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Article

Solar Radiation in Architectural Projects as a key Design factor for the recovery of Alzheimer's outpatients.

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Abstract: The beneficial effects of solar radiation on human health are well documented. One necessary mechanism triggers the production of vitamin D whose insufficiency has been linked to a variety of disorders like diabetes, hypertension and more recently amyloidosis and Alzheimer disease. However, there are few architectural designs capable on ensuring adequate provision of solar radiation inside buildings. Conventional fenestration is not sufficient to provide for significant doses of sunlight even to prevent seasonal affective disorder (SAD). In this paper we discuss the effect of new design alternatives for skylights, especially in the refurbishment of obsolete facilities. After such complex retrofit is executed, we have analyzed the performance of a building in warm and sunny climates as is the case of southern Spain. It has been considered as a priority the study of the factors that relate sunlight and energy, as well as, to a certain extent, other aspects like ventilation and insulation. Many architectural designs are presented as correct if the thermal requirements alone are met, even at the risk of later energy waste in lighting devices and visual or physical discomfort. On the other hand, large glazed areas allow more daylight into a space, but they may also allow excessive heat gains or losses which increase the air-conditioning cooling or heating load. To avoid these problems, we have considered the combined effect of daylight and energy from the beginning of the skylight design-process. A daylighting software based on configuration factors that we have apply in former researches to study the problems of direct sun over architectural structures have been used. This question cannot be treated adequately with conventional programs for overcast skies. The skylights have already been constructed and on-site measurements in the offices have been taken to complement the computer simulations data. The results show that it is possible to achieve energy saving and high radiation levels in winter without increasing heat loads during the summer. All this is considered beneficial to improve the condition of users with cognitive diseases as Alzheimer's disease by virtue of adapted spaces.

Keywords: Alzheimer's disease, daylighting simulation, radiative exchanges, design strategies, Healthy Architecture

1. Introduction

One of the main objectives of environmental sciences applied to architecture has been to determine how the built environment is transformed due to the physiognomy of the constructions and how the design should be adjusted to obtain a better climatic performance. In other words, how to optimize the architectural design to attain a satisfactory and coherent distribution of the natural energy. Particularly daylighting seems to show a direct repercussion on the behavior of the user suffering from Alzheimer's disease (AD) and its subsequent cerebral processes. Lighting is part of a set

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of project parameters previously detected as significant due to its impact on the well-being of the person suffering from Alzheimer's. The acquisition of sunlight is possibly one of the most influential factors in the Design Project with a direct impact on the patient. Design control of solar radiation sources and their intensity is required to achieve adequate regulation of the daily activities of users with cognitive impairments such as Alzheimer's outpatients [1,2].

To attain this goal, we think that it is necessary to relate energy use and luminous efficacy during the design-process [3,4]. In this regard, previous works have stated that a correct design of glazed surfaces in the buildings envelope, in which thermal aspects and lighting are both considered, can considerably reduce the energy consumptions while contributing to improve the environmental quality of the indoor spaces [5]. Specially in the case of sunny climates, the excess of glazed surfaces must be reviewed carefully to reduce energy consumptions, since they have a very important repercussion in the heating demand [6,7]. Nevertheless, the energy impact of the design of windows is not being considered by most of architects in the decision-making process.

By the other hand, the problems of direct sun over the architectural structures cannot be treated adequately from the illumination point of view with conventional software for overcast sky. A careful understanding of solar geometry for the particular situation is demanded, and then, tools to analyze the paramount contribution of solar gains to the day lit interiors [8,9]. Often the proportion of solar gains in the overall lighting balance is higher than 80% and still it is surprising how few scientific designers are concerned and familiar with sunlight concepts [10].

2. Methodology

The modelling of the characteristic structural, acoustic and lighting properties of conoids encompassed a significant amount of the career of the authors. Based on that, we can attest to its sustainability and endurance [11].

From the structural point of view, as a ruled surface it can be built directly through straight lines (beams or poles), this fact greatly facilitates the construction and scaffolding, as more natural materials like bricks or bamboo rods can be used without difficulty, even for reinforcement or repair.

Carbon-fiber coating has become a recent alternative for reinforcement although moderately expensive.

