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Daylighting Contribution for Energy Saving in a Historical Building

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Abstract

The purpose of this study is assessing the reliability of the software DIALux 4.12 for daylighting design, comparing experimental data with simulation results; the comparison was performed for an office.
The daylight illuminance distribution inside the room, the external zenith luminance and the external horizontal diffuse illuminance were measured during the weeks from January 19th to February 20th; the data gathered were further reduced to match conditions related to the CIE sky type #12 (CIE Standard Clear Sky, low luminance turbidity) and finally the comparison was carried in terms of daylight illuminance distribution and relative percentage error.

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Keywords: Daylighting performance; existing building; field measurements; energy saving potential; daylighting simulation.

1. Introduction

Many studies underlined that daylight can be considered as the best strategy in order to reduce the energy consumption connected with lighting of a building and to enhance the visual comfort of building occupants [1-6]. The knowledge of the real daylighting availability inside a building represents the starting point for both a proper daylighting design and an accurate evaluation of the energy saving potential of a retrofit action. Once the daylight illuminance distribution inside rooms is evaluated, it is possible to quantify the light from natural source and select the best strategy to achieve the largest energy saving and environmental comfort.

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The sky luminance distribution represents the capital information for the simulation software in order to perform an accurate evaluation of the daylight availability inside a room; usually, the measurements of the sky luminance distribution are available only for few localities. The easiest manner to ride out the lack of experimental luminance data for a place is to calculate the sky luminance distribution through a simulation model.

In order to give a reference model for predicting the sky luminance distribution, the ISO 15469:2004(E)/CIE S 011/E:2003 [7] define 15 standard sky types. Those models allow describing the possible luminance distributions of the sky that can occur and can be used for daylighting design purpose.

In this paper the daylighting conditions of an office of the Abbey of San Lorenzo ad Septimum, that is located in Aversa (southern Italy, latitude 40°59' - longitude 14°11') and hosts the Department of Architecture and Industrial Design "Luigi Vanvitelli" of the Second University of Naples, were experimentally evaluated. In order to characterize the room from the photometrical point of view, the reflectance values of the internal surfaces and the transmittance values of the window have been experimentally evaluated. Inside the room, nine luxmeters for the acquisition of the daylighting illuminance distribution were placed at 0.85 m from the floor level.

Following the method proposed by Bartzokasa A et al. [8] for the classification of the sky with a solar altitude lower than 35°, the measurements of the zenith luminance and the horizontal diffuse illuminance were performed together with the internal illuminance acquisitions.

With the aim to evaluate the accuracy of the software DIALux 4.12 [9] for daylighting design for the location considered, in the present work the results of the comparison between the daylight illuminance values obtained from the simulation software and the experimental data recorded during selected days of winter season were presented.

The software DIALux was chosen because it is one of the most diffuse and used simulation programs for lighting and daylighting design, it is free downloadable and presents a very user friendly interface; the daylight simulation available within the software is based on the assumption of three sky models and only for the so-called "Clear Sky", that corresponds to CIE Standard Sky Type #12, and its occurrence during the measurement period, were estimated the difference between the experimental data and the simulation results.

2. Experimental and simulation set-up

This work analyzes the daylight availability in a room that hosts an office at the first floor of the Abbey of San Lorenzo ad Septimum. The room has a floor area of about 26.0 m^2, a height of about 5.45 m and an orientation of 15° South-South West. The window, with a total surface of about 3.70 m^2 and a ratio glass area/total window area equal to 0.38, is placed on the external side of the perimeter wall that has a thickness of 1.00 m; the distance between the middle point of the window and the ground is about 8.00 m.

The reflectance values of all surfaces in the room were measured with the spectrophotometer Minolta CM – 2600d (size of integrating sphere: ø52 mm, wavelength range: from 360 nm to 740 nm and spectral reflectance: standard deviation within 0.1%). The reflectance measurements were recorded using the standard illuminant D65 and considering the Specular Component Included (SCI). The average values of the reflectance values recorded on three different points of every surface were used as the values of the reflectance for modelling the room via the simulation software.

