20th International Conference on Renewable Energies and Power Quality (ICREPQ'22)
Vigo (Spain), 27th to 29th July 2022
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.20, September 2022

Daylighting system based on single-axis polar heliostat

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Abstract. The fight against climate change makes it necessary, among other measures, to improve the energy efficiency of buildings. One way of doing this is to improve the levels of natural lighting inside buildings. In this sense, this paper analyses the possible use of heliostats as natural illuminators in an educational space. For this purpose, a classroom in the Leonardo da Vinci building of the Rabanales Campus of the University of Cordoba (Spain) and an illuminator system based on a single-axis polar heliostat have been reproduced at a scale of 1:15. These devices have been exposed to the same solar irradiance conditions and the illuminance levels registered inside both devices have been compared. It was found that there is an increase in daylighting levels in the recreated classroom ranging from 70.40% to 242.58% compared to the situation without heliostat illuminators. Therefore, it can be concluded that heliostats can play a fundamental role to improve the efficiency of buildings and, therefore, in the fight against climate change.

Key words. Heliostats, Natural lightning, Energy efficiency of buildings, Sustainability, Climate Change.

1. Introduction

The growing need to increase environmental and energy sustainability in buildings (housing, offices, warehouses, etc.) requires the use of solar radiation as a renewable source of energy that can help to lower the carbon footprint, making buildings more efficient and thereby contributing to a more sustainable planet, while enhancing the health and wellbeing of its occupants.

One of the technologies deployed in the use of solar energy in buildings are heliostats. A heliostat is a device consisting of a mirror that follows the path of the sun and aims to maintain the reflection of the solar rays into a fixed direction or point [1]. Therefore, beyond its use in large electricity-generating thermal stations, it can play a significant role in sustainable technological applications in urban environments [2].

One of the possible applications of heliostat in buildings is as illuminators. Electric lighting is the most important source of power consumption in buildings [3]. Consequently, the use of natural lighting elements in buildings reduces the economic costs for the inhabitants, favors a more comfortable environment, has a positive impact on health and improves the energy efficiency of the buildings [4-6]. For these reasons, in recent years, the use of systems based on heliostats to redirect sunlight towards the interior of buildings is increasing [7-11]. In that sense, Kischkoweit [12] presents a general revision of systems that use natural light, which recognise the systems based on heliostats as the most complex. It is therefore necessary to deepen the understanding of the behaviour of heliostats and their possible application as illuminators in buildings.

In this context, this paper presents an analysis of the performance of a heliostatic illuminator (based on the single-axis polar heliostat prototype developed by Torres-Roldan et al. [2,13]) to improve illumination in a classroom at the Campus of Rabanales of the University of Cordoba (Spain).

2. Methodology

The study was conducted in the Leonardo da Vinci building of the University Campus of Rabanales of the University of Cordoba, located in Cordoba (Spain), with latitude 37.85ºN. The roof of the building is sawtooth with glazed vertical surfaces facing North (Fig. 1 and 2). The sloping surfaces face South at an angle of 25º. The light penetrating the building through the roof lights up the upper part of a false ceiling of panels supported on a reticular structure. Aiming to make the best use of this light, some of the plaster panels have been replaced with translucent ones. However, lighting levels, even on clear days, are very insufficient for conducting day to day teaching and professional work (Fig. 3). Consequently, the installation of heliostat illuminators according to the scheme in Fig. 4 may be convenient to improve the building's energy efficiency and working conditions inside. According to the proposed installation scheme, the heliostatic illuminators would redirect the sun's rays through the windows of the sawtooth roof of the building, directing them onto the translucent plates of the false ceiling of the classroom, passing through them and improving the natural lighting in the classroom.

In the present work, a scale evaluation of this proposal is conducted. To this end, scale models of the chosen classroom and the proposed system of heliostatic illuminators have been developed and the increases in the levels of natural lighting thanks to these devices have been analysed.