The arched section of the conoid whether circular or elliptic presents a vertical tangent. Therefore, if adequately constructed it is free from horizontal thrusts which might compromise the supporting frame. In other words, it transmits all the loads of the structure vertically and avoids the use of buttresses.

These consistent and diminishing arches function as girdles for most part of the surface and provide increased resistance to a significant amount. It is true that calculation of hyper-static arches is not widely treated in the literature but we suggest the column analogy method proposed by H. Cross [12] as a helpful and programming-friendly procedure.

Due to its curvature the aerodynamics of the roof is excellent for bearing wind loads and other meteorological phenomena as rain, drizzle or snow. At the same time, because of the former it enhances air flow from the outside or from internal stack effect with appropriate vents.

Regarding lighting properties if, as usual, the glazed apertures lie in the curvilinear extremes of the forms, they bring uniform illuminance as we have calculated and can be easily shaded by eaves protruding from the same brim of the surface.

Acoustic properties stem from the circumstance that the inside surface of the conoid is mostly convex as we have checked mathematically [13]. Sound waves are diffused in this kind of ceiling and consequently, noise and reverberation become dampened. If, through appropriate design, the conoid covers a trapeze or fan-shaped plan the effect of an even sound pressure is manifest [4]. (In this last case the surface is not a proper conoid as the forming lines are not all parallel to a common plane).

The aforementioned acoustic benefits are extensive to interior illumination for the same reason of convexity of forms.

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Although strictly-speaking not a conoid, because its equation differs from what we have explained above, the cover of a fan shaped plan with this kind of surface offers a very interesting structural property: the larger spans between pillars are covered by arches while the tapered end of the trapeze features a common slab or planar beam, what seems very logical from the constructive aspect [4]. In this way, the shells' materials can be lighter and smoother. The result has proven to provide increased insulation and adds variety of light effects.

Based on the former, we have created different design alternatives in time, to introduce sunlight in the core of the buildings that could perform satisfactorily for residential facilities. The main output is based in conoidal shapes. The more evolved alternative for advanced skylights is presented in Fig. 1 in which the glazed parts instead of being planar are also conoids. Bearing in mind the problems of heat and light transfer, this feature presents undoubted advantages [14]. Firstly, the glazing is better shaded and protected by the opaque upper surface. Secondly, sunlight and heat transmission are modulated by the smooth curves conjoined to the innovative glass properties. In this way the glass surface becomes load-bearing and collaborates with the general structure. The form can be easily adapted to arrays of skylights (Figure 2).

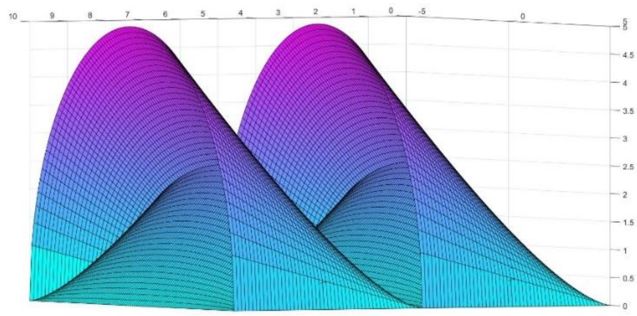

Figure 1. Outline of proposed Skylights with internal conoid glazing.

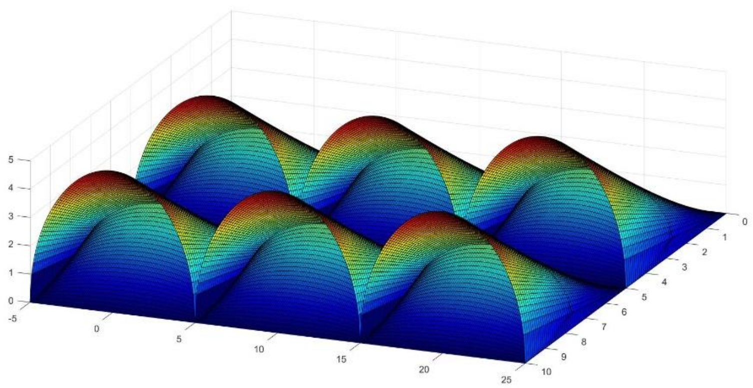

Figure 2. A suggested array of six conoidal skylights.

