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A method to evaluate the adaptability of photovoltaic energy on urban façades

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Abstract

Solar simulation and evaluation tools are essential for the design of novel energy and environmental strategies. To date, a number published studies in this area focused on the analysis of flat roofs and small urban areas. This paper presents a method, based on Geographic Information Systems (GIS), for defining the potential of photovoltaic solar energy over urban façades. The method enables the generation of 3D solar maps from two standard data sources, namely cadastral cartography and data on solar irradiance registered by the Spanish State Meteorological Agency (AEMET, for its initials in Spanish).

A series of charts have been generated relating the urban and solar geometries as a result of the numerical model. The charts permit the study of the optimal parameters for the photovoltaic integration over façades. In addition, a study conducted over a representative urban area of Madrid is discussed as an example of the applicability of the discussed methodology.

Finally, the adequacy of the Spanish Technical Edification Code (CTE, for its initials in Spanish), defining thresholds regarding the usability of photovoltaic energy, has been tested both theoretically and through the case study. Our study concludes that this regulation hinders the architectural integration of photovoltaic devices given the strict usability thresholds adopted.

Keywords: Solar radiation; Irradiation on façades; Shading factor; Buildings integration photovoltaic

1. Introduction

Building-Integrated Photovoltaics (BIPV) represent an energetically and environmentally recognised strategy with a promising future (Caamaño, 2000; Oliver and Jackson, 2001; IAE, 2002; SEUS, 2010). It is one of the priorities for the European Union to achieve energy efficiency in buildings (directive 31/2010/UE). Specific photovoltaic systems offer many possibilities for an improved architectural integration thanks to the correct combination of design and technology (semi-transparencies, colours, etc.), as well as the possible synergetic effects between functionalities such as solar protection, glare protection and the bioclimatic effects of natural ventilation (Martín, 2012). Still, in addition to issues related to grid parity and the necessary consumption model (EPIA, 2011; ASIF, 2011), photovoltaic systems should still provide the necessary consumer confidence in order to become a constructive element within the buildings themselves.

In urban areas, it is estimated that façades comprise 60–80% of building surfaces (Esclapés, 2012). Despite this fact, a number of studies on the architectural integration of

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Nomenclature

A_{usable}	usable façade area (m^2)
tw	track width (m)
tw_s	solar track width (m)
B	direct irradiance (W h/m^2)
B_o	extra-atmospheric irradiance (W h/m^2)
D	diffuse irradiance (W h/m^2)
D_c	circumsolar diffuse irradiance (W h/m^2)
D_i	isotropic diffuse irradiance (W h/m^2)
E	produced energy (Kw)
F_h	height factor on façade
F_{usable}	façade usable percentage area (%)
G	global irradiance (W h/m^2)
h_o	obstruction angle (°)
h_{oh}	obstruction hour angle (°)
h_{sun}	height of the sunlit façade (m)
h_{shade}	height of the shading façade (m)
LOI	losses due orientation and inclination (W h/m^2)
LS	losses due to shading (W h/m^2)
P_{usable}	potential, usable façade (binary coefficient)
I	insolation (h)
α	angle of orientation of the photovoltaic sensor (°)
β	angle of inclination of the photovoltaic sensor (°)
ϕ	latitude (°)
γ	correcting solar angle (°)
γ_s	height or elevation, solar coordinate (°)
ψ_s	azimuth, solar coordinate (°)

solar energy have largely focused on flat roofs (Wiginton et al., 2010; Cellura et al., 2012; Orioli and Di Gangi, 2013; Hachem et al., 2012; Celik et al., 2009; Cheng et al., 2006; Garrido et al., 1994; Pelland and Poissant, 2007; Escolano, 2004; Pellegrino et al., 2008). In order to encourage the architectural integration of photovoltaic energy on façades, this article considers a simple procedure to rapidly determine its applicability within large urban areas, based on inputs readily available from standard data sources, namely cadastre survey and meteorological records.

A key aspect of the problem resides in the shading of the façades, which makes the estimation of solar irradiance particularly difficult. There are many computational models for this estimation over partially shaded surfaces (Tregenza and Sharples, 1993; Tregenza and Wilson, 2011; Robinson and Stone, 2004; Drif et al., 2008; Mardaljevic and Rylatt, 2003; Quachning and Hanitsh, 1998), these models differ mainly in the computation of the diffuse component of radiation (Hay, 1979; Muneer, 2004; Perez et al., 1990; Gueymard, 1987). Some of these equations have been implemented in software tools such as Radiance (Mardaljevic and Rylatt, 2003) or Townscope (Teller and Azar, 2001). These equations allow to perform studies on an urban area for any period of time. The main limitation of such equations is that they require importing a 3D virtual model previously generated with CAD (Computer Assisted Design), which makes the study of wide urban areas limited. Alternatively, automatic data processing based on 2D Geographical Information Systems (GIS), generally based on raster, have been proposed to address larger urban areas (Carneiro et al., 2008; Rylatt et al., 2001; Nguyena and Pearceb, 2012).

The present article describes an intermediate 2,5D GIS based vector model that directly relates the solar irradiance with the urban geometry, further allowing a solar analysis of the façades of large urban surfaces. As initial inputs, this model use a vector a vector cadastral database, typically providing the outline and number of floors of buildings, and solar irradiance data recorded by the Spanish State Meteorological Agency (AEMET). The validation of this model has been performed through the comparison of results with the solar simulation software Townscope.

Given the potential of this methodology and with the aim of defining the concept of usable surface area, this work has adopted the description of current Spanish legislation for the architectural integration of photovoltaic systems (Technical Code for Edification, CTE). This allowed us to use the method as a tool for the analysis and revision of the current regulation.

The discussed method still has an international scope of applicability, as it relies on standard data (historical data on weather and cadastral cartography databases). Its country specific dimension is related to building regulation parameters that should be adapted if the model was to be used outside Spain. Considering these, our method aims to be a survey tool for solar simulation, with the capability of generating large solar maps and demonstrating the potential of photovoltaic architectural integration on façades in large urban areas.

The present article is organised in eight sections. Sections 2–4 present the development of the method (parametric model for urban geometries, insolation, solar irradiance calculation and energy losses). Section 5 then summarizes the usability thresholds fixed by the technical building standards for photovoltaic energy in Spain. Section 6 outlines the implementation of the method within a GIS, emphasising the assumptions that were adopted so as to provide all required geometric variables required by our model. Based on these, Section 7 presents and discusses theoretical irradiance charts derived from the method and an application of the GIS tool to a case study in Madrid. The last section outlines the conclusions with a special interest in the practical effects of the technical standards adopted in Spain.