Research Article

Enhancing the Performance of the Standalone Rooftop SPV Module during Peak Solar Irradiance and Ambient Temperature by the Active Cooling of the Rear Surface with Spraying Water and the Front Surface with Overflowing Water

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The usage of the solar photovoltaic (SPV) module to meet the power demands, especially in residential and office buildings, is inevitable in forthcoming years. The objective of this study is to experimentally investigate the possibility of improving the performance of the standalone rooftop SPV module used in the residential and office buildings during peak solar irradiance and ambient temperature with active cooling of the rear surface alone by spraying water and the front surface alone by water overflowing over it and cooling of the rear and the front surfaces simultaneously. The underneath of the SPV module is attached with a tray with a length of 1580 mm, a width of 640 mm, and a depth of 100 mm. It is filled with 40-70 litres of water. Accouters are made for water overflowing from the tube over the front surface of the module and cooling of the rear surface by spraying water. The rear surface cooling, front surface cooling, and simultaneous cooling of both the surfaces reduce the average operating temperature of the module by 15.52°C (maximum 18.6°C), 24.29°C (maximum 28.7°C), and 28.52°C (maximum 34.7°C), respectively. This temperature reduction leads to the increase in the power output of the 150 W module by 10.70 W, 18.48 W, and 20.56 W and percentage increase in efficiency by 8.778%, 15.278%, and 16.895% for rear, front, and simultaneous cooling of surfaces, respectively. The net power output of the module with the front surface cooling by overflowing (0.9 litre/min) water is higher, i.e., 15.88 W/150 W, and produces installation capacity of 0.4234 watt-hour (Wh) of more energy per watt during the test period 10 AM to 2 PM in a day. The recommended cooling methods eliminate the need for freshwater and separate arrangements to dissipate the heat carried by the circulated water and reduced the power required and quantity of water circulated. They also reduced the heat loads of the room by the shadow effect and by maintaining the tray water above the roof.

1. Introduction

The availability of energy and its consumption are the perfect replica of a nation's industrial growth and the people's standard of living. The energy demands of most nations are met by the fossil fuels, which are limited and are nonrenewable energy sources. With limited availability, fossil fuels are also

a core pollutant and they affect the ecosystem when their energy is converted into a utilitarian form. It results in global warming, which is a threat to the entire world. The preeminent natural alternative to fossil fuels is the harnessing of the solar energy into electrical energy by SPV cells. Solar energy is an inexhaustible and feasible source of energy in terms of power consumption of the earth's surface compared

to any other energy source. It is capable of meeting considerable portion of the energy requisites of the nations with minimal environmental degradation. It is the best suitable means of energy to meet the requirements in offices and residents with reasonable initial cost and nearly nil running cost for years. SPV cells are sensitive to temperature variation. The operating temperature of SPV cells is influenced by the solar irradiance on the cells and the ambient temperature [1]. The commercially available SPV cells can convert only up to 18% of the solar irradiance on them into electrical energy. The remaining solar irradiance will be converted into heat, which will increase the operating temperature of the SPV module. Radziemska [2] stated that the electrical conversion efficiency of the SPV module decreased with an increase in operating temperature. Chander et al. [3] noted that the maximum power and efficiency of cells are affected by the operating temperature. The reduction in power output and electrical conversion efficiency may range from 0.4% to 0.5% per °C. Hence, the SPV modules require the proper cooling to overcome the effect of operating temperature and to maintain the execution of SPV modules within the manufacturer's specified values. The objective of this study is to develop a novel and cost-effective and efficient cooling method by using the water stored in the tray underneath the SPV module to provide active cooling on the rear and the front surface of the SPV module.

2. Overview on Cooling of SPV Modules by Water

Sargunanathan et al. [4] discussed the various types of cooling techniques used in improving the functionality of SPV modules and highlighted that water cooling is a highly promising method to improve the outcome. The conduct of the SPV panel with cooling the front surface of the SPV panel by spraying water over the front surface was experimentally investigated by Krauter [5] who described that the reflection losses are reduced by 2–3.6% and the efficiency is increased by 10.3%. Abdolzadeh et al. [6] announced that spraying even a lower rate of water on the PV modules improves the power output and efficiency of the SPV module used to drive the water pump. Further reduction of front surface temperature from 58°C to 32°C using water cooling was verified by Odeh and Behnia [7]. Kordzadeh [8] proclaimed that cooling with a thin film of water over the SPV array surface increased the short-circuit current and reduced the cell temperature up to 25°C at noon.

