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Chapter

# Recent Advances in Photovoltaic-Trombe Wall System: A Review

*Omer K. Ahmed*

## Abstract

Management of energy consumption for building's air conditioning is a vital issue for resource saving and environmental protection. The use of solar energy to generate electricity by solar cells is essential nowadays. However, the disadvantage of solar panels is the elevated temperature in work, especially in the hot sunny climate that leads to efficiency decline. Also, there is a problem with heating during the night and cloudy days. For the last 20 years, there has been a rapid development in the field of integrated solar technologies. A hybrid PV/Trombe wall (PV/TW) system suggested being an efficient and durable conversion system of solar energy. The design of the PV/TW system considered one of the focusing areas of the present research to make it more economically feasible. The idea of building the photovoltaic-Trombe wall has appeared as one of the green technologies. Several published works at that time are included for integrating PV/TW system. This chapter devoted to reviewing the theoretical and practical studies conducted on this system for developing and improving electrical and thermal performance.

**Keywords:** PV/Trombe wall, efficiency, building, review

## 1. Introduction

Today mankind is facing the problem of severe shortage of power supply as a result of current consumption rate and low conventional energy reserves [1, 2]. Increased human activity has led to increased energy consumption and reduced conventional fuel reserves to dangerous levels, leading to the high price of world oil [3]. Scientists and researchers have begun to look for new sources of energy to replace conventional sources and replace it with a clean and environmentally friendly option [4]. Solar energy has been a priority for these concerns because it is cheap, is nonpolluting, and does not require high technology [5].

The passive solar heating system is a technique that generates thermal energy by collecting solar radiation and then moving it into the building naturally [6]. It is one of the most economical ways for solar energy utilization, which can reduce yearly heating demand by about 25% [7]. Among the passive solar heating systems that have been developed are solar roofs, solar chimneys, and a Trombe wall [8].

The Trombe wall is a method to use solar energy for heating without using any mechanical or electrical assistance, as shown in **Figure 1** [9]. The name of the Trombe wall was taken from a French scientist named Michel Trombe, who discovered in 1880 [10]. It is considered a simple and inexpensive solution that uses solar energy in heating, which reduces heat load up to 47% [11]. A Trombe wall is always located on the southern face of buildings in the northern hemisphere to increase solar energy throughout the year. It consists of a wall of concrete or bricks for heat storage, and the wall is coated with black paint to increase the absorption of solar radiation. There are layers of glass at 5–10 cm distance from the concrete wall to increase the intensity of solar radiation. A Trombe wall is covered in the summer to prevent excessive warming [12]. The wall has two openings at the top and bottom to circulate the air. Solar heat is transferred from the Trombe wall into the room by convection heat transfer and conduction. Cold air passes from the lower opening of the wall, then the air is heated through the channel and moves into the room through the upper vent. Meanwhile, heat transfer through the thermal wall needs more time to move into the room. Although a commercial PV system is widely available, however, further research and development are necessary to improve efficiency and reduce costs. Passive solar techniques can reduce yearly heating demand by about 25%. Different architectural devices such as Trombe walls, solar roofs, solar chimneys, and others are used in buildings [13]. In the last years, modern technologies introduced that use solar cells to generate electricity. The photovoltaic cell can be integrated with buildings such as the PV-Trombe wall [14]. The increase in the solar cell temperature leads to lower efficiency as shown in **Figure 2**.

