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Determination of optimum location and tilt angle of solar collector on the roof of buildings with regard to shadow of adjacent neighbors

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ABSTRACT

Solar systems have been widely used in recent years to supply some portion of buildings energy demands. Solar cells and flat collectors usually installed on the roof of buildings to keep away from the shade effects. Moreover, those must be installed incline at optimum angle to maximize the receiving energy. Determination of the optimum tilt angle of solar collectors is the subject of many investigations. These studies had supposed that, there is no barrier between the sun and collectors from sunrise since to sunset. In fact, any building may be surrounded by taller neighboring buildings. In these conditions, previous studies could not estimate the optimum tilt angle, truly. In addition, there are locations on the roofs which have more sunny time. These areas are more suitable for installation of collectors. Determination of optimum location and optimum tilt angle of solar collectors on the roof, with respect to the shadow of adjacent buildings is the main aim of this paper. Obtained results revealed that for earth's northern hemisphere, solar collectors should be installed on the southern edge of the roof as far as possible away from the taller neighboring building. If the roof is surrounded by two taller buildings, solar collector should be installed approximately on the center of the southern edge. Accordingly, received energy form the direct solar radiation on the optimum location could be increases more over the 15%. In addition, it was found that shade has minor effects on the optimum tilt angle for the parts of the roof near to the taller neighbor. In contrast, there is a considerable change of optimum tilt angle (up to 10°) for the farther regions form the taller neighbor.

1. Introduction

In recent decades, price increasing of common energy sources (especially fuel source) and environmental considerations cause to global attention has been drawn to the application of renewable energy. Among of several kinds of renewable energies such as wind energy, geothermal energy, ocean wave energy, and so on, many researches and experimental applications attracted by solar energy. In fact, solar energy is the origin of other renewable energy types. In addition, it is accessible in many areas of the earth. Solar energy is not only applicable in large scale (such as solar electricity power plant), but it also can be used in small scale (such as domestic heating and cooling, desalination, and so on). Straight domestic usage of energy cancels the costs of energy distribution networks and its losses. Nowadays, a considerable portion of household heating load (hot water and air heating) (Hazami, Naili, Attar, & Farhat, 2013; Martinopoulos & Tsalikis, 2014; Nematollahi, Alamdari, & Assari, 2014; Rogers, McManus, & Cooper, 2013) and electricity requirement (Ban-Weiss et al., 2013; Kalogirou & Tripanagnostopoulos, 2006), could supplied from the solar energy. In fact, some portions of energy requirements of modern buildings are supplied from the sun by solar system. Solar collectors are one of the important parts of solar systems which collect the solar energy. Performance of solar system could decrease enormously when the shadow of spatial barriers cast over the solar collectors. Thus, solar collectors are usually located on the roof of buildings, where the effect of shade is minor. In addition, flat collectors usually installed incline to gather the higher amount of solar energy (Ahmad & Tiwari, 2009; Skeiker, 2009). It is suggested by different researches that flat collectors must be installed at tilt angle approximately equal to location latitude as optimum annual inclination (Elminir et al., 2006; Gunerhan & Hepbasli, 2007; Moghadam, Tabrizi, & Sharak, 2011). It is supposed by these researches that there is no barrier between the sun and collectors. Therefore, reaching the solar beams to the collectors from the sunrise to the sunset is the fundamental assumption of these investigations. Nevertheless, solar collectors are not completely far away from the shade affects even on the roofs.

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Nomenclature

W	hour angle
θ	incident angle
Wf	forward hour angle
Wb	backward hour angle
θh	incident angle of neighbor height
d	distance from the taller neighbor

Investigation the effect of shade on the efficiency of solar systems is often limited to the solar cells arrangement in the solar electricity power plants. Several researches indicated that, the output power of a solar panel decreases severely when the small part of its surface lies on the shade (Ibrahim, 2011; Karatepe, Hiyama, Boztepe, & Colak, 2008). However, Karatepe, Boztepe, and Colak (2007), Quaschning and Hanitsch (1996), Sharma, Dwivedi, Srivastava, and Pathak (1994), and many other researchers showed that bypass diodes could lighten the power loss of solar cells due to shading. In contrast, bypass diodes increase the price of solar cells and lead to difficulties in assemblage process. Effect of partial shadowing of photovoltaic arrays on the power production of PV plants is the subject of various studies (Bany & Appelbaum, 1987; Groumpos & Khouzam, 1987; Weinstock & Appelbaum, 2007). It is reported that in a solar field, all but the first rows of PV array loss the some portion of their power output due to shadow of neighboring, even when sufficient spacing between the rows is provided (Groumpos & Khouzam, 1987). Therefore, different suggestions were presented by researchers for optimization of PV array arrangement in the solar farm such as the work of Diaz-Dorado, Suarez-Garcia, Carrillo, and Cidras (2011).