Fig.1. Roof of Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

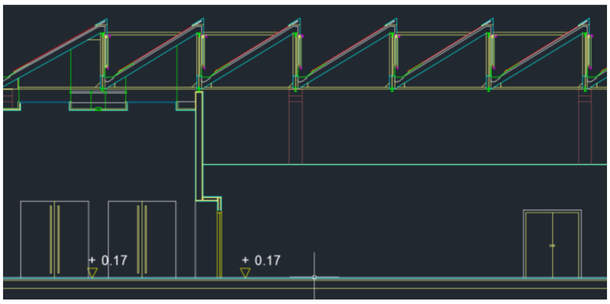


Fig.2. Cross-section of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

Fig.3. False ceilings installed in the classrooms of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

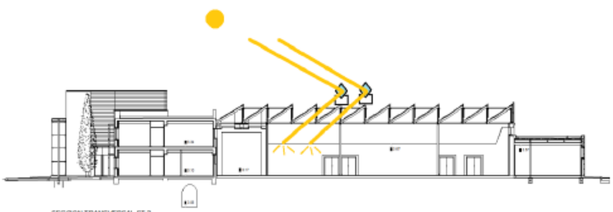


Fig.4. Installation scheme of heliostats as a daylighting element for the classrooms of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

A. Single axis polar heliostat used as illuminator

The proposed daylighting system is based on the single-axis polar heliostat prototype developed by Torres-Roldan et al. [2,13]. This heliostat, unlike commercial ones, is fit both in elevation and azimuth with a single engine. This fact simplifies the control mechanism and reduces the economic cost of the device. Specifically, the device consists of a deformable polygon A’DCBAA’ (Fig. 5) where:

1) AA’ is a fixed rotation axis, parallel to the Earth’s rotation axis.
2) A’D and BA are pieces perpendicular to AA´.
3) DC and CB are bars articulated in the points B, C and D with 1 dof and its movement is restricted to the same plane as the axis AA’.

The mirror of the heliostat (1) is leaning on the DC bar perpendicularly to the A’DCBAA’ plane.

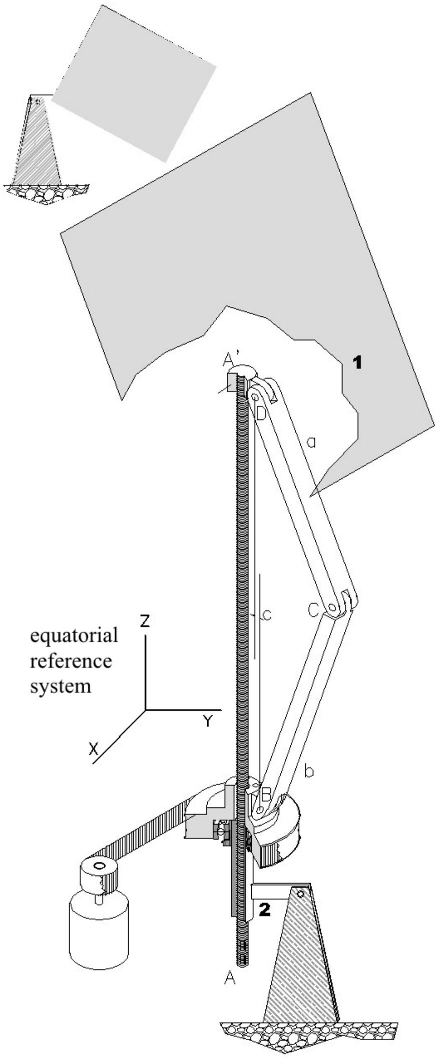


Fig.5. Mechanic scheme of the heliostatic illuminator

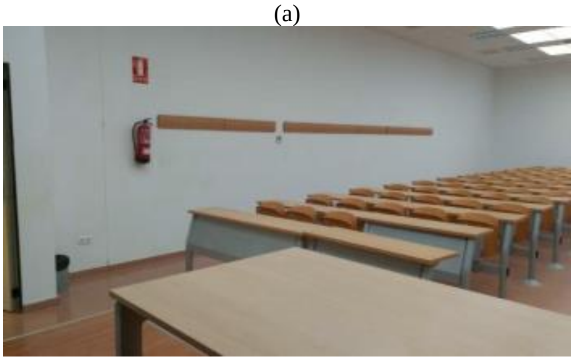
When the AA’ axis rotates, the distance between B and D varies and, consequently, the orientation of the mirror changes. In that way, it is possible to redirect the reflected sunbeams towards a desired point. The control of the engine that makes possible this movement is based on free software and hardware.

B. *Scale Model of the selected classroom*

In order to study the impact that this heliostatic illuminator technology can have on the energy efficiency of buildings, two 1:15 scale models of the B2 classroom in the Leonardo da Vinci building of the Rabanales Campus of the University of Cordoba (Spain) have been built (Fig. 6). The final dimensions of the scale models obtained are 100 x 72 x 60 cm. Likewise, the interior of the classroom has been reproduced with a prominent level of realism to simulate the levels of reflectance of the materials in the classroom (Fig. 7).

