Application of photovoltaic-thermal (PV-T) Power for cooling systems - syafar uddin.pdf

by Syafaruddin Syafaruddin

Submission date: 03-Nov-2018 10:56AM (UTC+0700)

Submission ID: 1032062077

File name: Application of photovoltaic-thermal (PV-T) Power for cooling systems - syafar uddin.pdf (164.39M)

Word count: 4203

Character count: 21936

ICIC Express Letters
Part B: Applications
Volume **9**, Number **12**, December **2018**

ICIC International ©2018 ISSN 2185-2766
pp. 1223–1231

APPLICATION OF PHOTOVOLTAIC-THERMAL (PV-T) POWER FOR COOLING SYSTEMS

Syafaruddin[1,*], Faharuddin[1], Moehammad Adymulya[1] and Satriani Latief[2]

[1]Department of Electrical Engineering
Universitas Hasanuddin
Jalan Poros Malino Km. 6, Gowa 92171, Indonesia
*Corresponding author: syafaruddin@unhas.ac.id

[2]Department of Architecture
Universitas Bosowa
Jalan Urip Sumoharjo Km. 4, Makassar 90231, Indonesia

Received May 2018; accepted August 2018

Abstract. *Solar energy for cooling system is one of the important applications for equator region. It is due to daily hot weather condition that results in the extremely high need of electricity consumption of air conditioning system. Nevertheless, the abundance of sun light energy in the region is the good news for the energy source of photovoltaic-thermal (PV-T) systems, especially for the cooling system applications. In this case, the paper presents the cooling systems powered by the photovoltaic panels by extracting the thermal energy from the heat extraction box designed at the backside of PV module. The water is used as the medium heat transfer, while the refrigerant is used as the working fluid in the cooling engine. In this study, the effectiveness of R22 and R134a refrigerants is compared in terms of producing lower cold temperature under different refrigerant pressures of 1 bar and 2 bars. Only small portion of electricity energy output of PV module is utilized for our designed cooling systems that make the PV module performance will be maintained high in terms of efficiency.*
Keywords: Solar energy, Refrigerant pressure, Photovoltaic-thermal system, Cooling systems

1. **Introduction.** The abundance of sunlight intensity in equator region can be used for the additional energy sources of different applications. In this case, the solar energy is applied for cooling system which is quite uncommon utilization of solar energy. The cooling system based solar energy is one of the most important applications in equator region due to hot daily temperature condition and high humidity. Mostly, the cooling system is provided with the conventional method by means of the provision of air conditioning systems. As a result, a significant portion of electricity energy consumption goes to the air cooling system due to the operation of air conditioning system for comfortable room temperature.

Conventional cooling system works basically following the principle of heat transfer. Initially, the compressor section functions as the driving force to drain the Freon refrigerant in the tube. The compressor motor rotates and provides pressure in all cooling materials. The refrigerant when given the pressure will be the gas pressure in high temperature. This is the reason why the electricity consumption of cooling system is quite high because the use of compressor to circulate and to raise the temperature of refrigerant. In this research, the use of electrical power can be saved by utilizing solar energy for cooling systems. The heat energy from sunlight can be used to replace the function of compressor to raise the temperature of the refrigerant. In addition, the proposed cooling

DOI: 10.24507/icicelb.09.12.1223

system may maintain the electricity power consumption of PV module after utilizing the low-power motor for water and refrigerant circulations.

The heat collected from the backside of PV module is utilized to raise the temperature and pressure on refrigerant of cooling system. The mechanism is to heat the water until reaching certain temperature which is good enough to raise the temperature of liquid refrigerant and make it evaporate. The evaporated refrigerant will be sucked in a vacuum motor so that it flows to the cooling tank. In the cooling tank, the evaporated refrigerant will be transformed back into liquid through condensation process so that the temperature in the cooling tank is going down and be cool. Such condition is utilized by transferring the cold temperature of the cooling tank into the room through the water medium which is diverted from a pipe connected to the cooling tank and the room target. The cold water temperature is then exhaled to make the room air temperature decrease and become colder.

