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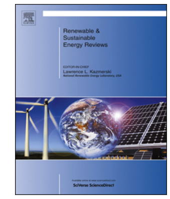

A review of solar radiation on vertically mounted solar surfaces and proper azimuth angles in six Iranian major cities

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ABSTRACT

To meet a part of the buildings energy demands, the buildings' exterior walls are proper places for installation of vertically mounting solar surfaces (VMSS). In this study, using long-term horizontal global solar radiation data and the Klein and Theilacke radiation model, the solar radiation components arrived at VMSS have been assessed at different periods of the year and better surface azimuth angles have been suggested for six Iranian major cities of Isfahan, Karaj, Mashhad, Shiraz, Tabriz and Tehran. The results demonstrate that the beam and global solar radiation on non-azimuth VMSS (south walls) decline significantly in spring and summer compared to those of horizontal surface, though they are higher in most months of autumn and winter. The highest relative gains are in December, while the highest relative losses occur in June and they increase with increasing the latitude. In general, the total radiation on a vertical surface depends on its azimuth angle significantly and for each city its variation with azimuth angle is distinctive. Considering three practical azimuth angles of 0°, 45° and 90°, during the colder period (October-March) the buildings' south walls and during the warmer period (April-September) the east and west walls (i.e. azimuth angles of 90° and -90°) are suitable ones, respectively.

Contents

1. Introduction

In recent decades, the dramatic escalations in global energy demands along with environmental issues have brought some serious concerns regarding the future status of the world. Owing to the rapid growth in world population as well as the needs for a more comfortable life, the energy consumption is increasing enormously [1–3].

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Nomenclature

D	ratio of monthly mean beam radiation on a tilted surface to that on a horizontal surface
G	empirical functions obtained using Eq. (18)
G_{sc}	solar constant (equal to 1367 W/m^2)
$\overline{H}$	monthly mean daily global radiation on a horizontal surface (MJ/m^2)
$\overline{H}_b$	monthly mean daily beam radiation on a horizontal surface (MJ/m^2)
$\overline{H}_{bV}$	monthly mean daily beam radiation on a vertical surface (MJ/m^2)
$\overline{H}_d$	monthly mean daily diffuse radiation on a horizontal surface (MJ/m^2)
$\overline{H}_{dV}$	monthly mean daily diffuse radiation on a vertical surface (MJ/m^2)
$\overline{H}_o$	monthly mean daily extraterrestrial on a horizontal surface (MJ/m^2)
$\overline{H}_V$	monthly mean daily global radiation on a vertical surface (MJ/m^2)
$\overline{K}_T$	clearness index
$n_{d\ ay}$	day number
$\overline{R}$	ratio of monthly mean total radiation on a tilted surface to that on a horizontal surface

Greek letters

α_s	solar altitude angle (°)
β	surface slope angle (°)
γ	surface azimuth angle (°)
δ	solar declination angle (°)
ρ_g	ground reflectivity coefficient
φ	latitude of the location (°)
ω_s	sunset hour angle for a horizontal surface (°)
ω_{ss}	sunset hour angle for beam radiation on a tilted surface (°)
ω_{sr}	sunrise hour angle for beam radiation on a tilted surface (°)

Generating energy in large scales by exploitation of fossil fuels has led to perilous influence on the environment such as global warming, climate change, air pollution and water contamination [4–6]. In view of the obligations imposed by some international agreements on environmental policy, such as the Kyoto protocol to diminish the aforementioned hazardous threats, harnessing the renewable energies including solar, wind, geothermal, tidal and biomass have been adapted by governments as the most efficient solutions [7]. The development of renewable energy technologies are expanding greatly. By the end of 2013 the total renewable energy capacity across the world, not including hydro, reached to 560 GW from 480 GW at the end of 2012 [8]. Among different kind of renewables, solar energy is considered to be the most promising and appealing renewable source to meet the energy demands in the future [9]. About the significance of solar energy it is worthwhile to state that in case of converting only 0.1% of the solar energy arrived at the earth surface to electricity with the efficiency of 10%, the output power would be 3000 GW, which is four times higher than the current global consumption [10,11].

Several solar energy technologies have been invented so far. Among all, the flat plate solar collectors and photovoltaic panels are being increasingly utilized for heat and electricity generations. Generally, among several parameters that affect the performance of a flat plate solar surface its tilt and azimuth angles stand out above all. The notability of these angles for a surface is owing to the fact that their variation would change the amount of solar radiation arriving at it.

Technically, the most efficient method to collect more solar energy is to utilize tracking systems. A solar tracker system is a mechanical tool designed to follow the direction of the sun in the sky to gain maximum possible energy. Nonetheless, in spite of achieving more energy via utilization of solar tracking systems, in some cases the required costs exceed the extra energy achieved. This makes the system to become economically unfeasible and inapplicable. Therefore, to receive more energy it is often viable to adjust the solar surface at optimal tilt and azimuth angles for specified periods such as day, month or season.

Basically, the knowledge of global solar radiation received by a tilted surface as well its optimal tilt angle are of particular importance to design, optimize and monitor the performance of solar energy conversion systems [12–14]. Likewise, the information about different components of solar radiation, either in terms of daily or monthly mean daily values, arriving at a surface with the optimum surface azimuth is also of indispensible significance for solar energy systems design and simulation procedures. The amount of radiation arrived at an oriented surface in different specific periods of the year is contingent upon several elements including the local solar radiation characteristics and climatic conditions, latitude and the specific period of time that the system is utilized.

There are three possible major options in order to mount the solar surfaces for the sake of solar energy harnessing: (1) on the ground, (2) on the roof of buildings and (3) on the vertical walls of buildings. In the case of lacking enough roof space on a building, mounting the photovoltaic panels and thermal collectors on the exterior vertical walls of buildings is an option. Moreover, the low level of requisite costs for construction, installation and structural materials of wall-mounted solar systems is a merit. Fig. 1 shows the PV panels mounted on the exterior walls of a building in San Diego, which is part of the largest project of this kind in the USA.

Iran is one of the countries located in solar belt of the world and the solar energy is abundantly available in most parts of the country, which provides the possibility of taking the advantage of harnessing solar energy via various technologies. Nevertheless, only a limited number of solar energy projects have been established in Iran. Also, the number of investigations related to solar energy is still limited.

Fig. 1. Solar panels mounted vertically on the walls of a building in San Diego, USA [15].