論文の内容の要旨

論文題目　Usability of Daylight for Energy Conservation
The Incidence of Glare Produced by Vertical Windows
and the Numerical Analysis of Illumination Energy

「省エネルギーのための昼光利用に関する研究
垂直窓のグレアの影響と照明エネルギーの解析」

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Abstract

Energy conservation in buildings has been an important concern for some time now. Yet, the many complex interrelations between the different building systems and between buildings and their occupants are still not fully understood. One of the main strategies for energy conservation in buildings is the use of renewable energy resources, and among these, the use of daylight to reduce artificial lighting is one of the most efficient. Daylight can replace electric lighting without any conversion between energy forms that is necessary with most renewable energy resources.

However, daylight is often not fully exploited for several reasons. Daylight sources are usually located in the perimeter of buildings, which makes it difficult to distribute it. Additionally, the high brightness from vertical windows can produce discomfort glare and induce the occupants of the building to protect themselves from it by reducing the amount of daylight allowed in.

The present work proposes a methodology for researching the relationship between daylight systems and building occupants, and the effects of visual discomfort in building simulation, design and energy consumption. The first part presents a new methodology for assessing the visual environment based on direct measurements made with digital cameras, and numerical simulations performed with the data obtained. The second part discusses the consequences of considering visual discomfort for building design and simulation. The concept of daylight usability is presented, which can be useful for the characterization of a façade’s daylight performance.

Part one

A new methodology to assess the visual environment of building's occupants is presented in this section. Three digital cameras were used combined in order to capture the daylight entering the windows of the considered room. The cameras registered the luminance values incoming from the hemisphere in front of the window. Each camera had a combination of neutral density filters to allow registering all the luminance values present in daylight.

In order to obtain reliable measurements, several calibrations were performed. The calibrations included geometry of the fish-eye lens distortion, vignetting, filter's transmittance, and luminance response of the camera's CCD. For this last calibration, the software HDRGen was used, which performs a self-calibration of the luminance response from a series of images taken with the cameras. Finally, the values obtained from the camera were adjusted by the relation between the illuminance measured at the lens' plane, and the illuminance obtained by integration of the hemispheric measurements from the camera.

This information was then used to illuminate a simulated scene of the room, respecting geometry and material characteristics. This allowed reproducing in a rendered image the visual field of each occupant, and the calculation of different glare indexes in post-processing. The Radiance software was used for the simulations. The glare indexes calculated included the Daylight Glare Index, the Visual Comfort Probability, J-Index, the Daylight Glare Probability, and the Vertical Illuminance, which is also a good indicator of glare probability.

The measurement of irradiance and illuminance values at the cameras' position permitted the calculation of irradiance values on the work plane, which is another usual index of visual discomfort. The use of computer simulations also permitted calculating the different glare indexes for different view directions from each occupant's viewpoint.

A survey research was conducted in an office building using this methodology. During summer, at nine different days, groups of three or four volunteers answered questions about visual and thermal comfort. The answers were given every ten minutes, during one hour. Each day, a different group of people participated. In total, 31 subjects produced 175 answers. 99 of these cases were also monitored with luminance measurements. The daylight conditions varied from overcast to clear skies. The glare indexes calculated from the simulation were then compared to the survey answers.

From the 175 answers, 19 declared thermal discomfort, while 40 declared visual discomfort. When asked if blinds should be closed, 28 declared they should be closed to control daylight, while only 6 said they were necessary in order to control heat, and 19 for both reasons.

The different glare indexes calculated were firstly compared to survey results by using linear regression. Survey answers were divided in nine groups of eleven cases, arranged according to the calculated glare index. Within each group, the discomfort probability was calculated, and this value was then compared to the average glare index.

The results showed that good correlation exists between most glare indexes and the probability that the occupant will want to close the blinds. Notably, vertical illuminance at eye level showed a very good correlation to the data, while Guth’s visual comfort probability, horizontal irradiance, and J-Index, showed the lowest correlation coefficients. These results also showed that the variation in the view direction, although changing the absolute values for glare indexes, did not change the correlation of the glare index to survey data significantly.

Secondly, logistic regression was applied to the cases that performed best in the first study. The results showed high significance, and permitted the derivation of equations that relate glare indexes to blind use probability. These were formulated for the daylight glare index, the daylight glare probability, the logarithm base 10 of the vertical illuminance, and the visual comfort probability and the horizontal irradiance for comparison. The logarithm is preferred in the case of vertical illuminance as it produced better correlation, and is also consistent with the Weber-Fechner law for the case of vision. These results were used in part two to calculate the use of blinds in dynamic annual simulations. Of particular interest is the case of vertical illuminance, which allows for faster calculations, permitting parametric studies of building characteristics.

Part two

Several annual simulations were performed, comparing different façade design variations, and different simulation methods. The results show the importance of considering visual comfort for daylight simulations, and its influence in the daylight performance of buildings. In order to clarify this relationship, the concept of usability of daylight is introduced. Usable daylight is defined as the difference between total daylight available on the work plane, and the amount of daylight that needs to be blocked with movable protection (e.g. venetian blinds) for glare protection. A design with more permanent solar protection will have less total daylight available, but also will require less use of the movable protection. The balance between these two quantities determines the optimum performance for daylight.

The cases studied included overhangs of different lengths, lightshelves, reflective lightshelves, different window sizes, orientations, etc. and were calculated with different simulation methods and glare indexes. The results show that the use of different glare ratings can produce differences of 25% in the calculated incidence of glare.

For the annual calculations, a method derived of the concept of daylight coefficients was implemented. In this method, the contribution of different sections of the sky and solar positions is calculated in advance for each reference point. These values, multiplied by the hourly sky luminance of each corresponding sky sector and the direct solar illuminance, produces hourly data inside the building without the need of running one simulation for each hour. This way, the simulation time is greatly reduced.

In this case, an adapted method was implemented in order to optimize its performance for vertical windows. Sky sectors of smaller solid angle were used near the horizon to improve accuracy, and bigger sectors were used near the zenith, to reduce calculation time.

Finally, a simple genetic algorithm for optimization of the daylight performance of a façade is presented. A simplified simulation method was used, as the algorithm requires the assessment of thousands of different cases. A set of 21 parameters was defined, which describes the characteristics of the façade. Different evolutionary methods were applied and daylight performance showed an increase of up to 30%. Results from this experience show how optimization methods can be implemented with computer simulations to improve the performance of building designs.

Conclusion

The different influences of visual discomfort in buildings were reviewed. These comprise from the evaluation and quantification of occupant’s response to daylight, to the effect of the different simulation methodologies can have on façade design. A new methodology for reproducing the visual environment of an observer was presented. It allows the reconstruction a-posteriori of the circumstances at a certain moment, which then can be compared to observed behavior or survey answers. In order to make explicit the relationship between visual discomfort, daylight availability, and energy consumption, the concept of usable daylight was introduced. Finally, the influence of daylight glare in energy consumption was assessed for several design variations, and a possible implementation of an optimization algorithm was presented.