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A comprehensive assessment methodology of the building integrated photovoltaic blind system

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ABSTRACT

Design: strategies that reduce energy demand of buildings and increase energy supply from renewable resources are strategies that improve a building sustainability. The Building Integrated Photovoltaic (BIPV) blind system reduces heat gains during summer therefore it reduces the energy demand for cooling while producing on-site electric energy. The design of the PV blinds should take into considerations issues regarding: the reduction of the cooling loads in summer, the increase of the heating loads in winter, the reduction of the daylight factor, the increase of the artificial lighting use, the reduction of the view to the outside, the shadow casted on the PV blinds and its impact on the PV panels' performance; therefore the identification of their optimal design parameters requires a holistic approach and a systematic methodology. This paper investigates the identification of the PV blinds' optimal design parameters based on a cost-benefit approach. A methodology, that encompasses thermal comfort, visual comfort, and energy savings requirements while resolving the conflicting issues resulting from the fulfillment of these requirements, is highlighted.

1. Introduction

The building integrated PV blinds have the benefit of acting as a shading device while producing energy from a renewable resource (solar radiation). The PV blinds may represent an important component of a zero net energy building; a building that produces as much energy as it consumes [1,2]. The determination of the design parameters of the PV blinds was assessed in various papers [3–6]. Most papers considered the energy harvested per square meter of panel area as a key assessment parameter. The assessment approach was based around the maximum electric energy production or the combined effect of electricity generation and cooling load reduction. Bahr [3] has noted that the annual electricity generation by the PV panels is much more relevant if compared to the amount of electric energy saved for cooling. The optimal design solution found resulted into the application of fewer blinds with more spacing between the PV panels in order to minimize the shading effect from one panel to another. Kang et al. [4] investigated the harvested electric energy and the shading effect of a blind system with integrated photovoltaic modules. The ratio (R) between the blinds installation distance (d) to the module depth (L) was set to 1 ($d/L = 1$). It was found that a 75° tilt angle of the blinds leads to a maximum energy production for all orientations. The building was located in Seoul, Korea (37°N latitude). Sun et al. [5] assessed the combined effects of electricity generation and building cooling load reduction of the shading type building integrated photovoltaic (BIPV) cladding applied on the vertical wall between two windows. This combined effect was measured through the annual electricity savings per unit of PV area. The optimum tilt angle of the PV modules was found and depended on the height of the opaque wall between two window openings. Hwang et al. [6] studied the maximum electric energy production of photovoltaic modules applied on a building façade according to the PV modules installation direction (horizontal or vertical), to the modules tilt angle (inclination), and according to the ratio between the panels' installation distance (d) and a module depth (L). The building was located in Incheon (37°N), Korea. For a south oriented facade the optimum PV installation was horizontal, 45° inclination, and a ratio $(d/L) \geq 2$. For southeast and southwest orientations the optimum PV installation was horizontal, with a 60° inclination angle, and a ratio $(d/L) \geq 2$.

The assessment methodology, taken into consideration in this paper, quantifies the profit rate of each design solution over one year of a PV panel's life. The integration of more PV panels, leading to more renewable energy production, is assessed by the designer based on a cost-benefit approach.

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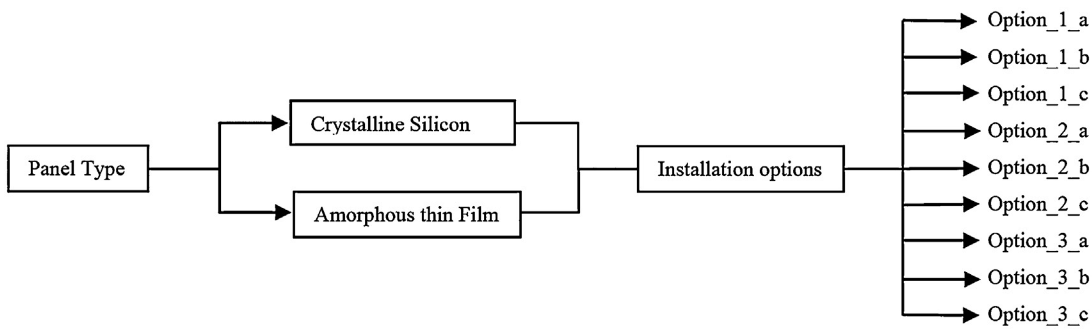

Fig. 1. Design options.

