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Solar energy potential of roofs on urban level based on building typology

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ABSTRACT

This paper describes a methodology developed for determining the solar energy potential of large scale urban areas based on building typology. As a result of the method, the solar yield at the roof can be determined, taking into account shading obstructions and assembly distances. In the model the utilized as well as the collected energy is calculated, taking into account the energy losses by unused energy, energy delivery and energy storage.

A main pillar of the method is the building typology that classifies buildings according to roof characteristics and other geometric factors influencing the domestic hot water demand. For each building type the following outputs are calculated: the solar yield, the maximum potential energy that can be produced by roof-integrated photovoltaic panels, the maximum potential energy that can be covered by solar thermal collectors and the realistic energy produced by solar thermal collectors taking into account economical considerations.

Based on the model, urban-level solar potential estimations can be carried out with the use of digital cartography at low costs. Such an estimation is presented in a case study for Debrecen, Hungary, but the model can be adapted to any settlement with different building types or climatic conditions.

1. Introduction and objectives

According to the EPBD Recast [1] in Europe all new buildings have to be built as nearly zero energy buildings (NZEB) and utilize on-site renewable energy after 2020. The directive does not explicitly say that it has to be applied for existing buildings as well, but includes a general rule since 2006 that for buildings that undergo a major renovation, the same rules have to be applied as for new buildings. In a densely built urban area solar energy can widely be applied on-site unlike other renewable energy sources. As a consequence solar energy will have a higher importance in the near future.

The solar energy potential of roofs on urban level has been a major pillar of renewable energy strategies and sustainable energy action plans on urban, on national or on even broader level. Internationally recognized initiatives have had the objective to develop processes, methods and tools capable of assisting cities in developing a long term urban energy strategy (e.g. Solar Heating & Cooling Programme established by the International Energy Agency [2] or the EnergyCity project supported by the Intelligent Energy for Europe programme [3]).

In practice, for estimating the solar energy potential in an urban setting different approaches are applied from simple estimations to airborne LIDAR (Light Detection and Ranging) technologies. With the latter method buildings can be automatically scanned and a 3D model of the city can be built up. Previous works on the topic are discussed in Section 2 in more detail.

The disadvantage of the mentioned technologies is that they still require a significant amount of manual processing work, otherwise significant errors remain. Furthermore, these technologies can be implemented at rather significant software and equipment costs that are many times not acceptable by decision makers.

This paper describes an alternative method for determining the solar energy potential of urban areas based on building typology. Once a building typology is set-up urban level estimations can be carried out without the above mentioned airborne technology based data, only digital cartography is required and no more manual work than by the above described methods. For municipalities

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with limited financial resources this method is a viable option. The most important added value of this method is that not only the solar yield at the roof can be determined, but also the utilized energy taking into account the energy losses by unused energy, energy transport and storage within the building. None of the above mentioned methods can provide such results. On the other hand it is also to be noted that this method is applicable only on urban level but not for single buildings.