Drobanțu and Popescu [9] proposed a system that cools the SPV module with a water film on the front surface and reported that the reduction in temperature leads to a gain of 1.5 V, a drop of 0.2 A, and the overall accumulated percentage of power output of 9.5%. Heating rate and cooling rate models were developed by Moharram et al. [10] to predict the performance of cooling of solar modules by water cooling and the duration of water that was sprayed to enhance the potential of the PV module, and they reported that the reduction of operating temperature by 10°C in 5 min increased the solar module efficiency by 12.5% for the water flow of 29 lit/min over six SPV modules each with

185 W capacity through 120 water nozzles and the optimum value of maximum allowable temperature to cool the solar panels with the least amount of water and energy usage was 45°C. Irwan et al. [11] studied the accomplishments of the PV panel with water cooling on the front surface for four different values of solar irradiance under indoor conditions and reported that the cooling increased the maximum power output for the irradiance of 1016 W/m² by 22.81%. An automatic water cooling system to cool the front side of the PV module was suggested by Elnozahy et al. [12], and they indicated that the maximum power output was increased from 68.4 W to 89.4 W and the efficiency was increased from 9% to 11.7% expending 5.4 W to operate a solenoid valve; 24.6 lit/m²/day of water was circulated. The numerical simulation carried out by Aldihani et al. [13] expressed that the cooling of the front surface of the SPV module by water compensated the power reduction caused under dusty environmental conditions. Kazem and Chaichan [14] highlighted that water cleaning was the best option to clean the dust accumulation from the PV panel surface in a dusty environment in addition to cooling. Mah et al. [15] detailed that water film cooling with an optimal flow rate of 6 lit/min on the front surface of the PV panels improved the power generated by 32 W per 260 W-rated PV module at 1150 W/m² solar irradiance.

Bahaidarah et al. [16] documented that back surface cooling reduced the operating temperature of the module (from 45°C to 34°C) about 20% and increased the efficiency about 9% expending 0.5 HP to drive the water pump and water flow rate of 3.6 lit/min. Sajjad et al. investigating posterior side cooling of the PV module [17] reported that the module with cooling has 7.2% higher electrical efficiency and 6% performance ratio as compared to a module without cooling. Haidar et al. [18] who indicated backside water cooling of the PV panel claimed that the panel temperature is reduced by 20°C and the efficiency is increased by 10 to 14% as compared to the panel without cooling. SPV panels with front and backside cooling were studied by Nizetic et al. [19], and they affirmed the maximal total increase in power output of 16.3% (effective 7.7%), the total increase in electrical efficiency of 14.4% (effective 5.9%), and an average temperature reduction of 30°C (from 54°C to 24°C) during peak solar radiation and at the water flow of 225 lit/h. Hachicha et al. [20] reported that cooling the front surface and the rear surface by water improved the efficiency up to 4% and reduced the temperature of the panel up to 7.7°C. The multiconcept cooling technique proposed by Idoko et al. [21] increased the power output of the 250 W module by 20.96 W and the efficiency by 3% compared to the module without cooling. Water and refrigerant cooling was examined by Bai et al. [22], and they declared that an increase in electrical efficiency was about 12% with water consumption of 22.5 litres. Al-Waeli et al. [23] analyzed the performance of a photovoltaic thermal system using a novel artificial neural network approach and concluded that the solar irradiance and the ambient temperature have a constant effect on electrical efficiency. The energetic performance of a building integrated photovoltaic thermal system was predicted by Alnaqi et al. [24] by combining two modern nontraditional techniques,

TABLE 1: Characteristics of SPV modules (150 W/12 V) at 1000 W/m² and 25°C.

Maximum power output (P_m)	153.8 W
Maximum output voltage (V_m)	18.4 V
Maximum output current (I_m)	8.37 A
Open-circuit voltage (V_{oc})	21.9 V
Short-circuit current (I_{sc})	8.82 A
Efficiency of the SPV modules (η_m)	15.5%
Efficiency of the cells (η_c)	17.6%
Cell type	Polycrystalline
SPV module size (mm)	1495 × 665 × 35
SPV module area (m ²)	0.99

namely, artificial neural network and particle swarm optimization, and they reported that both the techniques had enough reliability in the prediction of performance evaluation criteria. Yang et al. [25] attempted to improve the power conversion efficiency of perovskite solar cells (PSC) by preventing the degradation of their layers. In this regard, they used a CsPbIBr₂ inorganic transport layer and showed that the increased power conversion efficiency is possible by the use of CsPbIBr₂ material. Zhai et al. [26] presented a detailed review which focused on the storage of energy harvested through renewable energy resources. Further, Zhai et al. [27] developed a 1D-MoS₂ nanorod/LiNb₃O₈ (NR/LNO) heterostructure for enhancing the photocatalytic H₂ production and proved that this structure can facilitate the enhanced photocatalytic performance due to the improved electron separation and transfer phenomena.

