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Solar energy potential on roofs and facades in an urban landscape

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Abstract

A solar 3D urban model was developed for the calculation and visualisation of the solar energy potential of buildings, integrating the potential of roofs with that of facades. To assess this potential, a digital surface model (DSM) of the urban region was built from LiDAR data and a solar radiation model based on climatic observations was applied. A shadow algorithm was developed in order to calculate shadow maps and sky view factor both for roofs and facades at once. Direct and diffuse solar radiation was then obtained for each point on the ground, roof and facades with a spatial resolution of about 1 m and a time resolution of 1 h. This method was applied to a case study of the Campus of the University of Lisbon. Results show that the irradiation reaching facades is lower than that of the roofs, as expected, but due to the large areas concerned, facades have a significant impact on the solar potential of buildings in an urban area.

Keywords: Urban landscape; Facades; Sky view factor; Solar radiation; Photovoltaic potential

1. Introduction

The successful deployment of photovoltaic (PV) systems in urban environments, where a significant fraction of the energy demand is located, requires the assessment of local PV potential. This depends directly from the local exposure to sunlight, which changes drastically in the urban landscape. In fact, the irradiation striking a spot over a time period varies according to global, local, spatial, temporal, and meteorological factors. An ideal solar potential model has to take all these factors into account. At the city or even more local scale, the use of geo-referenced urban fabric models associated to solar radiation tools to determine the incoming solar radiation is particularly interesting since it allows modelling inclined surfaces, while taking into account shadows from surrounding buildings or other topographic features. Several solar radiation models have been implemented in proprietary as well as in open source software. Well known examples are the ArcGis Solar Analyst (Fu and Rich, 1999) and the GRASS r.sun (Hofierka and Šúri, 2002). These models can work on a raster based geographic information layer, allowing consideration of spatially changing attributes in the radiation model, such as inclination, orientation and latitude over large regions. They have been successfully used to determine the solar potential of an entire region based on a digital terrain model (Hofierka and Kanuk, 2009) at the municipal level (Nguyen and Pearce, 2012) and the potential in a city department based on roof geometry (Brito et al., 2012).

However, a cityscape includes also the non negligible surfaces of facades, which can be used for collecting sunlight. In modern cities, facades are much larger than roofs, are mostly devoid of building infrastructure (chimneys, elevator engines, ventilators) and usually present better

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maintenance conditions for PV panels since vertical surfaces do not accumulate so much dust and are seldom covered by snow in the winter. Furthermore, the European Directive 2010/31/EU establishes that from 2020 onwards, all new buildings will have to be Nearly Zero Energy Buildings, requiring that the local energy production has to cover the local energy demand, which will entail the need for much larger PV areas than those available on standard apartment block roofs (Scognamiglio and Røstvik, 2012). In addition, vertical PV facades will produce relatively more power in winter and less in summer, and more in the early and late hours of the day, when the sun is lower in the sky. Typically, a building will have four, or at least two, exposed facades with opposite orientations and therefore the different solar facades of a building will produce at maximum power at different hours of the day. This effect will lead to a widening of the peak of power production through the day/year which allows a better adjustment to the load diagram, thus enabling significant savings regarding electricity storage and/or fossil fuel based backup power reduction.

The above mentioned solar radiation models are generally not able to consider the facades of the buildings since the facades correspond to (vertical) discontinuities in the 2.5D digital elevation models they are based on. In such a model, vertical facades are represented as more or less inclined surfaces or just disappear all together, not allowing any trustworthy calculation on them. Yet Carneiro (2011) refers an approach for the facades using 3D Urban Models, this requires the pre-existence of such models and involves separated calculation just for facades. One ought to mention that windows are, of course, common features in facades but are not necessarily impeditive of the installation of solar panels, in particular as BIPV (building integrated photovoltaics) become easily accessible (Jelle et al., 2012).

The algorithm presented below calculates the solar irradiation in every point on the roofs, ground and facades, for every hour of the typical meteorological year and thus enables the assessment of the impact of facades on the PV peak power. Furthermore, it only requires the input of a geo-referenced regular height grid describing the relief of an urban site and containing all shadow relevant objects, a digital surface model (DSM), and it simultaneously calculates diffuse, direct, and global solar irradiance for all points of the cityscape at any instant of time, allowing for the computation of the irradiation over any period of time, from 1 h to 1 year. Since such height grids in urban environments can be nowadays easily obtained by airborne Light Detection And Ranging (LiDAR) surveys, the developed algorithm was optimised for this type of 3D data.

2. Method

The algorithm, named SOL, starts from the LiDAR data of the urban region. Together with solar radiation and solar astronomical models it calculates the global solar irradiance for a set of points located on roofs, ground and facades with a spatial resolution of about 1 m and a time resolution of 1 h. The whole process is summarised in the workflows shown in Figs. 1 and 2. Although the algorithm simultaneously tackles roofs, ground and facades, for the sake of a better understanding, the workflow of roofs and ground processing (Fig. 1) and for facades (Fig. 2) are shown separately. In the following four sections inputs and outputs will be described as well as each of the most relevant steps.

2.1. Urban relief model

Urban environments are geometrically characterised as having strong variable heights and steep slopes caused by the existence of buildings of different height limited by vertical walls and separated by more or less narrow streets. In terms of solar energy assessment one can classify urban objects as ground, buildings and trees. The ground is not only interesting for solar potential study when planning the location of structures yet to be built, but its relief (natural or manmade) influences also the solar potential of other objects due to cast shadows and sight obstructions, especially in urban environments with high amplitude terrain. Trees are considered in this study as solid shadow casting objects and their own solar potential will not be considered. Buildings are actually the most relevant urban objects from the solar energy point of view. They have to be both considered as shadow casting objects, over other buildings and over the ground, and as solar collectors. Buildings are composed by roof and facades whose geometric complexity has an influence in the local PV potential. The three kinds of urban objects are considerably well depicted in airborne LiDAR data. Although some details on facades, such as balconies, are not detected in this kind of data due to the view geometry of the sensor, the simplification done in this study of considering the most exterior facade of the building as a vertical planar surface does not reduce significantly the scope of the conclusions due to the relative high spatial density of 1 m and the local scale of the study. All facades that are far from being vertical are treated either as inclined roofs, for outwards slope, or as vertical facades in the rare case of inwards slope.

LiDAR data caught from an airborne platform (plane or helicopter) are a very dense source of height information. They are originally captured in parallel strips along the platform trajectory by emitting an infrared laser beam that is reflected on the ground. The return of each pulse reflected from the ground or from the objects on the ground allows determining the pulse time of flight that can be transformed in distance between emitter and reflecting point. Associated with positioning and navigation data from a GNSS/IMU instrument, installed on the platform, and with the actual emitting angle of the pulse, the 3D coordinates of each reflecting point can be determined.