Sustainable Cities and Society 30 (2017) 118–127

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

Investigating solar energy potential in tropical urban environment: A case study of Dar es Salaam, Tanzania

Kevin Ka-Lun Lau[a,b,c,*], Fredrik Lindberg[c], Erik Johansson[d], Maria Isabel Rasmussen[d], Sofia Thorsson[c]

[a] Institute of Future Cities, The Chinese University of Hong Kong, Hong Kong
[b] Institute of Environment, Energy and Sustainability, The Chinese University of Hong Kong, Hong Kong
[c] Department of Earth Sciences, University of Gothenburg, Sweden
[d] Housing Development and Management, Lund University, Sweden

ARTICLE INFO

Article history:
Received 26 September 2016
Received in revised form 1 December 2016
Accepted 19 January 2017
Available online 25 January 2017

Keywords:
Solar energy potential
Urban morphology
Solar irradiance
Developing countries

ABSTRACT

Solar energy is considered to be an alternative sustainable energy source in the urban environment. The potential of using solar energy in urban areas is highly dependent on urban morphology which affects the level of solar irradiance received by individual buildings. Many studies focus on solar energy potential of building form in urban areas but relatively few studies examine how urban morphology affects solar energy potential of urban neighbourhoods. It leads to inefficient design of neighbourhoods in terms of solar energy potential. The present study investigates the potential of exploiting solar energy in Dar es Salaam, Tanzania by using numerical modelling of solar irradiance on building roofs and façades. It is shown that there is substantial solar irradiance received by building roofs in all four study neighbourhoods and urban morphology has considerable effects on annual solar irradiance. Solar irradiance of different orientations of tilted roofs and façades is subject to seasonality of the solar azimuth angle. It is suggested that such abundant solar energy sources would provide solutions to accommodate the increasing energy demand and to improve living quality in urban areas due to the rapid urbanization of the city.

1. Introduction

Solar energy is widely considered to be a sustainable and readily available energy source in the urban environment. As about 54% of the world's population being resided in urban areas, enormous amount of energy is used and a large proportion of the greenhouse gases are released at the same time. In particular, urban population in developing countries is expected to vastly increase in the next few decades (United Nations, 2014). In Africa, it was estimated that a 1% increase in urbanization leads to a 14% increase in charcoal consumption, in turn leading to increased air pollution and emissions of greenhouse gases and thus a contribution to global warming (World Bank, 2009). It results in the urgent need for the exploitation of solar energy in order to mitigate the impacts of fossil-fuel consumption and improve the living quality of urban areas (Pearce, 2002).

In developing countries in Africa, the use of electricity has been increasing in the last decade. For example, in urban areas of Tanzania, the proportion of urban population having access to electricity has increased 39% in 2005–52% in 2009 (Shkaratan, 2012). In particular, the annual electricity consumption of high-income households is over 360 kW h and is expected to increase due to the rapid economic development in Tanzania (Hosier & Kipondya, 1993). Half of Tanzanian's charcoal is used in Dar es Salaam, mostly for urban household energy, with an increase of 70% in 2009. On the other hand, the limited access to grid electricity in rural areas leads to an overall 6% of the total population having access to grid electricity in Tanzania (Bauner, Sundell, Senyagwa, & Doyle, 2012). Tanzania's electricity generation, which is mainly based on hydropower and natural gas, is however sensitive to variations in precipitation rate and fossil fuel prices and consequently power failures are common. To cope with this, many industries, hotels, shops and private households have installed their own diesel-driven generators, especially in Dar es Salaam (Bauner et al., 2012). This leads to increased emissions of toxic and greenhouse gases and the cost to install and operate these generators is a large burden on the economy. There is thus an enormous demand for more reliable electricity generation which can potentially be accommodated by the exploitation of solar energy in the urban environment.

* Corresponding author at: Institute of Future Cities, The Chinese University of Hong Kong, Shatin, NT, Hong Kong.
E-mail address: kevinlau@cuhk.edu.hk (K.K.-L. Lau).

http://dx.doi.org/10.1016/j.scs.2017.01.010
2210-6707/

One of the problems associated with the exploitation of solar energy in urban areas is the high-rise and compacted urban form which prevents solar radiation from reaching building surfaces (Yun and Steemers, 2009). It reduces solar energy potential since solar irradiance is the most crucial parameter to photovoltaic (PV) systems. Several studies have previously examined the relationship between solar energy potential and urban morphology. Compagnon (2004) quantified the potential of façades and roofs for PV electricity production in Switzerland by numerical simulations of solar irradiance. It was shown that different building layouts with the same density exhibit large variations of solar energy potential on buildings facades, suggesting that solar availability can be increased even for dense urban areas. Cheng et al. (2006) analyzed the effect of urban form and density (in terms of plot ratio) on the PV potential of the building envelope. Vertical randomness in building height is found to be more favourable at lower site coverage since it provides better solar access to building façades. Sarralde et al. (2015) further used a number of descriptors of urban morphology to describe various urban forms which are parametrically analyzed for their corresponding solar energy potential. By modifying specific descriptors of an existing neighbourhood, they found that the availability of solar irradiance of building façades can be increased by 45%. Therefore, careful design of urban neighbourhood is very important to optimizing solar energy potential in urban areas.

