



Alexandria University
Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com



ORIGINAL ARTICLE

Optimization of daylight utilization in energy saving application on the library in faculty of architecture, design and built environment, Beirut Arab University



Osama Omar^{a,*}, Berta García-Fernández^b, Antonio Álvarez Fernández-Balbuena^b, Daniel Vázquez-Moliní^b

^a Faculty of Architecture, Design and Built Environment, Beirut Arab University, Beirut 11072809, Lebanon

^b Department of Optics, University Complutense of Madrid, Faculty of Optics, Madrid, Spain

Received 16 July 2018; revised 14 August 2018; accepted 30 October 2018

Available online 22 November 2018

KEYWORDS

Daylight;
Energy saving;
Daylight factor;
University building;
Library

Abstract Considering that reading and research are the main functions of use in libraries of all educational facilities, proper lighting becomes a crucial factor in the overall success of a library design. In this framework, daylight is essential for both energy saving and improvement of the quality of life in newer buildings where visual tasks are more diverse, and technology poses new types of lighting requirements. Furthermore, emphasis on the importance and methods used to utilize energy will be implemented; provided by nature as the first step in achieving optimum energy saving and reducing our dependence on fossil fuels. Thus, this study will examine the conditions of indoor daylight and the library's energy performance in the faculty of Architecture, Design and Built Environment, Beirut Arab University with various architectural elements including space depth, window size, external obstruction angle, and glazing visible transmittance. This is done by first analysing the existing situations of daylighting (using Autocad Ecotect software), the situation of the artificial lighting inside the space (using Dial DIALux software), and the behavior of the users throughout the day (using Hobo loggers). Then, the outcomes will be analyzed to specify the challenges, therefore providing solutions related to environmental, technological, and energy saving as well as sustainable and green building designs. As a result, daylight designs based on hollow prismatic light guides are proposed. These designs act as luminaires increasing guide efficiency and uniformity distribution of natural light into the library spaces. The proposed designs are configured and analyzed by ray-tracing simulations for achieving high illumination levels and uniform lighting in the working plane of the library.

© 2018 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

* Corresponding author.

E-mail address: o.omar@bau.edu.lb (O. Omar).

Peer review under responsibility of Faculty of Engineering, Alexandria University.

<https://doi.org/10.1016/j.aej.2018.10.006>

1110-0168 © 2018 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V.

This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Avital factor in significantly reducing energy consumption for electric lighting depends on a wider benefit of daylight accompanied with the use of energy efficient lighting technologies such as LEDs and lighting controls. Also, it is important to state that daylight harvesting in indoor spaces has a specific effect on the global energy performance of a building in terms of heating and cooling loads. In fact, the solar radiation that enter through the openings function alongside the load emitted by electric lighting systems effect the internal gains from lighting. Evidently, the challenge is to find the optimum trade-off between cooling, heating, and lighting energies, which can only be attained through an integrated approach that combines daylight and thermal analyses [1]. Within the classification of daylight lighting systems, light pipes can transfer natural light from a buildings roof inside the building [2], allowing a significant reduction in the overall wattage of installed lights which is accompanied by a decrease in the consumption of electricity due to lessening the dependency on artificial lighting [3]. Furthermore, tubular light guides can supplement any artificial lighting in the areas that are not covered by neither windows nor skylights. Also, prismatic light guides are another alternative, though technical, as light transporters in the tubular guidance systems [4,5]. As well, Hollow Prismatic Light Guides (CPLGs) are transparent optical systems internally covered with a prismatic sheet able to transfer high amounts of daylight in buildings with minimal losses.

Daylight design begins with an understanding of basic physical characteristics of daylight. Controlling it and tailoring it for use in a library requires some knowledge of this energy media that is entering the building.

- The first requirement for library lighting is to provide enough light to accomplish a visual task such as reading. For daylight, this means tuning the aperture designs to minimize solar heat gain while achieving the illuminance levels required for visual acuity [6].
- The second requirement is that the contrast brightness of other objects within the field of view must not be excessive, such that the library user can view the task comfortably and not become visually fatigued over time [6].

The amount of daylight and its direction at the window or roof of a building are dynamic systems, which continuously change during a typical day as the sun moves, and seasonally as the sun's predominant position in the sky changes. There is additional variation depending on sky conditions. Daylight direction on cloudy days is still variable, though the light is more diffuse than on a clear day. On overcast days, the daylight is uniform, though varying in absolute brightness somewhat from sunrise to sunset [6].

There are some particularities of the effect of daylight inside the spaces in relation to the perception and needs of the human being [7]. The most important of these characteristics are:

- Biological Needs: From the beginning of humankind until this day, no human kind can deny the blessing of the sun. It is a wonder how a simple daylight plays such a huge role on the lives of all beings. This role never just stops at giving

light for every single corner of the world, but it has been associated with different effects, whether psychological or physical, on humans and animals as well. When it comes to thinking about the human body, the question that lingers in the air is “How does it affect the human body?” This is where “Ultraviolet Radiations” step in [8]. Circadian cycle is strongly influenced by daylight exposure of human been [9].

- Uniformity of Stimulus: The impact or impulse of a specific matter or situation, also known as the “stimulus”, is something that unintentionally triggers a reaction from the human body. The variety of the stimulus often draws the continuous attention of the person. Both the degree/way of lighting/daylight are the reasons the interest/attention in this stimulus is lost or preserved in one's mind.
- Excessive Brightness and Windows: Any excessive light and brightness will harm more rather than benefit. Abnormal daylight that comes through the windows leads to inconvenient disturbance in the vision; unless this amount is deflated to a suitable percentage compared to the indoor lighting's degree [10].
- Color Constancy: Lights affect the way the colours of the objects or places are seen. How the light is used or the different light colors throughout the day, along with the strength of illumination, are what make the appearance different in each condition.
- Effects of daylight on the human body: Exposure to UV radiations in reasonable amounts has been proved to be beneficial for the function of the body (health, skin, Vitamin D, germ destruction) [11,12].

1.1. Library conditions and situation

Beirut has a Mediterranean climate presented by a summer that is high in temperature and quite dry, a pleasurable fall and spring, and finally, a winter that is cold and rainy. August is known to be the hottest month in Beirut. It has an average temperature of 28 °C (82 °F) and February is known to be its coldest month having at temperature drop to 13 °C (55 °F) with the daily sunshine hours at 14 in July. On the other hand, January is the month when most rainfall occurs at an average of 130 mm of rain (Fig. 1) [13,14]. The case study will be the Library of Faculty of Architectural Engineering in Beirut Arab University, Debbiah, Campus and Beirut, Lebanon (Fig. 2).