The new skylights are more impervious, break-proof, safer and cleaner in the absence of maintenance, as dust collection is diminished with the curvature.

Regarding sunlight controls in the skylights, we have evaluated various sky models to achieve an optimal design, using a daylighting calculation method that we have developed and applied in previous studies [15-16]. This method, based on the calculation of luminous radiative transfers, represents an advance in relation to the research of J. H.

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Lambert and his theorem of reciprocity, which was later continued by H. H. Higbie, Yamauchi and Moon among others [17].

The procedure extends the properties of radiance of diffusing surfaces to luminous exitance of all kinds of building surfaces of whatever shape that are accordingly treated as radiative exchangers by means of the generalized principle of the projected solid angle [18]. One the initial intensity of each surface is known and the primary shape of the exchangers is fixed, successive interchanges can be obtained until a balance of the required accuracy is achieved.

This simulation procedure has the capability to take into account the effect of sunlight both in the radiation quantities and in the illumination field. From the beginning, the daylighting simulation was developed in several phases following the different design possibilities of the new skylights.

2.1. *Ceramic Materials*

The techniques previously described are concomitant with the use of environmental-friendly materials like ceramics and brick masonry. Ceramics is a natural light-weight insulation known since antiquity. The authors have incorporated this cost-effective material in different projects [19] with positive results in a variety of fields and especially in the cognitive adaption issue that is one of the key aspects pursued in the ensuing research (Fig. 3).

Figure 3. Vault pieces constructed in hollow thin brick by the authors in Seville

3. Design scenarios in a practical case

Bearing in mind the aforementioned issues and the experience gained, a new type of skylight for a former office building that needed to be converted into residential units, has been designed in Gelves, town located near Seville. The so-called new "monitors" have been designed to control the incident solar energy in the building through the roof. We should note that this is the surface with the highest incident solar radiation and that it allows the greatest flexibility in connecting the living rooms with the outside environment.

We have evaluated various proposals for skylights in order to determine the forms with better results for a particular situation. The use of such dynamic daylighting systems is due to the necessity of providing new sources of radiation for persons suffering from cognitive diseases such as Alzheimer's. Expected advantages are maintenance of daily circadian rhythms and avoidance of excessive glare and other stimuli which could result in stress augmentation of agitation.

The paradoxical question was how to achieve a good day-lighted environment and energy savings in winter without increasing the thermal loads in summer. This question is not an easy one and cannot be treated as an isolated factor. We have to take into account that energy savings should not be obtained at the risk of visual discomfort or severe air conditioning loads leading to thermal stress.

Therefore, we analyzed the solar positions of Seville in relation to its climatic parameters. We studied the ideal orientation and the critical situation of which solar penetration in the offices is not advisable, according to the high probability of clear sky in Seville.

In general terms, the followed procedure of design for the monitors was to open the apertures in the orientations that receive direct sunlight for more hours a day, and to control them by the geometry of the skylights and the design of overhangs. In this regard, we would like to stress that the south is the sole orientation receiving more gains in winter tan in summer in Europe.

Taking into account this design strategy, we have simulated the effects of various proportions of glazed surfaces in the thermal performance of the offices. We have analyzed the most advisable orientations in this case, SE and SW. The other surfaces have been designed opaque and insulated to reduce solar radiation.

We found that it is advisable to avoid the penetration of direct sunlight at times of maximum heat during the summer afternoons. Therefore, the aperture oriented SW has been reduced in W direction and protected by an overhang that increases its dimension in this direction. Regarding the daylighting issues, we simultaneously have carried out a pre-dimensioning to check the minimum size of the elements that ensures a sufficient daylight.

We have selected conoidal geometries to formalize the design strategy. This geometry allows that the monitors can be designed with different sections in SE and SW directions. Moreover, the obverse of the conoid is convex and therefore, can distribute more conveniently the luminous and acoustic radiative transfers.

Within the diverse solutions considered, that include inverted conoidal geometries and various proportions of glass and dimensions of overhangs, figure 4 shows one of the designs which offer the best estimated performance in terms of energy savings, visual comfort and reduction of thermal loads.