The optical transmittance of the window was estimated using a spectroradiometer Konica Minolta CS-1000 according to the Standard ISO 9050 [10].

The daylight measurements were performed during winter and they included the illuminance distribution inside the room, the diffuse outdoor illuminance on a horizontal plane and the zenith luminance.

The internal daylight illuminance values were measured using nine illuminancemeters (T-10 manufactured by Konica Minolta) with cosine correction, measuring range from 0.01 lx to 300 klx and accuracy of ±2%. The sensors were placed at 0.85 m from the floor level on support structures through which the horizontal position and the height of the sensors were adjusted. The measurement points were identified dividing the floor area of the room into nine equal small areas; the sensors were placed at the centre of each small area. The Fig. 1a shows the layout and the size of the room considered with the identification of the points where the illuminance sensors were placed. In the Fig. 1b, the layout and the dimensions of the window were also reported. The dimensions reported in the Fig. 1a and 1b are expressed in meters.

The external measurements were performed on a position free from external obstructions. The outdoor diffuse horizontal illuminance was measured by a luxmeter (Chroma Meter CL-200 manufactured by Konica Minolta) with cosine correction, measuring range from 0.1 lx to 100 klx and accuracy of ±2%. An occulting-disc was used as shading system instead of a shadow ring in order to minimise the error in the acquisition of the horizontal diffuse illuminances; the disk has a diameter of 55 mm and was placed 0.30 m from the sensor to cover a sky solid angle of 0.026 sr centred on the sun. The disk was black painted in order to reduce any reflection towards the sensor and, as first approximation, it has not been considered any correction factor on diffuse sky measurements due to the anisotropic distribution of sky radiance [11-12].

The zenith luminance was measured by a traditional luminancemeter (LS110 manufactured by Konica Minolta) with an acceptance angle of 1/3° and accuracy of ±2%; both the instruments were placed on a support structure for their correct positioning.

The ratio between the zenith luminance (L_z) and the horizontal diffuse illuminance (D_v) values was used to identify the sky type. Indeed, for solar altitudes lower than 35°, for each solar altitude γ_s, the ratio L_z/D_v allows to identify the sky typology among the 15 standard skies defined by CIE [7].

The solar altitude was evaluated using the software Weather Tool of Ecotect [13]. Each measurement of the sky condition was classified as one of the 15 sky types only when the experimental value of the ratio L_z/D_v completely agrees upon theoretical CIE sky type curve.

The software DIALux is a fully free simulation software based on radiosity method developed by DIAL GmbH [14] and, starting from the version 4.0, the software was implemented also for daylighting evaluations.

Three types of sky [7] are used in the software to reproduce the luminance distribution of the sky in order to perform daylighting calculations:

- The model applied as "Clear Sky" corresponds to the CIE Standard Sky Type #12;
- The model applied as "Intermediate Sky" doesn't correspond to any CIE Standard Sky Type;
- The model applied as "Overcast Sky" corresponds to the CIE Standard Sky Type #16.

The simulation program allows taking into account the direct sunlight only for the clear sky.

Using the measured geometrical and photometrical characteristics, a virtual model of the room was realized through the simulation software.

As mentioned before, the window is placed on the external side of the perimeter wall and then wall's thickness between the external surfaces of the window and the perimeter wall were not considered, while the internal wall's thickness was modelled as the other internal surfaces of the room.

Because of the complexity of the external obstruction, in the software model they were modelled assigning to the surface an average value of the reflectance. For the same reason, the ground was modelled as a surface with a reflectance value of 30%. The figure 1b shows the external obstructions viewed from the window of the office considered.

