A STUDY ON THE FORMATION OF INDOOR DAYLIGHT CONDITIONS WITH RESPECT TO THE URBAN LANDSCAPE

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Abstract

Nowadays the benefits of daylight on every aspect of human life are well known. Several strategies have been developed in order to exploit the daylight and enhance the visual conditions indoors. However, these techniques cannot always be implemented successfully, since the dense urban fabric of the modern cities often prevents daylight from reaching deep into the spaces. Therefore, it is very important to study the availability of daylight under realistic conditions at an early stage of the design process particularly for spaces that face obstructions, in order to be able to confront potential problems caused by a poorly lit environment. Such a study should include the analysis of the daylight availability in the region, as well as the investigation of the effect of the obstruction's characteristics on the determination of indoor daylight conditions and the energy requirements for lighting. The implementation of such a study in the Greek region forms the main objective of this paper, the steps and the findings of which are presented below analytically.

1. Introduction

Under the frame of "sustainability" and in a world newly concerned about carbon emissions, global warming and sustainable design, the use of natural light in buildings has become an important strategy for improving energy efficiency by minimizing lighting, heating and cooling loads. However, the integration of common or advanced daylight strategies at each phase of the building design requires information regarding the daylight climate of the region and the distribution of illuminance on a regional, as well as a seasonal basis.

All daylighting strategies are based on the utilization of the luminance distribution from the sun, sky, buildings and ground. Their performance is influenced by the availability of daylight, which is determined by the geographical location of the building, as well as by the conditions immediately surrounding the building, i.e. the presence of obstructions. It is therefore essential to investigate the daylight climate of the region along with the impact of the obstructions surrounding the site, in order to optimise the design of the building's façade and enhance the indoor daylight conditions.

These two essential issues form the objectives of the current paper. It involves the study of daylight availability in the ambient environment for the Greek region and the implementation of its results on the prediction of indoor daylight levels in relation to the urban fabric layout.

2. Daylight availability in the Greek region

The study of daylight availability in the Greek region was considered necessary, since basic daylight data are not available for most regions of Greece, as well as for many areas worldwide.

The National Observatory of Athens (N.O.A.) is the only research establishment in Greece, which has a long and complete solar illuminance database. It is situated on the Hill of Nymphs within the urban area of Athens (latitude: 37.97^{o}N, longitude: 23.72^{o}E, altitude: 107m above mean sea level). The climate of Athens is Mediterranean, with hot summers and mild winters. The average temperature during the summer is 25.80^{o}C and during the winter is 9.90^{o}C [1]. N.O.A. is equipped with a first class meteorological station and a research class daylight station, which complies with C.I.E. recommendations. The necessary shadow band corrections are made according to Littlefair.

For the study of daylight availability, N.O.A. has provided climatic data of 5 years (1996-2000). More specifically, 14603 hourly mean values of global and diffuse irradiance, global and diffuse illuminance, relative humidity, air temperature and atmospheric pressure were used for the analysis. All data were subjected to the quality control recommended by C.I.E. [2]. After the quality control there were 13275 “safe” data sets of irradiance and illuminance, 35% of which were observed under clear sky conditions. The frequency of overcast sky was found approximately equal to 18%, while the remaining referred to intermediate sky conditions.

Daylight availability was derived as the cumulative frequency of global, diffuse and direct illuminance on an annual and seasonal basis. Figure 1 shows the probability to observe global, diffuse and direct daylight illuminance lower than a datum level on horizontal plane during the year. The x-axis refers to the illumination level intervals, while on y-axis the cumulative frequency of their occurrence is plotted. According to the diagram, there is a probability of 22% to observe values of global illumination lower than 20klx during the year. For the same level of illuminance, the probability for direct and diffuse daylight is equal to 46% and 60% respectively. In general, during the year global illuminance is distributed over a greater range and direct illuminance is higher than diffuse.

By comparing daylight availability in Athens with relevant data from other European cities [3] it is derived that there is a higher probability to observe high global illuminance values in Athens than at other northern cities. For example, a global illuminance lower than 20klx is exceeded for only 50% at Aberporth, UK, compared with 22% at Athens [3]. The higher daylight availability in Athens can be attributed to the limited appearance of overcast sky conditions in Athens compared to northern European regions and to the extended sunshine probability during the year [4].

Figure 2 indicates the availability of global, diffuse and direct illuminance under clear sky conditions. The curves for global and direct illuminance have narrower inclination than that of Figure 1, demonstrating that global and beam daylight reach much higher levels under clear sky conditions. On the contrary, the range of diffuse illuminance is limited, since under clear skies the scattering of radiation is confined.