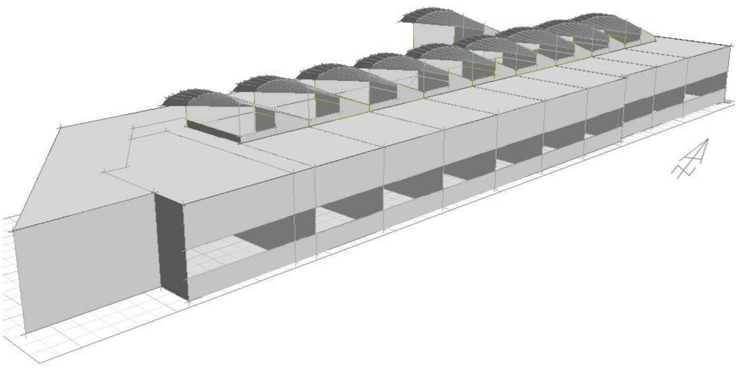

Figure 4. Sketch of the final proposal for skylights.

It was necessary to accurately dimension the monitors to avoid overshadows between them in winter. We also took into account the increase of daylighting owing to the reflected solar radiation at the conoidal monitors. Figure 5 shows the penetration of solar radiation into the offices.

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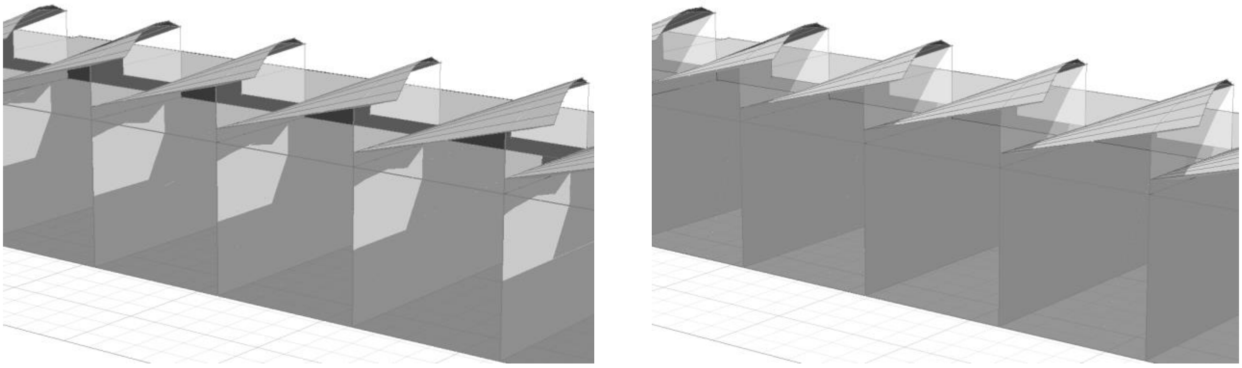

(a) (b)

Figure 5. Comparison of the interior shadow range at 12:00 hours. (**a**) Winter solstice; (**b**) Summer solstice.

The adopted solution not only produces the benefit of having sunlight into the modules when the temperature is below the comfort range, but also considerably increases the daylighting because this radiation is incident on high-reflectance surfaces. This type of solar design in warm climates would not be possible using design methods for overcast sky.

The possibility of natural ventilation was also studied. The monitors have automated ventilation apertures that can be opened at certain levels of temperature and wind speed. They are located on facades with different orientation to facilitate cross ventilation (Figure 6).

Regarding the materials, the conoidal surfaces were designed with the thermal mass on the inside, because, due to their geometry and orientation, a high solar radiation incidence is expected. After studying various material combinations, we decided to use the following construction system (from inside to outside): 40 mm perforated brick with plaster inside 10 mm, 150 mm concrete, 40 mm extruded polystyrene (XPS), and finally an external self-protected waterproofing sheet.

(a) (b)

Figure 6. Views of the new skylights. (**a**) Final View; (**b**) Under construction.

The entire intervention has been developed at low cost and takes into account the architectural integration of the final proposal (Figs. 7-8).

Figure 7. View of the new ceramic vaults.

Figure 8. Interior view of the aspect of the residential units.

4. Daylighting simulations

Two situations have been investigated, overcast conditions (where orientation and hourly and monthly variation) and clear sky with sun conditions (where orientation and hourly/monthly variations are mandatory). Such variations of hours and orientation have been selected taking into account the necessities of the user with AD and alterations that they could experience taking into account the possible discordances in the circadian rythms.

