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FRAGMENTED LIGHT SHELF, A MODULAR ELEMENT THAT DECREASES THE ENERGY CONSUMPTION

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ABSTRACT

Some studies have shown that well-designed solar shading can reduce the thermal load on a building in the range of around 15% to 30%. Furthermore, it can help to maintain a more stable and comfortable indoor temperature, reducing the use of heating and cooling systems in the range of around 10% to 20%. If this device/element/system also improves natural light and reduces the need for artificial lighting in a building by up to 20% to 40% (depending on the design of the building and the amount of sunlight available), the associated energy savings with electric lighting is quite significant.

Overall, successful implementation of solar shading can lead to an overall improvement in the building's energy efficiency, which could result in total energy savings of 20% to 40% or even more in some cases.

This is the continuation of the research carried out in the PhD work, called Fragmented Light Shelf (FLS), in which the operation of FLS was studied through scale models (in real conditions), and then with computer programs (with models characterized according to real conditions). Placing it in the window hole, facing south, at 2 p.m. on June 21st for Madrid. With this study, it was possible to demonstrate that FLS worked properly as a sun protection element/system, since it achieves the perfect balance between solar gains + daylight improvement (in winter) and sun protection + without losing daylighting (in summer).

This article aims to show how the incorporation of this modular element in a space/building, could significantly decrease the energy consumption in buildings, and consequently reduce the carbon footprint.

KEYWORDS

Daylighting; energy; indoor climate; sustainability; light shelf

1. INTRODUCTION

The necessity to achieve natural lighting and sun protection has existed for many centuries. However, it is after the industrial revolution when new building materials and new building systems allow for the emergence of large windows, openings in the roofs and glass enclosures, while shading devices that are part of the window opening, brise-soleil and large overhangs appear as well (Lechner, N. 2001). Nowadays, rolling shutters and awnings are one of the shading systems most commonly installed in Spanish dwellings, but they don't allow for visual contact with the exterior, and condition the ventilation, causing overheating in the window area, whereas sunlight is considered by occupants as an important factor of well-being in the indoor environment (Darula, S., et al. 2015).

According to the Healthy Homes Barometer (HHB), the Indoor Environment Quality (IEQ) have as principal indicators to improve mental and physical health in healthy buildings by Indoor air quality, Thermal comfort, Daylighting, Lighting and visual comfort, and Acoustics comfort. In this sense, daylight is very important, so much so that some EU Eastern countries have regulations in place for the minimum natural light required in a dwelling, an example being the simple criteria of evaluation formulated in the UK, in winter for kitchens and bedrooms should be at least for 1 hour sometimes, in a day during not less than 10 months within a year from February to November, contrary to summer, where there is a lot of indoor space who the solar radiation should be shaded, to avoid glare and overheating. In several countries, local authorities have the responsibility of ensuring certain environmental conditions in the buildings, part of these conditions being the standards for daylighting buildings that have been upgraded in the last decades, especially in residential buildings, but, is the society that should demand the implementation of the minimum acceptable conditions defined like mandatory standards to have well-being in any place (Darula, S., et al. 2015, Tregenza, P., 2018, Christoffersen, N. et al. 2017). In Spain, the last update of the Spanish Regulation CTE (in Spanish: Código Técnico de la Edificación) regulation for solar control in dwellings, in order to reduce the overheating in the window area (Ministerio de la Vivienda Government of Spain. 2018).

Historically a Light Shelf (LS) is in generally a horizontal or nearly a horizontal element, positioned inside and/or outside of the window façade. The LS can be an integral part of the façade or mounted on the building. LS are not standard, off-the shelf products. They must be made to fit the architectural situation in which they will be used (Ruck, I. Nancy et al., 2000).

This research emerges from previous work conducted in the School of Architecture by Oteiza and Soler, 1995, and Soler and Oteiza, 1997, where the main objective was to show the experimental behaviour of the daylighting performance comparison of different shading devices, including light shelves and overhangs in Madrid. In the same line, other work developed by Claros and Soler studied the daylighting performance at a point placed at 50cm from a south-facing opening in 1:10 models painted for realistic reflectance values of two light shelves and an overhang. The same authors studied as well the influence of light shelf and model reflectance on light shelf performance, using four different material reflectance.

