Experimental Optical Performance of a Nonimaging Fresnel Reflective Concentrator for Building Integration Applications

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Abstract

A transmissive Fresnel reflector has been constructed to match the needs of building integration for concentrating photovoltaic (PV), thermal (T) or hybrid photovoltaic/thermal (PVT) generation. The device concentrates radiation towards a static receiver, in a manner analogous to a lens, by means of an array of mirrors which rotate collectively. All rotation axes are coplanar and parallel.

The system concentrates solar radiation up to 20 suns. The movable parts of the structure are the mirrors. The mechanism to track the Sun has been performed through connecting rods, one in each line of reflectors and another one connected to a single linear driver and to the strips of mirrors.

The angular rotation of the mirrors is equal in all of them, and at the same time is the half than the angular movement of the Sun. To transfer this relation a very simple reduction gear is used. The tracking control is done by means of 2 photo resistances and a shadowing plate connected to a Peripheral Interface Controller (PIC) microchip.

The research aims to characterize the optical performance of a concentrating system capable of being integrated in buildings adequately.

1 Introduction

At present, use of solar concentrator systems is mainly limited to large installations with devices of considerable size: solar power towers, parabolic-trough concentrators, parabolic-dish concentrators and large Fresnel concentrators with 2-axes tracking systems-are clear examples.

Most of the manufacturers of solar concentrators are focusing their developments to these huge solar plants and there are very few examples in the market, of middle or small scale installations. The medium or small scale installations would allow for a feasible integration of the concentrated solar systems into the buildings, leading to more distributed energy production scheme. However, the restrictions and requirements of the integration constitute really hard drawbacks which must be overcome by means of big changes in the design and conception of these new small scale solar concentrated systems.

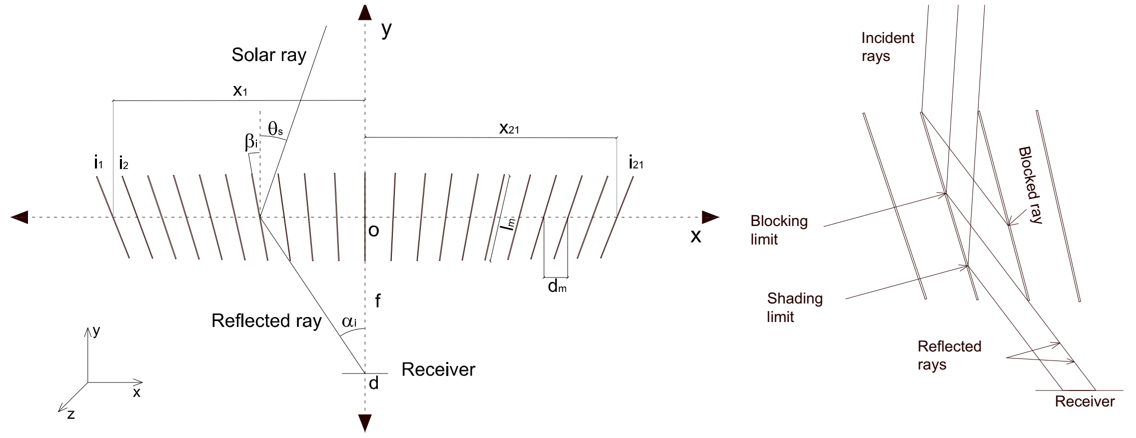
Buildings Integrated Concentrating Photovoltaics (BICPV) need to be designed in such a way that minimises-costs, allowing them to be competitive with the standard flat panel technology, which manufacturing costs are falling continually. BICPV systems may be installed either on the building façade or on the rooftops (which may be flat or sloped) leading to different visual impacts. Depending on the type of device, the system may be integrated in such a way that it is either unseen, or plays some role in the architectural aesthetic or that it constitutes in itself an architectural concept.

The objective of this research is to characterize the optical performance of a concentrating system capable of being integrated in buildings adequately.