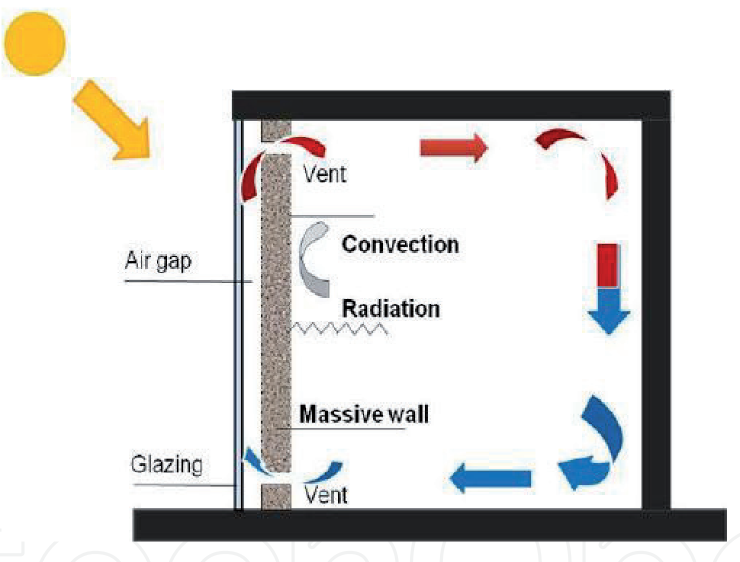


**Figure 1.**
*Classical Trombe wall.*

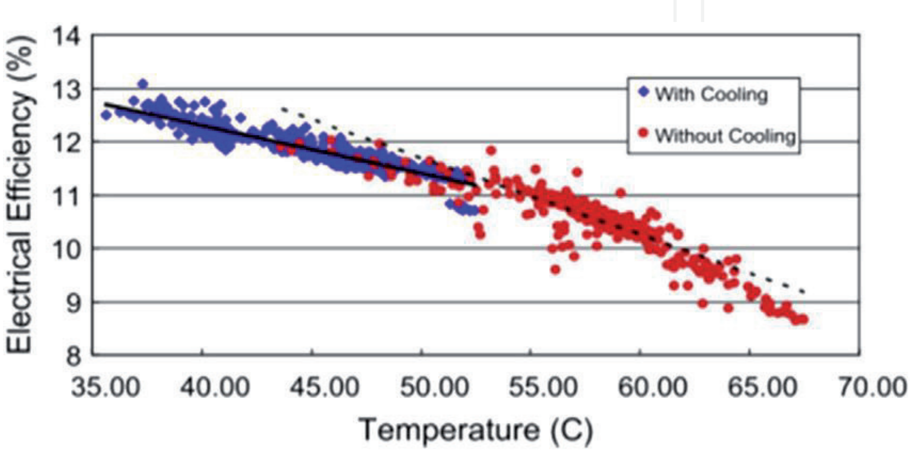


**Figure 2.**
*Electrical efficiency as a function of solar cell temperature.*

## 2. Building-integrated photovoltaic/thermal systems

In early 1990s, the idea of building-integrated photovoltaic/thermal (BIPV/T) systems emerged. It has attracted increasing attention since 2000 because of its potential to facilitate the design of net-zero energy buildings by improving solar energy use [15]. Generally, a BIPV/T system has the following features:

1. BIPV/T system is physically attached to buildings.

2. The system produces electricity.

3. The system provides thermal energy ready to be collected and used by the building.

**Figure 3** shows the PV modules installed on the roof of a room with an air duct at an angle of 34° to the horizontal, which corresponds to the latitude of Srinagar, India.

Chow et al. [16] presented a comparative study of three different parameters for BIPV technology in China. The results showed no significant difference in electricity production as the indoor space with 24-hour temperature supplied continuous cooling of the solar cells through the outer façade. For semi-equatorial climate, PV/C and PV/T systems are better than the BIPV system because of their ability to limit the increase of space temperature. The PV/C system considered a better option because of its effectiveness in reducing the cooling power of elimination and has a simple design.

Hu et al. [17] compared three types of systems [i.e., solar cells affixed to glass (BIPVGTW), solar cell attached to the mass wall (BIPVMTW), and PV-blind-integrated Trombe wall system (BIPVBTW)] as illustrated in **Figure 4**, and the results showed that the electrical performance of BIPVGTW was better and the system adopted electrifying performance at the blindness angle. In terms of thermal performance, the BIPVBTW system increased room temperature during the winter season higher than other systems. The BIPVGTW system is better than BIPVBTW and BIPVMTW systems.