The first condition refers to conventional models for cold and cloudy climates, with limited application to Seville. The second condition is more innovative and typical of warmer regions where some places reach 3.000 sun-hours per year. We need to use it in order to save energy, as the luminous efficacy of free and over-abundant solar radiation is much higher and pleasant than the one registered with artificial luminaires.

Besides, with controlled beam radiation as the main lighting source, we are able not only to produce a more suggestive internal environment, but also to greatly reduce energy-use, especially in air conditioning overheads, as the size of the glazed apertures can be significantly diminished in comparison with conventional skylights [20]. Those skylights did not control radiation and, therefore, they admitted excessive quantities of heat for an equivalent or even lesser luminous effect.

Regarding the simulation that we have developed, the times of the year under study have been the most representative ones, that is, winter and summer solstices and equinoxes. Within each of these days, several hours have been analyzed. Henceforth, a complete knowledge of the performance of daylighting throughout the year is achieved.

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5. Meteorological data and coefficients

The reflection coefficients of the walls were taken at 0.50 and 0.65 including maintenance, the transmittance considered for the glasses was 0.60 and general cleaning of the offices 0.9.

For daylighting calculation, we have used the sky model of Gillet, Pierpoint and Treado [21], that defines the vertical illumination (in lux) for clear sky based on the azimuth (Φ) and the height (θ) by the equation below.

$$Ev = 4000 \times \theta 1.3 + 12000 \times \sin 0.3\ \theta \times \cos 1.3\ \theta \times [(2 + \cos\Phi) / (3 - \cos\Phi)] \quad (1)$$

And in the case of overcast sky, similar to the CIE model, using the following equation.

$$Ev = 8500 \times \sin\theta \quad (2)$$

Regarding the possibility of overcast or clear sky plus sun we have the following values (Table 1).

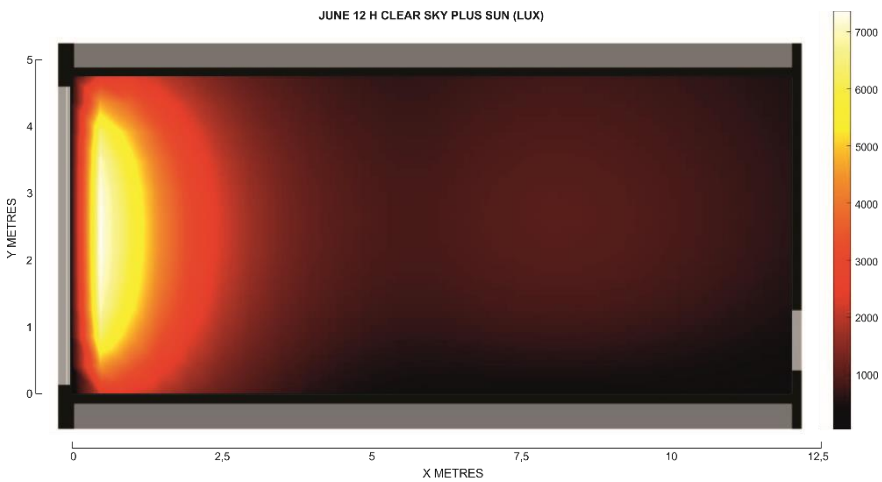
Table 1. Probabilities of occurrence for overcast and clear sky at Seville (Spain). State Meteorological Agency, AEMET. Source: authors.

Type of sky	Clear + sun	Overcast
March/September	76.40%	20.00%
August	86.30%	12.20%
December	78.60%	24.10%

Both probabilities do not add up to 100% provided that there are other types of sky as partly cloudy or average sky.

6. Results of the simulation

We show below some computer results of the simulations (Figures 9 and 10). Horizontal daylighting values refer to a reference plane located 0.6 m above the floor. The sectional views cut across the loft units by its center point. Notice that the grid points are taken every 1 meter in the width, length and height axes.