Utilization of thermal energy by means of the photovoltaic-thermal systems has been investigated in order to improve the efficiency performance of photovoltaic systems. The electrical efficiency is denoted very low; however, the overall efficiency can be improved by simultaneously obtaining the thermal energy for heating systems [1]. In this case, the extraction of heat energy by fluid media provides some kind of radiator or cooling systems and this approach enhances indirectly the electrical efficiency of photovoltaic systems since the heat degrades the output voltage and power as well, especially for polycrystalline solar cell materials [2]. The heat removal by air or water prevents the deterioration of the PV cell efficiency due to the overheating of cells [3]. The benefits of thermal energy on rooftop household photovoltaic systems have also been investigated for drying systems and the economic impact might be obtained from such household utilization [4]. More detail about the performance of water as regime fluid for photovoltaic thermal system is evaluated regarding the other supporting components in order to maximize the exergy efficiency thermal [5]. The important point in thermal utilization of photovoltaic system requires constant researches support and challenges in order to maximize the benefits performance of building integrated photovoltaic thermal systems [6].

The cooling system is important either to improve the photovoltaic system performance or to be target dehumidifying system as further utilization of thermal energy extracted from photovoltaic module. Simple approach to cooling systems has been designed in terms of the control of air circulation obtained from the electricity energy output of photovoltaic system [7]. The main challenge to improve the solar thermal cooling technology is necessary to have the high operating temperature of heat source [8]. In our paper, it is not important to have the high temperature for heating the refrigerant since the type of R22 refrigerant is characterized as low temperature evaporation and the cooler temperature is possibly obtained with increasing the refrigerant pressure. Nevertheless, the solar energy for cooling system applications is still questionable compared to the conventional ones; therefore, the complete life cycle assessment has been conducted for the best topology configuration of grid connected and standalone photovoltaic plants for heating and cooling system application with the case study in Europe [9]. Similar parametric study of heating and cooling systems has been conducted in Algeria under variably climate condition [10]. Based on the wide-ranging review, it may be predicted that with the swelling growth of solar PV electricity worldwide, the compatible cooling system is becoming obligatory in order to ensure better energy harvest and utilization [11].

The important part of our proposed cooling system is actually the heat extraction box which is designed at the backside of PV module. The heat is transferred from the extraction box using water as the medium fluid, while the refrigerant is used as the working fluid in the designed cooling engine. Basically, the main component of our proposed cooling system consists of vacuum motor, windshield pump, refrigerant tank, water tank and solar panels. Because no electricity energy output of PV module is utilized in our design, the PV module performance in terms of efficiency will be maintained high. The efficiency output is also very dependent on sunlight intensity and the characteristics of medium heat transfer and the type of refrigerant. The cooling system can be developed into a large scale system with updating the type of vacuum motors and upgrading the model construction.

The outline of the paper is presented as follows. It begins with the importance of the proposed design of cooling systems in gaining the solar energy utilization. Then, configuration of the proposed system is presented prior to the measurement results and discussion. The conclusions are denoted in the end.

2. **Configuration of the Proposed Systems.** The configuration of cooling system utilizing solar energy is basically similar to the conventional refrigeration systems. The different component is the solar panel for electricity energy output and heat energy collector. The electric current from the terminal output of PV panel is used to power the vacuum motor pump, while the heat energy from the extraction box of the backside of PV module is used to raise the temperature of the liquid refrigerant so that the refrigerant evaporates in the heater tank. The evaporated refrigerant discharges to the cooler tank where the refrigerant temperature reduces by condensation process. The decreased temperature in the cooling tank will be used to cool the water that passes through pipe from the cooling tank to the evaporator connected to the room cooling target. The indoors evaporator will continue to process the cold temperatures that is distributed by a fan in the room. The cycle will be repeated as long as the equipment is working. The circulation of hot water, refrigerant and cold water is clearly shown in Figure 1.

