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CIE STANDARD SKIES IN SWITZERLAND: RELATIVE OCCURRENCE AND IMPACT ON DAYLIGHTING SYSTEM PERFORMANCE

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ABSTRACT

The purpose of this work is the definition of a representative sky for the Geneva Lake Region (south-west Switzerland). A representative sky is a theoretical blended sky based on the relative occurrence of a subset of the 15 standard general skies suggested in 2003 by the Commission Internationale de l'Eclairage (CIE) [1]. By employing Tregenza's method [4] and the Swiss Norm 150 911 [5], a reduced set of CIE standard skies (and their relative frequency of occurrence), named the Geneva Lake Region Representative Sky (GLRRS), is proposed. In addition, by means of a GLRRS-based Virtual Sky Dome (VSD) and the lighting software Photopia 3.0, the behaviour of three different kinds of mirror lightducts is simulated for the Geneva Lake Region.

INTRODUCTION

Climate change is one of the major challenges that humanity will have to deal with. In order to correctly face this hazardous problem, it is necessary to intervene on one of our society's key parameter, which is energy. A way of decreasing greenhouse gases emissions, which trigger global warming, is to use energy in a more efficient way. An important field to focus on is the building segment, in particular the lighting sector; electrical lighting in office interiors can in fact contribute to more than 30% of the total building energy consumption [2].

A representative sky is a theoretical blended sky based on the relative occurrence of a subset of the 15 CIE standard skies [1]. The first five (1-5) describe daylight conditions under various overcast conditions, the second group (6-10) reflects the influence of sunlight with some clouds in the sky and the last group (11-15) models sunny situations with various levels of turbidity (haziness in the atmosphere due to aerosols). Focusing on the above mentioned issue, a representative sky could play an important role towards a more sustainable building lighting segment. It could give, for given location and a given time, an accurate knowledge of sky luminance distributions. By taking already into account a determined range of standard sky types which have the highest relative frequency of occurrence, representative skies simplify daylight simulations, allowing a much faster implementation of simulations. The knowledge of a representative sky for a given location is highly important, for instance, for energy saving programmes employing simulations which model the daylight distribution in complex interior spaces with and without the integration of particular daylighting systems. Worldwide, representative skies have been defined in the UK, Japan [10], Singapore [9, 10], Hong Kong [11], Greece and Slovakia [3] and overall it was seen that errors in predictions of interior and exterior daylighting resources based on the 15 standard skies were significantly less than when calculations were based on an overcast sky alone. Moreover, local best fit sky types have been used for assessing the performances of Anidolic Integrated Ceilings in Singapore and in the UK [2].

In Switzerland, daylight and irradiation data have been recorded for many years in Geneva and Lausanne, but so far no representative sky has been defined for the region. The present paper is structured in two main parts: the first one regards the definition of the Geneva Lake Region Representative Sky (GLRRS), while the second one deals with computer simulations of different mirror lightducts using the GLRRS. Both parts begin with a brief introduction, followed by the adopted method and the obtained results.

DEFINITION OF THE GENEVA LAKE REGION REPRESENTATIVE SKY (GLRRS)

The Geneva Lake Region lays in the south-western part of Switzerland, at the north-western tip of the Alps. A coarse, but very useful definition about Geneva's climatic and environmental main features states: "Temperate maritime climate, with central Europe continental influence. Persistent nebulosity enhanced by "blocking position" at foot-hill of the Alps" [6, 7].

The GLRRS has been determined by means of a detailed analysis, based on Tregenza's method [4], of the available data from the International Daylight Measurement Programme (IDMP) station located in Geneva.

Methodology

To determine the typical sky luminance distributions, Tregenza's method uses the ratio L_p/E_{dh} (sky scanned luminances of the sky vault/diffuse horizontal illuminance). The database employed comes from Geneva's IDMP station and consists of hourly sky luminance data (measured by means of a PRC Krochmann scanner), hourly values of global horizontal illuminance (E_{gh}) and direct normal illuminance (E_{bn}). The available measurements from the IDMP station go from the second half of 1994 until the first half of 1995.

In order to determine a local representative sky, mainly for daylighting-linked energy studies, it has been considered opportune to focus on a daily hour range included between 9.00 and 17.00, which corresponds to the main office working period. The initial volume of 4363 observations, after a data pre-processing consisting in quality tests [3, 8] and other specific selections among measured data [3, 9, 10], has been globally reduced to 1027 data, which represents the final database of this work. Each scanned sky has been analysed individually and the standard distribution giving the closest fit to the scan has been determined in the following way: the sky scan luminances have been normalized with respect to horizontal illuminance calculated from these monitored luminances and then the same has been applied to the 15 Standard General Sky types for the solar angles at the time of scan.