The main problem at hand can be summarized in two main points. Insufficient amounts of natural daylight within the space itself, and relying on artificial lighting systems during the day, hence consuming higher amounts of energy (Fig. 3). Therefore, the main objective of this study is to specify an appropriate method to reduce the dependency on artificial lighting during daylight hours as an attempt to consequently reduce the amount of energy consumption and enhance the daylight factors of behavior within the library, the user comfort, and general sustainability.

A main factor in significantly reducing the dependency on electric lighting depends on the scenario of a more efficient utilization of available daylight while increasing its amounts and spread within a space, accompanied with using energy efficient lighting technologies, such as LEDs and lighting controls. In addition, the global energy performance of a building can be

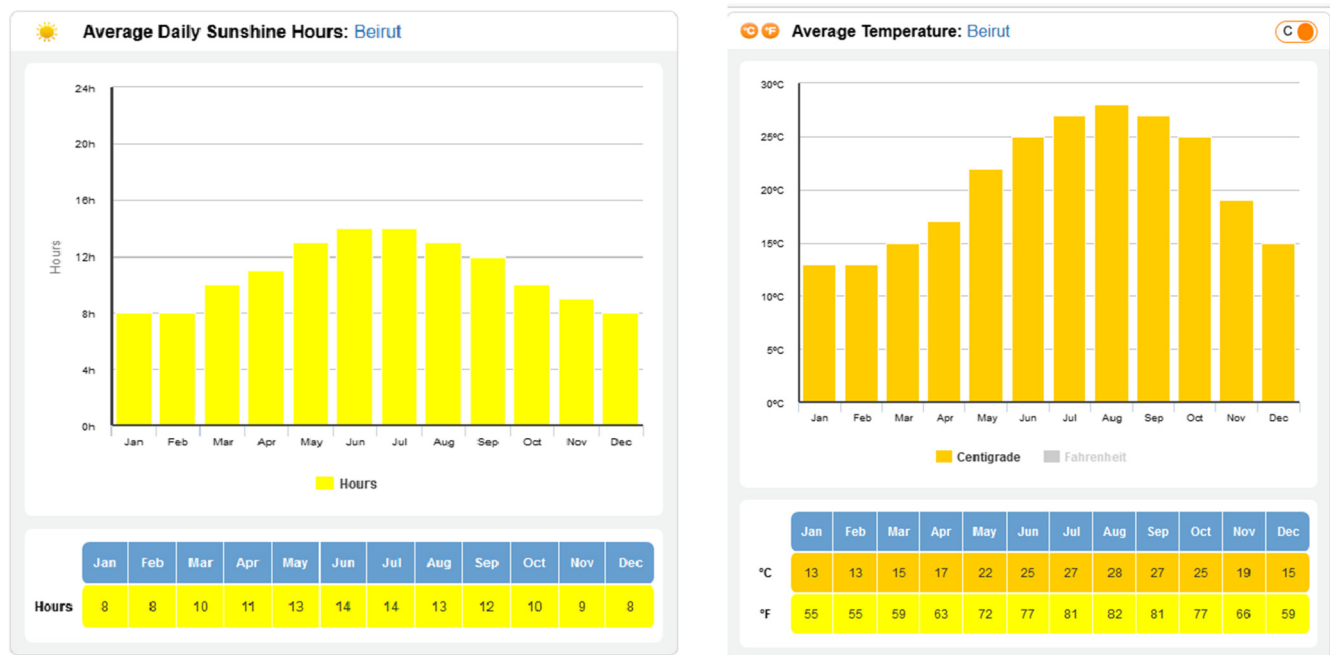


Fig. 1 Average Daily Sunshine Hours (Left), Average Temperature (Right) [13].

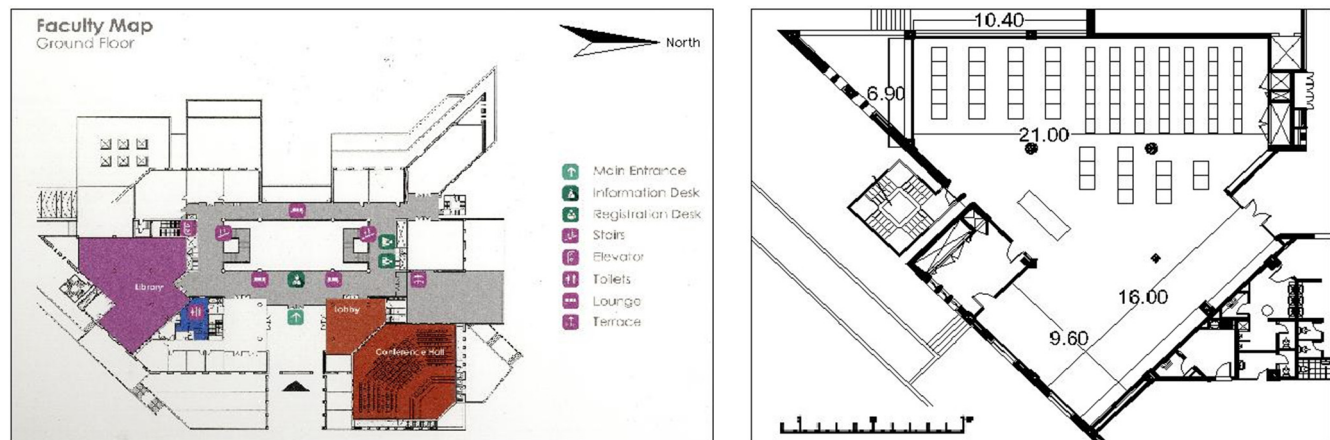


Fig. 2 Faculty Map Ground Floor Level with highlighted for library location (Left), Library Plan with Dimension (Right).



Fig. 3 Indoor images for Library (Artificial Light was Off) (Left), (Artificial light was on) (Right).

subjective to heating and cooling loads by harvesting daylight in indoor spaces. In reality, the solar radiation that enters through the openings alongside the load emitted by electric lighting systems can significantly affect the internal gains from lighting. However, the challenge is to acquire the most appropriate methods that facilitate the trade-off between cooling, heating, and lighting energies, which can only be accomplished through an inclusive approach that demands a cohesive daylight and thermal analyses [1].