3. Results and discussion

The simultaneous acquisition of the external daylight quantities (zenith luminance and horizontal diffuse illuminance) and the distribution of the daylight inside the room allowed correlating the daylight availability in the room with the luminance distribution of the sky. By means of the method proposed by Bartzokasa et al. [8], each external acquisition was categorized into one of the 15 standard skies defined by CIE [7]; the data gathered have been further reduced to match conditions related to the CIE sky type #12 (CIE Standard Clear Sky, low luminance turbidity) that occurs 13 times during acquisition period.

Fig. 2 shows the simulated and the experimental values of the daylight illuminance inside the test room in each measuring points (Fig. 1a) for the acquisition performed on February 9th at 11:03. The figure highlights that the greatest difference between predicted and measured daylight illuminance values can be observed for the measurement point placed close to the window (Point #6). For this point, a difference between the experimental and the simulated illuminance values of about 770 lx was observed.

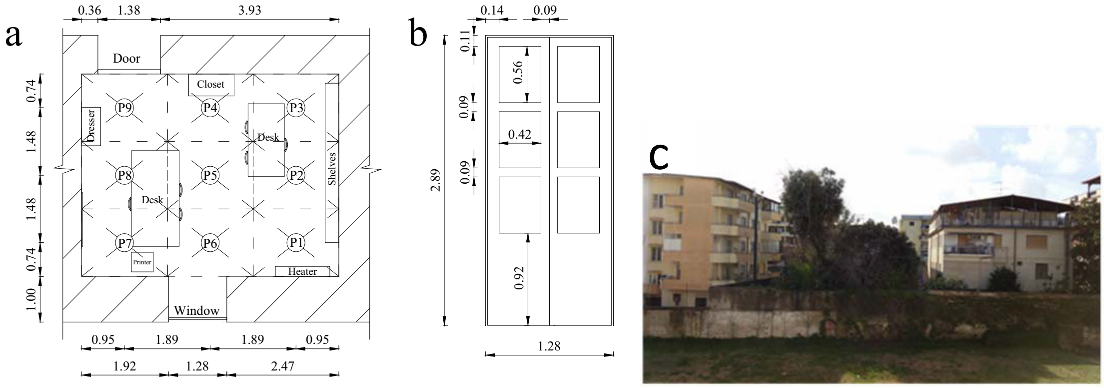

Fig. 1. (a) Reference room and identification of the points for illuminance measurements (measurements expressed in meters); (b) layout and dimensions of the existing window (measurements expressed in meters); (c) external obstructions.

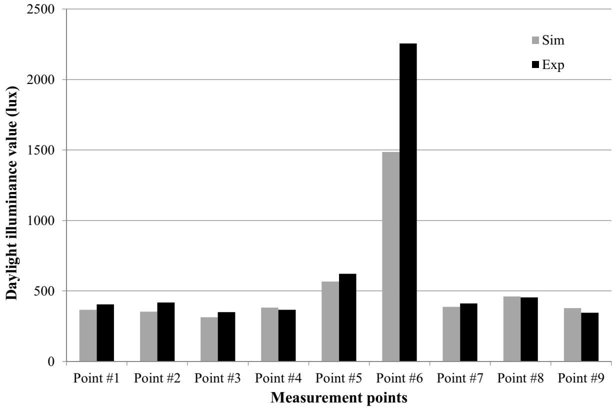

Fig. 2. Comparison of simulated and experimental illuminance values for all measurement points inside the test room acquired on February 9th at 11:03.

Assuming the values of the experimental daylight illuminance E_{exp} as reference values, the relative percentage error E% between E_{exp} and the simulated daylight illuminance E_{sim}, for each measurement point, is defined as follows:

$$E\% = \frac{E_{sim} - E_{exp}}{E_{exp}} \times 100 \quad (1)$$

In the table 1, the calculated values of the solar altitude and azimuth were reported.

Fig. 3 shows the results of the comparison in terms of relative percentage error between experimental and simulated daylight illuminance values acquired under the sky type selected.

According to the data highlighted in Fig. 3, it can be noticed that the minimum difference between experimental and simulated values is observed in the Point #8 with a percentage error of about 1.6%, while the maximum difference is observed in the Point #9 with a percentage error of about -61.6%.