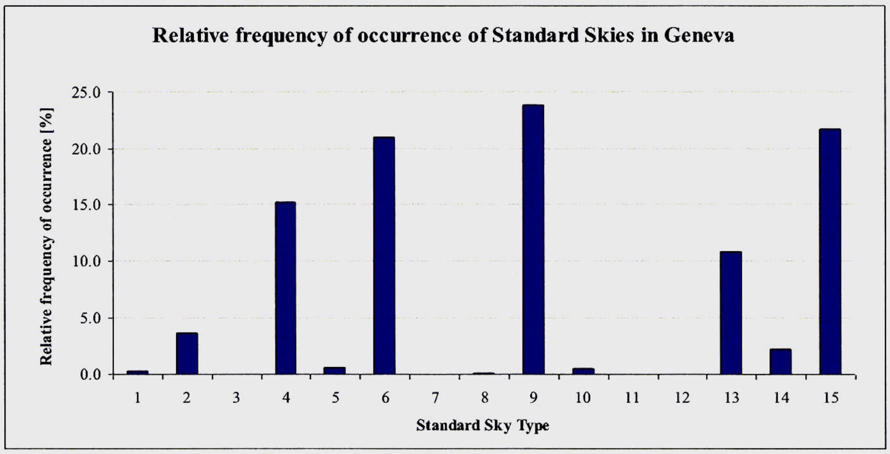

Figure 1: Relative frequencies of occurrence of the 15 standard sky types in Geneva according to Tregenza's method.

The RMS error between the measured normalized luminances and each of the standard distributions has been computed: the standard luminance distribution that had the minimum least-squares error over the whole hemisphere was the best fit standard sky type. The obtained relative occurrence frequencies for the 15 sky types are shown in Figure 1.

After applying the overall procedure, it can be seen on Figure 1 that, during the given monitored period, partly cloudy skies are globally the predominant ones (45%), followed by clear skies (35%) and then by overcast skies (20%).

Results

Tregenza's method has given valuable and useful outcomes, but, due to the limited sample size, the results obtained might not necessarily be representative for a long term sky luminance distribution in Geneva. Nevertheless, it is important to underline that the typical local standard skies are likely to have been correctly determined, the relative frequencies of occurrence being however not fully representative. That is why these results, together with the Swiss Norm SN 150 911 on "interior lighting with daylight" [5], were taken as a basis for the development of the representative sky for the Geneva Lake Region.

By adapting the percentages of this norm (see Figure 2) to the three CIE standard sky groups for Geneva, the annual sky can be described as: 43% overcast over the year (7.5 to 10 tenths of cloudiness), 36% intermediate (7.5 to 2.5 of cloudiness) and 21% clear (0 to 2.5 tenths of cloudiness). Knowing these percentages, together with the standard sky types determined by means of Tregenza's method, it has finally been possible to assess the Geneva Lake Region Representative Sky (GLRRS).

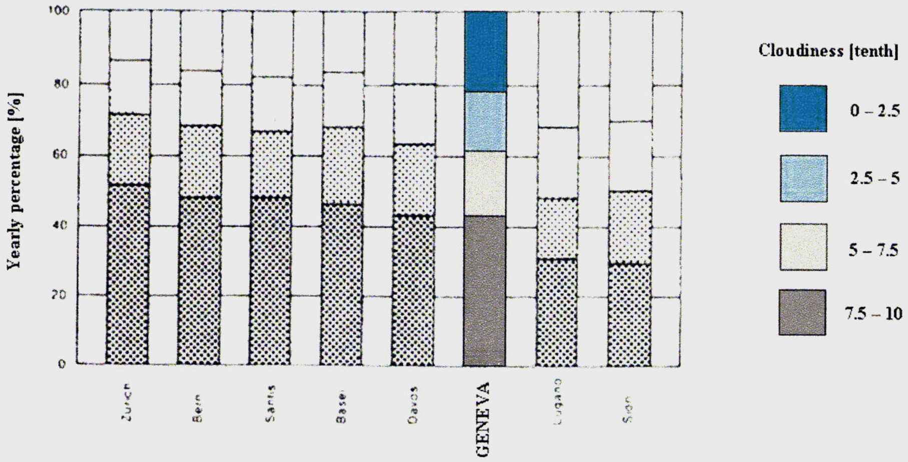

Figure 2: Yearly percentage, in tenths, of the different levels of cloudiness in some Swiss locations, adapted from [5].