Nagano et al. [18] studied the experimental thermal/PV hybrid exterior wallboards that incorporate PV cells, as shown in **Figure 5**. The clapboard-shaped hybrid wallboards permit modular assembly that is more suitable for building applications than former PV systems. Solar heat collected in the form of heated air

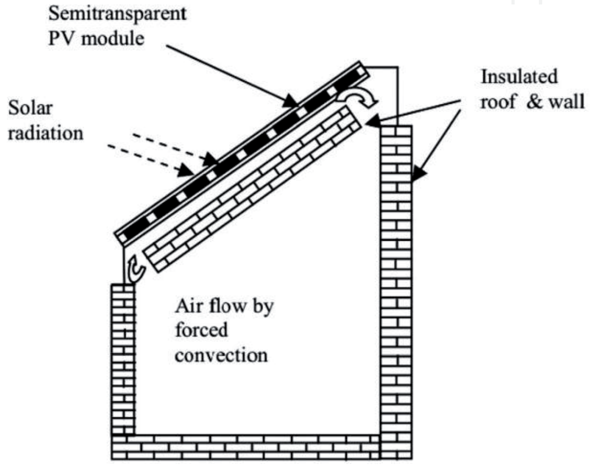


**Figure 3.**
*Photovoltaic-thermal system integrated on the roof.*

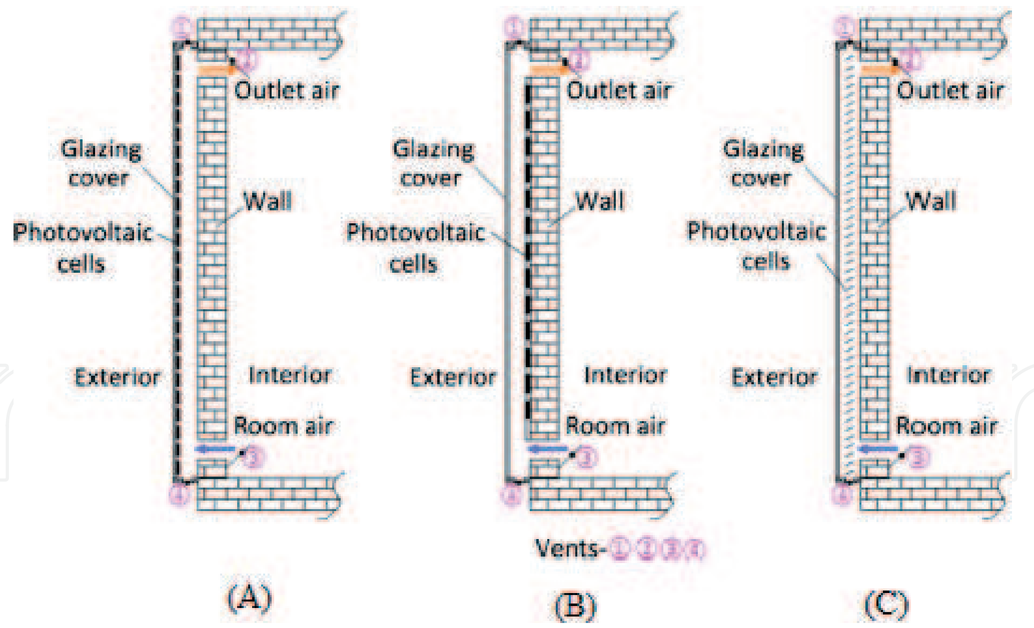


**Figure 4.**
*Three models of BIPV Trombe wall systems. (A) BIPVGTW. (B) BIPVMTW. (C) BIPVBTW.*

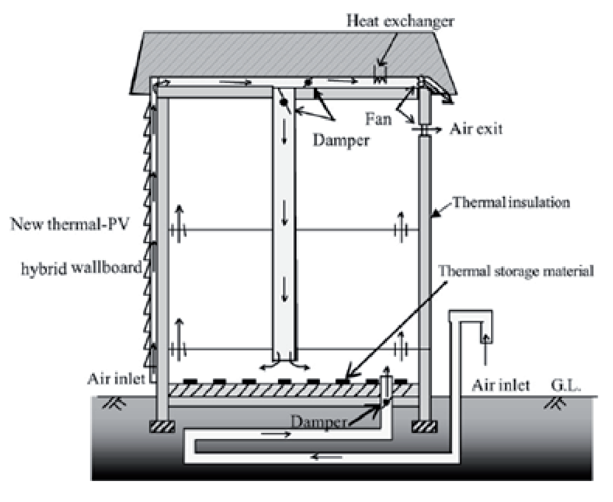


**Figure 5.**
*The concept of a new type of hybrid wallboard.*

circulating in the air duct between the thermal insulation of the exterior walls and the composite wallboard.