Under clear sky conditions the direct component of solar radiation prevails; therefore it could be expected that at each wavelength the attenuation of global radiation would follow the attenuation of beam radiation due to the absorption and scattering processes encountered in the atmosphere, though to a lesser extent [5]. Rayleigh scattering by air molecules depends on the wavelength and affects mostly

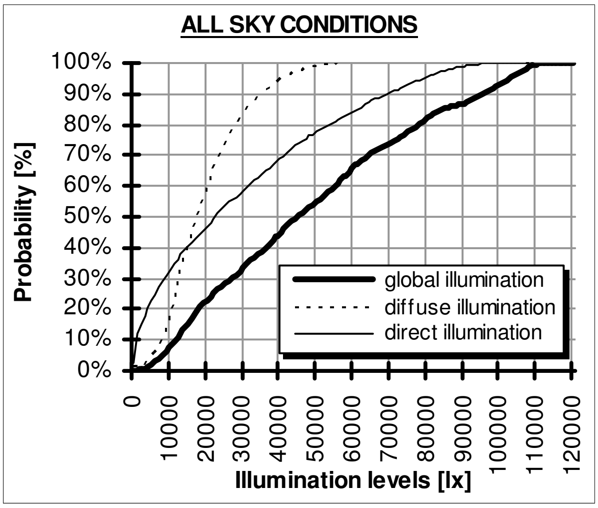

Figure 1. The probability to observe values of global, diffuse and direct illuminance lower than a datum level on a horizontal plane in Athens during the year (all sky conditions).

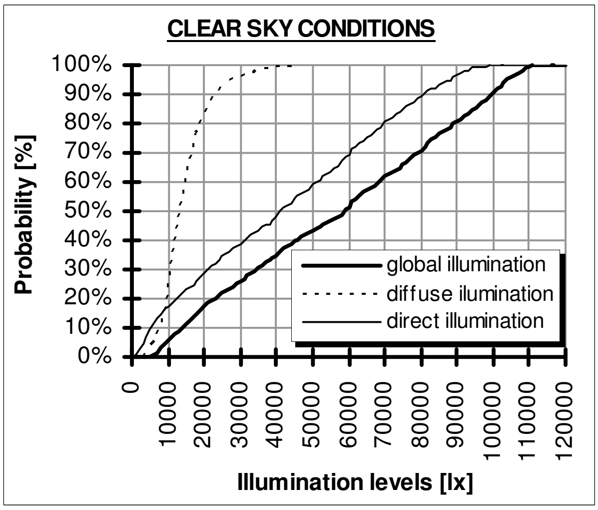

Figure 2. The probability to observe values of global, diffuse and direct illuminance lower than a datum level on a horizontal plane in Athens during the year under clear sky conditions.

the visible radiation. Furthermore, the dust and the particulate matter suspended in the atmosphere reduce the direct radiation (Mie scattering). The overall effect of these mechanisms is the reduction of beam radiation reaching the earth and the consequent increase of the diffuse component and is more evident under overcast sky conditions.

Therefore, the probability to observe values of diffuse illuminance higher than 20klx under clear skies is lower than that during overcast conditions. Lower values of diffuse illuminance occur more often under clear skies; such values are observed in Greece during early morning in summer (06:30-07:30).

3. The effect of the urban fabric layout on indoor daylight levels

The achievement of visual comfort is the most critical task involved in the analysis of the indoor conditions, since the perception of the visual environment is subjective, relative and related to age, gender and the time of day or year. However, the adequacy of lighting levels can be easily estimated and is directly related to the use of the indoor space: the more intricate the task, the higher will be the level of illuminance required. Therefore, most of the European countries have incorporated recommendations for minimum illuminance values for different activities taking place indoors in their building regulations. For residences or offices the recommended lighting levels range from 300lx to 500lx, regarding the activity to be performed.

Since the quantity and quality of available daylight varies significantly with the hour of the day, time of year and meteorological conditions, the indoor daylight conditions are very often assessed through daylight factor. But when studying the adequacy of daylight or the energy consumption for lighting, it is very important to enquiry whether the minimum requirements of illuminance are fulfilled, by multiplying the daylight factor with the horizontal illuminance of the ambient environment and comparing the resultant value of indoor illuminance with the recommended values.

