Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 111 (2015) 225–235

SOLAR ENERGY

www.elsevier.com/locate/solener

Solar potential in urban residential buildings

Dapeng Li, Gang Liu, Shengming Liao *

School of Energy Science and Engineering, Central South University, Changsha 410083, China

Received 13 August 2014; received in revised form 11 October 2014; accepted 30 October 2014
Available online 19 November 2014

Communicated by: Associate Editor Matheos Santamouris

Abstract

This paper investigates solar potential in urban residential buildings at low, medium and high levels of site densities. The effects of three major design parameters (i.e. building aspect ratio, azimuth and site coverage) on solar potential are evaluated, respectively. Solar potential is measured, respectively, by photovoltaic (PV) and solar thermal (ST) yields per building floor space, taking into account the effect of irradiation threshold and incidence angle of the Sun's rays. The results show that increasing building aspect ratio tends raise solar potential, and so does increasing site coverage. Additionally, there is a preferred range of building azimuth, under which PV yield remains at a higher level and out of which PV yield plummets. However, ST yield is affected modestly by building azimuth. This study also reveals that while mutual shadings may decrease PV yield by up to 50% and ST yield by up to 26% in the high-density scenario, it is still possible for PV and ST yields to meet annual electrical and thermal demands of residential buildings, respectively, by selecting appropriate design parameters. Most importantly, a promising result is observed that 6-story buildings in the low-density scenario can achieve net zero energy status when considering combined use of PV and ST.

Keywords: Solar potential; Urban residential building; Photovoltaic; Solar thermal

1. Introduction

Urban residential buildings account for 46% of total building energy consumption in China. This share will further rise as the proportion of urban residents is expected to increase from 53.7% in 2013 to 60% by 2020. To curb this growing trend, one of effective strategies is to transform buildings into energy producer (Hachem et al., 2014) by using, such as, building integrated solar energy technologies. Thus, it is crucial to assess solar potential in urban residential buildings.

Advanced in building integrated solar energy technologies provides the possibility of large-scale solar application in urban buildings. Solar applications, such as photovoltaic (PV) and solar thermal (ST), cannot be only integrated into building envelope (Matuska and Sourek, 2006; Chow et al., 2011; Cerón et al., 2013), but also be used as external separation elements, like balconies and shadings (Zhai et al., 2008). The development of smart grid (Sechilariu et al., 2013; Yan et al., 2013) and seasonal thermal storage (Hui et al., 2011) can solve the spatial and temporary limitations of PV and ST applications. The application potential of solar energy in the stand-alone building has been well studied (Hachem et al., 2011; Urbanetz et al., 2011; Liu, 2014). However, buildings in the urban areas cannot capture as much solar radiation as stand-alone buildings do, due mainly to the adverse effect of mutual shading of buildings. Therefore, there is a need of careful evaluation of solar potential within the urban setting before solar applications are deployed.

* Corresponding author. Tel.: +86 731 88836936.
E-mail address: smliao@csu.edu.cn (S. Liao).

http://dx.doi.org/10.1016/j.solener.2014.10.045
0038-092X/

Nomenclature

A	area (m^2)
C	the percentage of usable area (%)
E	exploitable solar radiation per floor space (kW h/m^2)
f	correction factor (–)
I	annual solar irradiation on the surface (kW h/m^2)
K	incidence angle modifier (–)
m	the number of the surfaces included in the considered domain (–)
S	distance (m)
Y	annual solar yield per floor space (kW h/m^2)

Greek

η	system efficiency (%)
θ	incidence angle of the Sun's rays (°)

Subscripts

e	efficiency
EW	east–west direction
$floor$	floor space
g	global solar irradiation
i	the index of surface
s	surface
SN	south–north direction
t	irradiation threshold

A large number of studies have concentrated on evaluating solar potential on the surfaces of the existing urban buildings in the specific locations (Wiginton et al., 2010; Redweik et al., 2013; Schallenberg-Rodríguez, 2013). However, there is a lack of focusing on new buildings, which can harness solar energy more conveniently and effectively than the existing buildings through detailed considerations during the whole design process. Such studies are of great significance, especially for the area where massive buildings will be constructed.

Urban forms selected in early design phase have a marked impact on final solar potential within the urban zone. But the diversity of urban forms limits the detailed evaluation of their effect. For simplifying urban forms, Martin and March, as cited in Ratti et al. (2003), proposed six generic urban forms, i.e. pavilions, slabs, terraces, terrace-courts, pavilion-courts and courts. The simplified urban forms have been applied to many studies regarding the effect of urban forms on solar potential (Cheng et al., 2006; O'Brien et al., 2010; Kanters and Horvat, 2012). In addition, some optimization algorithms (Kämpf and Robinson, 2010; Kämpf et al., 2010) and comprehensive design methodologies (Hachem et al., 2013) have been proposed to appropriately design urban forms and hence maximize solar energy benefit. However, there is little available general information about the effect of urban forms on solar potential in urban buildings.

This paper aims to investigate and compare solar potential of urban residential buildings under different urban forms affected mainly by building plane form, building azimuth and site coverage. The effect of these three factors on solar potential is evaluated through performing computer simulations at low, medium and high levels of site densities, respectively. Irradiation thresholds and efficiency degradation for PV and ST are taken into account, to accurately evaluate solar potential. Solar potential is measured by annual PV and ST yields per building floor space, respectively, and also by total solar yield per floor space with combining PV and ST. In addition, solar share of building energy demand is presented. This study highlights the great potential of urban buildings to capture solar energy, and provides valuable design guideline for determining proper urban forms in the early design phase. The results from this research can be used as a reference to set more ambitious goals in the process of building sustainable city.

2. Methodology

The research is undertaken using the radiation model based on Perez all-weather model (Perez et al., 1993) and simplified radiosity algorithm (Robinson and Stone, 2004), with sample urban settings and the given weather data as the inputs. This section first defines solar potential, and then introduces the detailed design of urban settings and simulation software.

2.1. Definition of solar potential

This study focuses on solar potential regarding PV and ST, which are represented by annual PV and ST yields per floor space (hereafter PV and ST yields for short), respectively. A simple and general efficiency-based model is used to calculate the yields of PV and ST systems, as displayed by Eq. (1).

$$Y = E \cdot C \cdot \eta \quad (1)$$

where Y, in kW h/m^2, denotes annual solar yield per floor space; E, in kW h/m^2, denotes exploitable solar radiation per floor space; C is the ratio of usable surface areas to total building surface areas that have exploitable solar radiation, here C is considered to be 75% based on the characteristics of real buildings in Beijing (MOHURD, 2010) and the related studies for high-rise residential buildings by Kanters et al. (2014) and Schallenberg-Rodríguez (2013); η denotes system efficiency.