The objective of this study is to experimentally investigate and identify the most effective and efficient method of cooling, which will require the least amount of water for cooling and the least power to circulate the cooling water for the cooling of the standalone rooftop SPV module used in the residential and office buildings during peak solar irradiance and ambient temperature.

3. Experimental Setup

Two identical solar photovoltaic (SPV) modules (each with 150 W/12 V) were used for the experimental investigation. The experimental investigation was done in the tropical climate of South India (latitude 9.959°N and longitude 78.81°E) during peak irradiance and atmospheric temperature conditions. The characteristics of the SPV modules are given in Table 1.

The two modules are kept inclined at 10° horizontally facing south. The two modules are mounted on the roof of the building. During the experiment, the maximum power output was measured by using a variable resistive load (10 A, 30 Ω). The temperatures of the SPV modules were measured with the help of PT100 RTD sensors. Solar irradiance was recorded with a solar power meter. It was observed that the intensity of solar irradiance increases from morning to 12:00 PM; after that, the intensity decreases, and its value ranged from 925 W/m² to 1063 W/m² during the test period

TABLE 2: Specifications of a solar power meter and temperature sensor.

<i>Solar power meter</i>	
Spectral range	400–1100 nm
Range	0–2000 W/m ²
Resolution	100–999.9 W/m ² : 0.1 W/m ² 1000–2000 W/m ² : 1 W/m ²
Tilt angle range	0–90°
<i>PT100 RTD sensors</i>	
Temperature range	–50°C to 200°C
Accuracy	±0.05°C from –50°C to 200°C
Response time	$T_{50} < 1$ sec, $T_{90} < 2$ sec

FIGURE 1: Solar irradiance from 10:00 AM to 2:00 PM.

of 29 March 2020 to 16 April 2020 between 10:00 AM and 2:00 PM. The performance of the SPV module is usually specified for the solar irradiance of 1000 W/m², and the readings were taken between 10:00 AM and 2:00 PM at the interval of every 10 minutes. The specification and accuracy of a solar power meter and temperature sensors used in this investigation are given in Table 2.

To identify the economical and efficient method of cooling of the rooftop SPV module, the performance of the module without cooling is compared with that of the module having cooling in three different conditions as follows:

- Cooling of the front surface by water overflowing over the front surface of the SPV module
- Cooling of the rear surface by spraying water over the rear surface of the SPV module
- Simultaneous cooling of the front and rear surfaces by the above methods

The solar irradiance recorded on three different testing days from 10:00 AM to 2:00 PM is shown in Figure 1.

(a)

(b)

(c)

FIGURE 2: (a) Experimental setup, (b) schematic layout of the front surface cooling, and (c) schematic layout of the rear surface cooling.

The experimental setup employed in this investigation for both reference and research purposes is shown in Figure 2(a).

