Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 205 (2017) 1157–1164

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Symposium on Heating, Ventilation and Air Conditioning, ISHVAC2017, 19-22 October 2017, Jinan, China

Study on Optimum Tilt Angles of Photovoltaic Shading Systems in Different Climatic Regions of China

Xue Li[a], Jinqing Peng[a,*], Nianping Li[a,**], Meng Wang[a], Chunlei Wang[a1]

[a]*College of Civil Engineering, Hunan Univeisity, Changsha, Hunan410082, China*

Abstract

Photovoltaic shading systems which can act as power generators and external shading devices in buildings have been widely used in recent years. In order to obtain the optimum tilt angles of photovoltaic shading systems in China, this paper develops a simulation model for PV shading systems based on EnergyPlus. Five cities, viz. Harbin, Beijing, Changsha, Kunming, and Guangzhou, are selected as representative cities for different climatic regions in this study. The annual and monthly optimum tilt angles of PV shading systems are investigated and analyzed for maximizing electricity generation and minimizing net energy consumption. The results show that PV shading panels installed with monthly optimum tilt angles are superior to those installed with annual optimum tilt angles. Moreover, PV panels mounted in the south orientation have larger energy-saving potential than those mounted in the east and west for all climatic regions. The conclusions of this study provide a theoretical basis for PV shading systems' design and installation.

Peer-review under responsibility of the scientific committee of the 10th International Symposium on Heating, Ventilation and Air Conditioning.

Keywords: Photovoltaic shading system; Optimum tilt angles; EnergyPlus; Net energy consumption

1. Introduction

Building energy consumption accounts for about 30% of the total energy consumption of the society in China. The daily energy consumption of buildings, consisting of building heating, air conditioning, lighting and other energy consumption, accounts for about 80% of the total energy consumption of buildings [1]. Thus, reducing the energy consumption of buildings is instrumental in relieving energy crisis. In recent years, with the further

*Corresponding author. Tel. +86 731 84846217
** Corresponding author. Tel.+86 731 88822667
E-mail address: linianping@126.com(N. Li), Jallenpeng@gmail.com(J. Peng)

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the 10th International Symposium on Heating, Ventilation and Air Conditioning.
10.1016/j.proeng.2017.10.185

enhancement of people's desire to use renewable energy, photovoltaic shading systems have been widely used. The photovoltaic shading systems can act as power generators as well as external shading devices of buildings, which have a significant potential to reduce the energy consumption of buildings [2]. In addition, photovoltaic shading systems can deliver electricity at lower cost than the grid electricity to end users in certain peak demand niche markets [3].

In recent years, many theoretical and experimental studies have been conducted to maximize the energy benefits of photovoltaic shading systems. Researchers at Hong Kong Polytechnic University [2,4,5] have done a series of studies on the application of photovoltaic shading systems to maximize the power generation and reduce the cooling load of buildings. The mathematical models of photovoltaic electricity generation and building cooling and heating load calculation were developed. Then, the annual electricity generation and shading effects of photovoltaic shading systems installed on the south facing facade was simulated. Finally, the structures of the systems were optimized by taking the total amount of electricity generation and air conditioning energy use as the optimial objective. In addition, they also improved the previous load calculation model and analyzed the energy saving effects of the building facade integrating with photovoltaic shading systems in different orientations. What's more, the calculation and analysis of the heat gain of the external window and wall were also given. Yoo et al. [6,7] examined the performance of a south-facing photovoltaic shading system and suggested that the photovoltaic shading systems should be applied for both generating electricity and providing shading for buildings. Hu et al. [8,9] took a typical office building in Changsha as the research object, a series of models of building energy consumption, heat transfer and electricity generation of photovoltaic shading systems were established, and then the comprehensive energy saving effects of photovoltaic shading systems were analyzed. What`s more, the influences of photovoltaic shading systems on the indoor light environment was investigated.

As for the research on photovoltaic shading systems, previous studies mostly focused on establishing models for simulating building energy consumption and electricity generation such that to optimize the size and installation modes of photovoltaic shading systems. However, there is little information about energy saving potential of photovoltaic shading systems in different climatic regions and with monthly and annual optimum tilt angles. Therefore, the research objectives of this paper are as follows: (1) study on the optimum tilt angles of photovoltaic shading systems with different azimuth angles in different climatic regions; (2) analyze energy saving potential of photovoltaic shading systems installing with monthly and annual optimum tilt angles, respectively.

2. Methods

This paper is based on a typical residential apartment in China. The whole apartment is divided into four zones viz. living room, bedroom, kitchen and bathroom. There were two windows on the each orientation of north, east and west. The south side of the apartment has three windows, and the size of each windows is 1.6m (height)*1.5m(width). The material of window frame is aluminum alloy and the single clear glazing was used as window. The design and heat transfer calculation of the aluminum alloy frame was conducted in THERM. Then, the files generated by THERM were imported in WINDOW. Finally, the IDF file of the whole window, containing the data of the aluminum alloy frame and the single clear glazing, was derived from WINDOW. The IDF file of the whole window was then integrated with the whole building's IDF file and run in EnergyPlus. In addition, a photovoltaic shading panel was mounted on each of the windows in the east, south and west. The size of photovoltaic shading panels is 1.65m (length)*1.0m (width). The light indensity is set to 10 W/m^2, and the lighting control points are set in the middle of each area with an altitude of 0.8 m and the control illumination is set as 400 lux. In addition, both the living room and bedroom are set up a separate split air-conditioning. The Equivalent One-Diode model was adopted to simulate the electricity generation of PV shading systems and the relevant parameters are shown in Table 1.

Table 1. The parameters of Equivalent One-Diode model

Model type	Cell type	Number of cells in series	Active area/ (m^2)	Short circuit current/ （A）	Open circuit voltage/ （V）	Module current at maximum power /（A）	Module voltage at maximum power /（V）
Equivalent One-Diode	Crystalline Silicon	60	1.64	9	38.2	8.5	30.6