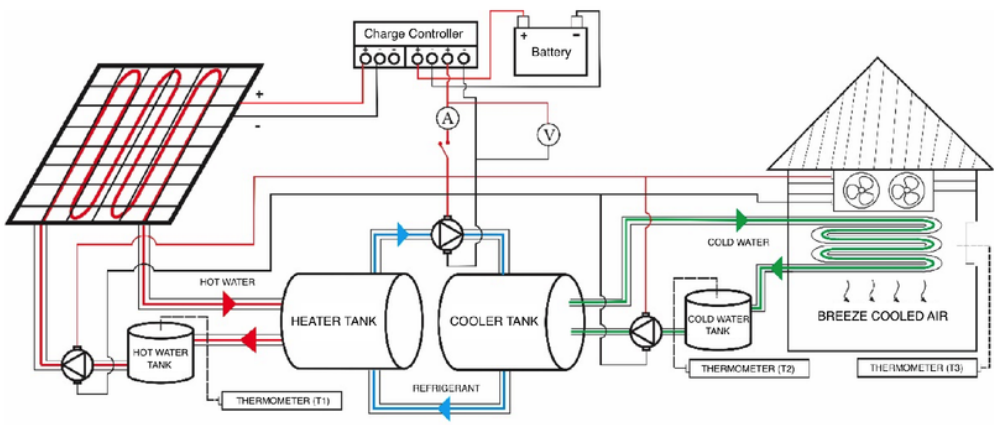

FIGURE 1. Schematic diagram of cooling system

The details of equipment and component are explained as follows. The photovoltaic panel with 50 W_p of WJ50-M polycrystalline Silicon modules is used as the power supply for the electric component and to capture the heat from the sun designed as the backside of panel. The terminal voltage of PV panel is 17 Volt connected to the charge controller and battery. The battery model is UXH100-12N of 100 Ah, while the charge controller is SCMTTP-10 type of the maximum load current of 10 A. The DC vacuum motor of 12 V rated voltage for R22/R134a of refrigerant circulation is with 0-6 psi operating pressure, while the water circulation by the windshield pumps with the flow rate capability of 2400 ml/mins. The room which is designed as the cooling room target of dimension of $30 \times 20 \times 40$ cm^3 completes with the motor fan of DC12025S model for air circulation. The additional components are NYA cable and switches. The operational model of components is shown in Figure 2.

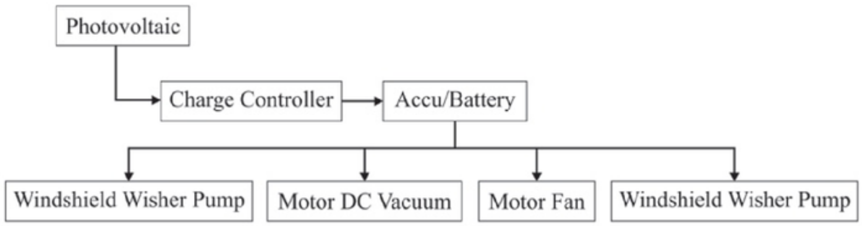

FIGURE 2. Operational model

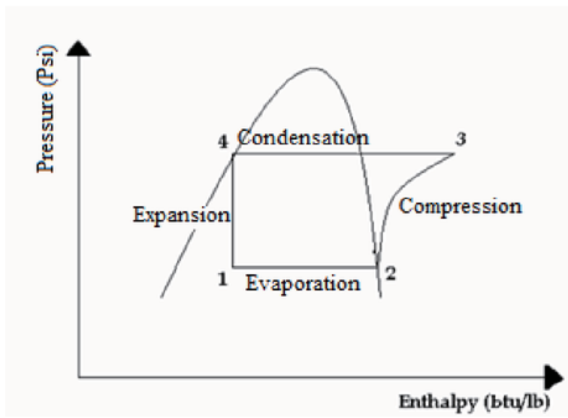

FIGURE 3. Ideal steam compression in pressure-vs-enthalpy

The box heat extraction is the most crucial component to be designed in our proposed cooling system. The box is designed with spiral copper pipe of 3/8 inch inside for the path of water as fluid media to transfer the heat of the backside of PV module. It has been explained that the hot water is used to heat the refrigerant and circulate in one complete process. The dimension of box heat extraction is $85 \times 55 \times 5$ cm^3 which is depending on the PV module dimension. The cooling performance is indicated by the capability to keep the radiated heat of PV module inside the box extraction.