The greatest range variation in terms of percentage error is noticed in the Point #7, for which the percentage error extends from 24.1% to -59.6%; the smallest variation is observed in the Point #6, for which the percentage error ranges from -34.1% to -60.0%.

Table 1. Solar altitude and azimuth at acquisition time.

Acquisition time (dd/mm/yy hh:mm)	29/1/15 11:34	29/1/15 11:44	9/2/15 11:03	9/2/15 16:03	9/2/15 16:13	18/2/15 14:52	18/2/15 14:57	18/2/15 15:02	18/2/15 15:07	18/2/15 15:17	18/2/15 15:42	18/2/15 15:47	18/2/15 15:52
Solar altitude (°)	29.9	30.2	31.4	13.2	11.6	25.9	25.2	24.6	23.9	22.5	18.8	18.1	17.3
Solar azimuth (°)	168.6	171.3	159.3	-124.0	-122.1	-137.0	-135.9	-134.8	-133.6	-131.4	-126.2	-125.2	-124.2

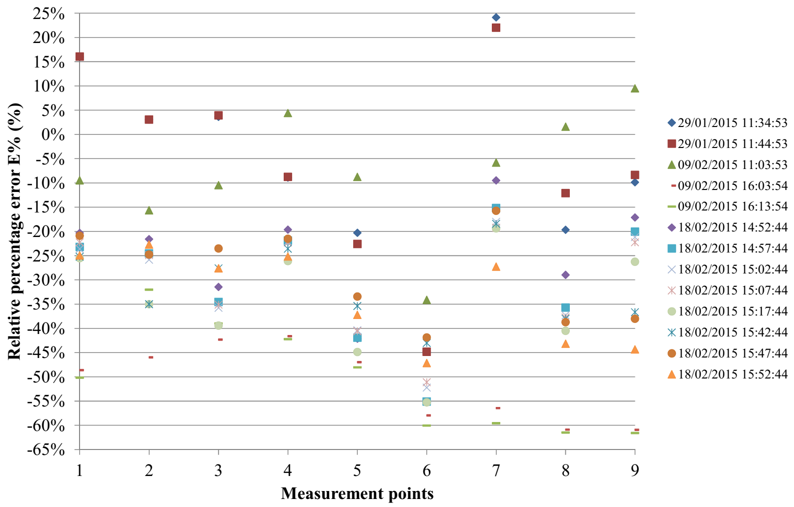

Fig. 3. Relative percentage error calculated for each measurement point.

Fig. 4 reports, for each acquisition time, the relative percentage error between the experimental and the simulated average illuminance values. The results showed in Fig. 4 were calculated with the Eq. (1) considering the average value on the nine measurement points.

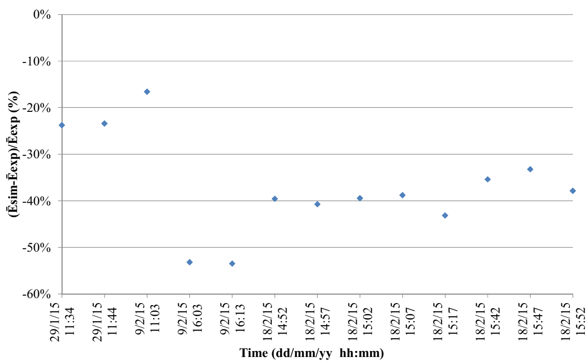

Fig. 4. Relative percentage error calculated for each acquisition time.

Fig. 4 shows that the simulation software always underestimates the daylight illuminance level inside the room and that the difference between simulated and experimental data varies strongly with the day and the hour of the acquisition.

Viewing the results presented in the Fig. 4, they can be gathered into three groups:

- measurements made on January 29th and on February 9th at 11:03 for which the percentage error ranges from -16.6% to -23.7%;
- measurements made on February 9th at 16:03 and at 16:13 that show a similar value of the percentage error range, -53.2% and -53.4% respectively;
- measurements made on February 18th for which the percentage error ranges from -33.2% to -43.2%.