Nomenclature

NZEB	nearly zero energy building
EPBD	energy performance of buildings directive
DHW	domestic hot water
LIDAR	light detection and ranging
SCOP	seasonal coefficient of performance
$A_{\text{building,av}}$	the average building area of the building type $\left[\text{m}^2\right]$
$A_{\text{building,tot}}$	the total area of the building type $\left[\text{m}^2\right]$
A_{coll}	area of the collector $\left[\text{m}^2\right]$
A_{PV}	area of the PV module $\left[\text{m}^2\right]$
c_w	the specific heat of water [kJ/(kg K)]
f_i	monthly share of solar energy
FR	the energy ratio which can be possibly used by the collector
FR′/FR	the section of the energy which can possibly be removed from the collector
h_{int}	internal height of the building type room [m]
I_{MPP0}	nominal current [A]
$k_1, k_2, K_{\text{dir}}(50^\circ)$	collector data, given by the manufacturer
n_{building}	total number of buildings of the building type
n_{dwelling}	average number of dwellings of the building type
n_{floor}	average number of floors of the building type
$n_{\text{inhabitant}}$	number of inhabitants
n_{mod}	number of modules
P_P	nominal peak power [W]
Q_{CIRC}	circulation heat losses of the DHW system $\left[\text{kWh}/\left(\text{m}^2\,\text{a}\right)\right]$
Q_{coll}	the energy produced by solar collectors $\left[\text{kWh}/\left(\text{m}^2\,\text{a}\right)\right]$
Q_{demand}	total heat demand of the DHW system $\left[\text{kWh}/\left(\text{m}^2\,\text{a}\right)\right]$
Q_{DHW}	DHW demand $\left[\text{kWh}/\left(\text{m}^2\,\text{a}\right)\right]$
Q_s	the monthly incoming solar energy $\left[\text{kWh}/\left(\text{m}^2\,\text{month}\right)\right]$
Q_{STOR}	storage heat losses of the DHW system $\left[\text{kWh}/\left(\text{m}^2\,\text{a}\right)\right]$
q_t	losses of the DHW tank [W/K]
T_{cw}	the temperature of the cold water, the yearly average of the location [°C]
T_{DHW}	the temperature of DHW [°C]
$T_{i,e}$	the monthly average external temperature [°C]
T_{ref}	the reference temperature of the water [°C]
V_{DHW}	DHW demand per inhabitant [l/(person a)]
V_t	volume of the DHW tank $\left[\text{m}^3\right]$
$V_{t,\text{a}} = 0.7 \cdot V_t$	active storage capacity of the DHW tank $\left[\text{m}^3\right]$
$V_{t,\text{opt}} = 0.075 \cdot A_{\text{coll}}$	the optimal DHW tank capacity $\left[\text{m}^3\right]$
$V_{t,\text{u}} = 0.3 \cdot V_t$	unused storage capacity of the DHW tank $\left[\text{m}^3\right]$
U_{MPP0}	nominal voltage [V]
$x_{\text{building}}; y_{\text{building}}$	overall dimensions of the average building of the building type [m]
X_{c1}/X	the temperature correction factor for solar collectors
X_{c2}/X	the DHW storage correction factor for solar collectors
α	temperature coefficient short-circuit current [%/K]
β	temperature coefficient open-circuit voltage [%/K]
η_0	the optical efficiency of the collector
η_{INV}	efficiency of the inverter
ρ_w	the density of water $\left[\text{kg/m}^3\right]$
τ_m	the number of hours in a month [h/month]

2. State-of-the-art

In practice, different approaches have been applied for estimating the solar energy potential in an urban setting. A state-of-the-art review has been carried out in [4] comparing 21 computational solar radiation models ranging from simple 2D visualization and solar constant methods, to more sophisticated 3D representation and web-based solar maps. A common element of the analyzed tools is that they mostly focus on the solar yield only, the demand side and the solar distribution system characteristics are not taken into account.

For very precise calculations the most appropriate option is 3D modeling and building simulation. A good example to mention is the DIVA tool developed for daylighting and solar energy performance evaluations of individual buildings and urban landscapes [5].

A 3D model of a test zone in the city of Compiègne is described in [6]. It includes a roof typology of Picardy France region for the evaluation of the local solar energy potential. In this study, identical roof inclination is assumed for all pitched roofs. Although this method does not require aerial measurements, the 3D modeling and simulation methods process every single building in the analyzed area requiring unrealistic efforts on a larger scale. It is also possible to introduce significant simplifications in the input data, but in this case it is reasonable to consider the application of simplified methods instead.

Another option is the application of remote sensing, such as aerial measurements. The Bologna SolarCity application estimates the amount of solar energy available on the roofs of buildings in the city of Bologna [7]. The model is based on two high-precision products, the Digital Terrain Model (DTM) and the Digital Surface Model (DSM). However, as explained by the paper [8] the model has certain limitations: The achieved data resolution (2 to 10 m) was too low, causing errors in the results. At this resolution, small roof devices and installations cannot be detected, even the precision of building contours is questionable.

These problems can be improved by the application of models with higher resolution LIDAR (Light Detection and Ranging) applications. Commonly LIDAR data are used to generate digital elevation models (DEM) [9,10]. Processing the LIDAR data leads to the recognition and the modeling of objects, such as individual buildings and, on a larger scale, to 3D city modeling [11–13]. As a consequence, this technology and knowledge is also used for the analysis of solar potentials of roofs [14]. In [15] a field test is described that locates roof areas with high solar potential and predicts the solar yield per m^2 based on data referring to 13 buildings within the urban campus of the University of Cologne, Germany. The problems of the airborne methods are already described in Section 1.

Another possible approach to estimate the solar energy potential of a certain building stock is bottom-up modeling based on building typology and statistics.

Building typologies are widely applied for modeling the energy consumption and retrofit options of building stocks. In such methods the buildings are usually classified in terms of their representativity, geographical distribution, size, material composition