In this proposed model, the cooling process is basically following the compression process, caloric discharge flow, refrigeration effect and coefficient of performance as in Figure 3. The compression process of btu/lb is the pressure change in the enthalpy of the process of expansion, condensation, compression and evaporation. The equation in the steady flow of energy can be expressed as:

$$h_2 + q = h_3 + w; \text{ and } w = h_2 - h_3 \tag{1}$$

where h_2 is the enthalpy from evaporator to compressor in W/m^2°C, h_3 is the enthalpy from compressor to condenser in W/m^2°C, q is the caloric discharge flow in kJ/sec and w is discharge capacity in liter/sec.

Meanwhile, the caloric discharge flow in btu/lb is the calor displacement of refrigerant during the condensation process. In Equation (1), the steady state energy output could be kinetic, potential energy or just output energy. The caloric discharge flow during the condensation process can be expressed as:

$$q = h_4 - h_3 \tag{2}$$

where h_4 is the enthalpy from condenser to expansion valve in W/m^2°C. In addition, the refrigeration effect (RE) in btu/lb is the caloric transfer during process of $h_1 - h_2$, where

h_1 is the enthalpy between expansion valve and evaporator. The refrigeration effect is the most important part as the main purpose of our designed systems.

$$RE = h_2 - h_1 \tag{3}$$

Finally, the coefficient of performance (COP) becomes the indicator of ideal power, which can be expressed as:

$$COP = \frac{h_2 - h_1}{h_4 - h_3} \tag{4}$$

In this research, the equation in the second cycle is very important where the refrigerant circulates from the heater to cooler tanks.

3. Measurement Results and Discussion. The testing design is to determine the performance of the cooling system. The working mechanism started when the photovoltaic module is constructed on top of the heat extraction box which is connected to heater tank. The heater tank stores the liquid refrigerant that will be heated by heat energy transfer from solar panel collected in the extraction box. The liquid refrigerant is heated to increase the temperature until the refrigerant evaporates. After that, the vapor of liquid refrigerant is sucked into the tank cooling where the temperature of refrigerant decreases. Finally, the lower temperature of liquid refrigerant flows in the evaporator to make the room temperature go down.

A refrigerant is a cooling agent that may absorb the heat of other materials. In steam compression cycles, the refrigerant is continuously evaporated and condensed. Chemical compounds can be used as the refrigerant if they are safe and economic in terms of chemical physical characteristics as well as the thermodynamic performance. In addition, management of temperature and pressure of refrigerant is also one of the important aspects in determining the performance of cooling systems. To fulfill these criteria, the common refrigerant which might be from halocarbon, inorganic, hydrocarbon chemical compounds is commonly used.

There are so many types and codes of refrigerant distinguished from color codes and chemical names. The research utilizes refrigerant of R22 and R134a according to the cooling purpose and availability type of compressor. The R22 type is a chlorofluorocarbon (CFC) refrigerant of $CHClF_2$ with pale blue color, while the R134a is a hydrofluorocarbon (HFC) refrigerant of tetrafluoroethane HFC-134a with light blue sky color. The R22 refrigerant is commonly used in the cooling system with low temperature due to the fact that the boiling temperature at atmospheric pressure is very low (-40°C); therefore, it is suitable for evaporator temperature of -87°C. However, the output temperature of such refrigerant is high so that the suction of super heat steam must be maintained at the minimum level. If it is necessary, the cooling of head compressor can be recommended, especially for cooling systems with lower temperature. The R22 refrigerant is sometimes mixed with oil; therefore, the oil separator is needed before the refrigerant reaches the evaporator. Meanwhile, the R134a refrigerant has better characteristics than the R22 refrigerant in terms of non-toxic, fireproof and relatively stable characteristics. Nevertheless, the utilization of R134a is not so simple to replace other types of refrigerant unless the refrigeration system is modified which can be more expensive. In addition, the R134a refrigerant is highly depending on the synthetic lubricants that may cause other problems due to the hygroscopic characteristics.

