Sustainable Cities and Society 37 (2018) 189–202

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Evaluation of the potential of solar energy utilization in Famagusta, Cyprus

Mahmoud Ouria*, Harun Sevinc

Faculty of Architecture, Eastern Mediterranean University, Famagusta, North Cyprus via Mersin 10, Turkey

ARTICLE INFO

Keywords:
SHC
Solar Energy
Urban Area
Climatic Factors
GIS
Famagusta
Ladybug

ABSTRACT

This paper investigates the use of solar energy in urban areas as exemplified by Famagusta in Cyprus. All the climatic and geographic factors were analyzed to compute the solar energy potential for Famagusta City. Next, the solar energy utilization potential in the Social Housing Complex (SHC) district of Famagusta was investigated in detail. The effective parameters of solar energy, including climatic factors, radiation types, geographic parameters, orientation techniques, height to width ratio (H/W) and landscape analysis, were evaluated based on Famagusta using DuffieBeckman and Stephenson's cousin methods. The rate of irradiation solar energy was analyzed for horizontal, vertical and tilted surfaces of blocks and routes in the SHC in Famagusta City using Ladybug for Rhino and MS Excel software programs. The results of this study showed that the district landscape is very poor from a solar energy point of view. While there is a great source of solar energy producing extreme heat, the solar energy is not utilized properly, as the district is not walkable, especially in the afternoons. It is recommended that pedestrians be helped by adding hardwood trees, by using solar panels to generate renewable power for lightning, and by using permeable materials for pavements.

1. Introduction

Considering the aims of sustainable development, renewable energy wins over fossil or nuclear energy sources in regard to the limitations of resources and the negative impacts on environmental factors in sustainable cities (Shukla, Sudhakara, & Prashant, 2017; Shukla, Manish, & Barve, 2017).

The role of urban energy consumption is significant because the majority of populations already live in urban areas or cities (United Nations Secretariat, 2012) and (Amadoa & Poggi, 2014). To become climate-neutral is a far-fetched goal that many municipalities have decided to adhere to, while there is little to no experience available for implementing local renewable energy resources on an urban scale.

Solar radiation data are the best source of information for estimating the average incident radiation necessary for the proper design and assessment of solar energy conversion systems (Shukla, Rangnekar, & Sudhakar, 2015a; Shukla, Rangnekar, & Sudhakar, 2015b). The solar potential of urban areas corresponding to their various local and geographical features needs to be measured and estimated accordingly (Jakhrani, Othman, Samo, & Kamboh, 2012), (Boehmea, Berger, & Tobias, 2015) and (Shukla et al., 2015a; Shukla et al., 2015b). To maximize active and passive solar heating, production of photovoltaic electricity, or daylighting, is required to quantify the potential of building materials, such as façades, streets and roofs (Lagaris, 2012) and (Shukla, Sudhakar, & Prashant, 2016). Building materials should be evaluated by simulations to estimate the solar irradiation and illuminance they absorb, reflect and transmit (Paulescu, Paulescu, Gravila, & Badescu, 2013) and (Sailor, Georgescu, Milne, & Hart, 2015).

Solar energy is important in cities because it preserves the natural environment economically and safely (Shukla, Sudhakara et al., 2017; Shukla, Manish et al., 2017) and guarantees a healthy society (Ouria & Sevinc, 2016). This paper evaluates the effective factors of solar energy that influence energy consumption and public activities in cities, in particular the case study of Famagusta.

The main objective of this study is the evaluation of solar effects in cities, especially in Famagusta City. The study focused on the solar urban conditions of the Social Housing Complex (SHC) district of Famagusta. Quantitative and comparative methods have been used to analyze orientation techniques, H/W ratio and landscape of routes and blocks. However, existing methodologies, including albedo computation, were applied to support criticism of the current district design of Famagusta City.

Famagusta City and the SHC district have low and moderate density characteristics, respectively, and were selected as case studies to evaluate their solar radiation, geographic and climatic conditions. The solar energy potential of Famagusta has been numerically and graphically modeled using quantitative methods in Microsoft Excel and Ladybug for Grasshopper.

Solar irradiation is calculated analytically for Famagusta City as a case study because there is no radiation measure available in the

* Corresponding author.
E-mail addresses: ouria@email.com (M. Ouria), harun.sevinc@emu.edu.tr (H. Sevinc).

https://doi.org/10.1016/j.scs.2017.10.036
Received 24 December 2016; Received in revised form 29 October 2017; Accepted 30 October 2017
Available online 21 November 2017
2210-6707/

weather file as input to Ladybug. The output of the analytical calculation has been fed as input to Ladybug using MS Excel and Elements converter. The value of sky density quantified for the Gen Cumulative Sky model of Famagusta City has been inputted to calculate yearly radiation in Ladybug using isotropic equations 16, 19 and 20. Finally, this paper recommends some alternatives to optimize the use of solar energy in Famagusta in Cyprus.

2. Solar theory and geometry

Solar energy analysis processes include four essential steps (Paulescu et al., 2013) and (Ouria, Akçay, & Azami, 2016):

- Analysis of the solar radiation on the latitude
- Analysis of climatic and geographic factors
- Analysis of site geometry
- Analysis of materials/context

Solar irradiance is the total beam flux density descending on a surface which is perpendicular with the radiation angle (β) with respect to the horizontal plane (Paulescu et al., 2013), (Steinhilber, Beer, & Frohlich, 2009). The sun rises and sets from different points in the sky (the horizon) at different times of the year. It moves across the sky along different paths. Measuring altitude and azimuth is essential to analyzing the sun's path. Altitude is the angular distance above the horizon measured perpendicularly to the horizon. It has a maximum value of 90° at the zenith, which is the point overhead. Azimuth is the angular distance measured along the horizon in a clockwise direction, as shown in Fig. 1. The number of degrees along the horizon corresponds to the compass direction (Paulescu et al., 2013) and (Jin You, 2017).