Therefore, the main objective of this study is to specify appropriate methods on how to reduce the dependency on artificial lighting during daylight hours as an attempt to consequently reduce the amount of energy consumption and enhance the daylight factors.

The contribution of natural light allows beneficial effects on the health and well-being. Thus, it is important the development of lighting designs which provide high luminous flux and uniform distributions avoiding glare and providing high color reproduction.

This paper is distributed as follows, in Section 1 a study will examine the conditions of indoor daylight, in Section 2 the existing situation for both daylight factors using Ecotect [15] software and artificial lighting by means of DIALux [16] is analyzed, In Section 3, we present as an alternative two lighting designs which act as a luminaire to distribute uniformly natural light in the interior spaces of the library, those models compound of CPLGs can increase light efficiency into the library spaces with high uniform light distribution. Finally in Section 5 conclusions will be given.

2. Light distribution analysis

In this section, the current situations of the library is studied and analyzed in three dimensions. The first section includes

studying and documenting the current situation of daylight, performance and efficiency. The second subsection looks into the performance of the artificial lighting within the space, the real difficulties and problems of lighting in the space can be specified.

2.1. Daylighting simulation using Ecotect software

The goal and purpose from using this software is to provide necessary data regarding the architectural elements that effect the daylight of the space in the current situation. This includes components such as windows, their attributes such as location and size, as well as their impact on the amounts of daylight penetration and lasting duration within the space. The below data is collected according to a specific sunlight azimuth and latitude, and regards different changes throughout seasons of summer and winter. The daylight simulation was done using Ecotect software on the first day of both seasons. (June 2016 and November 2016 correspondingly). On each simulation, the information was gathered at three distinct times per day (09:00 am, 12:00 am, and 3:00 pm respectively). From Figs. 4 and 5, we can find that the highest amounts of daylight can be found at the periphery of the space in the area near the windows while it becomes null as we go deeper into the space and away from the windows. Thus, it is necessary to find methods to increase the depths of space with contribution of daylight.

2.2. Artificial lighting simulations using DIALux software

The goal behind studying and tracking the artificial light within the library is to specify the effect of a definite number of luminaire units in the illuminance within the space. DIALux 4 Lighting Wizard software has been used to design and evaluate artificial lighting scheme space through the use of three

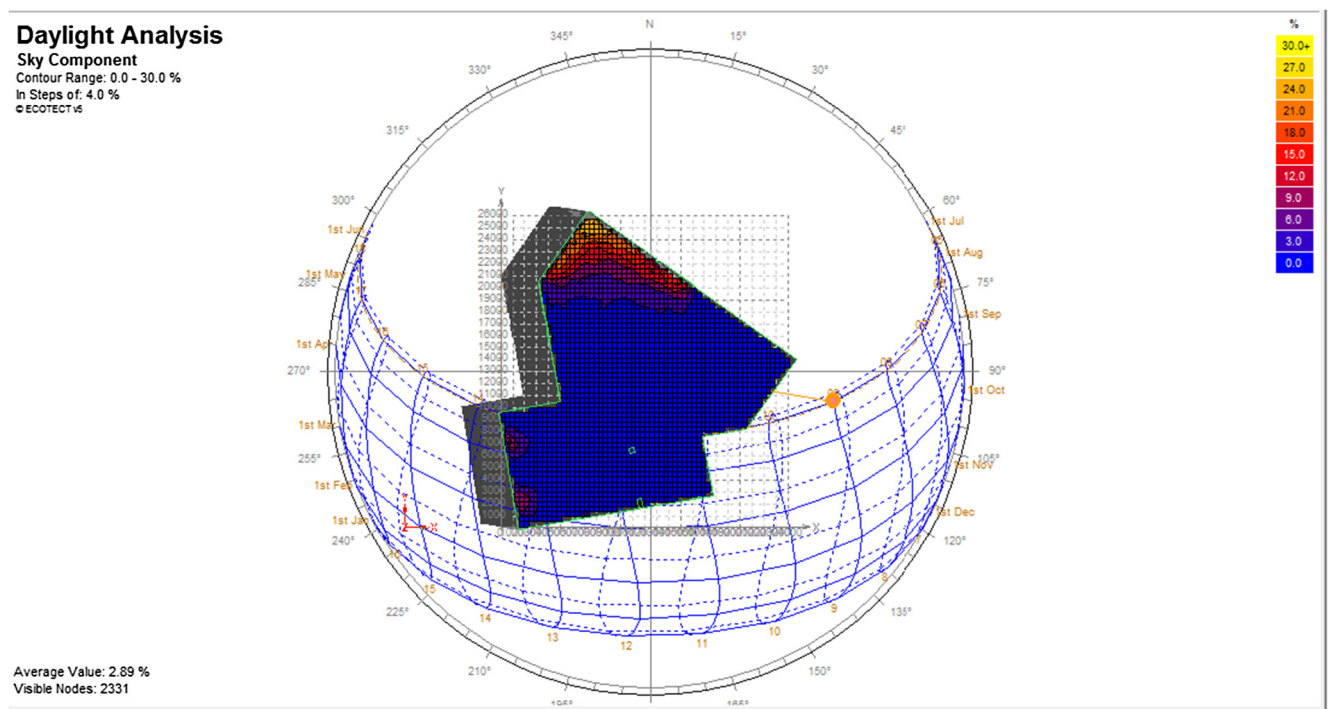


Fig. 4 Daylighting simulation (June, 09:00 am).