2 Design Characteristics

The most important parameters and characteristics involved in the system design are briefly described in figures 1a and 1b.

Fig. 1 shows the position of the end points of the mirrors for a specific configuration. The positions of the upper and lower limits of the shaded and blocked rays (respectively) have been calculated for each mirror using a geometric algorithm (Fig. 1b). The rays that fall on the mirror to the left of the shading limit are shaded and those that fall to the right of the blocking limit are blocked. These limits have been calculated using an algorithm based on the projection and intersection of three lines on the XY plane. The 3 lines are: the line along which the mirror lies, the line followed by the extreme incident rays, and the line followed by the reflection of these rays. Once the algorithm converges, the size and position of the focal area on the receiver are also obtained.



a) b)

Fig. 1. a) Schematic showing parameters used in the mathematical model. b) shading and blocking effects

3 Mechanical structure

The movable parts of the structure are the reflectors. The mechanism to track the Sun has been performed through connecting rods, one in each line of reflectors and another one connected to a single linear driver and to the strips of mirrors.

The angular rotation of the mirrors is equal in all of them, and at the same time is the half than the angular movement of the Sun. To transfer this relation a very simple reduction gear is used (see Fig 2.). The tracking control is done by means of 2 photo resistances and a shadowing plate connected to a Peripheral Interface Controller (PIC) microchip.

The system has been fixed on a moving support to vary and to position in order to experimentally simulate a wider number of situations.

Taking into account the symmetry of the results with respect to the central axis of the concentrator obtained in previous analysis [1-3], it was decided to build a concentrator containing one half of the mirrors. This highly simplified the assembling, reduced the mechanical load and made easier the whole experiment.

In this configuration, reflector strips rotate horizontally. It keeps track of the solar altitude in its daily path. Its incorporation as an architectural element could replace a constructive element such a vertical lattice arrangement. In addition to solar generation, there is an illumination control inside the building. Receivers can be placed at the façade or in any location akin to facilitate the interconnection of different facilities.

Fig. 2. Details of the mechanical structure of the tracking system.

4 Optical performance

The objective of the optical experiment is to determine the spatial concentrating profile produce by the concentrator depending on the angle of solar incidence. The procedure used in this work for characterizing the Fresnel reflector is based on the use of a CCD camera taking pictures of the light intensity profile over a white painted target, which operates like a lambertian reflector, placed at the focus of the optical concentrator (see Fig. 3). The characteristics of the CCD camera must be adequately selected to assure a linear response with respect to the light intensity and a good sensitivity of the CCD sensor. According to these requirements, the chosen camera is the model AVT Marlin manufactured by Allied vision Ltd.

Fig. 3. Photograph of the experimental set-up. It can be seen on the right the lap top controlling the CCD camera (on the left). In front of the camera, the image shows the concentrator focusing incoming radiation towards the lambertian surface.

Ray tracing simulated results obtained in [4] have been used as a reference for comparison. An aspect to consider, as described in detail in section 2, is that the experimental testing device is constructed with the half of the mirrors included in the referred research. The simulated concentration angular patterns obtained for a design analogous to Fig. 1 are shown in the next graph:

