A NEW SCANNING SKY SIMULATOR

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ABSTRACT

A sky simulator has been developed to study daylighting systems on scale models (diffuse component of daylight). This apparatus is of a completely new concept (scanning sky simulator) and has numerous advantages in comparison with similar devices. It allows in particular the reproduction of any sky condition and distinguishes itself by easy calibration, reduced maintenance and moderate electric consumption. The simulator is equipped with a measuring and visualisation system which allows the user to simultaneously carry out quantitative studies (profile of daylight factors) and qualitative studies (visual lighting effects). In this paper, a description of the system and its functioning as well as an application example are given.

1. INTRODUCTION

The objective of this paper is to present a sky simulator of a new generation (scanning sky simulator). This device allows the study, on scale models, of the contribution of the diffuse daylight component from the sky to the lighting of a room [ROB 84]. It thus complements other natural lighting design and planning tools created to facilitate the lighting designer’s task (heliodon [DEN 91], computer programs [PLE 91]).

The main advantage of this simulator is that it allows the development of new daylighting systems. The study of such systems relies principally on the evaluation of their luminous performance (daylight factor, visual comfort, etc.) and includes:
- quantitative analyses based on the use of photometers (photometric measurements);
- qualitative analyses based on the use of a video system (visualisation of lighting effects).

A description of this apparatus and the way it works as well as a presentation of its application possibilities in architecture are given in this paper.
2. SIMULATOR DESCRIPTION

2.1 Technical Data

The diffuse lighting simulator functions on the basis of the following combined elements:
- artificial light sources which reproduce the luminous characteristics of the sky vault (artificial sky)
- a automated support for the models
- miniature photometric probes
- digital visualisation techniques.

Fig. 1 illustrates the simulator as well as the principal elements required for its use.

**Figure 1:** Diagram of the components of the sky simulator

The quantitative analysis of the performance of a daylighting system is based mainly on the measurement of daylight factors. Qualitative studies can be performed using video recordings (CCD high-definition camera) or photographs. The images and data corresponding to a given type of sky (the complete sky vault) cannot be obtained directly through the simulator (model of one sixth of the vault); the following steps have to be applied:
- successive rotations of the model co-ordinated with an appropriate distribution of the intensity of the sources (possibly modified at every rotation);
- recording of light measurements (photometers) and digital images (video) at every rotation;
- addition of the six partial components after the six rotations (measurements and images);
- calculation of daylight factors and visualisation of the resulting digital image.

In absence of luminous interferences and by virtue of the superposition principle, this procedure is justified.

The whole procedure is automatic; it is carried out by a micro-computer PC486 (control unit), which is responsible for the handling of the automated supporting structure, the acquisition of photometric data, the video recordings as well as the final processing of these elements.
2.2 Sky Vault Modelling

To dispose of natural lighting conditions which are close to reality, it is essential to reproduce the distribution of the sky luminance under any given condition as accurately as possible. Different approaches have been chosen for the existing ‘artificial skies’ (mirror skies [ROB84], sky dome illuminated by light sources [SPI 86], point light sources which were uniformly distributed over a hemisphere [SZE 89]). None of these configurations is without disadvantages, for example:

- the limited number of reproducible sky conditions (mirror sky);
- calibration difficulties (illuminated sky dome);
- the different ageing patterns of the sources (point light sources);
- maintenance and electricity consumption problems.

To circumvent these disadvantages, a new sky vault modelling configuration has been adopted. It distinguishes itself through the fact that the hemisphere is ‘paved’ regularly with identical geometric figures (discs).

This configuration was proposed by P.R. Tregenza [TRE 87], within the framework of the International Daylighting Measurement Year (IDMY). It offers the following advantages:

- the hemisphere is paved with identical discs for an near to optimal covering (covering rate of the hemisphere: 68%);
- it features a vertical symmetry axis of multiplicity 6 (use of rotations possible);
- it corresponds to the standard in which the sky luminance measurements will be transcribed (the use of this data is facilitated).

Figure 2a: Effectively constructed part of the sky vault (25 luminous discs of an intensity that can be modulated from 0 to 100%).

Figure 2b: Complete sky vault reconstructed by six rotations of the supporting structure of the simulator (CIE clear sky, sun altitude $h_s = 30^\circ$).
Figure 2b illustrates this configuration, containing 145 luminous discs distributed over the hemisphere according to a precise pattern [TRE 87]. Due to the symmetrical properties of this configuration, only one sixth of the sky vault had to be constructed (see fig. 2a). This translated itself into a substantial reduction in the number of light sources (25 discs instead of 145), which in turn facilitates maintenance and calibration and reduces the consumption of electricity. The complete sky vault is obtained by rotation of the models mounted on the simulator (six rotations of 60°).

The luminous discs are in fact customised luminaires which were developed for this simulator (study performed using the computer program ADELINE) and consist of:
- two fluorescent toric tubes (Circline, daylight, 32 and 40 W);
- three reflectors of optical quality (2 cones, 1 disc);
- a lamberian diffuser (opal Plexiglas);
- an HF electronic ballast (intensity variable from 0 to 100%).

These discs all have uniform luminance (|ΔL|/L = 11 %). Their photometric solid is of the lambert type and their colour temperature identical to that of daylight (5700 K).
Figure 3 shows a section of these luminaires.

![Diagram of section of a luminaire of the sky simulator.](image)

**Figure 3:** Section of a luminaire of the sky simulator.

### 2.3 Advantages of the device

Due to its novel design this simulator shows numerous advantages in comparison to others. It allows in particular the reproduction of any type of sky:
- the isotropic overcast sky
- the CIE overcast sky (Moon et Spencer)
- the CIE clear sky (urban and countryside)
- the CIE intermediate sky (Matsuura)
- the real sky (IDMY measurements, statistical sky).

The considerable effort put into the development of a convivial interface program 'Man-machine' much facilitates start-up (commands through Windows) and calibration (automatic procedure).
3. APPLICATIONS

The simulator has been operational since the beginning of 1993. It has already been used for more than a dozen studies (student projects, mandates). Figure 3 illustrates an application example: the project of an underground gymnasium, where only zenithal openings can be used for daylighting purposes. The evaluation of the available daylight was obtained by measuring the daylight factors (data processed and displayed in the figure). The lighting effects can be visualized using a video recording from the miniature camera inserted into the model (scale 1:100). This digital image can be transferred onto various media (magnetic tape, floppy disc), in particular for a computer analysis of the visual comfort.

Figure 4: Daylight factors and digital image resulting from the addition of six intermediate components (project for an underground gymnasium; the photometric probes can be seen in this picture).
CONCLUSION

A diffuse sky simulator of a new generation has been developed. This novel apparatus (scanning sky simulator) possesses numerous advantages in comparison with other existing systems. It allows in particular the reproduction of any sky condition without tedious calibrations or difficult maintenance. Connected to a sunlight simulator (automated heliodon), this device constitutes an efficient design and planning tool which not only allows the study of new lighting systems but also the teaching and demonstration of daylighting techniques in a greatly facilitated way.

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