There is scant evidence which indicated on the investigation the effect of shade on the utilized solar collectors in buildings. In fact, any building may be surrounded by taller neighboring buildings. In these conditions, shadow of taller building may cast over collectors for several hours and previous studies could not estimate the optimum tilt angle, truly (due to their simplifier assumption). In addition, there are locations on the roofs which have more sunny time. It seems that, these areas are more suitable for installation of collectors. Therefore, determination of optimum location and optimum tilt angle of solar collectors on the roof, with respect to the shadow of adjacent buildings is the main aim of this paper.

2. Methodology

Buildings in crowded cities are surrounded by their neighbors. If a building has a taller neighbor, sun may rise from or set behind this building, instead of horizon. In this condition, shadow of taller building fully or partially covers the roof of shorter building for a certain time. This phenomenon affects the optimum inclination of flat solar collectors. Surely, there are locations on the roofs which have more shady time. Thus, solar collector must be installed under optimum inclination angle at optimum location of roofs which have must sunny time. Fig. 1 shows a typical view of some buildings of an East-West Street.

Shadow of southern buildings has no effect on received solar energy on the roof of northern buildings due to the high value of zenith angle of sun on midday time and existence of considerable distance between the buildings in the north and south side of the street. However, shadow of taller buildings affects the received energy on the roof of their eastern and western neighbors. In fact, the shadow of a certain tall building may cast on its shorter western neighbors roof from sunrise to noon, and may cast on its shorter eastern neighbors roof from noon to sunset. Thus, there are three possible cases. In first case, an individual building situated between

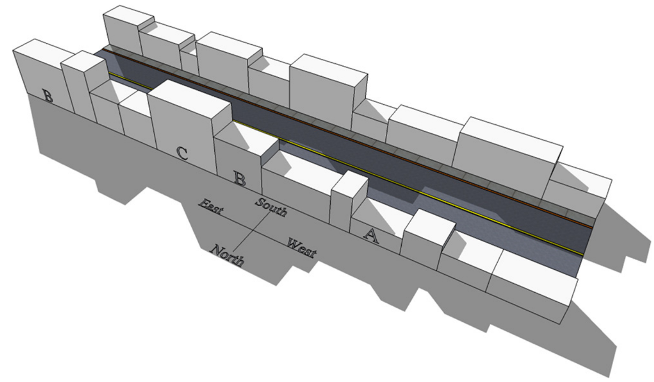

Fig. 1. Typical demonstration of buildings of an East-West Street.

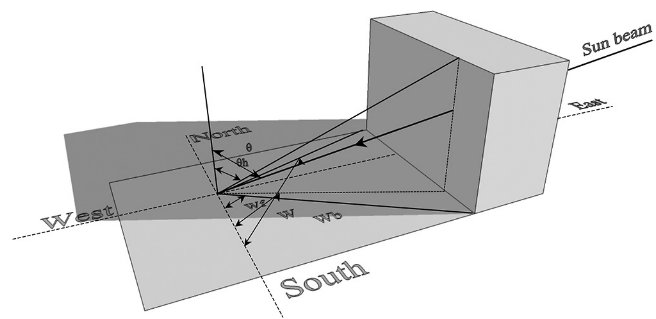

Fig. 2. Graphical presentation of required details for mathematical description of shading.

two other taller buildings, like the one which is labeled by A in Fig. 1. In second case, a taller building located in the left or right side of a considered building, like those marked by letter B. The last case is that, there is not any taller construction around it, like C. in this case sun beams could reach to the roof of such buildings from sunrise to sunset, and all the roof points receive the same value of energy. Previous studies could predict the optimum inclination angle of a flat solar collector, accurately for this case. However, determination of best location and inclination for the two other cases (A and B) need to more surveys.

2.1. Investigating the effect of shadow of adjacent buildings on received solar energy

For buildings which have taller neighbors in the left or right side (or both side), shade cast over at all or some area of roof in a period of time, especially when the sun is near to horizon (sunrise and sunset times). Time determination of shade covering on a certain place of a roof is the key point in investigation the effect of shadow on received solar energy. Clearly, shade appears when the straight line between the considered point and sun cut with a barrier. Mathematical description of the problem could perform using the illustrated details in Fig. 2.

W and θ, in Fig. 2 are hour and incident angle of sun, respectively. According to this figure, shade cast over considered point if $Wf < W < Wb$ and $\theta > \theta h$, simultaneously. In such a case, received energy from the direct solar radiation reaches to zero. Therefore, total daily received energy from the direct radiation on a certain place of a roof is estimable. In this regard, we use of MATLAB programming language and modify the code which is used in our previous work (Moghadam et al., 2011). Effect of shadow on received energy on the building's roof from the direct solar radiation for two possible cases which are mentioned earlier, investigated in the following section.

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