Fig.6. External appearance of the 1:15 scale model of the chosen classroom of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

(a)



(b)

Fig.7. Comparison between the interior of the developed model (a) and the real environment (b) of the chosen classroom of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

On the other hand, an illuminance sensor system has been developed for each model. Specifically, it consists of an Arduino MEGA 2560 board based on the ATMEGA2560 microcontroller, a set of TSL 2561 illuminance sensors, an RTC DS1302 real-time clock and an SD module to store the data collected by the sensor circuit. Fig. 8 shows the illuminance sensor layout in each of the scale models.

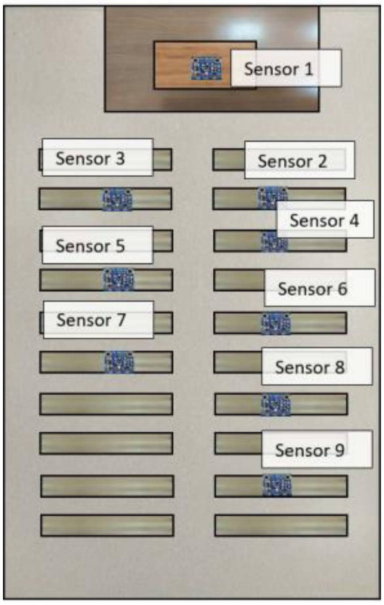


Fig.8. Layout of the TSL2561 sensors inside the 1:15 scale model of the chosen classroom of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

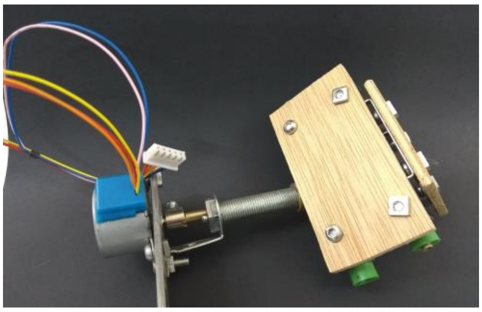


Fig.9. 1:15 Scale model of the single axis polar heliostats

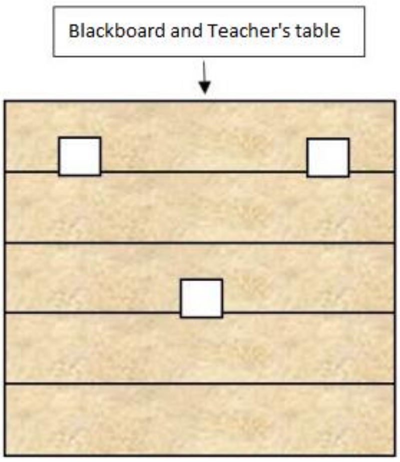


Fig.10. Layout of the 1: 15 scale models of the heliostatic illuminators on the plan view of the chosen classroom of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

Fig.11. Layout of the 1: 15 scale models of the heliostatic illuminators on the roof of the chosen classroom of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

The proposed heliostatic illuminator system has also been built at 1:15 scale. The movement of the primary reflector of the heliostat is also controlled by the Arduino MEGA 2560 board. These heliostats have been installed on the sawtooth of the roof of one of the models with an inclination of 37º corresponding to the latitude of Cordoba (Spain). Fig. 10 and 11 show the arrangement chosen for the heliostats, which has ensured that the natural lighting introduced by the heliostats falls on the first rows of the classroom, closest to the blackboard and the teacher.

3. Results

Once both models were built, they were placed in an area where they were not shaded and with the same orientation as the replicated classroom to ensure that they received similar levels of solar irradiance as the classroom (Fig. 15).

Fig.15. Measurement campaign on the 1:15 scale models of the selected classroom of the Leonardo da Vinci building of the Campus of Rabanales at the University of Córdoba (Spain).

Fig. 16 shows the image of the interior of each of the scale models, captured by two webcams, at the same instant of time and under the same conditions of solar incidence on the outside. It qualitatively demonstrates that the presence of heliostatic technology favours a higher level of light inside the classroom.

Table I shows the average illuminance levels registered by the sensors in each scale model, as well as the increment registered in the case with heliostatic illuminators. Once again, an increase in the illuminance levels is observed for all the sensors distributed in the classroom, being this increase more noticeable in the first rows of the classroom where the students are concentrated due to their proximity to the blackboard and the teacher.