Assigning sky 4 as representative for overcast skies, sky 6 for highly intermediate skies, sky 9 for slightly intermediate skies and sky 15 for clear conditions, the GLRRS can be defined as follows (analogically to the Hong Kong Representative Sky (HKRS), introduced by Ng et al. in 2007 [11]):

$$\text{GLRRS} = 0.43(\text{sky}4) + 0.20(\text{sky}6) + 0.16(\text{sky}9) + 0.21(\text{sky}15) \qquad (1)$$

This means that the contribution to the GLRRS sky luminance distribution is given by sky 4 (43%), sky 6 (20%), sky 9 (16%) and sky 15 (21%). In daylight simulations where sky models based on different sky patches are used, the luminance of each patch can be calculated according to equation (1).

SIMULATION OF MIRROR LIGHTDUCT DEVICES' PERFORMANCES USING GLRRS

After having defined the representative sky for the Geneva Lake Region, the acquired result has been applied in a specific daylighting case study. Together with a reference case, the performances of three different types of mirror lightducts have been assessed using the GLRRS for four façade orientations (north, east, south and west).

Mirror lightducts are devices which collect diffuse and direct daylight through an external collector and channel it into a reflective ceiling plenum. The exit apertures located on the ceiling distribute the daylight flux to the deep and gloomy zones of the room and thus reduce the demand for electric lighting, which is one of the major building loads. Furthermore, by efficiently redirecting daylight into the interior, it also enables to achieve a uniform daylight distribution in the room [2, 12].

Methodology

The assessment of the daylighting performances was made by means of computer simulations. The Virtual Sky Dome (VSD) approach was used to generate a CIE general sky consistent with the daylighting conditions to be used in 3D-CAD simulation software. A VSD imitates the spatial luminance distribution of the sky vault by 145 distinct light sources, whose distribution over the hemisphere follows the IDMP conventions for sky patch luminance measurements and whose individual luminous flux is calculated using the equations of the 15 sky types [12]. In the current work the VSD approach was used to generate the sky patch luminances [cd/m^2] for a given Sun position and a local sky distribution reproduced by the GLRRS. A solar elevation $\gamma_s = 34°$, an average between the lowest and the highest solar angles that occur in Geneva, and a solar azimuth $\alpha_s = 180°$ have been selected for the simulations.

Using the on-line VSD software [13], the luminance of each patch was obtained for every standard sky, giving a total matrix of 145 x 15 data. Subsequently, through equation (1), the values were weighted in order to determine a luminance distribution corresponding to the GLRRS. The obtained VSD has then been imported into the software Photopia 3.0, together with the 3D-CAD models of the open space office (with and without the mirror lightducts) for four different façade orientations (north, east, south and west).

The room chosen for the simulations is a large and deep open space office (18m width x 9m depth x 3.6m height) located at the ground floor of a three floor building. The room is illuminated only from one side and is shaded by the upper floors. The "reference building" case refers to the default façade configuration, without any integrated device. It is used for comparing the mirror lightducts' performances, which are modelled for three different cases. Each model includes six ducts, but the differences are basically given by the ends of the ducts and the number of openings (see Figure 3). The first type has got straight vertical endings and four openings (basic ducts case); for the two other types the ducts' ends are tilted (inclined of 45°), one is characterised by three openings (tilted ending ducts with three openings), the other one by four (tilted ending ducts with four openings).

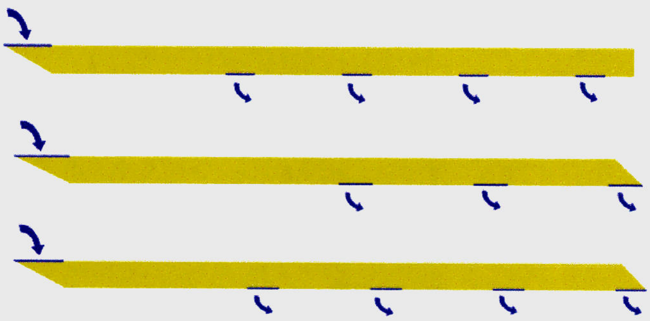

Figure 3: Details of the openings of the three different kinds of mirror lightducts: basic ducts, tilted endings with three openings and tilted endings with four openings, respectively.