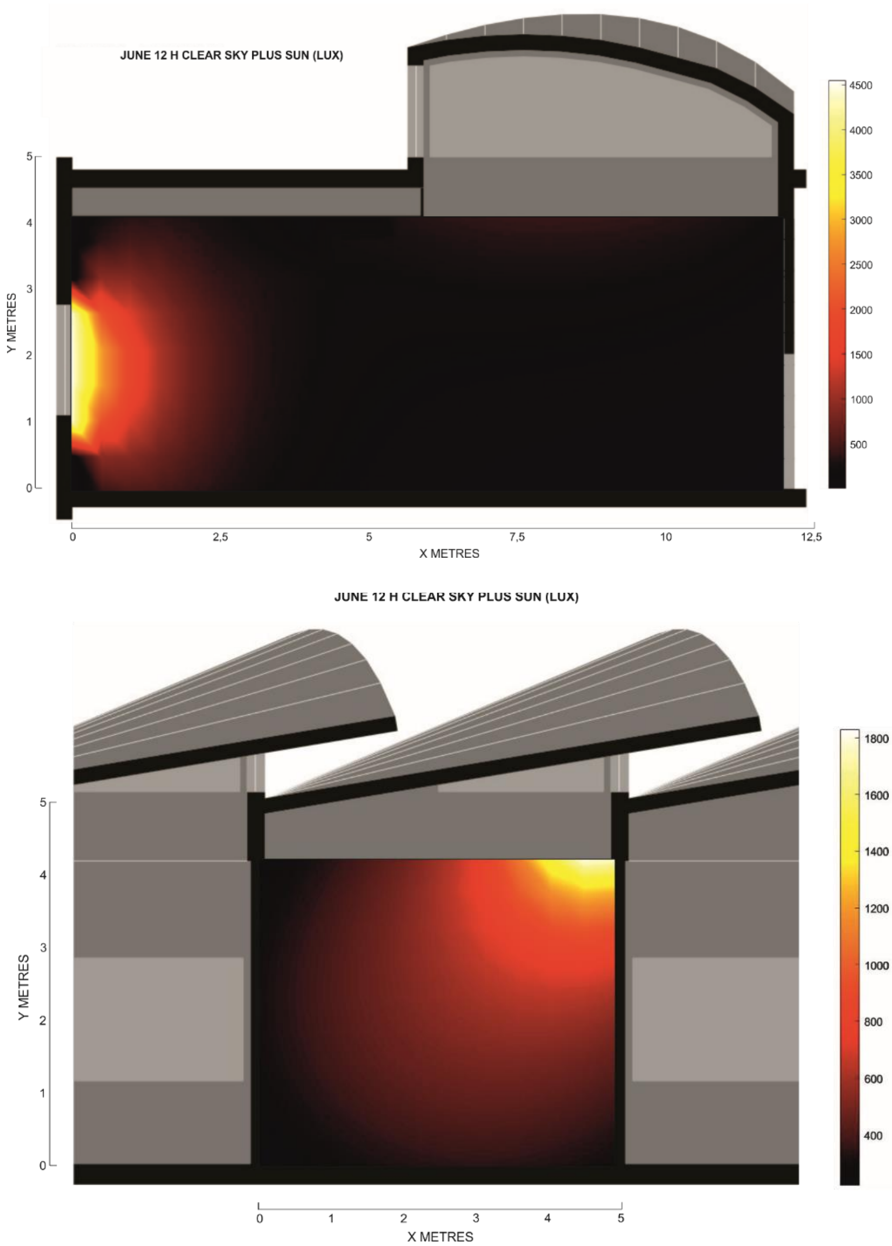
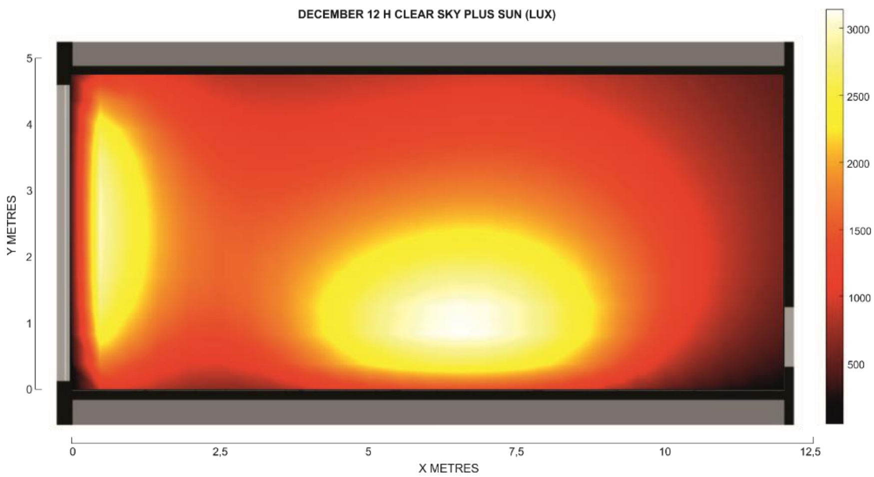