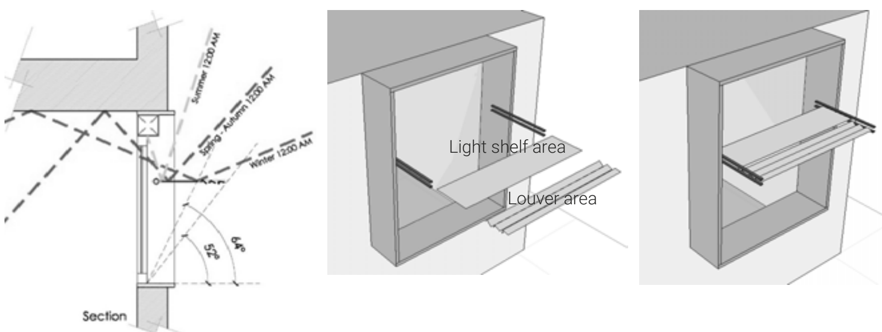
Some authors said that the LS has significant factors which affect the performance, dimensions, location, reflectance, room's surface reflectance, and ceiling geometry and design a system (CUN-OKAY) who answer to all the factors (Kurtay, C.,2017). Another suggested that daylighting systems should be tailor-made and designed to suit different circumstances (Wong, I.L. 2017). The authors of this paper use a LS like a system to avoid the direct sun light and improve daylighting, as well as Ochoa and Capeluto 2005, who also study and compare the three options through a computer program, a single window without any external protection, a horizontal light shelf and a basic anidolic concentrator, in climates with high radiation. Meresi (2016) evaluate different cases of a combination of light shelves and movable semi-transparent external blinds to efficiently exploit daylight in a typical Greek classroom with south orientation. By using the Radiance software, he addressed the way in which daylight could be efficiently used in a typical classroom, by improving its distribution in the space and providing shade. Kurtay and Esen (2017) explorer on a sample office the effect of the location of the light shelf position, size and the correlation between latitudes with light shelf dimensions, by using theoretical simulation. Warrier and Raphael (2017) evaluated the potential of light shelves to improve daylighting and visual comfort, by using/with experimental models and theoretical simulations. There are other authors with different classifications in the same line, but more recently and from another point of view, Wong classified daylighting systems according to the constructive material, the Light Guide Systems (LGS) and the Light Transporting Systems (LTS). Both types of daylighting systems can be used to improve daylight distribution in building space and to control direct sunlight. Wong includes the light shelves in the LGS and describes it/them as a system able to find solar shading and thermal reduction, although easy maintenance and application in the window and allow viewing.

Until now, the effectiveness of these systems/elements has been mostly evaluated from the perspective of lighting and/or shading, but not how this can influence and/or reduce energy consumption. In this regard Susan et al. implement the Energy Utility Index (EUI) as an indicator to study the optimization of a vertical Façade integrated (T)PV through folding design in the Tropics [16].

This paper is based on previous PhD work FLS (Pérez, M., et al., 2012) that was proposed as an innovative system that could provide the balance required, as well as being easily adapted to the window opening of a new construction or in the refurbishment of residential buildings. This individual system improves the natural lighting while at the same time obtaining the adequate shading in the window. FLS is divided in two areas, the light shelf area, and the louver area, which can easily be incorporated into the side of the window opening. Lighting and shadow behaviour were evaluated in the FLS for a window facing south to an open sky, by using scale models with combinations of light shelves and louvers in wood and aluminium.

2. METHODOLOGY

The aim of this paper shows how much decreases energy consumption with the incorporation of a solar protection element in the window, without forgetting that improving natural lighting in the interior space is also important. To achieve the main objective this process was divided in two phases:



a. *b.* *c.*

Figure 1. a. Section scheme with FLS and solar angles of Madrid. b. FLS areas. c. FLS's view in a window. Source: (The Author 2016).