The schematic layout of the front surface cooling of the overflowing water is shown in Figure 2(b). One SPV module is used as a reference module (SPV module without cooling attachment), and another SPV module is attached with a tray with a length of 1580 mm, a width of 640 mm, and a depth of 100 mm. The tray is secured in a horizontal position at a distance of 30 mm beneath the SPV module. The tray is filled with 40 litres of water, and provisions for flowing of water from the tube over the front surface of the SPV module are made. The main aim of this method is to maintain a thin film of water over the front surface of the module to provide uniform cooling and cleaning effect. A low-power variable-speed microsubmersible pump is used to retrieve the water from the tray to the tube held on top of the front surface of the SPV module. A linear low-density polyethylene (LLDPE) tube of 12 mm diameter and 665 mm long which is used in drip irrigation is used as the water container over the SPV module. There are 21 holes, of which each has the maximum 2 mm diameter, which are punched at the interval of 30 mm on the tube. The tube is positioned in such a way that the water is overflowing from the tube through all 21 holes. The microsubmersible pump is immersed in the tray water and delivered 0.9 litre/min of water to the LLDPE tube at a constant head of 400 mm. The water delivered by the pump is varied by varying the speed of the pump. The speed variation of the pump is done by varying the power input with appropriate equipment. The water overflowing from the LLDPE tube maintains the thin layer of water over the front surface of the SPV module. The pump was continuously operated from 10:00 AM to 2:00 PM for the better accountability of the SPV modules with a timer. The profound features of this experimental setup are as follows: it does not require freshwater for continuous circulation and the water stored in the tray can be reused for a day or two depending on the TDS (total dissolved solids) value of the water. The same water gets collected in the tray after cooling the SPV module, and also, no separate arrangement is necessary to dissipate the heat carried by the circulated water, because the water circulated per minute is only 0.9 litre. But the tray contains 40 litres of water; the used water falls into the tray drop by drop over a width of 665 mm. Some amount of heat from the used water automatically dissipated into atmospheric air, and the remaining mixes with water in the tray. The tray with water has an open top surface area of nearly 1 m²; this will facilitate the heat dissipation by natural convection. The open top and side surface areas are void enough for the heat to easily exhaust by a mixed mode of conduction and by natural convection. The specifications of the microsubmersible pump are given in Table 3.

Three PT100 RTD temperature sensors were held on the rear side of each SPV module. The front surface temperature of the SPV modules is measured with an infrared temperature sensor.

The schematic layout of the rear surface cooling is shown in Figure 2(c). It is very difficult to cover the rear surface of the module with cooling water uniformly. Hence, a

TABLE 3: Specifications of the microsubmersible pump.

Operating voltage	12 V
Operating current	130 mA–220 mA
Flow rate	30 lit/h–90 lit/h
Maximum lifting height	400 mm–1100 mm
Power consumption	1.5 W–2.6 W

3960 mm long flexible LLDPE tube of 16 mm diameter with 29 holes (uniformly placed) each with 3 mm diameter is placed in a zigzag manner at a distance of 30 mm from the hinder side of the module. One end of the tube is closed, and the other end is connected with a submersible pump outlet. The holes are at 15° vertically so that the water strikes, flows, and covers the maximum surface area of the panel. A submersible pump with delivering capacity of 6 lit/min is submerged in the tray with water (70 lit) which is attached to circulate the water through the water tube. The power required to run the pump is 19 W. During simultaneous cooling, the microsubmersible pump supplies water for front surface cooling and another submersible pump supplies water for rear surface cooling.

4. Results and Discussion

The measurements on 09 April 2020 have been taken in analyzing the performance improvement of the front surface cooling by overflowing water over the front surface. The intensity of solar irradiance, the atmospheric temperature, and wind velocity varies from 925 W/m² to 1055 W/m², 35°C to 38°C, and 2.1 m/s to 3.5 m/s, respectively. The measurements taken on 04 April 2020 have been analyzed for the performance improvement by the spray water cooling of the rear surface. The average solar irradiance during the test period was 998 W/m². The performance improvements by the simultaneous cooling of rear and front surfaces have been analyzed by using the measurements taken on 16 April 2020. The average solar irradiance during the test period was 1002 W/m². The efficiency is calculated as described in

$$\text{Efficiency } (\eta) = \frac{\text{Power output}}{\text{Energy input}} \times 100 = \frac{V_m I_m}{I_{rr} A_m} \times 100, \quad (1)$$

where

$$\text{Power output} = \text{Output voltage } (V_m) \times \text{Output current } (I_m), \quad (2)$$

$$\text{Energy input} = \text{Intensity of solar irradiance per unit area } (I_{rr}) \times \text{Area of the module } (A_m). \quad (3)$$

4.1. Effect of Cooling on the Mean Operating Temperature of the Module. The experimental results showed that the cooling of the front surface by overflowing water over the front surface, cooling of the rear surface by spraying water, and simultaneous cooling of front and rear surfaces reduced the

FIGURE 3: (a) Average surface temperature of front surface-cooled SPV modules from 10:00 AM to 2:00 PM. (b) Average surface temperature of rear surface-cooled SPV modules from 10:00 AM to 2:00 PM. (c) Average surface temperature of front and rear surface-cooled SPV modules from 10:00 AM to 2:00 PM. (d) Mean temperature variations of SPV modules with and without cooling from 10:00 AM to 2:00 PM.