Figure 9. Horizontal and vertical illuminance distribution in an office. June 12:00 hours solar time, clear sky plus sun. Values in lux. Source: authors.



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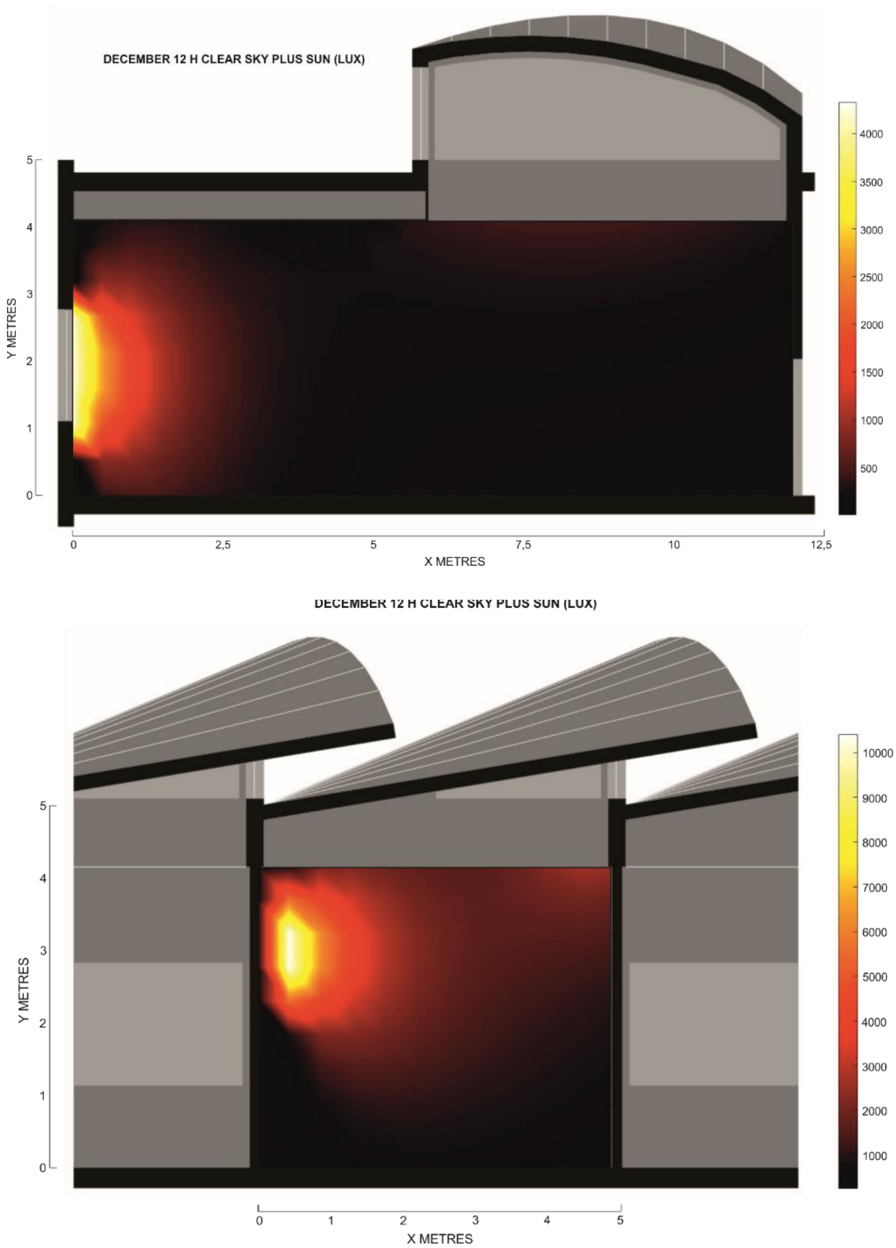

Figure 10. Horizontal and vertical illuminance distribution in an office. December 12:00 hours solar time, clear sky plus sun. Values in lux. Source: authors.