## 3. Photovoltaic-Trombe wall (PV/TW)

For the last 20 years, there has been a rapid development in the field of integrated solar technologies. The idea of building the photovoltaic-Trombe wall has appeared as one of the green technologies. The concept is to use solar cells with a Trombe wall to generate electricity as well as heating. The photovoltaic/thermal (PV/T) systems convert solar radiation into heat and electricity together, such as PV-Trombe wall (PV/TW) system.

The design of the PV/TW system is like the original design of the classical Trombe wall, just replacing the thermal wall by a solar cell, as shown in **Figure 6** [19]. They are less expensive, environmentally friendly, and more suitable for a given house or building, and it is more efficient than the separate solar thermal

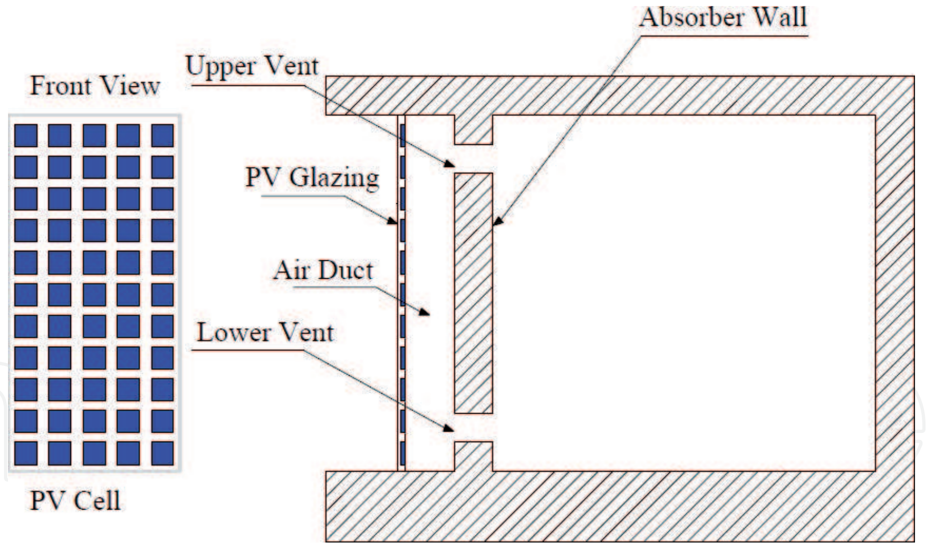


**Figure 6.**
*Photovoltaic-Trombe wall.*

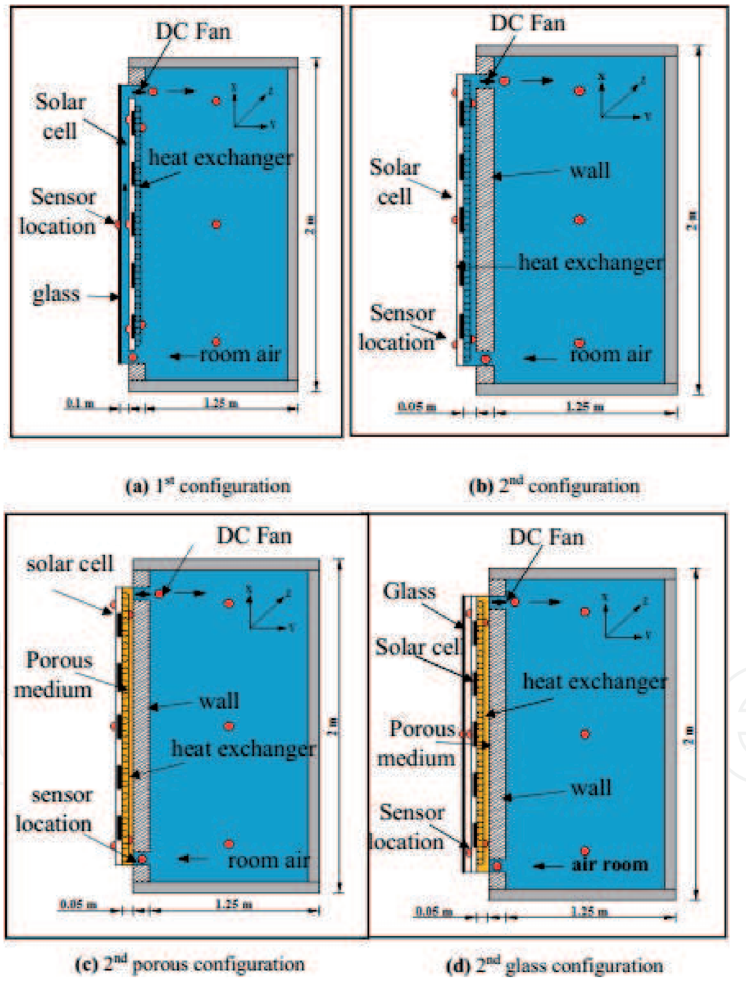


**Figure 7.**
*Modified Photovoltaic-Trombe walls.*

and electrical systems. Furthermore, the PV/TW system can contribute to the reduction in the consumption of fossil fuels for large combined production [20].

Several modifications were performed to improve the performance of PV/TW. Verifying the thermal and electrical performance of the PV/TW system has been done by Ahmed et al. [21, 22]. The base configurations were modified to improve the performance of the PV/TW system. These modifications are inserting the DC fan, heat exchanger, porous medium, and glass cover. Incorporating the DC fan and bi fluid (air and water) cooling circuit offered desirable features of the system performance. This study dealt with the design of two different configurations PV/TW system, as shown in **Figure 7** as follows:

1. The first configuration consists of a glass cover on the front, then the air duct, and the solar cell panel attached to the massive wall, as shown in **Figure 7a**.

2. The second configuration includes the solar cell panel in the front, then the air duct, and the massive wall, as shown in **Figure 7b**.