mean operating temperature of the module. The mean operating temperature of the modules with cooling ranges from 42.10°C to 44.80°C, 49.90°C to 54°C, and 37.70°C to 39.60°C for the front, rear, and simultaneous cooling of the surfaces, respectively. The mean operating temperature of the module without cooling varies from 60.80°C to 74.20°C. The mean operating temperature reduction of 28.52°C (42.403%) and maximum temperature reduction of 34.7°C were recorded with simultaneous cooling of the surfaces. The operating temperature reduction of 15.52°C to 18.6°C was observed in the rear surface cooling of the SPV module. The mean operating temperature reduction recorded in the case of the front surface cooling by overflowing water over the front surface was 24.29°C (35.784%), and the maximum temperature reduction was 28.7°C. The range of operating temperature variation is minimum in simultaneous cooling of the surfaces and was 1.9°C. The range of operating temperature variation of 2.7°C and 4.1°C was observed in front and rear surface cooling of the SPV module.

The rear surface temperature of the rear surface cooling module was 1°C to 1.5°C less than the front surface temperature, but for the reference module, it was 1°C to 2.5°C more

than the front surface temperature. The temperature difference between the rear and front surfaces of the simultaneous cooling module is less than 0.5°C, and the temperature of the module was much closer to the atmospheric temperature. Front surface cooling yields much better temperature reduction per litre of cooling water used than the rear surface and simultaneous cooling of the surfaces. For the three different cooling arrangements, the mean temperature variations across the modules are shown in Figures 3(a)–3(c). The temperature variation with and without cooling arrangement is graphically shown in Figure 3(d).

4.2. Effect of Cooling on the Power Output of the Module. The experimental results showed that the reduction in operating temperature caused by cooling leads to the improvements in the power output of the modules. The peak power output from the SPV module to the proposed front surface cooling is 144.81 W at the solar irradiance of 1045 W/m². The average power output of the front surface-cooled module and reference module was 138.97 W and 120.49 W, respectively. The increase in the average power output from the SPV module in proposed front surface cooling during the test period of

FIGURE 4: Continued.

FIGURE 4: (a) Power output and efficiency of the module with front surface cooling from 10:00 AM to 2:00 PM. (b) Power output and efficiency of the module with rear surface cooling from 10:00 AM to 2:00 PM. (c) Power output and efficiency of the module with simultaneous cooling of surfaces from 10:00 AM to 2:00 PM. (d) Power output of SPV modules with and without cooling from 10:00 AM to 2:00 PM. (e) SPV module efficiency with and without cooling from 10:00 AM to 2:00 PM.

10:00 AM to 2:00 PM is 18.48 W, and the percentage increase in the power output is 15.337%. The maximum power spent to drive the microsubmersible pump is 2.6 W only. Therefore, the net increase in the power output is 15.88 W. The front surface cooling by overflowing water over the front surface of the SPV module increased the net average power output of the SPV module by 13.180% and produces installation capacity of 0.4234 Wh of more energy per watt during the test period 10 AM to 2 PM in a day. The average power output of the rear surface-cooled module was increased by 10.70 W as compared to that of the reference module. The percentage increase in the power output was 8.827%. The simultaneous cooling increased the power output of 20.56 W as compared to the reference module. The percentage increase in the power output is about 16.909%. When the power spent for

circulation of cooling water is taken into account, the front surface cooling by overflowing water over the front surface yields much better results than the rear surface cooling and simultaneous cooling of the surfaces.

4.3. Effect of Cooling on the Efficiency of the Module. The improvements in the power output due to the temperature reduction caused by cooling increased the electrical conversion efficiency of the modules. The efficiency of the modules with simultaneous cooling of the surfaces ranged from 14.154% to 14.569%. The average efficiency of the simultaneously cooled module and the reference module was 14.336% and 12.264% on the test day of 16 April 2020 between 10 AM and 2 PM. The increase in efficiency with simultaneous cooling was 2.072%, and the percentage

TABLE 4: Comparison of the proposed SPV cooling system with several studies on a water-cooled SPV system.