(a) (b)

Fig.16. Qualitative comparative analysis of daylighting levels inside the scale model without heliostat illuminators (a) and the one with heliostat illuminators (b).

Table I. - Quantitative comparative analysis of daylight levels inside the scale models with and without heliostat illuminators.

Sensor	Average Illuminance (lx)		Increase (%)
	Without heliostats	With heliostats	
1	68,9	178,4	158,73
2	70,3	197,3	180,79
3	71,3	213,6	199,71
4	73,9	253,1	242,58
5	76,0	164,5	116,50
6	80,3	181,8	126,22
7	86,2	157,4	82,63
8	87,2	151,5	73,82
9	93,5	159,2	70,40

4. Conclusion

In this work we have presented a heliostatic illuminator system based on the single axis polar heliostat prototype developed by Torres-Roldan et al. [2,13]. In addition, its possible use to illuminate a teaching space with low solar incidence at the University Campus of Rabanales of the University of Cordoba (Spain) has been analysed. To evaluate the behaviour of the proposed system, the classroom has been recreated on two 1:15 scale models, installing the heliostatic illuminator system in only one of them. In this way, exposing both scale models to the same conditions of solar incidence, the levels of natural lighting inside both scale models have been compared. It was found that these levels are considerably higher in the case of the scale model with heliostatic illuminators, with increases ranging from 70.40% to 242.58% compared to the situation without heliostatic illuminators. Heliostat illuminators can therefore improve daylighting conditions inside buildings, reducing daylighting requirements and improving energy efficiency.

Acknowledgement

The authors would like to thank to the Junta de Andalucía and the University of Córdoba (Spain) for its support and funding of the Project "Helio4Learning" by means of "Convocatoria de ayudas a proyectos de I+D+i en el marco del Programa Operativo FEDER Andalucía 2014-2020" (Grant reference: 1380888-R).

References

[1] Han, H., & Kim, J. T. (2010). Application of high-density daylight for indoor illumination. Energy, 35(6), 2654-2666.

[2] Torres-Roldán, M., López-Luque, R. & Varo-Martínez, M. (2016). Assessment of the pointing error of heliostats with a single not polar rotation axis for urban applications. Solar Energy, 137, 281- 289.

[3] Ullah, I., & Shin, S. (2014). Highly concentrated optical fiber-based daylighting systems for multi-floor office buildings. Energy and Buildings, 72, 246-261.

[4] Nicolow, J. (2004). Getting the green light from the sun-The benefits of daylight harvesting. Construction Specifier, 57, 58-65.

[5] Boubekri, M. (2007). Daylight, architecture and people's health. WIT Transactions on Biomedicine and Health, 11, 53-59.

[6] Kim, J. T., & Kim, G. (2010). Overview and new developments in optical daylighting systems for building a healthy indoor environment. Building and Environment, 45(2), 256-269.

[7] Tsangrassoulis, A., Doulos, L., Santamouris, M, Fontoynont, M, Maamari, F, Wilson, M, et al (2005). On the energy efficiency of a prototype hybrid daylighting system. Solar Energy;76(1):56–64.

[8] Ullah, I., & Shin, S. (2012). Heliostat based daylighting system for multi-floor office buildings. In Proc. The 19th Conference on Optoelectronics and Optical Communications (COOC) (pp. 85-86).

[9] González-Pardo, A., Chapa, S. C., Gonzalez-Aguilar, J., & Romero, M. (2013). Optical performance of vertical heliostat fields integrated in building façades for concentrating solar energy uses. Solar Energy, 97, 447-459.

[10] González-Pardo, A., Rodríguez, A., González-Aguilar, J., & Romero, M. (2014). Analysis of solar shading caused by building-integrated Vertical Heliostat Fields. Energy and Buildings, 76, 199-210.

[11] Rosemann, A., Mossman, M. and Whitehead, L. (2008). "Development of a cost-effective solar illumination system to bring natural light into the building core," undefined, vol. 82, no. 4, pp. 302–310, DOI: 10.1016/J.SOLENER.2007.09.003.

[12] Kischkoweit-Lopin, M. (2002). An overview of daylighting systems. Solar Energy, 73, 72-82.

[13] Torres-Roldán, M., López-Luque, R. & Varo-Martínez, M. (2015). Design of an innovative and simplified polar heliostat for integration in buildings and urban environments. Solar Energy, 119, 159- 168.