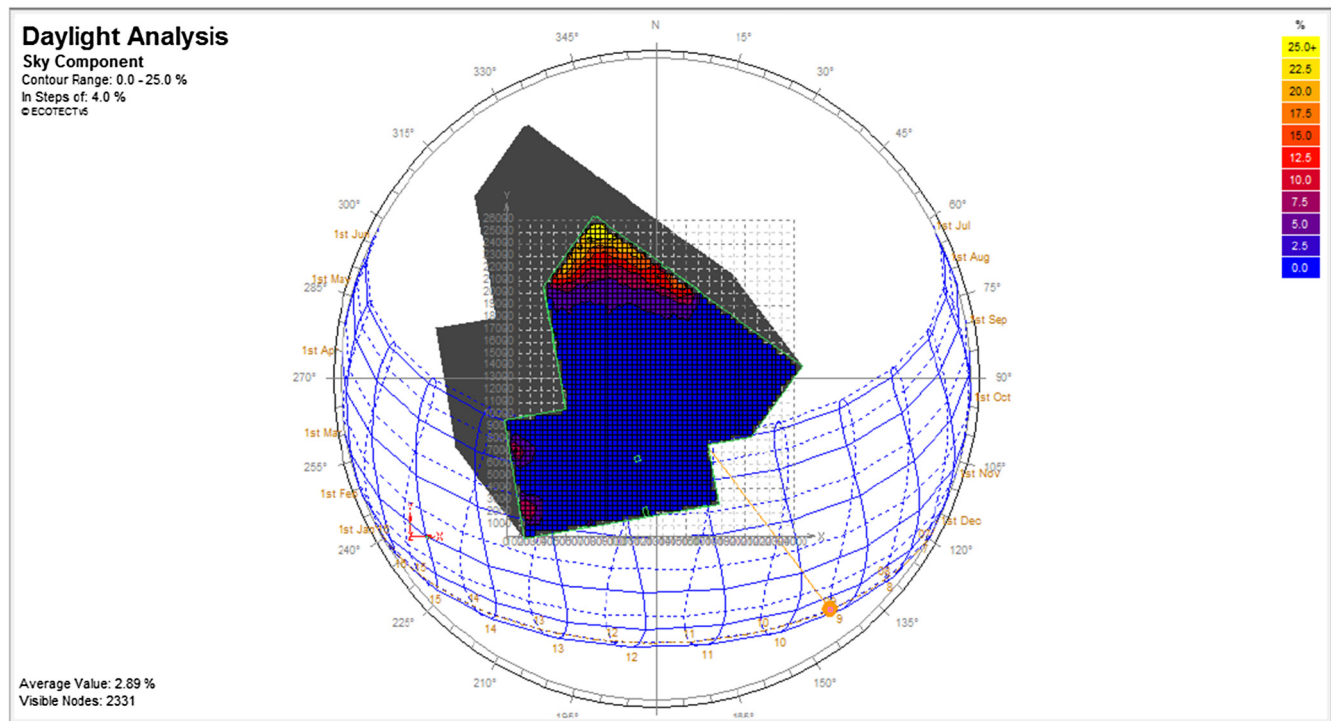


Fig. 5 Daylighting simulation (November, 09:00 am).

Table 1 Characterization of the luminaires.

No	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	43	3FFILPPI 13,603 3F Travetta 2 × 28 T5 LD HF 2S(1.000)	3035	5200	60.0
2	13	3FFILPPI 2861 L 323 × 14 T5 LD HF 2 M (1.000)	2686	3600	48.0
3	17	3FFILPPI 3087 3F Dodeca 220 AC 2 × 18 CD HF 2MG (1.000)	1604	2400	37.0
			Total: 192,671	Total: 311,200	3833.0

types of luminaires (Table 1) with illumination abilities for the same library.

Fig. 6 shows the illuminance level at calculation points on the work plane (Height: 0.760 m, Grid: 128 × 128 Points, Boundary Zone: 0.000 m). Some of the values obtained are not enough values obtained as minimum average illuminance should be 500 lux with a high uniformity and low glare (16). This means that the amount of daylight penetrations needs to be increased. We can find that the amount of light in some points is not sufficient for the user using this area optimally.

Table 2 shows the summary of the results of DIALux simulation: reflectance, illuminance and uniformity. The simulation shows work plane illuminance mean values E_{av} of 449 lux. The uniformity U_0 defined as the ratio between the mean illuminance (E_{av}) and the lowest (E_{min}) level on the working plane is 0.221 (1:5), and E_{min}/E_{max} : 0.114 (1:9). The illuminance quotient according to LG7 is Walls/Working Plane is 0.370 and Ceiling/Working Plane 0.192.

Specific connected load: $11.10 \text{ W/m}^2 = 2.47 \text{ W/m}^2/100 \text{ lx}$ (Ground area: 345.39 m^2).

3. Daylight illumination system by hollow prismatic light guides

In this section, prismatic light guide models are applied theoretically in order to enhance the amount of daylight inside

the library. In buildings with minimal colour shifts, the prismatic light guide leads light beams by Total Internal Reflection (TIR) and provides light transmission with high efficiency and homogeneous light distribution [17,18]. The prismatic film, which makes up the guide, has one even surface and one textured surface made using extruded prisms. In Cylindrical Prismatic Light Guides (CPLGs), light rays are spread by TIR when the input light is incident under the angle accepted for flux transmission according to the prismatic geometry [19,20].

It is also necessary to note that any Light that falls less of the requirements is partly removed from the guide. In spite of the fact that the manufacturing process in actual technologies allows the development of optimal prismatic film to be applicable, prism defects unfortunately dismissguide efficiency. Those defects have to be taken into account in lighting calculations and consider corners which are not firmly 90 degrees, surfaces which are not optically plane and optical inhomogeneity in the film material [21–23].

In this paper is presented an innovative approach made of cylindrical prismatic hollow light guide which enables high transmission of light by upper roof openings in building's interior.

The CPLG guide allows to optimize the light output angle, in such way that it is possible to conduct light along indoor building distances. The use of prismatic thin film is valued

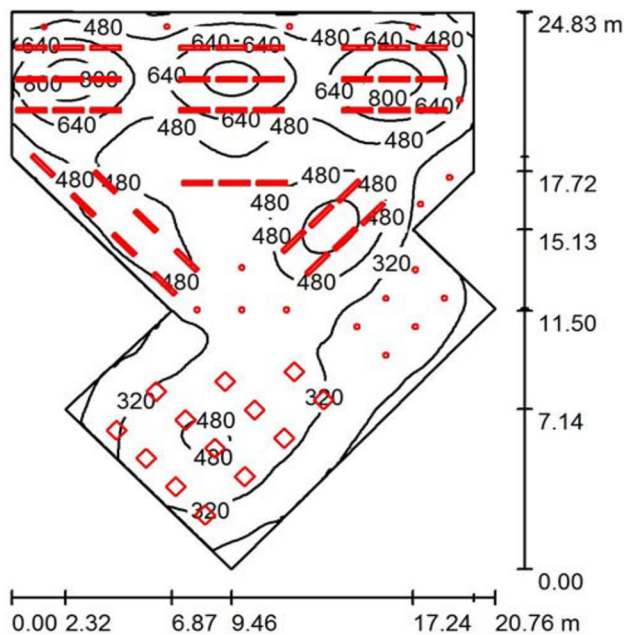


Fig. 6 Simulation results with position and light distribution of the luminaire on the work plane (The values are indicated in lux) (Height of Room: 4.0 m, Light loss factor: 0.80 Values in Lux, Scale 1:319).

due to the fact that it reduces the optical path length in dielectric media. Subsequently, bulk absorptivity of the material causes minimal light absorption losses allowing the film to reach high transmittance and therefore, creating the possibility to guide light with minimal losses.