Results

In order to assess the global performance of the three mirror lightduct devices used in the simulations, the criteria IR (Illuminance Ratio: ratio of indoor horizontal illuminance [lx] over the external horizontal illuminance [lx], expressed in percent), IR IF (Illuminance Ratio Improvement Factor: quantifies the performance improvement over a reference façade without a mirror lightduct device) and UF (Uniformity Factor: ratio between the minimum and the average of the indoor horizontal illuminances [lx]) are employed for the four given orientations of the building's façade.

Figure 4 shows that out of the three proposed daylighting systems, the better overall results are achieved for the one which has three exit apertures per duct and a tilted end. The inclined back of the ducts is a key solution for an optimal redirection of daylight into the rear of the office room. Moreover, for the given cases, it is seen that four openings in the ducts do not lead to an improvement, but actually decrease the performances. With this configuration, in fact, the aperture close to the window (where the IR is anyhow high), contributes to a considerable loss of the daylighting flux which is more useful in the back of the office room. Focusing on the four building orientations, the simulations' results suggest that the most suitable directions of the façade with the integrated mirror lightducts are (considering both the UF and the IR IF) the west and east orientations.

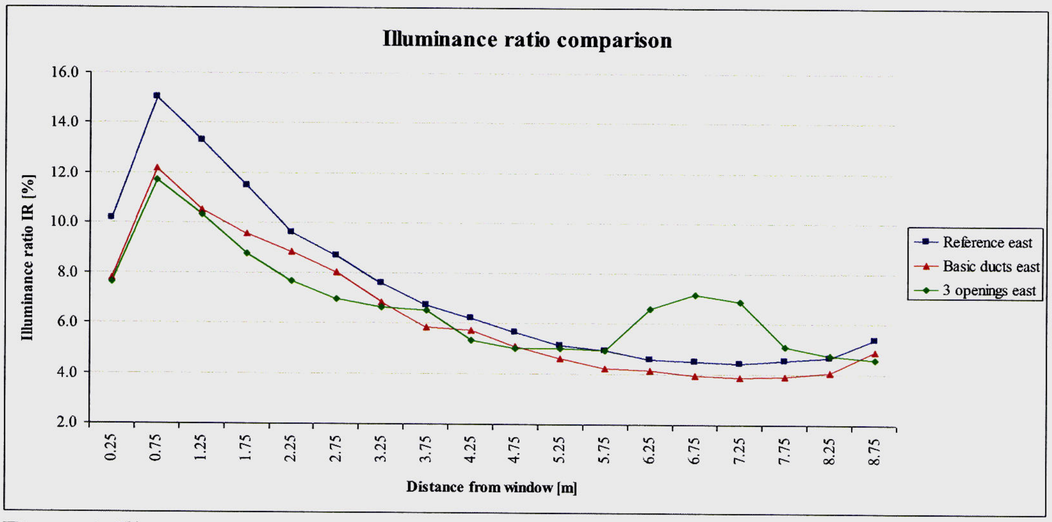

Figure 4: Illuminance ratio comparison between the reference, the basic duct and the 3 openings case, for an east facing façade.

CONCLUSION

The aim of this work was the assessment of a representative sky for the Geneva Lake Region (south-western Switzerland), which can be used to reproduce a typical local sky luminance distributions for daylighting and energy saving studies. In order to determine the Geneva Lake Region Representative Sky (GLRRS), Tregenza's method [4], together with the Swiss Norm 150 911 [5], have been employed.

The obtained GLRRS has then been used to evaluate the performance of three kinds of mirror lightducts. Their behaviours, compared to a reference case (without any device), have been simulated by means of a Virtual Sky Dome (VSD) based on the GLRRS and the Photopia 3.0 software. In order to determine to what extend the chosen daylighting systems improve the illuminance ratios (IR) and the uniformity in a given open space office, both the illuminance ratio improvement factor IR IF and the uniformity factor UF have been employed. The results show that the most performing daylighting device is the mirror lightduct with three openings and a tilted end; the best outcomes are achieved for the west and east orientations of the building facade. Further research should be carried out to implement and optimize the new solutions for the considered mirror lightduct: this would mean for instance the use of anidolic collectors, the integration on two or three different facades or the optimization of the lightduct's dimensions.

Further studies, possibly with more complete data sets, have to be conducted in order to improve the GLRRS obtained in this work, to get more detailed simulations of the mirror lightducts as well as to assess the performances of other daylighting systems.

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