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Potential increase of solar irradiation and its influence on PV facades inside an urban canyon by increasing the ground-albedo

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ABSTRACT

Due to the large demand for electricity in cities, photovoltaic (PV) installations inside the urban environment will increase in the near future. It is known that the yield of PV systems on facades can be increased by increasing the ground-albedo. White surfaces are also proposed for urban heat island mitigation. Thus, increasing the ground-albedo inside the urban environment has multiple advantages. However, solar potential simulation tools are not yet designed for simulating in an urban canyon. The ground-reflected irradiance is either neglected or the known approximation is applied. The potential contribution of ground-reflected irradiance to the electricity production of PV facades in an urban canyon is not yet investigated. Therefore, measurements were made in a street canyon to show the potential effect of an increased ground-albedo on the power output of south-facing, vertically mounted PV modules and the total in-plane irradiance. Further, the potential increase of PV yield on a reference point was estimated, when asphalt on an approximately 15 m wide street canyon was replaced with a highly reflective concrete and an albedo of 0.5. For the latter case, at a wall point 12 m above ground and with a ground view factor of 0.16, it was found that during an eleven days reference period in August 2016, in Vienna, the PV yield increases by 7.3%.

1. Introduction

Today, many governments strive to increase the use of renewable energies, particularly photovoltaics (PV). Given that most electricity is consumed in cities, it is proposed that PV systems will play a more important role in urban environments in the future. Decentralised systems can then provide electricity close to where it is consumed (Fechner et al., 2016; IEA, 2014; Krawietz et al., 2016). In Vienna, for example, the city council already addressed those topics and developed strategies to increase the amount of PV installations in the city (Dvorak, 2016).

In the past, several institutions have created tools to estimate the solar potential of residential areas (Freitas et al., 2015). In early and simple solar potential estimations only roofs were considered (Freitas et al., 2015). The urban solar potential algorithm SOL was one of the first algorithms to address the solar potential on walls in addition to roofs. However, ground reflections are neglected in SOL (Redweik et al., 2013). Only more recently have tools been developed that include the ground-reflected irradiance on facades, e.g. SEBE (Solar Energy on Building Envelope) (Lindberg et al., 2015).

Usually, the ground-reflected irradiance is estimated by the term $1/2\,\rho\,G\,(1-\cos\beta)$, where ρ is the albedo, β is the tilt of the receiving plane and G is the global horizontal irradiance. This approach assumes an isotropic reflecting and infinitely large ground surface and is argued to be sufficiently accurate (Ineichen et al., 1990). Nevertheless, the authors of this paper argue that this approach overestimates the contribution of ground-reflected irradiance to the total irradiance on facades inside an urban canyon. The obvious reason is that the ground view factor is significantly limited inside an urban canyon, which is inconsistent with the assumption of an infinitely large ground area.

Previous studies regarding the effect of ground-albedo on the performance of PV modules focus on either the spectral effects of albedo or the effect of snow (Andrews and Pearce, 2013, 2012; Brennan et al., 2014). Additional potential PV yield due to increasing ground-albedo has not yet been addressed.

In the meantime, urban climatologists have been researching methods to mitigate urban heat island effects. Adding white surfaces to cities is one of many suggested methods to reduce the heat island effect

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in urban environments (Mohajerani et al., 2017; Santamouris, 2014; Taha, 1997). Technological developments on reflective pavements and their effects are discussed in Qin (2015a), Santamouris (2013). Positive and negative effects of reflective pavements inside urban canyons are discussed as well. Examples include their effect on cooling and heating loads in buildings (Yaghoobian and Kleissl, 2012) and their effect on the thermal and visual comfort of pedestrians (Rosso et al., 2016). Preliminary results of a recent case study within the PVOPTI-Ray project also show that increasing the ground-albedo up to 0.56 does not significantly effect human thermal comfort (Revesz et al., 2017).

Considering the reported benefits of an increased albedo of the ground surface to the urban climate, the shortcoming in irradiance estimation for predicting the PV power output in an urban environment, as described before, leads to two important questions: How much irradiance is realistically reflected from the ground onto a wall inside an urban canyon? And how much does increasing the ground-albedo increase the solar irradiation and thus increase the yield of PV facades inside an urban canyon? This work attempts to address these questions.

For this purpose, gains were measured at the University of Natural Resources and Life Sciences (BOKU) in Vienna during August 2016. In addition, the potential effect of replacing asphalt with highly reflecting concrete on the total irradiance inside an urban canyon was estimated.

2. Methods

Measurements were made to investigate the potential increase of electricity production of vertically mounted PV modules due to an increase in ground reflectance. Those measurements validate a simple method to estimate the ground-reflected irradiance on a wall point. In addition, simulations were performed assuming a more reflective ground surface material. Whenever irradiance was estimated the diffuse sky irradiance and the irradiance reflected from the ground or the building facade (except for the glass facade) were assumed to be isotropic.