Two designs of hollow CPLGs are developed acting as luminaires to increase guide efficiency and uniformity distribution of natural light into the library spaces. The proposed designs are configured by ray-tracing simulations for achieving high illumination levels in working plane by the means of an adjustment procedure.

Tridimensional simulations were carried out in a non-sequential optical ray tracing software, TracePro 7.4 [24] to carry out an transmission efficiency study in the case study. The transmission efficiency (T_g) used to characterize the flux of light transmitted through the guide, is defined as:

$$T_g = \frac{\Phi_d}{\Phi_i}, \quad (2)$$

where Φ_d is the flux intercepted by the plane and Φ_i is the flux at the input of the guide. In order to study the transmission efficiency of the system, it is evaluated the flux rate at the end of the guides and in work plane.

Cylindrical prismatic light guides of polycarbonate were developed according with parameters of the prismatic material commercially called OLF (Optical Lighting Film) [25]. The prism base is $356 \mu\text{m}$ wide and its height is $178 \mu\text{m}$ and the refractive index material of the guide is considered 1.59 determined by using a polycarbonate polymer with a linear absorption coefficient of $1.10^{-3} \text{ mm}^{-1}$ according with datasheet. Defects in prismatic corners has been set to be a corner radii of $3 \mu\text{m}$ [22].

The optical designs have been developed by 3D modelling through an optimization process to achieve a high level of uniformity and efficiency in the work plane while preserving the optimal design parameters for proper use. Both efficiency and spatial lighting distribution have been evaluated. Those designs are compound of two CPLGs engineered to increase efficiency providing great uniformity in work plane of tables. The first configuration called Model 1 (M1), has two guides with diameters of 0.25 m and a total lengths of 3.9 m. The distance between centers is 0.74 m. Model 2 (M2) has two guides with diameter of 0.5 m and a total length of 3.23 m. The distance between centers is 0.80 m. The dimensions of the guides are suitable alternatives to take full advantage of the luminous flux provided by the prismatic guides in the work plane. The schematic ray-tracing of the hollow prismatic guide designs is represented in (Fig. 7). The image of the prismatic guides in the figure is distorted from the real due to the aliasing.

The dimensions used to characterize the guides are given as aspect ratio (p) defined as length to diameter ($p = L/d$). For the simulation the 3D modelled systems are illuminated with a collimate emission pattern according to the guide diameter size. This emission pattern simulates the light distribution provided from the Sun (and a heliostat, which act as light collected system). The wavelength has been set as 590 nm.

For this application, three holographic diffusers of plastic with Gaussian diffusion functions from Luminit Optics [25] were chosen according to the scene and optical requirements of guiding. The transparent diffuser sheet called Luminit 30×5 degree LSD (called D1) is located at the input of each guide and the dimensions agree with the diameter of the guide. The input diffuser D1 [26] emits in a semi-angle of 30° which approximately maintains the maximum acceptance angle determined by the refractive index of the prismatic film. This sheet disperses the light and provides a luminous distribution curve determined by a Bidirectional Transmittance Distribution Function (BTDF) allowing to obtain an optimal angular distribution to internally reflect the light beam optimizing to the maximum light transmittance in the system. Several diffusers are placed at the end of the models, providing an improvement in light distribution improving uniformity in the work plane of the library's tables. Model 1 is composed of Luminit 60 degree LSD (called D2) plus Luminit 40 degree LSD (called D3). D2 is a centered octagon with a side length of

Table 2 Summary of the results obtained with DIALux.

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	U_0
Work plane	/	449	100	871	0.221
Floor	20	434	120	745	0.276
Ceiling	80	86	49	153	0.562
Walls(9)	50	169	54	666	/

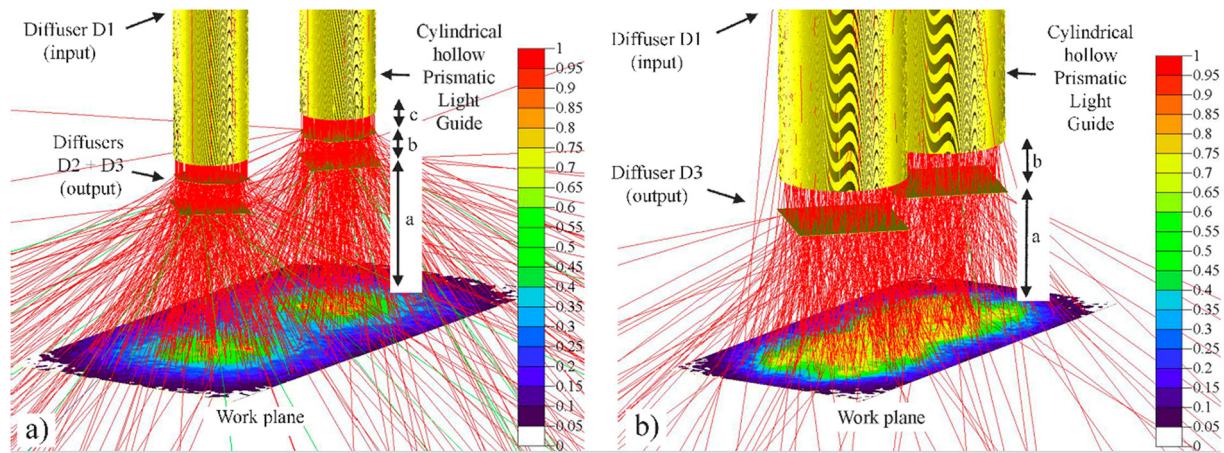


Fig. 7 Schematic ray-tracing of the hollow prismatic guide designs. Model 1 (a) and Model 2 (b). From top to down: Diffuser D1, CPLG, D2 + D3 (in Model 1) and D3 in Model 2.