2.1. First Phase – Environmental and physical requirements.

In this phase was study the climatic conditions of Madrid (1981-2010) to determine the thermal comfort requirements (A.E. de M. AEMET. 2012). The hours of shadow and solar gain required were taken from Isopleth's diagram, just to quantify the hours when these strategies were needed in Madrid (Neila González, F.J. 2004). And finally, the isopleth's diagram and shadow mask to have an adequate dimension of the FLS (Olgyay, V. 2006).

Following this it was defined the range of dimension for the shadow systems, modulating the FLS, for a window of 1.10 x 1.10 m. With the results it was make a visualization study, with the maximum, minimum of the shadow elements over the window hole, and taking advantage of the window jamb that already exists, like the fig. 2 show.

2.2. Second Phase - Case study.

The model / The room

In order to build a model with real characteristics, it was taken from the PhD work the same model / a place/ a bedroom of the representative typology (A1), a dwellings builder between the 60th – 70th years of Madrid, located in the Ciudad de Los Ángeles neighbourhood, on the 3rd level (of 5 levels), with a south-facing (Cuerda, E., et al., 2014).

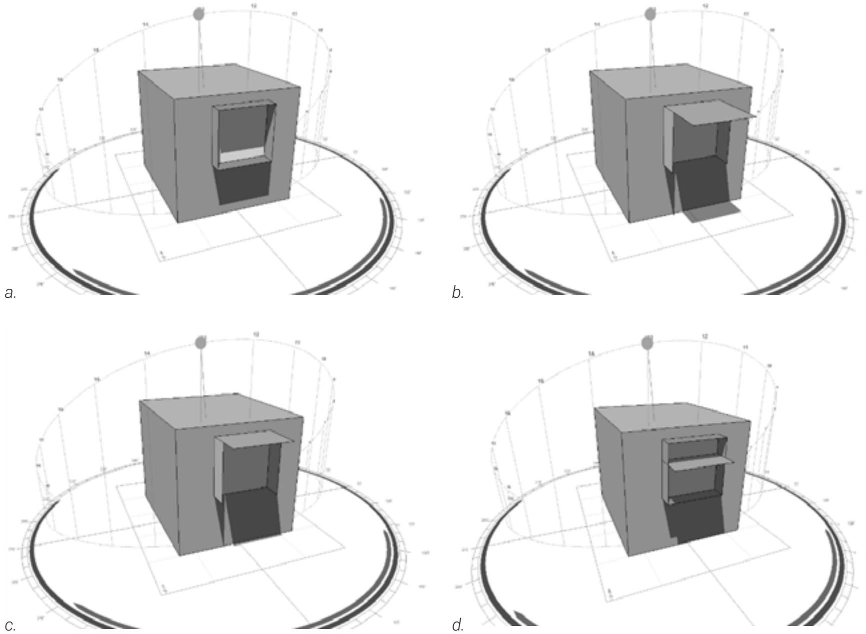
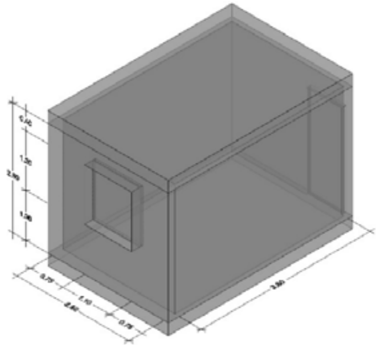


Figure 2. a. Window jamb of 0.40 m; b. Shadow elements of 1.24 x 0.44 m (maximum dimension); c. Shadow elements of 0.80 x 0.40 m (minimum dimension); d. Light shelf 0.60 + window jamb 0.40 m. Source: (The Author 2016).

a.



b.

Figure 3. a. Case study location in the building. b. Dimensions of the case study. Source: (The Author 2016).