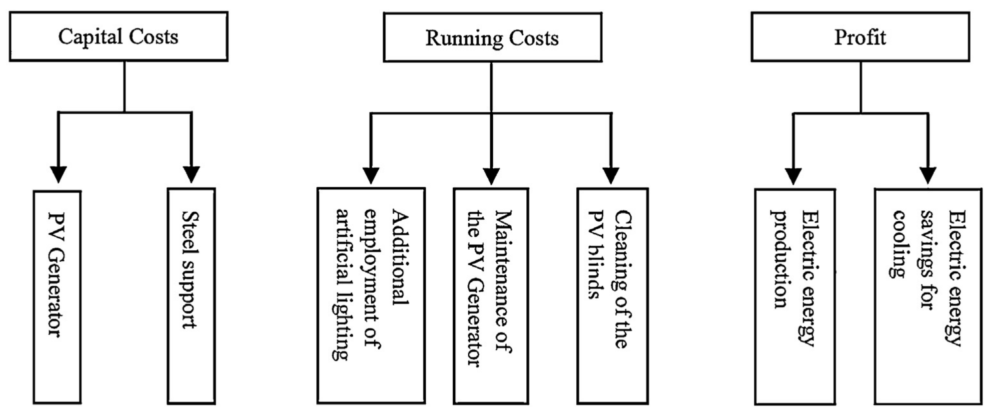

Fig. 2. Assessment parameters.

Table 1
The blinds design variables.

Design condition	Design variables		
Horizontal blinds tilt angle	0°	25°*	60°
Ratio $R = d/L$ (between the blinds installation distance to the module depth)	1	2	3
Panel type	Crystalline	Amorphous	

* Tilt angle equal to Abu Dhabi latitude.

2. Methodology

The application of PV blinds on a vertical glass curtain wall is studied taking into consideration a holistic approach. The benefit of each design solution, in terms of energy production and energy savings, was assessed taking into consideration the capital cost (initial cost) and the running costs (maintenance costs) resulting from the PV blinds application.

The variables taken into account consist of two categories. The "design options" category, consisting of the PV panel type and the installation options, is summarised in Fig. 1 and in Table 2. The assessment parameters category, consisting of the capital costs, the running costs and the profit of each design option, is summarised in Fig. 2.

2.1. Design variables

The installation variables of the PV blinds are illustrated in Fig. 4 and are listed in Table 1. The different installation solutions resulting from the combination between different design parameters are listed in Table 2.

2.2. Assessment parameters

The assessment parameters represent the costs and benefits deriving from the application of a design option. These costs and benefits are calculated in USD per square meter of façade area.

(1) Capital cost (PV generator cost + steel frame cost)
The capital cost includes the cost of the PV generator (this includes the cost of the PV panels, the grid tie inverter, cables, breaker, junction box, and installation costs)+ the cost of the steel frame that holds the PV blinds (this includes the fabrication and erection of the steel frame, the civil work for footings and connection, and engineering works).

Table 2
The PV blinds' installation options.

Installation options	Ratio $R = d/L$	Tilt angle (°)	Installation options	Ratio $R = d/L$	Tilt angle (°)
option_1_a	1	0	option_2_c	2	60
option_1_b	1	25	option_3_a	3	0
option_1_c	1	60	option_3_b	3	25
option_2_a	2	0	option_3_c	3	60
option_2_b	2	25			