We have to point out that 80% of the studied points showed a level of over 400 lux for all weather conditions and 20% of the points considered were always over 250 lux. In the clear with sun conditions, the daylighting values are higher in the winter solstice than in summer due to the contribution of direct solar radiation to the day-lighted interior.

Daylighting in this new system is greatly dependent on solar illumination and is rarely dependent on overcast or clear sky, and this is in our opinion an important innovation.

7. Monitoring

The authors conducted a thorough monitoring campaign to modulate the range of the simulations and simultaneously check the usefulness of their outputs. An objective validation of our simulation program took place in other controlled experiments [22,23].

We acquired measurements of light with a lux-meter PCE-170A with International Organization for Standardization (ISO) calibration, a measuring range from 0 to 120,000 lux, and an accuracy of ±0.2%. Of these measures, we present a comparison to simulated

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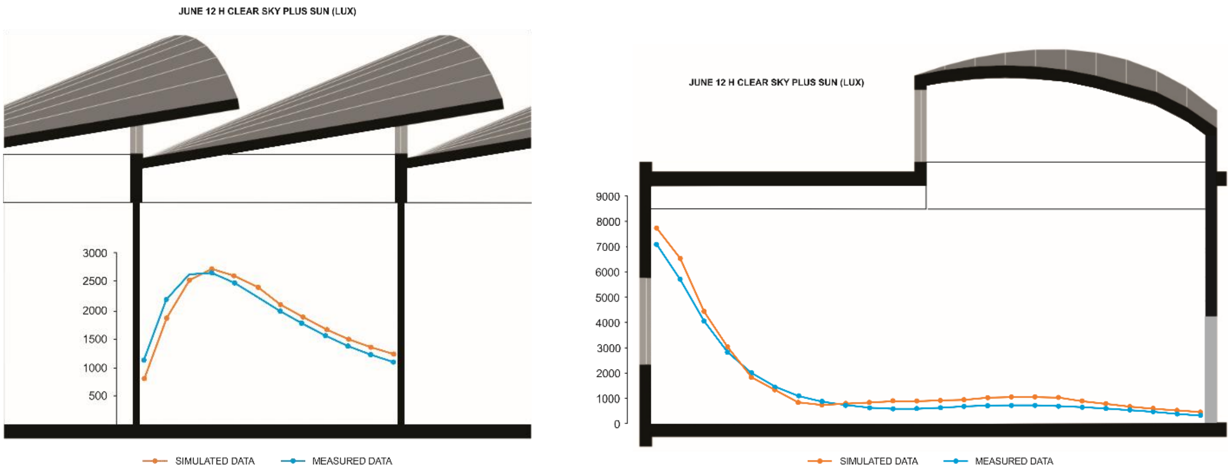
values for a partly cloudy sky, which corresponded well due to not showing relevant discrepancies.

The slight differences registered between the simulated and measured data were presumably due to the sky being partly cloudy on the days the experiments were performed (Figure 11).



(**a**) (**b**)

Figure 11. Comparison of measured and simulated data for partly cloudy sky at midday on 21 June. (**a**) Transverse axis; (**b**) Longitudinal axis. Source: authors.

8. Conclusions

In general, relatively high and well distributed daylighting levels have been achieved inside the refurbished residential units. The horizontal daylighting ranges over 400 lux; with higher values in winter than in summer. The daylighting levels in the vertical planes are significantly lower, which is suitable for comfortable living spaces. By the other hand, the new skylights improve the comfort level both in winter and in summer, an improvement which is not obtained at the cost of visual discomfort. The natural light supply systems work effectively, proving to be a project parameter with direct incidence and repercussion on the well-being of the user with Alzheimer's and extrapolated to any other space of direct use by this population group.

The skylights are currently being monitored. The first data from on-site measurements show that they work properly.

We have to stress that this example and many others that have been built in recent years validate the results of the scientific determinations outlined above. Therefore, they represent an advance in the knowledge of skylights and a clear example of how the prediction of the energy or climate response of architectural structures has become a real possibility.

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