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Impact of Multiple Parameters on Energy Performance of PV-DSF Buildings †

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Abstract: Double Skin Façade (DSF) has been widely used in buildings to enhance energy efficiency and bring daylight and aesthetic benefits. Solar photovoltaic (PV) modules can be integrated in DSF to fully or partially meet the electricity demand. Therefore, in this study, the energy performance of a 3-storey PV-DSF building is analyzed for three cities of Iran with distinctive climates namely Tehran, Tabriz and Kish Island considering different orientations, cavity widths and different optical properties for the PV system. The results indicated that the south facing PV-DSF have the maximum electricity generation and the minimum net electricity consumption. With increase in cavity width from 0.4 to 1.2 m, the annual electricity consumption is reduced by 5.88, 5.19 and 7.49 MWh for Tehran, Tabriz and Kish, respectively. The cavity width tends to have negligible impact on electricity generation. The analysis of the outer PV skin showed that the glazing with lower Solar Heat Gain Coefficient (SHGC) offers more energy saving benefits for all the considered cities.

Keywords: PV-DSF; energy performance; cavity width; optical properties

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1. Introduction

Double Skin Facades (DSF) have been widely used in buildings to boost energy performance, maintain indoor thermal comfort and bring daylight and aesthetic benefits [1]. Photovoltaic materials can also be integrated in DSFs to not only further enhance thermal performance but also directly generate electricity [2]. However, the efficiency of PV-DSF is decided by climatic conditions and design parameters. Only a few studies are available on PV-DSF. For instance, Peng et al. investigated the energy saving potential of PV-DSF in Mediterranean climate using EnergyPlus software developed by US Department of Energy, and showed that nearly 65 kWh per unit area electricity can be annually produced by PV-DSF [3]. The thermal performance of a PV-DSF was experimentally analyzed considering various ventilation modes [4]. It was revealed that non-ventilated PV-DSF minimizes the heat loss while the ventilated one has the minimum solar heat gain coefficient.

To best of authors knowledge, few studies have assessed the impact of design parameters on PV-DSF performance. Moreover, PV-DSF performance has not yet been evaluated in climatic conditions of Iran. In this regard, to attain the optimal design of PV-DSF in terms of energy saving and electricity generation, different design parameters including cavity width, orientation and optical properties of PV are analyzed for three distinctive climatic conditions of Iran namely Tehran, Tabriz and Kish island. It is worth mentioning that findings of this study can also be true for other regions with similar climatic conditions.

2. Methodology

The impacts of several parameters namely building orientation, cavity width and optical properties of PV on energy performance of a PV-DSF building are examined considering three distinctive climates. For this reason, a typical building is simulated in DesignBuilder software which is an advanced energy simulation tool. The software is accredited by many researchers as a reliable tool for DSF and other advance energy simulations.

2.1. Site Description

Three cities of Iran namely Tehran, Tabriz and Kish Island with distinctive climatic conditions are considered in this study to assess the impact of climate on PV-DSF performance.

2.2. Building Description

A three-story office building with a total area of 360 m^2 is selected as a case study. A packaged terminal heat pump (PTHP) is used to supply the heating and cooling demands. A north-facing air-tight PV-DSF is analyzed. The outer skin of the DSF is a crystalline silicon module while a generic double glazing unit with two 3-mm glass panes and a 13-mm air gap is used for the inner skin. The specifications of the PV system are summarized in Table 1.

Table 1. Specifications of PV module.

Parameters	Value
Short circuit current (A)	6.20
Module current at maximum power (A)	5.6
Open circuit voltage (V)	60
Module voltage at maximum power (V)	50.5
Rated electric power output (W)	48,000

2.3. Considered Parameters

The energy consumption and electricity generation of the PV-DSF building are assessed considering multiple parameters to achieve the optimal configuration.

- Building orientation: To find the optimal orientation, the energy performance is assessed for north, south, east and west oriented PV-DSF.
- Cavity width: The distance between inner and outer skins is one the influential parameters on energy performance. For this reason, the electricity consumption and generation are calculated for three different widths of 0.4, 0.8 and 1.2 m.
- Optical properties of PV: The optical properties such as solar transmittance can significantly affect the energy performance and thus, four scenarios as shown in Table 2, are considered for the PV.

Table 2. Considered optical specifications for PV.

Parameter	A	B	C	D
Solar transmittance	0.837	0.409	0.298	0.114
Solar reflectance (front)	0.075	0.431	0.369	0.08
Solar reflectance (rear)	0.075	0.53	0.201	0.04
Visible transmittance	0.898	0.301	0.14	0.06
Visible reflectance (front)	0.081	0.501	0.414	0.12
Visible reflectance (rear)	0.081	0.275	0.174	0.03
Emissivity (front)	0.84	0.447	0.637	0.83
Emissivity (rear)	0.84	0.703	0.779	0.9

3. Results and Discussion

3.1. Building Orientation

The impact of PV-DSF orientation on electricity consumption and generation of the building is investigated and the results are shown in Figure 1. The annual electricity consumption varies from 58 MWh to 65 MWh for Tehran, from 52 MWh to 56 MWh for Tabriz and from 78 MWh to 85 MWh for Kish island according to PV-DSF orientation. The minimum annual electricity consumption occurs for the north facing façade in Tehran and Kish island and for the south facing façade in Tabriz while the maximum is for the west-oriented PV-DSF in Tehran and Kish island and for the east-oriented PV-DSF in Tabriz. The electricity production increases from a minimum of 7.1 MWh for the north-oriented facade to a maximum of 21.1 MWh for the south-oriented one in Tehran. For Tabriz, the maximum production is 12.4 MWh in the south while the minimum is 5.5 MWh in the north facing PV-DSF. Similarly, the minimum and maximum electricity generation in Kish island are 7 MWh for the north oriented PV-DSF and 14.1 MWh for the south facing façade, respectively. The minimum annual net electricity consumption for Tehran, Tabriz and Kish island with values of 40.36, 40.39 and 66.91 MWh occurs for the south facing PV-DSF. Moreover, it is observed that the PV systems perform better in semi-arid climate of Tehran due to higher solar irradiation.

