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Feasibility PV Integration in Trombe Wall for Iran Climates

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A B S T R A C T

Trobme wall is a system to provide passive solar heating in a clean way. Trombe wall combined with a dynamic system like photovoltaic (PV) system to produce heat and electricity simultaneously. It consists of a thick wall, a transparent cover glass and the air gap between them. This paper attempts to identify the factors affecting the performance of the system and its design. Of course, many factors including vents, fans, insulation, dimensions, and solar cells as well as variables related to the direction, slope, plan form effect on the photovoltaic Trombe wall. The windows' placement on the south façade can be effective, but the heating rate efficiency would be reduced by 27%. PV utilization covers the interest rates and increases the system thermal performance by more than 17%. As a result, this system is a useful method for the dessert territory of IRAN and good solution to supply energy in a critical environment.

1. Introduction

The importance of using solar systems in buildings is due to the limited resources of energy and its effects on the environment [1]. Trombe wall is one of the many types of static solar systems which is designed and used to store heat energy per day and distribute it at night or when the air temperature is reduced [2]. This solar system receives and stores solar radiation indirectly [3]. A sample of Trombe wall contains 0.2 to 0.4 meters of thick wall which is covered by a dark matter and heat absorbent and there are one or two layers of glass on the outer face [4]. The glass should be placed at a certain distance from the wall to create a small air gap [5]. The heat of the sun is absorbed and stored through the wall by passing through the glass and is steered slowly through the wall to the inside of the building [6]. The most important types of Trombe walls consist of: classic Trombe wall, aquatic Trombe wall, water Trombe wall, zigzag Trombe wall, composite Trombe wall, solar compound wall and photovoltaic Trombe wall (figure.1) [7].

The photovoltaic Trombe wall is a new example of Trombe walls which transforms the sun radiation into electricity and heat simultaneously by the photovoltaic cells on the glass (figure.2). By the addition of photovoltaic cells on the glass surface, the dark colour of the cells provides a more appropriate appearance [8,9].

One of The most important questions to be asked is how much the Trombe walls productivity is affected by the photovoltaic panels which cover the glasses? To answer this question, an experiment was conducted in which the indoor temperature was measured by a computer model. In the southern facade on which the glasses had 0.83 m width and 2.6 heights, photovoltaic panels were installed. The result showed that the installation of photovoltaic panels on the glass surface reduced the thermal performance of the Trombe wall by 17%. This temperature drop prevents solar heat from penetrating into the Trombe wall [10].

Figure 1. Photovoltaic Trombe wall

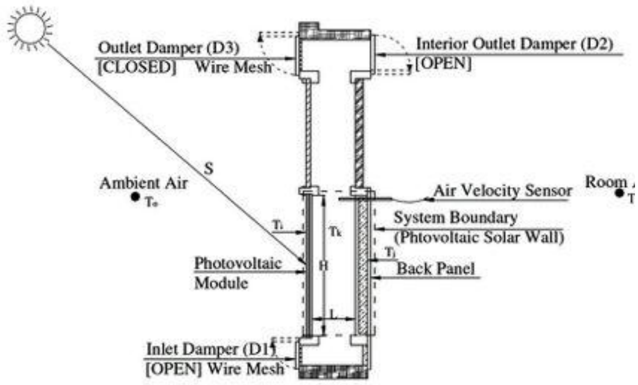

Figure 2. Photovoltaic Trombe wall details

2. Effective factors in Trombe wall design

In general, many personal factors are effective to increase the productivity of Trombe wall. These factors include: valves, blowers, insulators, dimensions, thickness, colour, material type, plastering and glass vents. Two of these factors are briefly discussed.

a. Valves effects

In the Trombe wall with valves, two heat circulation valves are installed at the top and bottom of the wall. These valves are designed to control the heat dissipation and help to warm and cool the building. In Trombe-photovoltaic wall, cold air enters through the lower valve and cools the photovoltaic cells and after warming up again it returns to the building through the upper valve. Reducing the temperature of photovoltaic cells helps to increase the electricity production and its productivity. When the valves are closed, the heat transfer coefficient for optimization could be calculated.

b. Blowers effect

Using blowers to help the heat flow between the valves is up to 8% effective. The effect of the blower on the operation of Trombe wall depends on the region's climate and also the thickness of the Trombe wall. The blower can reduce the internal temperature by 0.5°. Studies have also shown that at intervals of 7.00 to 17.00, the blower can reduce the temperature of cells up to 1.28 ° and temperature drop would cause the cells to perform better (Figure.3).