Also, various suggestions were performed to improve system performance. These modifications for both configurations are inserting a cooling coil and DC fan. Moreover, the second configuration, the porous medium, was added inside the gap, as shown in **Figure 7c**, and a glass cover was attached to the front of the solar cell, as shown in **Figure 7d**.

## 4. Variables affecting the performance of the PV/Trombe wall

PV/TW considers favorable architectural technology and utilizes solar energy for cooling and heating in different climate areas. Many factors affect the efficiency of PV/TW, and these factors should be considered when designing this system in buildings. These factors include operation parameters (mass flow rate, cooling, partial covering, southern window, air duct, and tilt angle of the solar cell) and design parameters [properties of glass, direct current (DC) fan, channel depth, thermal insulation, packing factor, and materials].

### 4.1 Effect of glass cover

During the design of PV/TW, the characteristics of glass, such as the number of glass, glazing thickness, and types of glass (single glass, double glass, and double glass filled with argon), significantly affect the amount of solar radiation absorbed and transmitted, as well as the heat transfer between the interior and the ambient. Irshad et al. [23] presented a simulated model of a room with PV/TW. The performance evaluated by varying the airflow velocity for three different PV/TW glazing types (i.e., single glazing, double glazing, and double glazing filled with argon). The results showed that double-glazing PV/TW loaded with argon demonstrated a significant reduction in cooling load and room temperature, while PV productivity increased.

### 4.2 Effect of DC fan

Jie et al. [14] introduced a novel system for PV/TW-solar cell connected to a DC fan and compared the performance of the system with a normal Trombe wall-solar cell, as shown in **Figure 8**. The results showed a significant increase in room temperature compared to the original room, as well as an increase in the electrical efficiency of the solar cell due to improved cooling. Yi et al. [24] presented a simulated system of novel PV/TW with a DC fan. The results showed that as fan speed increased, the electric and thermal efficiencies also increased.