4. Conclusions

In this paper, daylight quantities were measured during limited winter period in order to evaluate the reliability of the simulation software DIALux for daylighting design.

The comparison was carried out for an office of the Abbey of San Lorenzo ad Septimum that houses the Department of Architecture and Industrial Design “Luigi Vanvitelli” of the Second University of Naples.

The experimental data (E_{exp}) were compared with simulation results (E_{sim}) in terms of point illuminances, room average illuminance as well as their relative percentage error E% for different days and different hours. In order to take into account the sky types made available by the simulation software, only the daylight illuminance distributions acquired under the sky type #12 were considered.

Considering the internal daylight illuminance distribution, the greatest difference between simulated and experimental data was found for the sensor closest placed to the window (Point #6). For this point, the data detected on February 9th at 11:03 show a difference of about 770 lx.

Analyzing the results obtained for each measurement point, it can be noticed that the Point #8 and #9 show respectively the minimum (1.6%) and the maximum (-61.6%) values of the error, while the Point #7 and #6 show respectively the greatest and the smallest range variation in terms of percentage error.

Finally, for each acquisition time, the experimental and the simulated data were compared in terms of average illuminance values showing that the simulation results always underestimate the daylight illuminance values and that the differences between predicted and measured values are strongly connected with the day and the hour considered.

References

[1] Bellia L, Pedace A, Barbato G. Winter and summer analysis of daylight characteristics in offices. Building and Environment 2014;81:150-161.

[2] Chena Y, Liua J, Peia J, Caoa X, Chena Q, Jiang Y. Experimental and simulation study on the performance of daylightingin an industrial building and its energy saving potential. Energy and Buildings 2014;73:184-191.

[3] Xue P, Mak CM, Cheung HD. The effects of daylighting and human behavior on luminous comfort in residential buildings: A questionnaire survey. Building and Environment 2014;81:51-59.

[4] Sibilio S, Rosato A, Scorpio M. Daylighting design in a low energy building. In: Lux Europa 2013. Krakow; September 17-19. 2013. p. 251-256.

[5] Rosato A, Scorpio M, Sibilio S. Use of a scale model under artificial sky for daylighting design. In: Napoli: La scuola di Pitagora editrice. Heritage Architecture Landesign focus on Conservation Regeneration Innovation Le vie dei Mercanti XI Forum Internazionale di Studi. Aversa. Capri, June 13-15. 2013. p. 1245-1252.

[6] Sibilio S, Falconetti P, Rosato A, Scorpio M. Effectiveness of light pipes in italy. In: ELPIT 2013, IV International Environmental Congress "Ecology and Life Protection of Industrial-Transport complexes". Togliatti-Samara, Russia, September 18-22. 2013. p. 170-176.

[7] ISO 15469:2004(E)/CIE S 011/E:2003 Spatial Distribution of Daylight - CIE Standard General Sky. Geneva: ISO, Vienna: CIE. [8] DIALux 4.12 DIAL GmbH, Germany.

[9] Bartzokasa A, Kambezidisb HD, Darulac S, Kittlerc R. Comparison between winter and summer sky-luminance distribution in Central Europe and in the Eastern Mediterranean. Journal of Atmospheric and Solar-Terrestrial Physics 2005;67:709-718.

[10] ISO 9050. Glass in building -- Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors.

[11] Kudish AI, Evseev EG. The assessment of four different correction models applied to the diffuse radiation measured with a shadow ring using global and normal beam radiation measurements for Beer Sheva, Israel. Solar Energy 2008;82:144-156.

[12] Kotti MC, Argiriou AA, Kazantzidis A. Estimation of direct normal irradiance from measured global and corrected diffuse horizontal irradiance. Energy 2014;70:382-392.

[13] http://usa.autodesk.com/ecotect-analysis/.

[14] http://www.dial.de/DIAL/it/dialux/about/browse/2.html.