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Daylit offices: A comparison between measured parameters assessing light quality and users' opinions

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The paper reports data referred to luminance and illuminance measurements performed in three offices located in Naples (latitude 40°51′ N, longitude 14°14′ E). Luminance maps are obtained through HDR imaging technique by means of a video-luminancemeter. Then users' opinions about comfort conditions in their workplaces are analyzed in typical days and compared with illuminances measured at the eye level and at the workplane and with some daylight performance indexes (Useful Daylight Illuminance and Daylight Glare Probability). Results demonstrate that, given a particular space, similar luminance trends can be observed when specific weather conditions occur. Moreover discomfort turns out to be referred to precise moments of the day and to particular weather conditions. A correspondence between daylight performance indexes and users' opinions is not always observed.

1. Introduction

It is commonly agreed that daylight entrance in indoor environments determines many benefits in terms of both comfort conditions and energy savings. Researches demonstrated that daylight is one of the most important regulator of human circadian rhythms [1], it is preferred by users and has positive impact on the maximization of visual performance, indeed it is characterized by a spectrum that ensures excellent color rendering [2]. Furthermore it can contribute to determine people mood by improving their physiological conditions and consequently can affect workers' productivity [3,4].

However daylight can cause visual discomfort such as glare, veiling reflections on computer screens, disturbing shadows and affects thermal balance, potentially determining overheating.

Therefore, the most ambitious challenge in daylighting design is to keep the balance between the maximization of daylight harvesting and the control of the correlated discomfort risks. This is a particularly complex task and requires an in-depth knowledge of the factors that influence visual comfort.

Generally discomforts related to daylight are due to discomfort glare, determined by high or non-uniform luminance distributions, high contrasts between light sources (i.e. windows) and the surrounding and also the position and the size of the source in the field of view [5]. Therefore comfort conditions in the same space are continuously affected by both daylight availability and observers' point of view.

Over the years researchers proposed different parameters to evaluate daylight provision in indoor environment. In particular these indexes aim at verifying if a sufficient amount of daylight enters the space, evaluating the direct sunlight penetration and describing discomfort phenomena.

Indoor daylight availability evaluation can be performed with two different calculation approaches: a static one, the goal of which is to verify daylight provision in particularly disadvantageous conditions (e.g. overcast sky or solstices); a dynamic one, that allows to calculate daylight availability during an entire year, considering variations due to time and weather conditions. The choice between the two approaches depends on the goal of the analysis. According to the evaluation method, different performance indexes are available as reported in Fig. 1 and Table 1.

On one hand, according to the static approach, the calculation of DF is very useful to evaluate the worst daylight conditions. Moreover some European standards recommend to verify minimum limits about sunlight duration. For example, German ones [6] suggest to verify 4 h of insulation on March 21st and 1 h on

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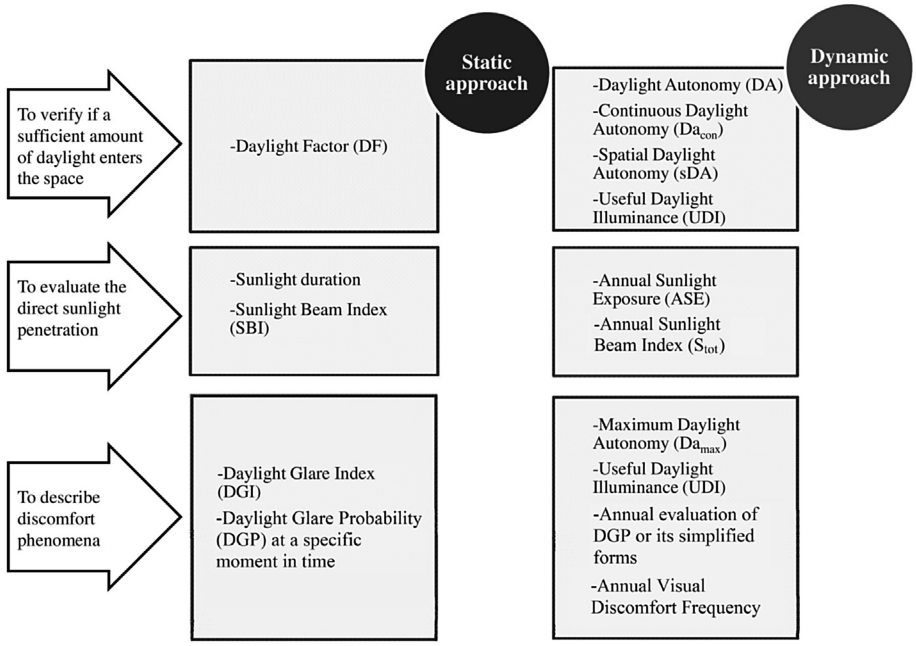

Fig. 1. Some of the main indexes used to describe daylit environment.