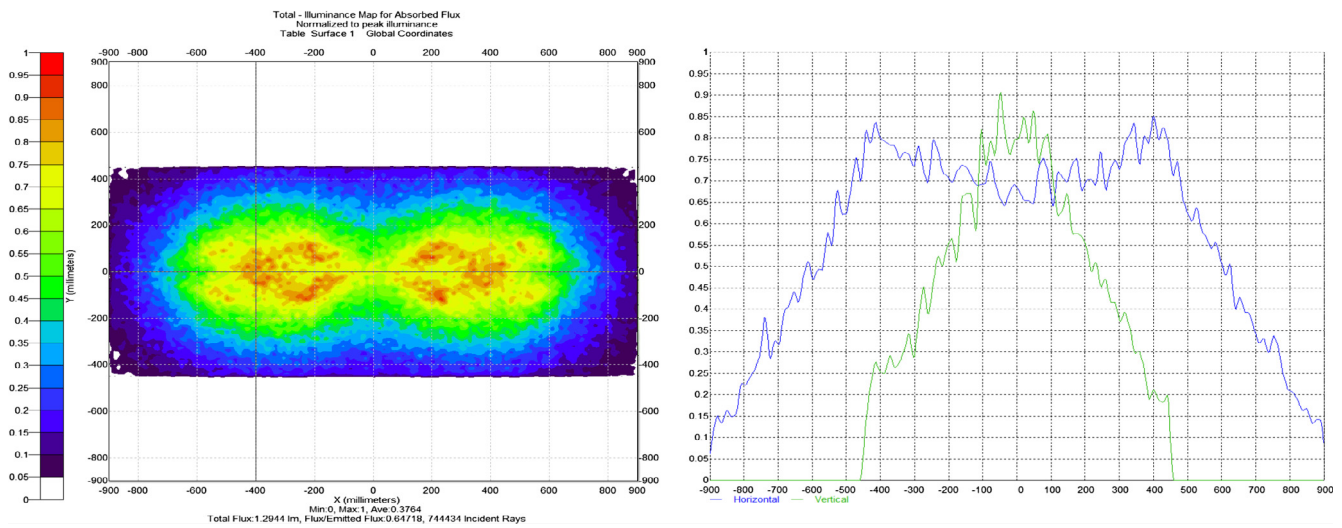


Fig 8 Illuminance map obtained in Model 1 ($\rho = 15,6$) on the working plane (a) with horizontal and vertical profiles (b).

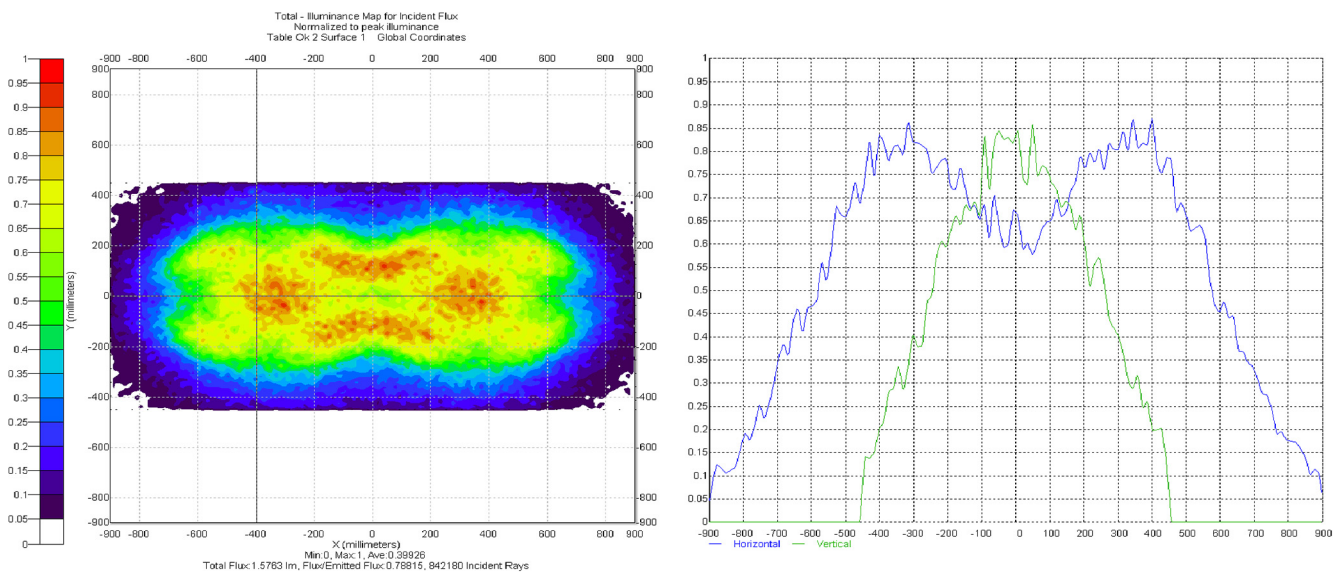


Fig. 9 Illuminance map obtained in Model 2 ($\rho = 6,46$) on the working plane (a) with horizontal and vertical profiles (b).

0.099 m and D3 is a side square of 0.44 m. Model 2 is composed of Luminit 60 degree LSD (D2). Fig. 1 shows a detail of dimensions, in model 1 $a = 0.5$ m, $b = 0.01$ m and $c = 0.07$ m, in Model 2 $a = 0.55$ m and $b = 0.175$ m.

Simulation has been made for a basic configuration of two squares tables together of 0.09×0.09 m. This configuration can be modified by adding several CPLGs preserving proportions according to the length of the tables. The ray tracing software, allows to define and validate the optical behavior of the system by quantifying the amount of flux and luminous distribution in work plane. In order to study the efficiency of the system, a plane detector record the light flux to the output of the lighting system and in a plane located at the exit of the system.