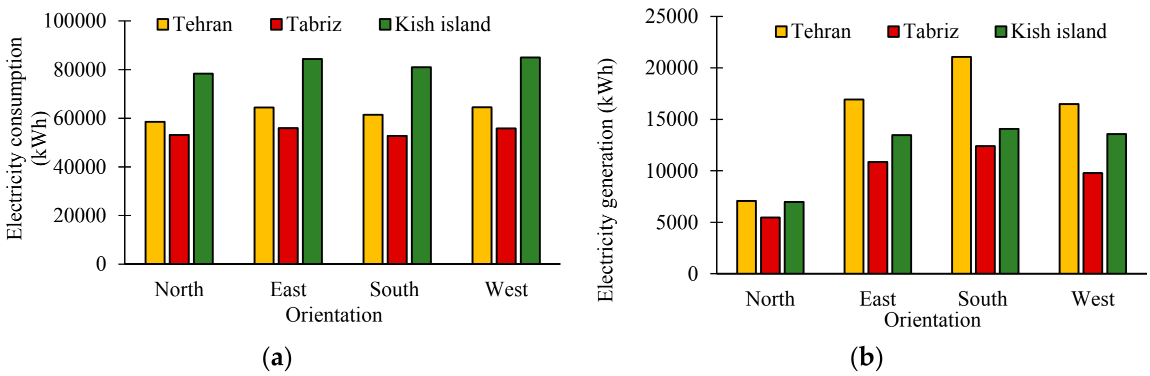

Figure 1. Energy performance of the PV-DSF building: (**a**) energy consumption of the PV-DSF building; (**b**) electricity generation of the PV-DSF building.

3.2. Cavity Width

The energy performance for different widths of the DSF cavity is analyzed. With increase in cavity width from 0.4 to 1.2 m, the annual electricity consumption is reduced from 64.2 MWh to 58.3 MWh for Tehran, from 58.4 MWh to 53.2 MWh for Tabriz and from 85.1 MWh to 77.6 MWh for Kish island. Considering that a trade-off between the energy saving and the space used by the cavity should be achieved, 0.8 m seems to be a reasonable width for the cavity. The cavity width tends to have insignificant impact on electricity generation compared to its energy saving benefits. The annual electricity generation is increased by 1.6, 1.9 and 2.04 kWh for Tehran, Tabriz and Kish island, respectively.

3.3. PV Module Transparency

The energy performance of the PV-DSF is examined considering different optical properties for the PV system. As shown in Table 3, the results indicate that the optical properties significantly affect the heating and cooling demand of the building in all the considered climates. More specifically, Solar Heat Gain Coefficient (SHGC) is one the most influential factors on heating and cooling demands. When SHGC decreases from 0.764 to 0.236, the annual cooling demand is reduced by 4.4 MWh for Tehran, 2.9 MWh for Tabriz and 5.52 MWh for Kish island while the annual heating demand is increased by 489.5 kWh for Tehran, 1248.32 kWh for Tabriz and 3.4 kWh for Kish island. It should be noted that cooling reduction is more significant than heating increase. With decrease in SHGC, the annual electricity consumption is declined by 4.04, 1.73 and 5.67 MWh for Tehran, Tabriz and Kish island, respectively. The glazing type leads to more energy saving in semi-equatorial climate of Kish island than in Tehran and Tabriz.

The annual generation differs from 6.97 MWh to 7.08 MWh for Tehran, from 5.40 MWh to 5.47 MWh for Tabriz and from 6.87 MWh to 6.98 MWH for Kish island considering different optical properties.

Table 3. Heating, cooling and total electricity use and electricity generation.

City	Type	Heating (MWh)	Cooling (MWh)	Total Electricity Use (MWh)	Generation (MWh)
Tehran	A	1354.45	26,469.47	58,551.60	7078.02
	B	1531.33	23,730.39	55,905.04	7047.71
	C	1684.23	22,886.90	55,190.84	7030.89
	D	1843.92	22,072.80	54,513.95	6968.22
Tabriz	A	8107.58	14,496.55	53,171.22	5474.40
	B	8570.56	12,705.65	51,789.56	5451.37
	C	8957.80	12,142.08	51,601.92	5440.31
	D	9355.89	11,593.97	51,441.91	5396.33
Kish island	A	0.97	47,154.91	78,320.38	6977.47
	B	1.90	43,557.72	74,619.19	6952.68
	C	2.96	42,569.03	73,602.45	6933.36
	D	4.36	41,639.13	72,646.52	6869.99

4. Conclusions

- The south-oriented PV-DSF has the maximum generation for all the cities. Considering the net electricity use, the south facing PV-DSF building has the superior performance.
- With increase in cavity width from 0.4 to 1.2 m, the building energy use is declined by 5.88, 5.19 and 7.49 MWh for Tehran, Tabriz and Kish Island, respectively. However, the cavity width has negligible impact on electricity generation for all the considered cities.
- With decrease in SHGC of the outer skin, the annual electricity consumption is declined by 4.04, 1.73 and 5.67 MWh for Tehran, Tabriz and Kish Island, respectively. The annual generation differs from 6.97 MWh to 7.08 MWh for Tehran, from 5.40 MWh to 5.47 MWh for Tabriz and from 6.87 MWh to 6.98 MWH for Kish Island considering different optical properties.

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