January 17th; in U.K. it must be controlled that sunlight enters a space for 25% of probable sunlight hours, and at least for 5% from September 23rd to March 21st [7]; in Poland the sunlight duration should be at least 3 h on March 21st and September 21st between 8 a.m. and 4 p.m. in schools and buildings for child care and from 7 a.m. to 5 p.m. in residential buildings on the equinox [8]. Furthermore, standards generally suggest to limit excessive sunlight penetration, but, in this respect, they simply recommend shadings use. Recently Mardaljevic and Roy [9] proposed SBI, a parameter that evaluates sunlight penetration depending on the daylit area of the window, the period of sun incidence and the cosine of the angle of incidence. Finally the evaluation of glare is performed thanks to different indexes such as DGI or DGP, the calculation of which is based on the processing of luminance maps, obtained through measurements or simulation software.

On the other hand, as for the dynamic approach, due to the complexity of the calculation, illuminance turns out to be the most simple variable to evaluate and the one that allows to reduce data processing time. Consequently the most of dynamic metrics are based on horizontal illuminance at the workplane and on the idea that it is possible to identify different illuminance ranges that correspond to comfort and discomfort conditions. As for sunlight penetration evaluation, ASE is based on horizontal illuminance as well and specifically on the calculation of the illuminance component due to sunlight. SBI can also be related to the entire year and, in this case, it is defined Annual Sunlight Beam Index (S_{tot}) [9]. Glare evaluation is not immediate in dynamic approach: through the use of simulation software, luminance maps, corresponding to each hour of the day during an entire year, should be generated. Clearly the same procedure should be repeated for each position and point of view. This would be really time consuming. For this reason, simplified methods to express DGP on an annual basis were tested and the so called Simplified Daylight Glare Probability (DGPs) and Enhanced simplified Daylight Glare Probability were proposed [10,11]. However, recent efforts have shown that annual evaluation of the full DGP index is possible and can be reliable, even under dynamic shading conditions [12]. Moreover, recently researchers have proposed a new metric called Annual Visual Discomfort Frequency [13]. It can be defined as the percentage of working time in the year during which none of the two following criteria are satisfied: 1) the beam illuminance (i.e. the illuminance due to sunlight) on the eye ($E_{v,beam}$) should be lower than 1000 l×; 2) the total vertical illuminance on the eye ($E_{v,total}$) should be lower than 2670 l×. The first criterion derives from a modification of ASE, i.e. it consists in applying the ASE threshold limit referred to workplane illuminance (1000 l×) to the eye level. The second one derives from DGPs. According to the simplified formula of DGP, indeed, when the vertical illuminance at the eye level exceeds 2670 l×, glare probability reaches 0.35, i.e. the lower limit of acceptable values.

Previous works underlined limits of parameters used to describe comfort conditions as reported in the following.

Indexes based on horizontal illuminance present different problems. As for DA_{max}, the idea to consider risky an illuminance value ten times higher than the design illuminance is based on intuition rather than documented research [23]. Moreover, the upper limit of UDI (2000 l×) cannot be applied to all design cases. In other studies [24] it is considered equal to 3000 l×; however it is suggested that sometimes trespassing this limit could be useful, because moderate occurrence of high daylight levels may be beneficial and may boost alertness and mood. Finally UDI definition is based on the observation of users' preferences in office and could not be representative of other tasks.

Parameters based on luminance distribution in some cases cannot be reliable as well. A previous study [25] demonstrated that DGI is not able to correctly describe people discomfort conditions and that different factors affect its calculations, such as the partition of the window in different patches, in order to define the average luminance of each of them. As for DGP, it was underlined that it might overestimate glare perception when sunlight falls on the occupant and more studies are needed on this topic [12]. Moreover a previous research highlighted that often, when vertical illuminance at the eye level is lower than 1000 l×, DGP can assume low values even if daylight conditions are judged uncomfortable [26]. Kleindienst and Andersen [10] tested the DGPs and found that it can be considered a good predictor of discomfort when glare is mostly caused by the quantity of light hitting the eye (for example