A wide range of tools have been developed to simulate solar irradiance at both building and urban scales (Compagnon, 2004; Lindberg, Holmer, & Thorsson, 2008; Šúri et al., 2005, 2007). High-resolution digital surface models (DSM) are used to estimate the availability of solar radiation for extensive areas due to the computational efficiency using 2.5-dimensional raster-based calculations. These models have been widely used to determine solar energy potential for roofs with various geometries (Hofierka & Kanuk, 2009; Nguyen & Pearce, 2012). The recent model developed by Redweik et al. (2013) provides estimations of wall irradiances by calculating diffuse and direct irradiances on ground, roofs and walls for individual hours on a high-resolution DSM.

The present study aims to examine the solar energy potential of different urban settings in Dar es Salaam, Tanzania. Four typical urban settings with different building geometries (buildings height and coverage) are chosen to compare the effect of various urban morphological parameters on the availability of solar radiation on both roofs and façades of buildings. Findings of the present study form a part of the project entitled “Efficient use of land and energy in Dar es Salaam, Tanzania – Urban planning and climate adaptation”, which aims to develop a set of planning recommendations for a sustainable, climate-sensitive urban planning in Dar es Salaam, Tanzania.

2. Methodology

2.1. Study area – Dar es Salaam, Tanzania

Dar es Salaam (6.8°S, 39.3°E), located on the eastern coast of the country, is the largest city of Tanzania. The city is situated on a relatively flat coastal plain which has a gentle slope towards the Indian Ocean. The general climatic conditions in Dar es Salaam are shown in Fig. 1. It has a tropical savanna climate according to the Köppen climate classification with annual mean temperature of 26.0 °C and annual rainfall of about 1000 mm. Pronounced dry period is observed from June to October and rain season is generally in April and May. Dar es Salaam has a population of over four millions in the metropolitan area. The city has experienced rapid urbanization which leading to a nearly doubled population in the last two decades (Brennan & Burton, 2007; Ndetto & Matzarakis, 2015). The annual growth of 4.4% is one of the highest in the world (Ndetto & Matzarakis 2013) and partly due to this an estimated 70% of the city's population live in informal (unplanned) neighbourhoods (UN-Habitat, 2010a).

Dar es Salaam is characterized by a radial structure with settlements along four major roads which all originate from the City Centre. Informal settlements have emerged in between the main roads and in the periphery in a pattern of compact, low-density residential areas. They are settlements developed in unsecure land tenure by organic subdivision of customary land and built outside urban norms. Diversity on dwellers income from middle to very poor is characteristic and in some neighbourhoods formal dwellers live next door to informal dwellers (Rasmussen, 2013). These settlements are mainly as one-storey houses, contributing to urban sprawl and inefficient use of land (Lupala, 2002). High-quality housing is found in the coastal areas north of the City Centre where low-rise and low-density development dominates with higher coverage of vegetation.

Representative study areas of 400 × 400 m from four neigbourhoods with characteristic urban morphology and building types are

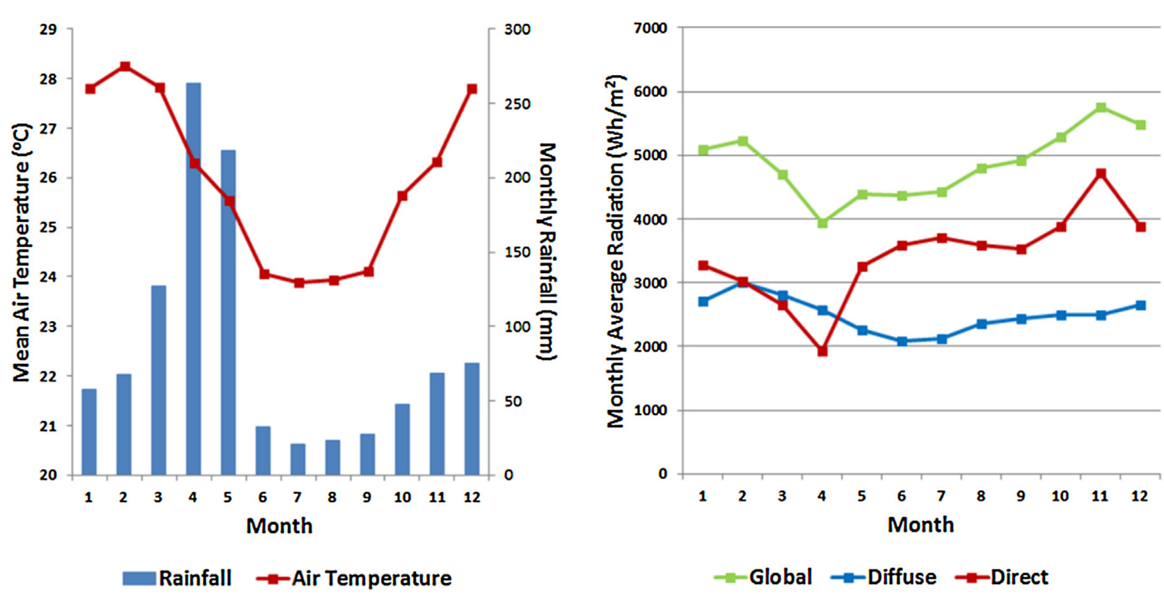

Fig. 1. Monthly distribution of mean air temperature and rainfall (left) and three radiation components (right) of Dar es Salaam.