This research focuses on the cooling systems performance according to the refrigerant types of different pressure levels. The refrigerant of R134a is used for the cooling system design under refrigerant pressure in 1 bar which was tested for Thursday, 25 June, 2015 from 12:30 to 14:00 under clear sky conditions with the irradiance of 800-1000 W/m^2. Meanwhile, the test of the same refrigerant and sunlight condition under refrigerant pressure in 2 bars was performed on Sunday, 28 June, 2015 from 12:30 to 14:00. Meanwhile, the measurement of cloudy sky condition with 1 bar air pressure was conducted on Saturday, 27 June, 2015 from 12:30 to 14:00 with the irradiance of 400-600 W/m^2. The 2 bars of refrigerant pressure in cloudy sky condition were performed on Wednesday, 1 July, 2015 from 12:30 to 14:00. The solar light intensity under clear sky condition is higher than the cloudy sky so that the electric and thermal energy yields are consequently high for the maximum performance of overall designed systems. In addition, there is no modified design in our proposed cooling system when implementing the R22 refrigerant for 1 and 2 bars refrigerant pressure, except the day where the measurement was taken.

Figures 4 and 5 show the performance of our cooling system using refrigerant R134a under refrigerant pressure 1 and 2 bars, respectively. Under refrigerant pressure in 1 bar, the cooling system is slowly started in 50 minutes operation for both clear and cloudy sky conditions. The minimum temperature that can be reached is 28.1°C when the measurement is taken under clear sky condition. If the refrigerant pressure are increased to 2 bars, the drop of temperature is significantly to 23.4°C under clear sky condition. It is due to the increase in water temperature in order to heat the refrigerant following the high level of refrigerant pressure.

In comparison, the performance of R22 type of refrigerant in 1 bar of refrigerant pressure with R134a is basically similar under cloudy condition. However, the lower temperature of 27°C can be reached under clear sky condition when using R22 type of refrigerant (Figure 6). When the refrigerant pressure increases, the minimum temperature that can be reached is 20.8°C under clear sky condition (Figure 7). Therefore, it is important to notice that the performance of R22 type of refrigerant is better that R134a regarding to room temperature results obtained in this measurement. However, the power consumption is gradually increased when the room temperature decreases as results of powering all the