Therefore, studies of the availability of daylight in the ambient environment, such as the one presented above, could be the basis for the prediction of daylight autonomy in interior spaces; that practically represents the time period, during which the requirements for lighting are fulfilled by using only natural sources and gives an indication for the energy conservation accomplished with different daylight techniques. Since under real conditions the density of the urban fabric prevents the total exploitation of the available daylight outdoors, it was considered worthwhile to evaluate the impact of surrounding buildings on the determination of illuminance levels and daylight autonomy indoors.

Table 1. The geometrical and the optical characteristics of the obstructions of the parametric analysis.

Model's name	**Obstructed sky view percentage [%]**	**Height of obstruction above the windowsill [m]**	**Reflectivity of the obstruction's façade, ρo [%]**
Ro	-	-	-
R1	20%	2.3m	30%
R2	20%	2.3m	50%
R3	40%	5.0m	30%
R4	40%	5.0m	50%
R5	60%	9.0m	30%
R6	60%	9.0m	50%
R7	80%	16.0m	30%
R8	80%	16.0m	50%
R9	100%	45.0m	30%
R10	100%	45.0m	50%

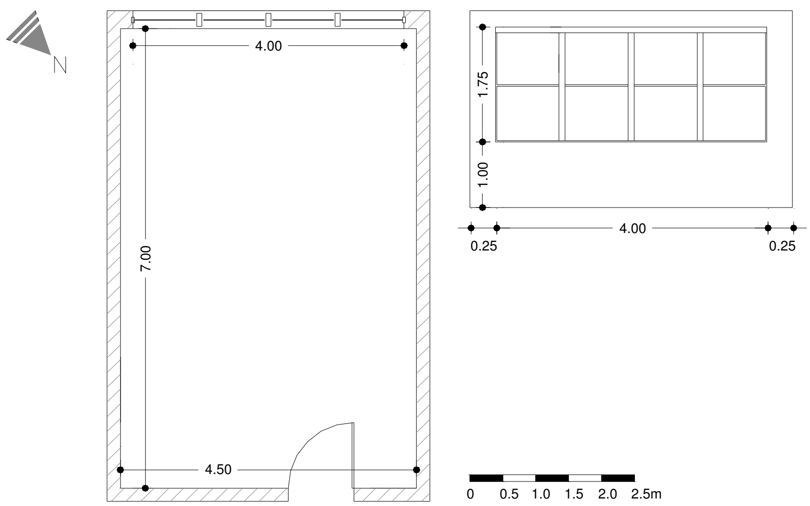

Figure 3. Schematic plan and view from the interior of the room considered as the reference case for the study of the effect of the urban fabric layout on indoor daylight conditions.

The study involved the analysis of the major parameters, which influence the indoor illuminance distribution in case of obstructed sky view, i.e. the view angle and the reflectance of the obstruction.

3.1. Methodology of the parametric study

The analysis of the impact of the urban fabric layout on indoor daylight levels was performed as a parametric study, by comparing the conditions prevailing in a reference case study interior space and models with different site characteristics. A room with design features representative for office buildings was adopted as the reference case for the study (named R0). It is of rectangular plan (5.00x7.00m) and is lit by one window (4.00mx1.75m, windowsill height: 1.00m), which represents a 20% ratio of window to floor area (Figure 3). The window is covered with a conventional glazing (visible transmittance Tv=85%). The reflectance of the surfaces covering the floor, ceiling and walls was considered equal to 18%, 30% and 30% respectively.

On the basis of the reference case study 10 more models were developed, which were identical to the former as regards the geometrical and optical characteristics, while their view to the sky dome was gradually obstructed by the opposite buildings. The distance between the obstruction and the examined models was considered equal to 8.0m, representing the conditions usually met in the dense urban fabric of many Greek cities. The estimation of the obstruction's height for each case was based on the percentage of obstructed sky view in conjunction with the view angle of sky from the windowsill of reference model R0. Moreover, taking into account the geometrical characteristics of the window of the reference model R0, it was found that the sky could not be seen from its windowsill, if the angle between the upper boundary of the opening and the work plane exceeds 80o. On the basis of that value, the heights of the obstructions facing the models of the parametric study were estimated, assuming that for each case the obstruction blocked the sky view at a rate ranging from 20% to 100% and increased gradually by 20% (Table 1).

Apart from the geometrical characteristics of the obstruction, the reflectance of the external obstruction was also investigated (Table 1). For each percentage of obstructed sky view, the reflectivity of the obstruction was set equal to 30% and 50%. These values are usually met on external vertical facades of different colors, ratios of transparent to opaque elements or accumulation of dirt. The daylight conditions prevailing on the work plane of the models were assessed through the use of a simulation tool (PHOTOsynthesis) developed by the author [6]. The accuracy of the results was evaluated both by in situ measurements and simulations with computer programs of acknowledged reliability (i.e. Adeline). The study was focused on overcast sky conditions.

