technique than ray tracing. The original surfaces are divided into a mesh of smaller surfaces. In the radiosity process, the amount of light distributed from each mesh element to every other mesh element is calculated. The final radiosity values are stored for each element of the mesh. These avails are retained even when the viewpoint is changed, making it possible to render numerous views with the same initial radiosity calculation. The radiosity technique is best suited for diffused reflections and shadows (Figure 7).

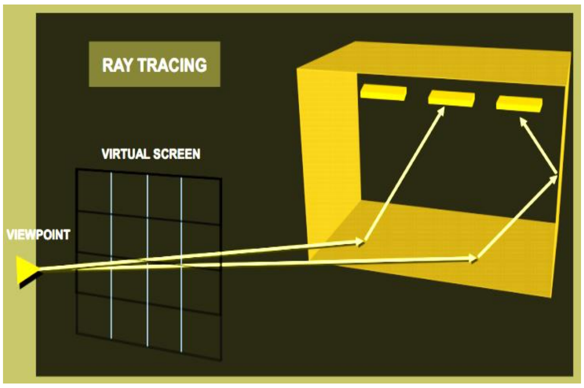

Figure 6. The ray tracing technique [6]

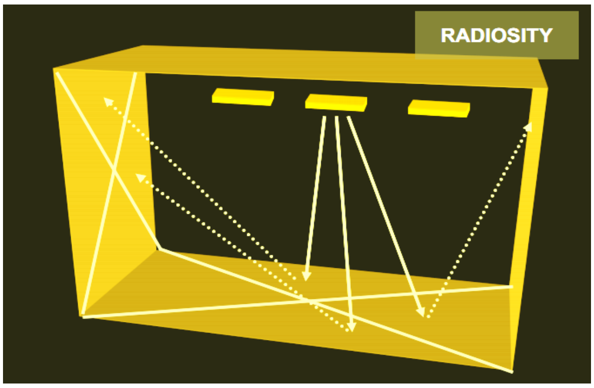

Figure 7. The radiosity technique [6]

There are several softwares that are available in the market for lighting simulation. Built by companies promoting daylighting and integrated lighting, each of these softwares cater to a separate application and hence has its own benefits. A summary of the list of softwares that are currently available is shown in Table 2 and by no means, this list is a complete one.

Table 2. Several softwares that are available in the market for lighting simulation [7]

Name of software	Light process	Details/salient features
RADIANCE	Ray tracing	Global illumination using Monte Carlo method
Relux	Radiosity	In built with reluxCAD,Energy calculation by EN15193 and DIN18599 standards
ADELINE	Radiosity	ADELINE contains SCRIBE-MODELLER as CAD interface,the light tools SUPERLITE and RADIANCE
DIALux	Ray tracing	Emergency lighting according to EN1838,Energy evaluation according to DIN V18599 and EN15899
Light scape	Radiosity	Made by Autodesk,possible to change viewpoints without recalculating the scene
Inspirer	Ray tracing	Appearance of aerospace objects and automobiles in outdoor spaces under clear or cloudy sky can be simulated
Rayfront	Ray tracing	Makes use of radiance engine and has interfaces for enhancement of geometry and complexity issues
3D studioMAX	Ray tracing	Improved rendering and integration with other toolkits for enhancements
Lumen-Micro	Ray tracing	Product library of over 70 manufacturers' luminaire data
Superlite	Radiosity	Quick on numerical feedback on a given design on aperture, reflectance and glazing
Specter	Ray tracing	Accurate simulation results for models involving arbitrary long sequences of specular and diffuse inter-reflections
ESP vision	Ray tracing	Simulated camera and rendering features
Light works	Ray tracing	Image with a fast preview of the lighting and materials within the scene
DAYSIM	Ray tracing	Precise sky modeling taking into account the sun position and real sky distribution

Even when the objectives for lighting simulation are well-defined, there remains much portable work that requires user expertise. The design in formation, essentially a building model, has to be remodeled with appropriate semantics for lighting simulation. Additional assumptions, such as geometric abstraction and material properties, have to be made. Often, part of this information is related to or reproduce by concurrent work in other domains. The sharing and checking of such information is done manually, error-prone and time consuming. Following the completion of the remodeling, much expertise is required to conduct the simulation and process the results. The entire process is thus time consuming, involves multiple tools and the problem of redundant data-entry and information exchange is further incorporated by the non-interoperability of these tools.

VII. CONCLUSIONS

As computer simulation tools are constantly changing and evolving, it is useful at this time to outline the current and future development of building energy simulation. Knowledge about the properties, applications and limitations of simulation tools is of practical importance because both current and potential users of the tools are, to some extent, frustrated and puzzled by the existing programs. To apply simulation tools and techniques successfully, a clear understanding of the building design process and its relationship with the simulation environment is advisable since humans (in other words architects) and not computers dictate the creative and evaluation process.

Advanced lighting simulation tools play a vital role in creating aesthetically pleasing, occupant friendly and energy-saving interiors. They help designers and planners visualize the space and decide whether the target requirements are met. There are two major light processes employed in advanced lighting simulation tools, namely radiosity and ray tracing. While classical tools made use of either one of these processes, most of today's tools model lighting combining both these techniques.

A daylight simulation is a computer-based which aims to predict the lighting situation in a building under a specific daylight situation. A daylight simulation program requires:

- Information on the building,
- Information on the prevailing sky conditions and
- A simulation algorithm which calculates indoor illuminances and luminances based on the former two data complexes.

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BIOGRAPHIES

Farzin Haghparast was born in Tabriz, Iran, 1967. He received the B.Sc. and M.S.E. degrees in Architecture in 1973 from Tehran University, Tehran, Iran and the Ph.D. degree in Architecture-Technology & Energy from Cardiff University, UK, in 2006. Currently, he is an Assistant Professor at Urban & Architecture Department, Tabriz Islamic Art University, Tabriz, Iran. His research interests are in the area of energy smart design in architecture, design process, architecture education, simulation based optimization, the architecture based on ecological and natural environment.

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