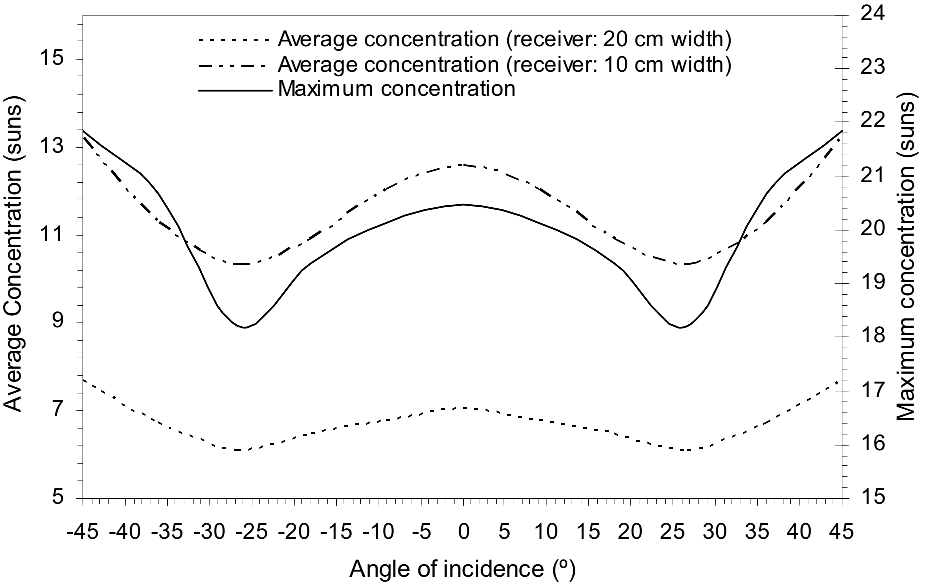


Fig. 4. Representation of the average and maximum concentrations as a function of angle of solar incidence.

Concentrating profiles have been experimentally characterized under five different angles of solar incidence, to cover the whole designed behaviour of the system. In all cases, the concentrator was oriented to azimuth 0º and reflectors tracked the solar altitude (Fig. 5). In the studied configuration the solar altitude corresponds to the angle of incidence because the reference system has been considered to be at the central axis (where the lambertian reflector or the collector are placed). The central axis is parallel to the horizontal roof. The five angles are: 12.7º, 15º, 20º, 37.7º and 56.8 º.

The reflectors installed were standard commercial mirrors, having lower average reflectivity than other better reflectors such as white glass mirrors . The measured average reflectivity of the mirrors was 80.4 %, without dusty effects. When comparing with the theoretical results, it is necessary to consider reductions concerning to the reflectivity and the number of mirrors. The reflectivity in the simulations was set to be 1 and the number of mirrors in the experiment is the half than in the theoretic system.

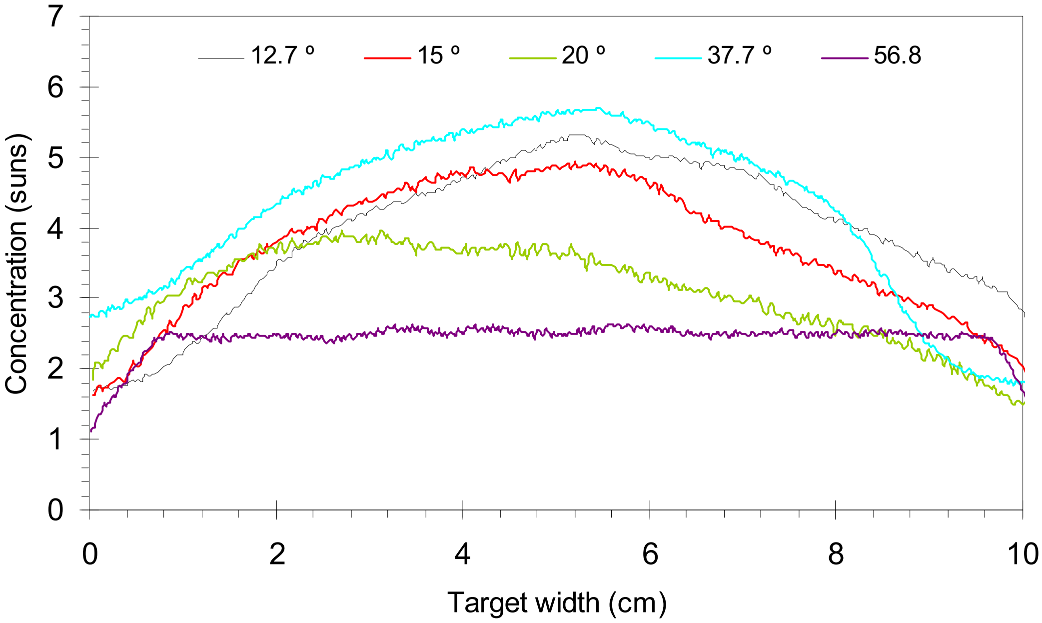


Fig. 5. Representation of the average and maximum concentrations as a function of angle of solar incidence.