This real case study was recreated with a similar condition that the original, with the same dimensions, and the same reflectance that the original place has, Wall 50%, Floor 20%, Ceiling 80%, Glass window 80% (IESNA. 2000) and for the FLS 97%. As well the thermal parameters, Exterior Wall 0.50W/m2.K, Adiabatic Wall 0.50W/m2.K, Floor 0.29W/m2.K, Ceiling 0.28W/m2.K and Glass window 2.71W/m2.K.

The Light shelves

The systems tested were two type of light shelves and one FLS, all of them located 60 cm below the top of the window. A reference model, a bedroom without light shelf (W), were compared with the alternatives (A), with these characteristics:

3. RESULTS

To apply the methodology defined, the theoretical simulation was carried out to evaluate the daylight behaviour and to estimate the energy consumption. With the thermal and reflectance parameters defined before. Employing Revit 2022 as software to build the model and the alternatives and Employing the Insight plugin to perform the daylighting analysis, and the energy estimation cost.

Buildings use more energy than any other sector, so it stands to reason that measuring energy use in buildings is a key performance indicator. The Energy Use Intensity (EUI) is measure of how much energy a building uses per area over a given

A1: 60 x 110 cm of inclined metal blinds (/), one of the typical solutions for shadow systems.

A2: FLS with a combination of the 30 x 110 cm light shelf and 30 x 110 cm angled blinds (/).

A3: 60 x 110 cm of a metal light shelf.

Figure 4. Alternatives: light shelf and FLS combination. Source: (The Author 2016).

period (kW/m²-yr). A Zero Energy Building or ZEB is a building with an EUI = 0. This indicator is mostly used in previous designs when the project is not yet complete and is precisely valid for making basic estimates.

The illuminance analysis has been carried out for the model geolocated in Madrid and facing south, on June 21 at 2 p.m., with the Perez sky type of sky. And the Energy Use Intensity has been carried out with the same geolocation and orientation. In bout analysis with the thermal and reflectance parameters defined before. The energy configuration is quite basic (the closest to the real case), residential use, one room, with a 24/7 operation schedule, using a gas air conditioning system and central heating with radiators. The utility rates for the EUI estimation were automated rates service, with an electricity rate of $0.125 per kWh and a gas rate of $3.368 per cubic meter.

The model has been assumed as it was used in the PhD work, in both analyses, it is estimated that the construction of the complete building and the context may vary the results, however, we wanted to do it this way with the intention of verifying how the by simply incorporating a shading element, Energy Use Intensity can be reduced, overheating in the glazed area can be avoided, and adequate lighting conditions can be maintained.

Using the Insight software, the percentage of illuminance at 9 a.m., 3 p.m., and the total within the defined range (300 – 3000 lx) was obtained. The summary of the data obtained can be seen in table 1. It can be observed that the total illuminance area percentages are quite similar: 33% (A1), 30% (A2), and 31% (A3). Therefore, with the light shelves raised, there is no significant variability in illuminance, as none of the areas exceed 33% of the total illuminance area. It can also be seen in the images of the total illuminance A2 and A3 how the illuminance decreases in the area near the window, from 6.000 lux to 1.506 – 1.416 lux.

The EUI of each of the models does not vary significantly either, 922 kW/m²-yr (A1), 910 kW/m²-yr (A2) and 903 kW/m²-yr (A3) are obtained, while in W it is obtained 944 kW/m²-yr. Therefore, differences of only 2% (A1) and 5% (A3) are obtained with respect to the W model for the room.

As can be seen in the comparative summary graph figure 5, the illuminance levels decrease at both 9 and 3 pm, as the shape of the light shelves becomes more compact, at the same time the EUI decreases in each model.

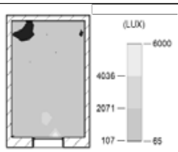
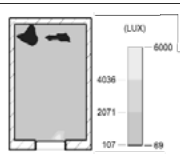
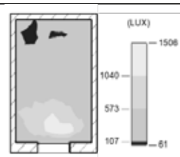
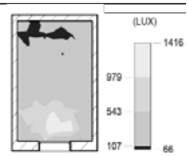
Time	W (%)	A1 (%)	A2 (%)	A3 (%)
9 a.m.	38	33	31	31
15 p.m.	86	79	77	71
Total	38	33	30	31
Image of the total % in lux				

Table 1. Illuminance area percentages. Source: (The Author 2024).