3.2. The effect of the obstruction characteristics in the determination of indoor daylight conditions

Figure 4 illustrates the mean daylight factor estimated for the reference model R0 and the models R1 to R10. Every pair of columns represents the daylight conditions for a particular rate of obstructed sky view, while each column of the pair corresponds to 30% and 50% reflectivity of the obstruction's façade respectively. It is obvious that the daylight levels decrease as the visible part of the sky becomes confined. However, no analogy between the reduction of daylight factor and the blocked sky view is observed. On the contrary, the value of average daylight factor is dramatically reduced when the rate of obstructed sky view exceeds 60% (models R5 to R10).

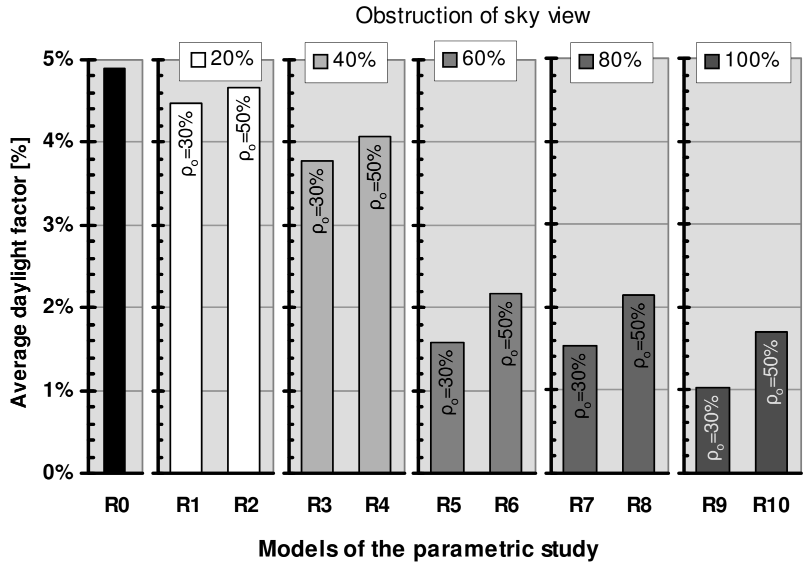

Figure 4. The average daylight factor on the working plane of the reference model R0 and the models R1-R10 of the parametric analysis in relation to the rate of obstructed sky view and the reflectivity of the obstruction's façade.

Furthermore, when the obstruction is of low reflectivity (30%) and blocks the sky view at a rate of 40% (model R3) compared to the reference model, the average daylight factor is reduced at a rate of approximately 20% in relation to the reference model R0. By increasing the impact of the obstruction to 60%, the proportional decrease of average daylight factor of model R5 is equal to 65%. When the sky view is totally blocked (model R9), the average daylight factor is reduced at a rate of 80% and reaches very low levels. The changes in average daylight factor due to the percentage of obstructed sky view follow the same pattern in the case of obstructions with higher reflectivity; however, they range in lower levels varying from 4% to 65% with respect to the obstruction's height.

Additionally, the thorough observation of Figure 4 leads to the conclusion that the difference in average daylight levels between the models that face obstructions with similar geometrical, but different optical characteristics becomes more intense as the view of the visible sky reduces. In more detail, the proportional difference of daylight factor in models R1 and R2 equals 4%. For the next pair of models (R3 and R4), which face obstructions of the same height but various reflectance values, the proportional change in daylight factor is doubled, whereas when the sky view is obstructed by 60% the relative alteration goes up to 37%. The maximum difference (65%) is observed when the obstruction blocks the view of sky from each point of the working plane. This pattern leads to the conclusion that the reflectivity of the obstruction's façade is more critical as the view to the visible sky is eliminated. On such situations, the sky component of the daylight factor is reduced and proportionally the contribution of externally reflected component becomes more important for the determination of daylight conditions indoors. However, under overcast conditions the low levels of exterior daylight and sky luminance are not usually adequate for covering the needs for interior lighting; in fact, this is often the fact for apartments located at the first floors of high buildings with openings facing narrow streets.