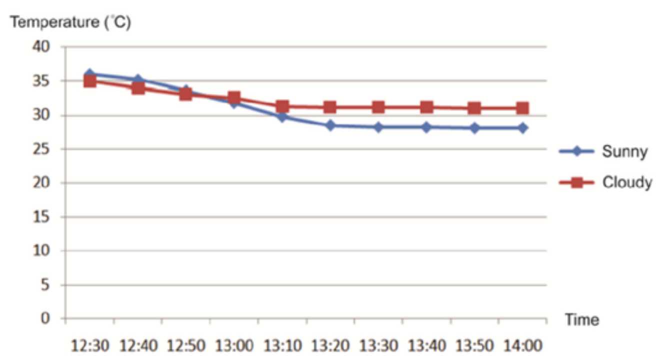

FIGURE 4. Cooling temperature with R134a type of 1 bar refrigerant pressure

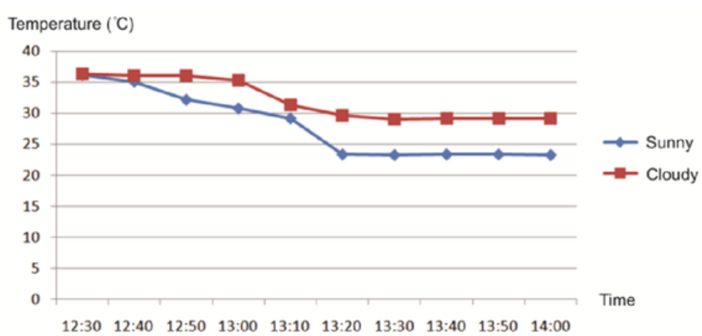

FIGURE 5. Cooling temperature with R134a type of 2 bars refrigerant pressure

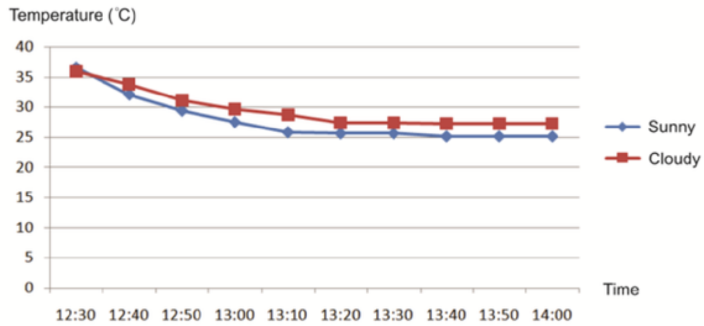

FIGURE 6. Cooling temperature with R22 type of 1 bar refrigerant pressure

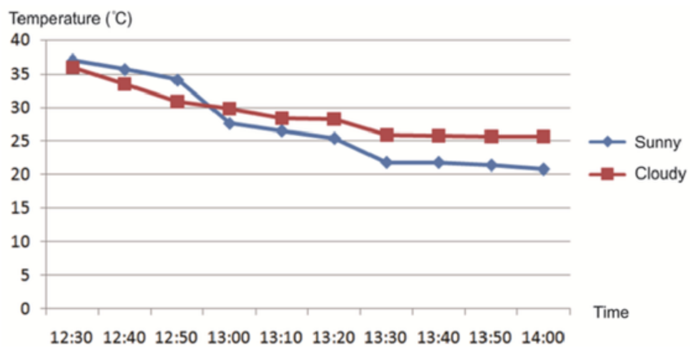

FIGURE 7. Cooling temperature with R22 type of 2 bars refrigerant pressure

TABLE 1. Power consumption utilized from solar panel output

No.	Time	Power (Watt)							
		Refrigerant R134a				Refrigerant R22			
		Sunny		Cloudy		Sunny		Cloudy	
		1 Bar	2 Bars	1 Bar	2 Bars	1 Bar	2 Bars	1 Bar	2 Bars
1	12:30	42.504	42.035	40.29	40.5	42.47	42.273	40.854	41.847
2	12:40	43.82	42.91	42.77	43.056	43.09	42.568	43.214	41.218
3	12:50	43.785	44.208	43.33	43.142	42.07	43.23	44.104	41.838
4	13:00	42.912	44.532	42.42	43.216	43.4	43.622	43.358	42.568
5	13:10	43.128	44.532	43.295	43.364	44.8	42.84	42.636	42.948
6	13:20	43.435	44.568	43.26	44.194	44.8	45.658	43.966	45.708
7	13:30	44.03	44.64	43.26	44.65	43.92	44.659	44.384	47.97
8	13:40	43.085	45.362	44.532	44.889	44.352	47.36	44.07	48.708
9	13:50	44.784	46.55	44.568	47.068	44.64	47.892	44.265	47.15
10	14:00	44.928	46.664	44.568	46.04	45.72	47.619	44.889	47.232
Average		43.6411	44.6001	43.2293	44.0119	43.9262	44.7721	43.574	44.7187

electrical components of system. Nevertheless, the change in power usage is stable for both clear sky and cloudy sky conditions under the same refrigerant pressure (Table 1).

The room temperature obtained in this research is not drastically reached very low but it is good enough to fulfill the standard cooling room temperature with low power consumption. The results are highly depending on the weather condition where the proposed system is based on the thermal heat from the Sun. That is why the lower temperature cannot be reached under cloudy or rainy condition. Also, the system components affecting the overall system performance, such as the vacuum motor and refrigerant tank are maximally designed for the refrigerant pressure under 3 bars. In this case, the lower temperature of cooling system might be reached if the refrigerant pressure increases. It means that some modification of component is necessary to make total improvement in terms of cooling temperature of the proposed system.