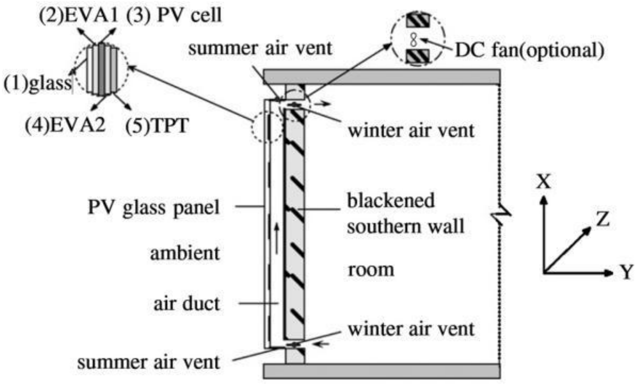

Figure 3. Blower performance on photovoltaic Trombe wall

3. Effective factors in photovoltaic systems design

Photovoltaic system is one of the new technologies for energy renewal. In the design of photovoltaic systems, factors such as determining the direction and slope of photovoltaics, shading, coordinating with the inactive solar system, system ventilation, the effect of the form of plan, the slope of the facade wall of the building should be considered [11].

a. Determination of the direction and slope of photovoltaic panels

By increasing the intensity of sun rays, the amount of electric power output would increase; therefore the photovoltaic power output system has a direct relation with the amount of solar energy it receives (Figure.4). On the other hand changing the angle of sunlight during the day also affects the production of photovoltaic energy. Therefore, the efficiency of the photovoltaic system depends on the direction and slope of the deployed panels.

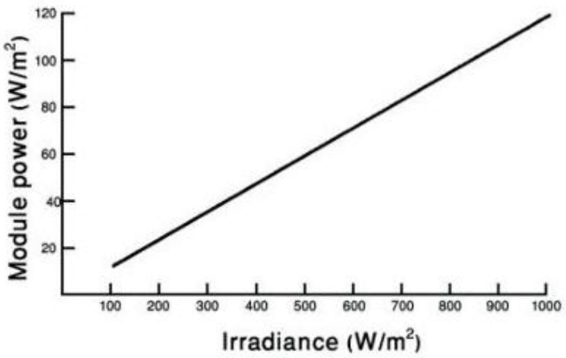

Figure 4. The variation of photovoltaic panels with solar radiation intensity

b. Effect of shadings on photovoltaic panels

Shadow Is one of the factors which would affect the amount of the light recieved. Such as the shasow of the surrounding buildings, the shadow of the building itself, the shadow of the panels on each other, trees and etc. The position and location of the panels should be designed in such a way in which the shadow wouldn't affect any of them; because in addition to lowering the efficiency, the cells would also be damaged. The intrusive shadow would cool down the interior up to 2°in warm seasons and reduce electrical performance up to 2%.

c. Form of the plan

The more elongated and thin the plan is, the more the environment would be increased, and the amount of solar radiation and electricity generation would increase and the more the plan is closer to the form of square the lower the level would be.

d. *Effect of the façade wall slope on the power of photovoltaic system*

As the wall slope approches from vertical to horizintal, the photovoltaic surface will receive more energy and generate more electricity and output.

e. Ventilation

As photovoltaic cells convert sunlight into electricity, they convert it into heat as well which should be used, controlled or ventilated [12]. Because photovoltaic panels perform better and generate more electricity if it is cool (Figure.5). In the climate of Iran in the city of Isfahan, regarding the degree of zonation of days required for heating and cooling, there is no need to use mechanical facilities in some months of the year. According to table1, which shows the average daily temperature in Isfahan during three consecutive years, it can be cocluded that during the period from september 11 to mid-november and from march 11 to mid-may, there is no need to use cooling and heating systems because the air temperature is within the range of human comfort and natural ventilation can be used [13]. For this purpose at the top and the bottom of the glass wall, where the phtovoltaic panels are installed there are openings which would cause natural ventilation (Figure.6).

