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Optical performance of vertical heliostat fields integrated in building façades for concentrating solar energy uses

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Abstract

One way for integrating concentrating solar energy systems based on central receiver technology in metropolitan areas consists of using building façades as frame for installing a heliostat reflector field that reflects radiation coming from the sun towards a common area where receiver is located. This work analyzes the optical performance of vertical solar field concept. It provides the effect of several geometric parameters such as receiver height, separation between heliostat edges, and different building typologies on the hourly and annual optical efficiency along the year including the contribution of different optical efficiency factors such as shadowing, blocking, cosine, and spillage.

The optical efficiency of a vertical heliostat field was found to be mainly controlled by shadowing, cosine and spillage factors. The field reaches the maximum overall optical efficiency during spring and winter at noon time and the minimum ones during the summer season mainly due to shadowing factor. Results obtained for best configurations are comparable to those ones reached by traditional horizontal field arrangements, what supports the feasibility of the vertical heliostats field concept as a CSP building integrated facility.

Keywords: Vertical heliostat field; Central receiver system; Distributed power generation; Optical analysis; Building façade

1. Introduction

One of the short and mid-term priorities for energy policies in the world concerns distributed electricity and heat generation and energy management in metropolitan areas, and access to robust and reliable energy in isolated rural regions. In this context, the contribution of technologies based on concentrating solar power may be relevant in the development of polygeneration and small distributed systems. Indeed, the higher the starting temperature of the polygeneration system, the greater the number of potential electricity generation stages and opportunities for heat usage will be. Besides the overall efficiency of the process will increase, if energy losses in the processing chain are properly controlled. The concentrating solar power allows achieving these high temperatures.

In the last three decades several theoretical works have analyzed this idea; McDonald (1986) proposed a parabolic disk based solar–fossil fuel cogeneration plant led to supply the demand of small urban and/or industrial centers, Romero et al. (1999) described the MIUS (Modular Integrated Utility systems) concept combining polygeneration systems using central receiver systems (CRS) equipped with a gas turbine. More recently, Buck and Friedmann (2007) analyzed a central receiver plant in trigeneration systems. In practice, the European Union has supported the development of hybrid solar–gas CR plants with a turbine of 100 kW through the project SOLHYCO (2006–2010) and recently the Aora Solar company (http://aora-solar.com)

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Table 1
Classification of concentrated systems applied to building integration (references and classification from Chemisana, 2011). Notation: NTS, non-tracking systems; TAT/ESM, two-axis tracking and entire system movement; OAT/ESM, one-axis tracking and entire system movement.

	1-High concentration C > 100×	2-Medium concentration (100× > C > 10×)	3-Low concentration (C < 10×)
Systems	(1.1) Point focus Fresnel systems (TAT/ESM) (Anstey et al., 2007) (Vasylyev and Vasylyev, 2002). (1.2) Cassegrain optics concentrators, (Gordon and Feuermann, 2005) (TAT/ESM) (Gordon and Feuermann, 2005) (Winston and Gordon, 2005) (Horne et al., 2006) (1.3) Light guide solar optics concentrators (TAT/ESM) (Morgan Solar, 2013)	(2.1) Parabolic trough concentrators (OAT/ESM) (Bernardo et al., 2008) (Luque et al., 1997) (2.2) Linear Fresnel reflectors (TAT/ESM) (Pujol et al., 2006) (Mills and Morrison, 1997) (Chemisana et al., 2009) (2.3) Linear Fresnel lenses (TAT/ESM; OAT/ESM) (O'Neill et al., 1990) (Kritchman et al., 1979)	(3.1) V-Trough (NTS) (Tabor, 1958) (Fraidenraich and Almeida, 1991) (Muñoz et al., 2010) (3.2) CPC-Compound parabolic concentrators (NTS) (Almonacid et al., 1987) (Mallick et al., 2004) (3.3) Fluorescent concentrators (Currie et al., 2008), quantum dot concentrators (Barnham et al., 2000) and holographic concentrators (NTS) (Magarinos and Coleman, 1981)
Advantage	High electricity conversion efficiency	(2.3) Splitting the beam from the diffuse solar radiation Internal building lighting control feasibility (2.3) Optical and structural cost effectiveness	Low-cost Concentrate direct and diffuse radiation Flexible aesthetical façade
Disadvantage	Require highly accurate tracking	Overheating of linear CPVs systems	(3.1 and 3.2) Interior lighting reduction
Integration	Flat roofs	(2.1) flat roofs, (2.2 and 2.3) flat or tilted roofs and façades	Static systems without sun tracking. At any building envelope location

sells a solar/combustion hybrid CRS plant using similar electric power. Simultaneously, new concepts have been proposed in the field of CR concentrating solar power plants based on small area heliostats (from 1 to 7 m^2), such as eSolar (esolar.com) or BrigthSource Energy (www.brightsourceenergy.com) companies, which allow great modularity, not necessarily aimed at managing low thermal capacities (less than 10 MW_{th}).

Modularity concept makes possible to integrate CSP technologies in metropolitan areas. So far there are initiatives for installation in commercial buildings, such as Wilson Solar Power in the U.S. (www.wilsonsolarpower.com), which proposes using the malls roofs to this purpose. This approach follows a route traced by solar thermal and solar photovoltaics and, more recently, concentrating photovoltaic (Chemisana, 2011) or concentrating solar parabolic trough and Fresnel technologies.

Until now most of implementations of solar fields for concentrating solar power plants (CSP) have not been architectonically integrated yet. For example, small aperture parabolic troughs (Petrakis et al., 2009), linear Fresnel or heliostat fields (González et al., 2010; Wilson Solarpower, 2013) are basically located on top of a large and flat roof and they not form part of the structure of the building. A literature survey reveals that main efforts to design different configurations of integrated concentrating solar systems are related to PV. Table 1 summarizes an overview on potential integration of concentrating photovoltaics (CPV) in buildings (Chemisana, 2011).

Other building integration solutions have been deeply analyzed, particularly those related to ready-to-use façade integration (some examples are illustrated in Fig. 1). According to this evolution, it may be expected to continue solar technologies integration in buildings by incorporating new features that combine passive functions (for instance, in the energy management and lightning) and aesthetic roles, from the architectural point of view.

The present paper analyzes optical performances related to a new approach for integration concentrating solar facilities in metropolitan areas. Fig. 2 illustrates this concept, named vertical reflector field or vertical heliostat field (VHF) (González et al., 2011), which consists of a central receiver concentrating solar facility using South-oriented building façades as frame for installing the heliostats. Radiation coming from the sun is reflected and redirected by the heliostats towards a receiver placed in front of the solar field. In adittion, vertical solar field might provide an elegant way to withstand visual impact associated to glazing due to sunlight reflection from large glass-covered façades. Annexed spaces required for power generation, thermal storage and/or control system are supposed to be located nearby the tower.

2. Vertical heliostat field

2.1. System description

It is assumed that a vertical heliostat field is installed on a south building façade located in the Region of Madrid, a highly populated area in center of Spain, at 40°N. Heliostat field is composed by 196 1-m^2 square heliostats with a reflectivity of 0.90. Optical error, which includes errors related to heliostat tracking, mirror curvature and reflecting surface imperfections, was set to 2.6 mrad according to typical values from CSP power plants already working such as PS10 (Monterreal et al., 1997). Among the different