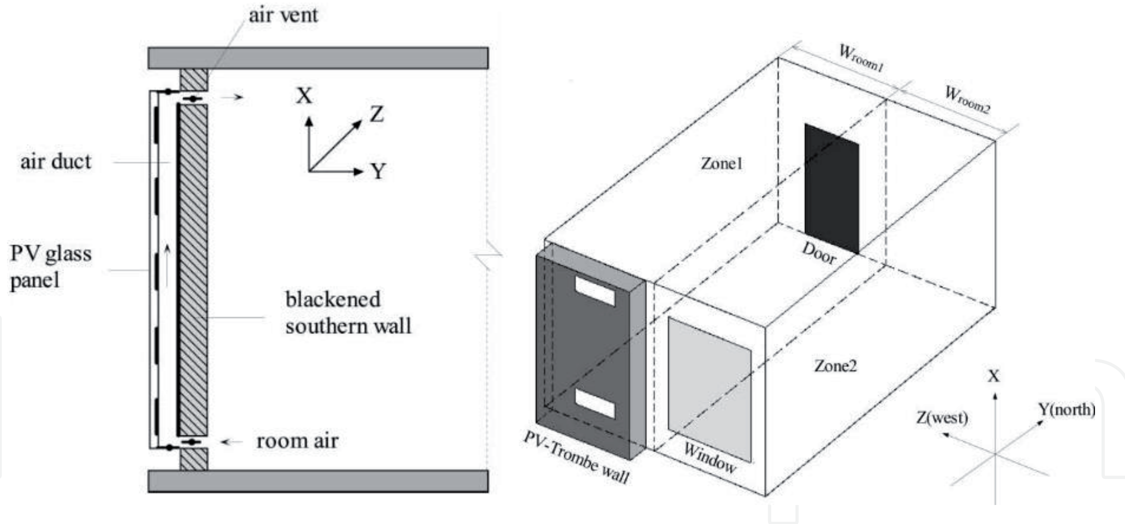


**Figure 8.**
*Modified Photovoltaic-Trombe walls.*

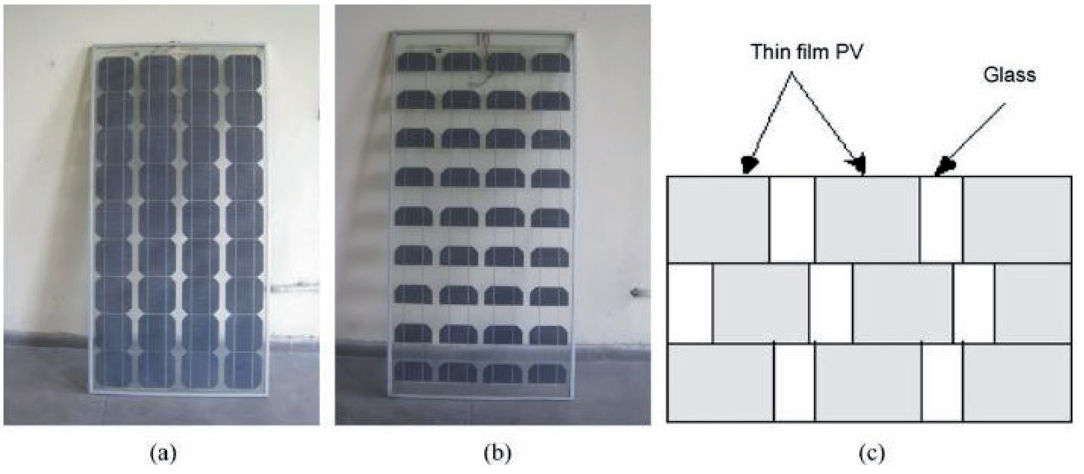


**Figure 9.**
*(a) PV module with a cell area of 0.0139 m², (b) PV module with a cell area of 0.0069 m², and (c) the proposed design of thin-film PV with glass.*

## 4.3 Effect of channel depth

The influence of channel depth, which represents the distance between a glass cover and a solar cell, was investigated. Ji et al. [25] studied the electrical and thermal performance of the PV/TW system utilized in Tibetan residential buildings, as shown in **Figure 8**. It was found that when the width of the PV/TW system increased, the room temperature also increased, although electrical effectiveness was almost constant.