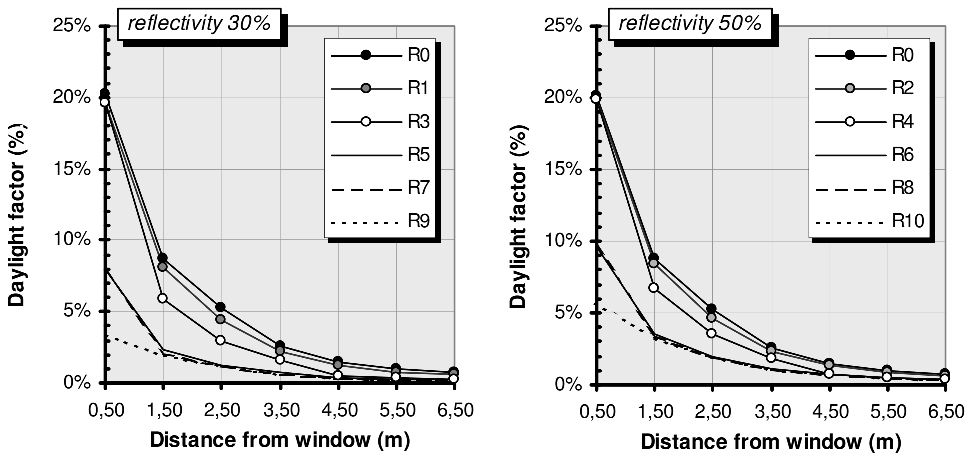

Figure 5. The distribution of daylight factor across the working plane of the reference model R0 and the models R1-R10 of the parametric study.

The disproportion in the reduction of daylight factor can be explained through Figure 5, which shows the distribution of daylight factor across the models R1, R3, R5, R7 and R9 (various angles of sky view obstruction, reflectance of the obstruction's façade ρo=30%). From the figure it can be depicted that points of the working plane of models R0, R1 and R3 located at a distance of 0,5m from the front wall appear to have similar values of daylight factor. In these cases the obstructions block the view of the lower parts of the sky, whose luminance is lower than that near zenith and consequently the daylight factor remains practically unaffected. The difference of daylight factor gets significant up to 2,50m from the window wall; for points located further on the depth of the room the change becomes more moderate and diminishes at points near the back wall.

The daylight factor on the points adjacent to window wall of models R5 and R7 is much lower than that observed in the reference model R0, since the sky view is obstructed at a considerable extent. For these models, the distribution of daylight factor ranges on similar levels, although the obstruction of sky view has different rates, indicating that the daylight received in the interior is mainly determined by the externally and internally reflected daylight, while the contribution of the sky component is low.

On the case of higher reflectivity of external obstruction (Figure 6), the daylight factor follows the same pattern of distribution across the models, only at higher rates. The downward displacement of the curves of models R6, R8 and R10 is more obvious due to the direct and essential interrelationship between the indoor daylight conditions and the amount of daylight that is reflected on the surface of the opposed buildings.

4. Conclusions-proposals

The quantitative approach of the above analysis showed that the availability of daylight in building interiors is significantly affected not only by the daylight climate of the region, but also by the geometrical characteristics of the site surrounding the building. The deep canyons that are usually met in the centres of modern cities often result in poorly lit indoor environments.

Towards the enhancement of daylight conditions in spaces of the urban fabric layout a lot can be done for new buildings, through their proper displacement with respect to the surroundings and the careful design of their façades, but not much can be implemented for existing constructions. In the latter case, refurbishment activities, which have actually increased in the industrialized countries in the last few decades, should address the exploitation of daylight in order to meet today's requirements. For example, daylight-redirecting systems, such as glass prisms, holographic elements and laser-cut panels, can improve the distribution of light to interior spaces. For heavily obstructed façades, the implementation of daylight systems that collect diffuse light from the upper sky vault, such as anidolic ceilings, can also be very useful.

Many of the solutions for capturing daylight may seem expensive and not cost effective. But we should all bear in mind that inadequate daylight would lead in increasing the energy consumption for lighting, which accounts for 20-30% in office buildings [7]. Moreover, the increased use of artificial lighting influences the energy balance of the buildings, since it causes higher internal heat gains, which can cause overheating during the warm summer period in Greece. In that case, the total energy consumed for cooling requirements is also increased. It is worth mentioning that in Greece the lighting and cooling requirements are usually met through the use of electricity, which is mainly produced by non-renewable sources (only 11% is generated from hydropower and wind energy [8]). Therefore, the increased use of artificial lighting is not only related with the economic performance of the building, but also with vital environmental aspects, such as the decrease of available primary energy resources and increase of power plant emissions that contribute to acid rain, air pollution and global warming.

Although the potential for reducing energy costs and environmental emissions is substantial, the most powerful impact of daylight is on the building's occupants, since it is strongly associated with human health, psychology, mood and productivity.

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