4. Ray-tracing simulations results

The luminous flux obtained in work plane of the library tables are shown in Figs. 8 and 9. Fig. 8 represents the flux ratio and irradiance map obtained in Model 1 and Fig. 9 represents the result obtained in Model 2. There is an increase of efficiency of Model 2 with regard to Model 1 mainly due to the smaller aspect ratio. In addition, Model 2 provides a more equitable distribution of light throughout the system. The illuminance map shows the flux received vs emitted (efficiency) and the profile plot in the horizontal and vertical axis. The measurements revealed a percentage of transmission efficiency of 64.7% in Model 1 ($\rho = 15.60$), and 78.82% ($\rho = 6.46$) in Model 2 in

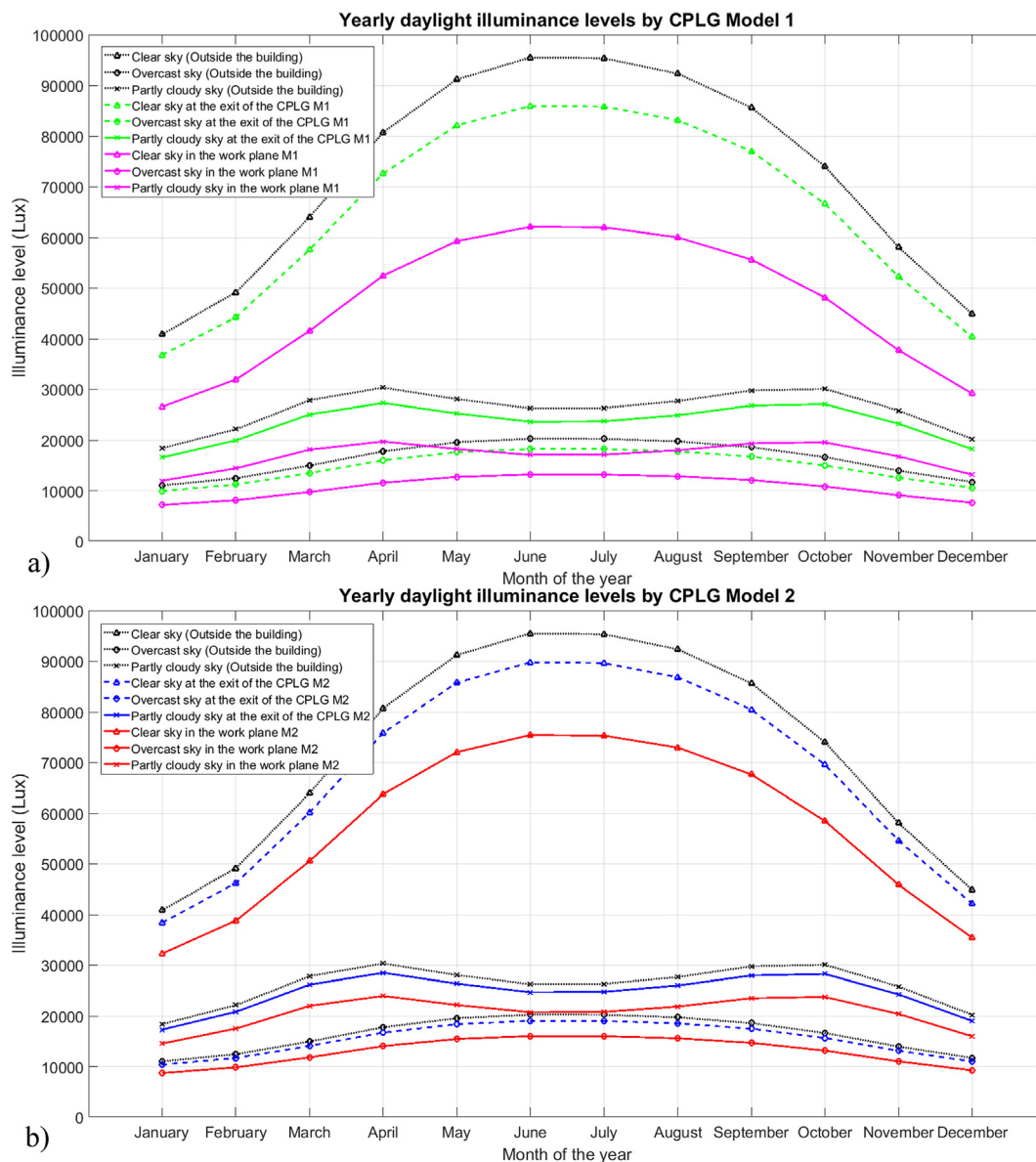


Fig. 10 Yearly daylight illuminance levels (LUX) obtained in library with CPLGs Model 1 (a) and Model 2 (b) for a partly cloudy day, clear sky and overcast at the exit of the CPLG and in the work plane.

work plane. In the exit of the guides transmission efficiency is 90% in Model 1, and 94% in Model 2.

The illuminance uniformity, U_o , on working plane can be calculated by:

$$U_o = \frac{E_{med}}{E_{max}}, \quad (3)$$

where E_{max} is the maximum value of the illuminance obtained and E_{med} is the average value. As a result, the system gave illuminance uniformity of 0.19 on the working plane in both models.

The cropped area from (−710, 260) to (710, −260) millimeters in Figs. 2 and 3 which corresponds to the work area has a high uniformity and has a U_o value of 0.49 in Model 1 and 0.54 in Model 2. This system therefore provides a high uniformity in working plane. In addition, this system directs the light in a suitable way on the work plane avoiding discomfort due to glare in the users.

5. Potential improvement of Cylindrical prismatic light guide models

The solar radiation that affects the optical system depends on factors such as the geographic coordinates in which the catchment area is located, the positioning of the Sun throughout the day and the composition and state of the atmosphere. The geographic coordinates of reference that are taken in the study coincide with Beirut (Lebanon) are Latitude 33°49'N and Longitude 35°29'E. From the climate condition and taking into account the daylight during the calculation, it shows that there can be a high potential for using light pipe system as a daylight system in Beirut (Lebanon).

A study of yearly daylight illuminance levels has been estimated by the use of DIALux software. During daytime incorporating the CPLG models M1 and M2 to building. This study incorporate the data obtained with three different types of sky from CIE 110-1994 [27]. These three types are the clear sky, overcast sky and partly cloudy sky.

The models were compared in consideration with CPLGs transmission efficiency theoretically obtained in software simulations. The illuminance ratio obtained at the output and in the working plane of each CPLG model are shown in Fig. 10. The distribution of interior illumination levels can greatly be improved by the use of both CPLGs. Within daylight hours, cumulative data of daylight availability show that a horizontal illuminance medium in work plane between 47 klx and 57 klx might be available for clear sky and 17 klx and 21 klx for partly cloudy sky. Within daylight hours of an overcast sky, the worst case of natural lighting, cumulative data of daylight availability show that a horizontal illuminance of 12,972 lx might be theoretically available in the work plane by the use of a CPLG Model 1 and 10,673 lx by Model 2.