Changing the air gap and different types of PV glazing (i.e., double glazing, single glazing, and double glazing filled with argon) was studied by Irshad et al. [26]. The results affirmed that double glazing PV/TW system filled with argon gives the maximum PV efficiency at a roof pitch angle of 20° and an air gap of 0.2 m. Ventilated PV/TW system and PV cell installed through the roof also reduced the cooling load of the room.

## 4.4 Effect of packing factor

Published studies have shown that reducing the packing factor leads to an increase in room temperature, as mentioned by Vats et al. [27]. The packing factor of a solar cell was dependent on changing the area of PV cells in a given area of the solar cell, as shown in **Figure 9**. The reduction in the temperature of the PV module was observed due to the reduction of the packing factor that enhances electrical effectiveness.

### 4.5 Effect of the coverage ratio

The coverage ratio of PV glazing is defined as:

$$e = A_{pv}/A_{glass} \quad (1)$$

where $A_{pv}$ is the area of PV cells, and $A_{glass}$ is the area of PV glazing. Jiang et al. [28] concluded that with the increase of coverage ratio, the thermal efficiency

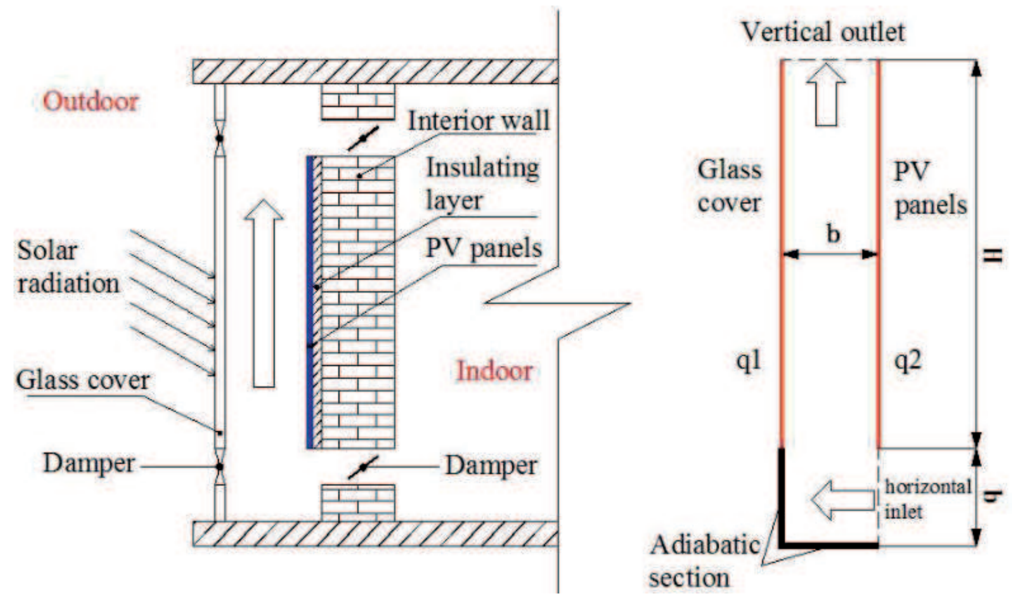


**Figure 10.**
*Physical and simplified models of BIPV-TW.*

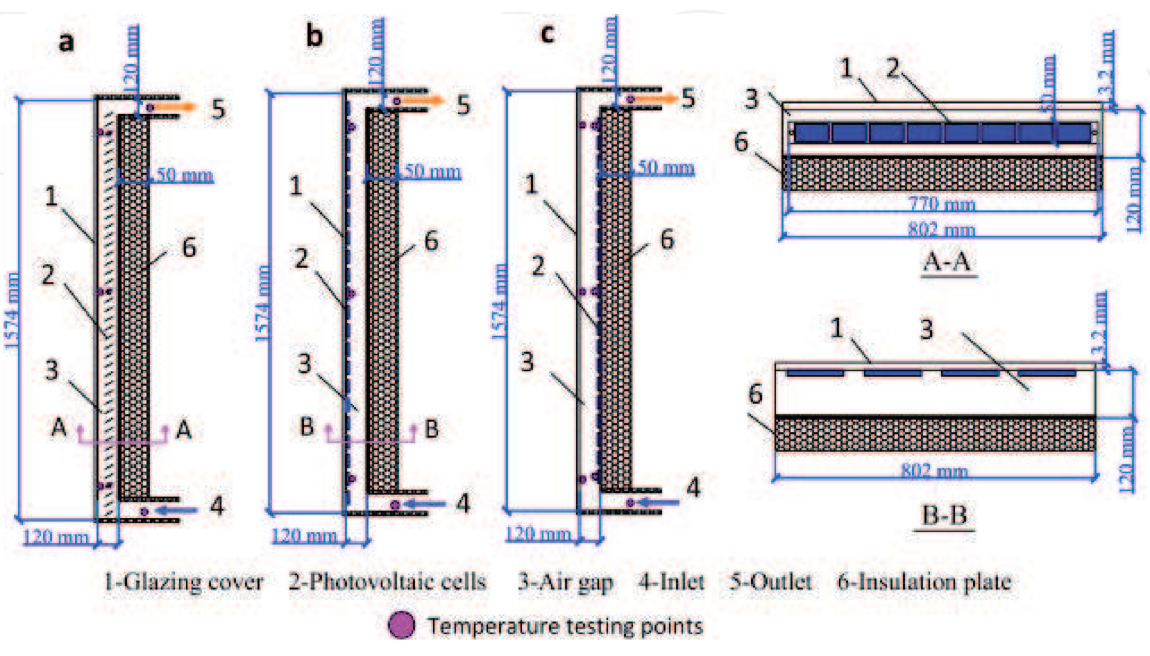


**Figure 11.**
*PV-Trombe wall modules of (a) PV-BTW, (b) PV-GTW, and (c) PV-MTW.*

and room temperature of the PV-TW decreased, but the electrical power and the total efficiency of PV/TW increased. Besides, the electrical efficiency of solar cells decreased, but the effect of the coverage ratio of electrical efficiency was small, less than 0.5%. If the glass were entirely covered with PVC, it would reduce solar radiation and might not be sufficient to provide heating. As a result, the air temperature in the channel was less than room temperature [29].