Ref.	% increase in efficiency	Rated power	Increase in power	% increase	Power spent for cooling	Net power increased	% increase	Temp. reduction	Water flow rate	Type of cooling
[5]	***	55 W	***	10.3	***	***	9	Up to 22°C	2 lit/min	Front side water cooling
[7]	***	60 W	***	4 to 10	***	***	***	Up to 26°C	4 lit/min	Front side water cooling
[8]	***	135 W	6 W	***	***	***	0.69	Up to 25°C	***	Front side water cooling
[9]	***	75 W	3.5 W	9.5	***	***	***	Up to 10°C	***	Front side water cooling
[10]	12.5	6 × 185 W	***	***	1 HP	***	****	Up to 10°C	29 lit/min	Front side water cooling
[11]	***	50 W	***	9 to 22	***	***	***	5°C to 23°C	***	Indoor front side water cooling
[12]		80 W	21 W	26	5.4 W	***	***	Up to 20°C	24.6 lit/m ² /day	Front side water cooling
[13]	***	180 W	21 W	***	***	***	***	Up to 20°K	***	Numerical simulation
[14]		125 W								Front side water cooling
[15]	***	260 W	32 W	***	14.25 Wh	17.8 Wh	***	Up to 28°C	6 lit/min	Front side water cooling
[16]	9	230 W	***	***	0.5 HP	***	***	***	3.6 lit/min	Back side water cooling
[17]	7.2	40 W	***	***	***	***	***	***	***	Backside air cooling
[18]	14	75 W	***	***	***	***	***	Up to 20°C	***	Backside water cooling
[19]	***	50 W	6.2 W		2.7W to 4.2 W	2 W	5.7	Up to 22°C	225 lit/h	Front and back side water cooling
[20]		20 W	***	***	***	***		Up to 7.7°C	***	Front and backside water cooling
[22]	***	***	22.9 Wh	***	9.38 Wh	12 Wh	**	***	22.5 lit	Water and refrigerant cooling
Proposed system	15.278	150 W	18.48 W	15.337	2.6 W	15.88 W	13.180	Up to 28.7°C (average 24.29°C)	0.9 lit/min	Front side overflowing water
	16.895	150 W	20.564 W	16.909	***	***	***	Up to 34.7°C (average 28.52°C)	6 lit/min	Simultaneous cooling of front and rear sides

increase in efficiency is about 16.895%. The front surface cooling by overflowing water over the front surface of the module increased the efficiency by 1.868%, and the percentage improvement in the efficiency was 15.278%. The rear surface cooling improved the efficiency by 1.078%, and percentage improvement in efficiency was only 8.778%. The variation of power output and electrical conversion efficiency of the SPV modules for the three cooling arrangements during the test period is shown in Figures 4(a)–4(c).

Figures 4(d) and 4(e) explain the variation of the power output and electrical conversion efficiency of the SPV modules with and without cooling arrangement.

5. Conclusions

The results of the experimental investigation of the SPV modules showed that the active water cooling on the module surfaces effectively reduced the mean operating temperature of the modules. The proposed system of front surface cooling by overflowing water requires only 0.9 lit/min/m² to achieve the mean operating temperature reduction of 24.29°C (35.784%) and up to 28.7°C during the peak irradiance (average 986 W/m²) and atmospheric temperature (37.1°C) conditions. The increase in electrical yield is 1.868%. The increase in the power output of 18.48 W is achieved expending 2.6 W for pumping the cooling water. The net increase in the power output is 15.88 W, and the percentage increase in the net power output is 13.180%. Front surface cooling produces installation capacity of 0.4234 Wh of more energy per watt during the test period 10 AM to 2 PM in a day. Simultaneous cooling of both front and rear surfaces yields a maximum mean operating temperature reduction of 28.52°C (42.403%) and up to 34.7°C, a maximum increase in the power output of 20.56 W, and a maximum increase in efficiency of 2.072%. The proposed front surface cooling and simultaneous cooling of both front and rear surfaces keep the mean operating temperature of the module always less than 45°C and 38°C, respectively, during peak irradiance and ambient temperature (37.5°C) conditions. The range of operating temperature variation is minimum in simultaneous cooling of the surfaces and was 1.9°C. The range of operating temperature variation of 2.7°C and 4.1°C was observed in front and rear surface cooling of the SPV module. The flow of water over the front surface always keeps the module dust free and clean. The cooling of the rear surface alone is not much more effective and efficient as compared to the other two methods. For the rooftop SPV module, cooling of the front surface by overflowing water is the least expensive, simple, effective, and efficient method as compared to the rear surface cooling, simultaneous cooling of front and rear surfaces, and methods proposed by the other researchers (Table 4). The proposed methods eliminate the separate arrangement to dissipate the heat carried by the circulated water and also eliminate the need for fresh water for every circulation. The same water can be used for a day or two. Keeping the tray of water below the SPV module and above the roof also reduces the heat inflow through the roof into the rooms, which is the indirect benefit of the proposed cooling method.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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