It can be observed that the angle in which the concentrator better works is 37.7º and in the range from 0º to 45º the lowest concentration achieved when the angle of the incident rays is 20º. These values directly are in agreement with graph trends describe in Fig. 4.

In the case of higher angles of solar altitude, what happens is that only work mirrors placed at the top of the system, because shading and blocking effects make useless mirrors situated at the bottom. This performance gets worse when the solar altitude is increases.

Comparing a specific value, for instance the maximum concentration under 37.7 º, the theoretic and the experimental value are 20.8 suns and 5.67 suns. Minimizing the simulated result because of the number of mirrors and the real reflectivity, it is fund that the maximum real concentration is 32% lower than the expected value. This difference can be explained attending to tracking errors, dust over the reflectors and structural off-sets.

The illumination pattern achieved in the target length reached a quite uniform distribution, as it can be seen in the next figure. This uniformity is not dependent upon the angle of incidence and the concentrating pattern produced over the target width.

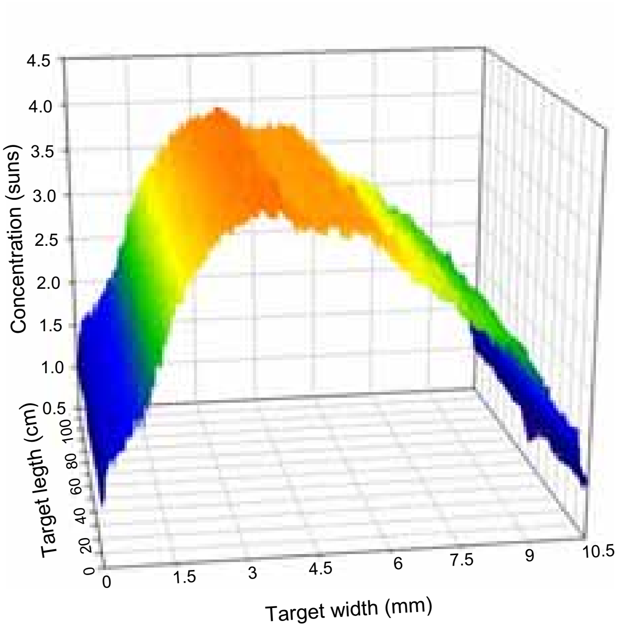


Fig. 6. 3D concentrating profile under an angle of solar incidence of 20º.

4 Conclusions

An optical experimental characterization of a Fresnel reflective concentrator has been performed. The system was designed to be suitable from a building integration point of view. The studied configuration was though to replace a constructive element widely used in recent years, the building lattice. Lattice is currently used to control illumination in the building interior space. The analyzed device, in addition produces a concentrated beam useful for producing thermal energy, electrical energy or both simultaneously.

A lambertian target has been placed at the focus of the optical system, and by treating the photographs taken under different angles of solar incidence the spatial concentrating profiles have been determined. The general graph trends are in agreement with the theoretical values, observing discrepancies of around 30% between the simulated and the experimental maximum concentration ratios.

Acknowledgements

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References

[1] Chemisana D, Ibáñez M, Barrau J. Comparison of Fresnel concentrators for building integrated photovoltaics. Energy Conversion and Management 2009; 50: 1079-1084.

[2] Chemisana D, Ibáñez M. Linear Fresnel concentrators for building integrated applications. Energy Conversion and Management 2010; 51: 1476-1480.

[3] Tripanagnostopoulus Y, Siabekou Ch, Tonui JK. The Fresnel lens concept for solar control of buildings. Solar Energy2007; 81: 661-675.

[4] Chemisana D, Rosell J.I. Design and Optical Performance of a Nonimaging Fresnel Reflective Concentrator for Building Integration Applications. Energy Conversion and Management, submitted in 2009.