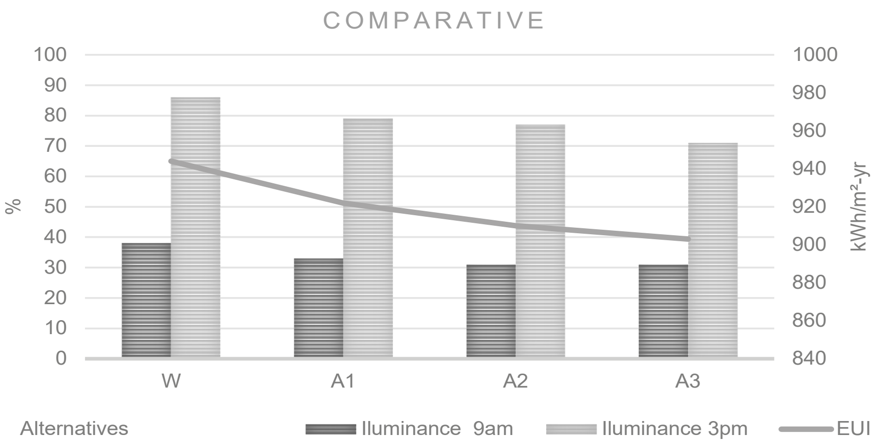


Figure 5. Comparative Summary Graph. Source: (The Author 2024).

4. CONCLUSION

Transitioning from the EUI to the energy cost estimate per square meter per year, for this room we get 84.00 USD/m²-year (A1), 83.10 USD/m²-year (A2), and 82.60 USD/m²-year (A3). In the W model, it is 85.80 USD/m²-year.

In figure 6, the decrease may seem insignificant for a room, but it must be considered that, being a room, the energy savings that could result from replicating this room in the building, and subsequently replicating this representative building typology in the southern neighborhoods of Madrid, have not been considered.

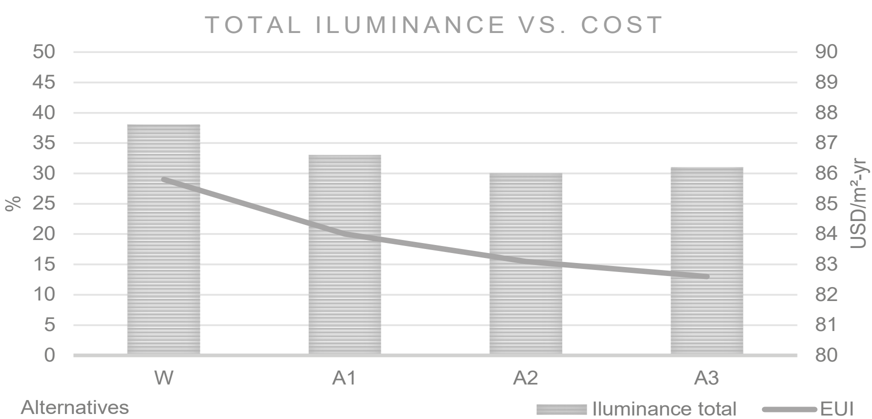


Figure 6. Comparative Graph of Total % of illuminance vs. Energy Cost per square meter per year. Source: (The Author 2024).

In figure 6, it can also be observed that the illuminance percentages obtained between A2 and A3 are quite similar. However, it was noted in table 1, in the total percentage images, that in option A3, the area of low illuminance (66 – 107 lux) increases at the back of the room. Therefore, option A2 is considered to have better performance.

In this regard, the behavior of these systems, especially A2, will continue to be studied to answer some questions that arise from the results. For example: What would be the final savings if the entire building is studied with these study parameters? What happens if the materials of the light shelves are changed? What could happen if the same model or building is geolocated in the north or south of Spain?

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