6. Conclusions

It can be concluded that a proper and controlled exploitation of daylight complemented with energy efficient lighting technologies can significantly reduce the energy consumption for electric lighting by a percentage of 33% per day. This study has examined the conditions of indoor day lightings and the library's energy performance in the Faculty of Architecture,

Design and Built Environment, Beirut Arab University (Lebanese). In order to reduce the amount of energy consumption and enhance the beneficial effects on the health and well-being of behavior within the library two optical designs have been developed by the means of Hollow Cylindrical Prismatic Light Guides (CPLGs) which allows guiding the light into the library of a building efficiently providing uniform light distribution in the work plane. The proposed designs theoretically allowed reaching high levels of efficiency between 64.7% and 78.8% in the work plane, avoiding glare and providing high color reproduction. The yearly daylight illumination levels could be improved by the use of CPLGs. Within daylight hours, cumulative data of daylight availability show that a horizontal illuminance medium in work plane between 47 klx and 57 klx might be available for clear sky and 17 klx and 21 klx for partly cloudy sky.

As a guidance for designers, we can suggest the following:

1. Integrate the simulation modelling in the conceptual phase of design for new building give the designer full image about the advantage and disadvantage of their design to change it to gain maximum benefits from outdoor the environment.
2. For exciting building, the architectural technics as light pipes, atrium, shading devices, etc, can play a role to improve daylight quality inside the spaces.
3. The designer should take in consideration the potential for increased daylight provision from a skylight to save electric lighting energy.
4. The psychology benefits from daylight is highly appreciated by occupancy which mean that it's highly recommended for designers.
5. Building rating systems as LEED, BREAM, etc. indicate different techniques to increase the daylight factors inside buildings to reduce the energy consumption.

References

- [1] Silvia Cammarano, Anna Pellegrino, Valerio R.M. Lo Verso, Chiara Aghemo, Daylighting design for energy saving in a building global energy simulation context, *Energy Proc.* 78 (2015) 364–369, <https://doi.org/10.1016/j.egypro.2015.11.672>.
- [2] D. Vázquez-Moliní, M. González-Montes, A. Fernández-Balbuena, Á. García-Botella, W. Pohl, T. Galan, E. Bernabéu, Horizontal daylighting system for office buildings, *Energy Build.* 67 (2013) 525–530.
- [3] A. Rosemann, H. Kaase, Lightpipe applications for daylighting systems, *Sol. Energy* 78 (6) (2005) 772–780, <https://doi.org/10.1016/j.solener.2004.09.002>.
- [4] L.A. Whitehead, R.A. Nodwell, F.L. Curzon, New efficient light guide for interior illumination, *Appl. Opt.* 21 (15) (1982) 2755–2757.
- [5] I.R. Edmonds, J. Reppel, P. Jardine, Extractors and emitters for light distribution from hollow light guides, *Int. J. Light. Res. Technol.* 29 (1) (1997) 23–32.
- [6] Edward M. Dean, "Daylighting Design in Libraries", this material has been created by Edward M. Dean, AIA and provided through the Libris Design Project, supported by the U. S. Institute of Museum and Library Services under the provisions of the Library Services and Technology Act, administered in California by the State Librarian.

- [7] I.E.S. Lighting Handbook: The Standard Lighting Guide, eighth ed., Illuminating Engineering Society, New York.
- [8] L. Edwards, P.A. Torcellini, A Literature Review of the Effects of Natural Light on Building Occupants, National Renewable Energy Laboratory, Golden, CO, 2002, p. 59.
- [9] K. Thapan, J. Arendt, D.J. Skene, An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans, *J. Physiol.* 535 (1) (2001) 261–267.
- [10] R.G. Rodriguez, J.A. Yamin Garretón, A.E. Pattini, Glare and cognitive performance in screen work in the presence of sunlight, *Light. Res. Technol.* 48 (2016) 221–238.
- [11] P. Boyce, H. Claudia, O. Howlett, The Benefits of Daylight Through Windows, Rensselaer Polytechnic Institute, Troy, New York, 2003.
- [12] K.M. Farley, J.A. Veitch, A room with a view: a review of the effects of windows on work and well-being, *NRC Institute for Research in Construction* 136 (2001).
- [13] General Directorate of Urban Planning, Ministry of Public Works and Transport with UNDP is the UN's global development network, Climatic Zoning for Buildings in Lebanon, 2005.
- [14] <http://www.holiday-weather.com/beirut/averages/>, 2016 (last seen January 2018).
- [15] Ecotect Software. <<https://www.autodesk.com/education/free-software/ecotect-analysis>> (last seen January 2018).
- [16] DIAL lighting Building Software. DIALux. <<https://www.dial.de/es/dialux/>>.
- [17] European Standard EN-12464-1:2012 Light and lighting – Lighting of work places – Part 1: Indoor work places.
- [18] B. García-Fernández, D. Vázquez-Moliní, A. Fernández-Balbuena, Lighting quality for aluminum and prismatic light guides, in: *SPIE Optical Systems Design*, International Society for Optics and Photonics, 2011, p. 81700T.
- [19] L.A. Whitehead, P. Dosanjh, P. Kan, High-efficiency prism light guides with confocal parabolic cross sections, *Appl. Opt.* 37 (22) (1998) 5227–5233.
- [20] B. García-Fernández, D. Vázquez-Moliní, A.Á. Fernández-Balbuena, Mathematical model applied to improve the natural lighting design, *Int. J. Sustain. Dev. Plan.* 12 (2) (2017) 273–282.
- [21] D. Vázquez-Moliní, A. Álvarez Fernández-Balbuena, B. García-Fernández, Dielectric Material, “Natural Lighting Systems Based on Dielectric Prismatic Film”, InTech, 2012.
- [22] B. García-Fernández, D. Vázquez-Moliní, A.Á. Fernández-Balbuena, A. García-Botella, J.C.M. Antón, Light losses in hollow, prismatic light guides related to prism defects: a transmittance model, *Chinese Opt. Lett.* 13 (9) (2015) 092201.
- [23] B. García-Fernández, A.Á. Fernández-Balbuena, D. Vázquez-Moliní, Analytical method to measure bending deformations in prismatic optical films, *Chinese Opt. Lett.* 14 (4) (2016) 042201.
- [24] TracePro® Opto-Mechanical Design Software, <www.lambdare.com>.
- [25] 2301 OLF Data sheet, Available at: <http://starlightsl.de/mb/3M_Lighting_Films/OLF1_neu.pdf>.
- [26] Luminit optics, <<https://www.luminitco.com/>> (last visited January 2018).
- [27] CIE 110-1994 Technical Report, Spatial Distribution of Daylight – Luminance. Distributions of Various Reference Skies.