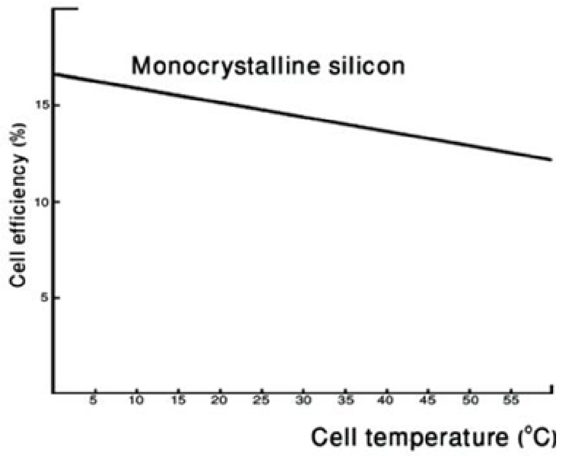

Figure 5. Effect of photovoltaic cells with increasing temperature

Table 1- average daily temperature in Isfahan

Year	2010	2009	2008
January	6/7	3/4	-0/2
February	9/1	8/2	5/7
march	14/9	12/8	15/2
April	17/6	14/8	18/3
May	22/6	22/2	22/6
June	28/1	24/9	28/5
July	30/4	30/1	30/0
August	26/3	30/2	26/6
September	23/5	23/7	24/5
October	20/2	17/3	18/5
November	9/9	11	9/0
December	6/2	5/2	4/9

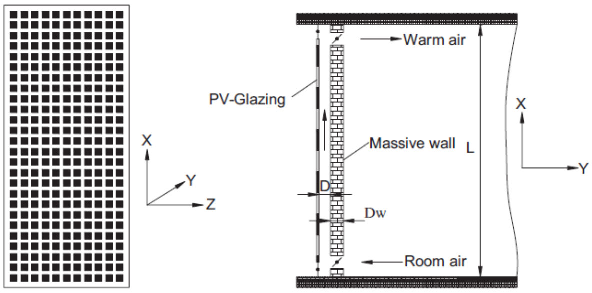

Figure 6. Schematic image of photovoltaic panels

4. Effect of the position of window in the southern façade

Southern façade windows are required to provide optimal light during the day, but they affect the function of Trombe wall as well as changes in the building temperature (Figure.7). Shows the temperature of the central part of the building in which the tests were carried out. Various modes have been compared such as the existence of a normal Trombe wall without a window, photovoltaic Trombe wall without a window, a window without Trombe wall, a wall without a window and Trombe wall and etc. In a part of this experiment, 1.4 square meters of window and 2.158 square meters of photovoltaic wall were placed in the southern façade. The photovoltaic Trombe wall with the window increased temperature by more than 25°. Also in comparison with the Trombe wall with full coverage of photovoltaic and ordinary Trombe walls, the result showed that the Trombe wall with full photovoltaic coating would increase the temperature by more than 8° (Figure.7). Compares the different types of south façade design and the results:

33.4 % PVTRW photovoltaic coating the Trombe wall with the existence of window.

33.4 % PVTRW photovoltaic coating the Trombe wall without a window.

NTR just a window

FPV Trombe wall with 100% photovoltaic coverage without a window

NPV Trombe wall without a window

NTRNW without Trombe wall and window

5. Modelling and testing of photovoltaic Trombe wall

A photovoltaic Trombe wall was installed along with a window on the south façade of the building. This experiment was conducted in winter and in a region with latitude of 36.37 ° north. The photovoltaic Trombe wall is 0.83 meters wide and 2.6 meters long and the depth of the air vent is 0.18 meters (Figure.8). The valves are insulated by polystyrene which is 0.4 meters thick to reduce heat loss. The exterior of the photovoltaic Trombe wall is networked with 5cm*5cm of solar cells. Heat box (Figure.1) is 2.6m* 2.96m* 22.9m and it is insulated by panels and the inner part is surrounded by a layer of air. The double glassed surface is 1.2 m*1.2 m. the amount of electric power generated by the ambient temperature and the temperature of the adjacent valves was measured and recorded by thermocouple during the test. Error in temperature measurement was ± 0.2°. The location of the thermocouples in the distance between the floor and the ceiling is determined in three different parts (M_1, M_2, and M3). The maximum temperature is measured near the ceiling and the lowest temperature is measured near the floor. The temperature of the heated air by the photovoltaic Trombe wall was more than 10° during the day and had 11.62% energy efficiency in one day.