### 4.6 Effect of mass flow rate

Xu and Su [30] carried out a numerical simulation of airflow in BIPV-TW, as shown in **Figure 10**. The results demonstrated that the airflow rate increased linearly with duct height. Also, Hu et al. [31] investigated experimentally three models of PV/TW, as shown in **Figure 11**, i.e., PV-BTW, PV-GTW, and PV-MTW at the University of Science and Technology of China. The results showed that the angle of 50° and the entry air flow rate of approximately 0.45 m/s were the best parameters for the PV-BTW type. The results also showed that the PV-GTW model produced the highest electricity output compared to PV-MTW and PV-BTW.

## 5. Conclusions and recommendations

Previous works have shown that researchers are interested in finding a way to use solar energy as a substitute, useful, and clean energy. The researchers concluded the importance of studying design and operational information that led to an increase in the electrical and thermal efficiency of the PV/TW system. The following conclusions can be extracted from the previous studied:

1. The use of water to cool the solar cell reduces the temperature of the solar cell, which increases the electrical power produced that increases the efficiency of electricity generation. Also, it increases the overall thermal efficiency but reduces thermal air efficiency.

2. The use of a DC fan increases the produced electrical power and room temperature, which increases thermal and electrical efficiency.

3. The use of glass cover increases the temperature of the solar cell, which decreases the power and efficiency of the electricity generation. Also,the use of glass cover increases the room temperature and thermal efficiency.

4. The use of a porous medium increases the area of heat transfer, which increases the thermal and electrical efficiency and temperature of the room.

5. Thermal and electrical efficiencies have decreased in a dusty and cloudy climate due to a decrease in the amount of solar radiation reaching the solar cell of the PV/TW system.

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