2.1. Measurements inside an urban canyon

The area between two buildings of the University of Natural Resources and Life Sciences (BOKU) in Vienna, Austria, was used for measurements. Fig. 1 shows the surrounding of the measurement site. The location "C" marks the position of measurement equipment inside the street canyon. Facing south, three vertical multicrystalline silicon PV modules and one vertical irradiance (G_v) sensor were mounted. Further, the horizontal irradiance (G_h), ambient air temperature (T_a), and module temperature (T_m) on each of the PV modules' backside were measured. Fig. 2 shows the installed equipment, which was mounted about 3.5 m above ground. BP solar SX 10 M modules were used and their short circuit current (I_{sc}) was measured. The vertical and horizontal irradiance sensors were EMS 11 which are silicon diode irradiance sensors with a calibration error of max. 7% (EMS Brno, 2016) and are expected to have a similar spectral response as the PV modules. The data-logger for those two irradiance sensors had a resolution corresponding to about 1.4 W m^{-2} and 1.8 W m^{-2} respectively. Within this work the position of the vertical irradiance sensor is referred to as "wall point".

On the roof of Schwackhöfer-Haus the global horizontal irradiance (G) and the direct normal irradiance (DNI) were measured, using a EKO MS-802 pyranometer and Kipp & Zonen CHP-1 pyrheliometer, respectively. Their position is marked in Fig. 1 with "R". The measurements of both devices were compared to measurements within the ARAD network (Olefs et al., 2016). The diffuse horizontal irradiance (DHI) component was estimated from G and DNI. All values were measured at 5 s intervals and aggregated by the data-loggers to record a 1-minute mean value. For the evaluation of the gain the data was further aggregated to 5-minute mean values.

The ground-albedo was measured 80 cm above the ground using two silicon diode irradiance sensors of type EMS 11 (by EMS Brno), one oriented upwards and one downwards (see Fig. 2(a)). In this configuration the influence of the equipment itself on the reflected radiation is negligible, while providing a good estimate of ground-albedo of a brighter surface with limited surface area. Further, Apogee SN-500 were used to determine the albedo of the non-glass facade and for occasional measurement of incoming irradiance onto the centre point of the plastered facade, opposite of the PV modules.

Measurements were performed for a period of one month in August 2016. During the measurements, the "low ground-albedo" condition was for asphalt in between the two buildings with ρ = 0.13. Several times, "high ground-albedo" measurements were made by placing

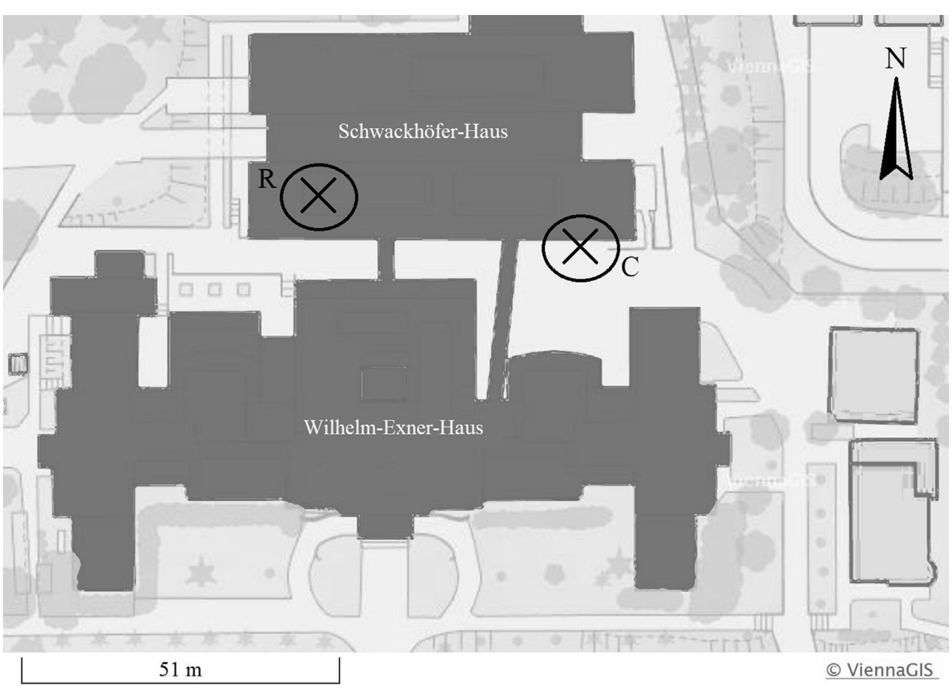

Fig. 1. Measurement site at University of Natural Resources and Life Sciences (BOKU) in Vienna between Schwackhöfer-Haus and Wilhelm-Exner-Haus (lat. 48.237 N, lon. 16.332 E). The location of the PV modules and the vertical irradiance sensor in the canyon is labelled with "C" and the location for the irradiance measurement on the roof is labelled with "R". Source of base-map: www.wien.gv.at/viennagis/ .