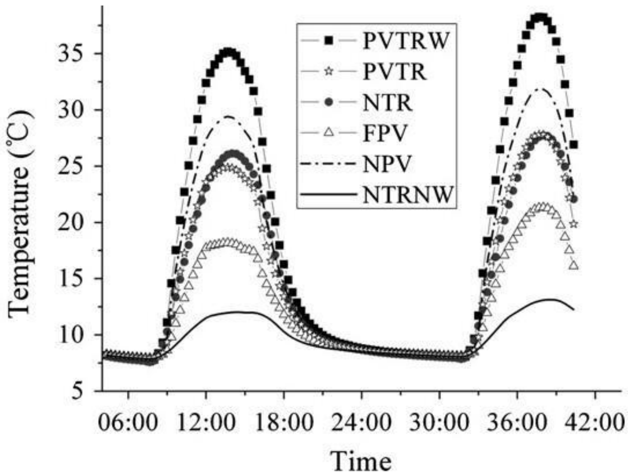

Figure 7. Interior temperature with different southern designs

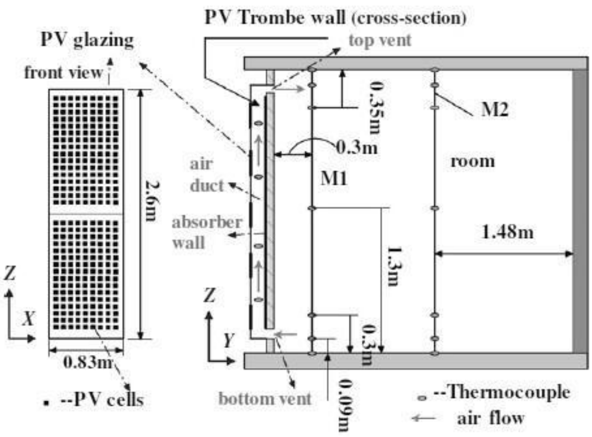

Figure 8. Glass photovoltaic cells and section of the study room

Table 2- material variables

layer	material	thickness	Thermal conductivity coefficient	density	Special heat capacity	Coefficient of radiation	Solar absorption
outdoor	Steel panel	0.005	16.27	8030	502	0.9	0.5
indoor	polystyrene	-0.2 floor-0.1 southern wall-0.05 other walls	0.04	15	1500	-	-

Analysing the theory of the Trombe wall in a two-dimensional model is done by UT zinger [14] Smolec has proposed a semi-experimental model for the heat transferring through the air valves and the Trombe wall theatrically [15]. The photovoltaic Trombe wall system structure is similar to the typical Trombe wall system structure; the difference is that photovoltaic

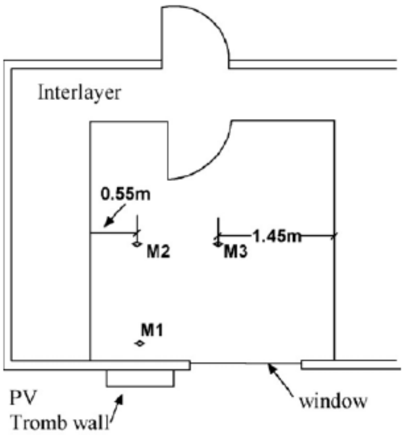

Figure 9. Study room plan

cells are located on its glass part. Because of the high absorption capacity of photovoltaic cells and the transparency of the glass, the glass surface is covered by a metallic network of photovoltaic cells to increase its temperature uniformly. Given the fact that the thermal requirements of solar cells must be observed in different geographical situation temperature distribution has been analysed in both vertical and horizontal directions. The amount of achieved energy is [16]:

(ρ Reflection rate/$c_{p\ \text{special heat}}$ heat capacity $w/_{m^3 k}$/ l_g glass thickness m / T_g glass temperature k/ t time/ k thermal conductivity coefficient/ q amount of heat/ q_{sw} short wave heat/ h vertical distance to the floor/ε coefficient of transit / c ceiling/ amb environment/ chair valves)

$$\rho c_p l_g \frac{\partial T_g}{\partial t} = k_x l_g \frac{\partial^2 T_g}{\partial x^2} + k_z l_g \frac{\partial^2 T_g}{\partial z^2} + q \qquad (1)$$

The calculation of the heat flux intensity of the glass surface covered by photovoltaic cells is:

$$q = q_{sw} + h_{c.amb}(T_{amb} - T_g) + \varepsilon h_{r,amb}(T_{sky} - T_g) + h_{c,ch}(T_a - T_g) + \zeta \varepsilon_i (T_{trombe} - T_g) \qquad (2)$$

The steel panel is located on the outside of the wall and photovoltaic cells are located on it. Its thermal resistance is:

$$R_{steelpanel} = \frac{D}{\lambda} = \frac{0.005}{16.27} = 0.003\, m^2 k/w \qquad (3)$$

Due to the low thermal resistance of the panel in the inner part polystyrene is located as an insulator, it prevents leakage and thermal penetration into the building and its thermal resistance is increased up to2.5 m^2k/w.

$$R_{polystyrene} = \frac{D}{\lambda} = \frac{0.2}{0.04} = 2.5$$
$$R_B = R_{steelpanel} + R_{polystyrene} = 2.5003 \qquad (4)$$

In accordance with clause 3-3-2-5-11 of article 11 of the national building regulations (Design and execution of industrial buildings) the thickness of the polystyrene in the wall panel should not be less than 40 mm [17]. Therefore in order to coordinate this plan with Iran rules, polystyrene thickness should be increased by more than 40 mm. According to table 2 article 19 of the national building regulations, the heat resistance of the light wall in buildings of group 1 with high energy consumption should be 2.8 m^2k/w. Therefore the thickness of the polystyrene should be increased up to 0.06 m in order to match the thermal resistance to the national regulations [18].

6. Conclusion

Considering the location of Iran in the proper geographic position in terms of the amount of solar radiation, using this clean and free energy has been considered more than ever. The photovoltaic Trombe wall is a solution for using this clean energy. This system converts solar energy into heat and electricity directly. Trombe wall has a better performance in deserted and semi- deserted areas where the temperature difference between day and night is high. In Trombe wall design parameters such as valves, blowers, dimensions, insulation, colour, materials, etc. are considered. Each of these parameters has an effective role in matching the Trombe wall with the regions climate.in the design of photovoltaic systems, factors Such as the direction and slope of panel deployments, the effect of shadings on panels, the coordination between photovoltaic systems and inactive solar systems, ventilation, form of the plan, etc. are effective the position and location of the panels should be designed in such a way in which the shadow wouldn't affect any of them. Ventilation is another factor which given the climatic conditions, can cause panels to cool down which leads to generating more electricity. Placing openings on the photovoltaic panel can provide natural ventilation in the months of the year which does not require the use of cooling and heating systems. Window design in the southern façade would reduce thermal efficiency of solar Trombe wall by 27 %. And also increasing the coverage of solar cells on the photovoltaic system would reduce the thermal efficiency by more than 17 %. The experiments and modelling performed on the photovoltaic Trombe wall showed that the system had an energy efficiency of 11.62 % over a day. And also by using the mentioned formulas, the generated energy and the heat of the photovoltaic cell surface could be calculated.

Table 3- minimum thermal resistance(R) of light-conducting walls in terms of m^2k/w

Group 3	Group 2	Group1	Building group in terms of energy saving	
1.5	2.1	2.8	Light	Wall
1	1.4	1.9	Heavy	
0.8	1.1	1.5	Near the uncontrolled space	
2.7	3.7	5.0	Light	Ceiling
2.2	3.0	4.0	Heavy	
1.7	2.3	3.1	Near the uncontrolled space	
1.6	2.2	3.0	Light	Floor
1.3	1.8	2.4	Heavy	
1.0	1.3	1.8	Near the uncontrolled space	

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