There are three parameters to measuring solar radiation in sites: Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and Global Horizontal Irradiance (GHI) (Cogliani, 2014), (Shukla et al., 2015a; Shukla et al., 2015b). Direct Solar Radiation or Direct Normal Irradiance (DNI) is the quantity of received solar radiation per unit area. The area of surface is perpendicular to the sun beams hitting directly. DNI is the maximum rate of radiation that can be measured (Paulescu et al., 2013) and (Cogliani, 2014).

Diffuse Solar Radiation or Diffuse Horizontal Irradiance (DHI) is the amount of the radiation scattered by dust, aerosols and particles (Rajput & Sudhakar, 2013). DHI has no unique or special direction (Cogliani, 2014). Global Solar Radiation or Global Horizontal Irradiance (GHI) is the total rate of diffuse and direct solar radiation, which means the sum of the received and scattered radiation on the horizontal surface (Cogliani, 2014), (Paulescu & Badescu, 2013) and (Shukla et al., 2015a; Shukla et al., 2015b). Fig. 2 shows a graphical representation of DHI and DNI.

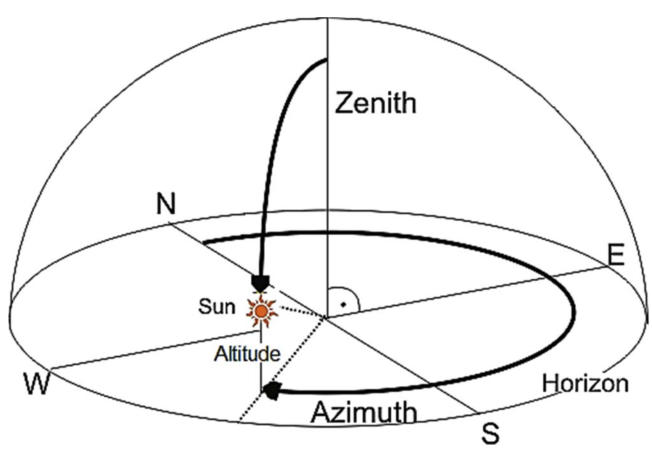

Fig. 1. Zenith, Altitude and Azimuth.

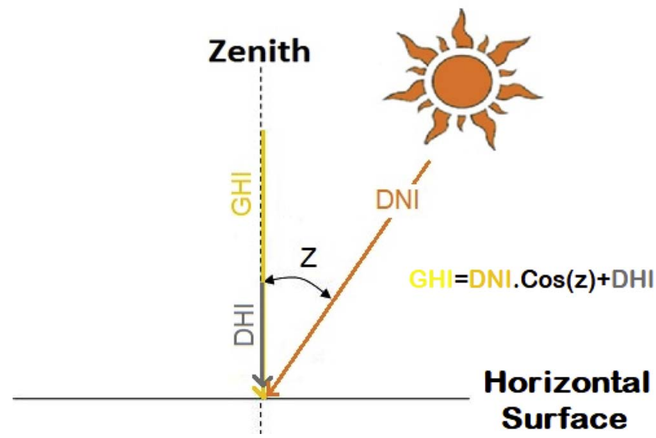

Fig. 2. Global, Direct and Diffused radiation.

The climate (temperature, humidity and pressure) of different regions is bound to four geographic aspects: altitude, sea level, latitude, and direction of prevailing winds.

Location is the most important factor in solar urban design. An inappropriate site selection leads the most discreetly outlined solar system to failure. Therefore, appropriate attention to solar geometry is very important (Cooper, 1969). There are two main parameters, namely, the declination angle (δ) and the sun height/altitude/radiation angle (β), required to describe the relative locations of Earth and sun (Paulescu & Badescu, 2013).

The angular position of the sun at the solar noon is shown by the declination angle with respect to the equator in Fig. 3. The angle varies between −23.45° on December 21 (winter solstice) and +23.45° on June 21 (summer solstice).

South-facing façades are the ideal orientation for living areas in northern hemispheres. Poor orientation can cause overheating in summer, creating a greenhouse effect at the wrong time of the year. Therefore, the best orientation should be selected. Living spaces with access to the winter sun with south-facing outdoor living areas will have optimum use of the sun's natural heat and lighting (Montavon, 2010).

The value of solar energy varies depending on atmospheric and climatic factors. Global solar radiation includes direct and diffuse radiation (NASA, 2005), (Gray, Beer, Geller, & Haigh, 2010).

The amount of the extra-terrestrial irradiance (ETR) does not depend on the position of the urban area on the Earth's surface. Fig. 4 illustrates the mechanism of ETR. The maximum ratio of solar energy and cosine effect can be collected on each surface if solar radiation is not being scattered and absorbed by the atmosphere.

The (ETR) insolation per hour equals the insolation on the horizontal surface at the place (Famagusta City in this paper) without the atmospheric effects (Duffie & Beckman, 1980), (van der Hoeven, 2011). It is presented as follows:

$$I_o = I_{sc}\left(1 + 0.034\cos\frac{360(N)}{265.25}\right) \tag{1}$$

and

$$I_{oh} = I_o.\ Cos\theta_z \tag{2}$$

and

$$\mathrm{Cos}\theta_z = \sin\varphi.\ \sin\delta + \cos\varphi.\ \cos\delta.\ \cos\omega \tag{3}$$

where

I_{sc} is (the solar constant) equal to 1366 Wm^{-2};
φ is the latitude angle of Famagusta (35);
ω is the solar time angle as follows;