The proposed design of cooling system has several advantages compared to other conventional cooling systems. The construction is simple where the system components are easily found in the nearby market. The photovoltaic panels including the charge controller, battery and other materials are nowadays inexclusively found in small markets. Especially the refrigerant liquid, the refrigerant types of R22 and R134a are commonly used for conventional air conditioning systems; therefore, they are available in refrigerant shops. In our design, the saving electricity energy consumption of domestic application might be reduced due to the fact that the increasing temperature of refrigerant is from the solar thermal energy, not from grid electricity as principally worked in conventional cooling systems. The overall result is that the efficiency of photovoltaic systems is indirectly improved as the electricity and thermal energy can be simultaneously utilized in the load side.

4. **Conclusions.** The cooling system design has been presented utilizing the thermal energy output of photovoltaic system for heating the refrigerant. This is another approach to cooling system since the heating refrigerant is not from electricity energy as commonly used in conventional cooling system. The results indicate that the performance of cooling system with type of R22 refrigerant is better than the R134a refrigerant in overall condition and different refrigerant pressures. The lowest cooling temperature is 20.8°C using R22 refrigerant under clear sky condition and refrigerant pressure of 2 bars. It is due to the fact that the R22 refrigerant is characterized as low temperature refrigerant. Therefore, it is not necessary to have high thermal energy to heat the R22 refrigerant in order to reach the low temperature of cooling systems. The results might be improved by designing the vacuum motor and refrigerant tank for refrigerant pressure over 2 bars. In addition, the proposed design of cooling system requires low power consumption utilized from the solar panel.

Acknowledgments. The research grant support is from Ministry of Research, Technology and Higher Education of Indonesia under research scheme of PTUPT 2017. We would like also to thank to the Funding Supporting Program of Attending International Seminar provided by the General Directorate of Research Affirmation and Development of Ministry of Research, Technology and Higher Education of Indonesia.

REFERENCES

[1] Syafaruddin, A. Achmad, T. Waris, Z. Tahir and Y. D. Putra, Application of microcontroller ATmega8535 for hybrid photovoltaic-thermal (PV/T), *International Journal of Engineering and Technology (IJET)*, vol.5, no.5, pp.4388-4399, 2013.

[2] S. Sargunanathan, A. Elango and S. T. Mohideen, Performance enhancement of solar photovoltaic cells using effective cooling methods: A review, *Renewable and Sustainable Energy Reviews*, vol.64, pp.382-393, 2016.

[3] J. C. Mojumder, W. T. Chong, H. C. Ong, K. Y. Leong and A.-A.-Mamoon, An experimental investigation on performance analysis of air type photovoltaic thermal collector system integrated with cooling fins design, *Energy and Buildings*, vol.130, pp.272-285, 2016.

[4] S. S. S. Baljit, H.-Y. Chan and K. Sopian, Review of building integrated applications of photovoltaic and solar thermal systems, *Journal of Cleaner Production*, vol.137, pp.677-689, 2016.

[5] F. Yazdanifard, E. E.-Bajestan and M. Ameri, Investigating the performance of a water-based photovoltaic/thermal (PV/T) collector in laminar and turbulent flow regime, *Renewable Energy*, vol.99, pp.295-306, 2016.

[6] T. Yang and A. K. Athienitis, A review of research and developments of building-integrated photovoltaic/thermal (BIPV/T) systems, *Renewable and Sustainable Energy Reviews*, vol.66, pp.886-912, 2016.

[7] Syafaruddin, S. Manjang and W. H. Piarah, Photovoltaic system powering automatic control of air circulation, *Proc. of the 2nd IEEE Conference on Power Engineering and Renewable Energy (ICPERE) 2014*, Kuta-Bali, Indonesia, pp.296-301, 2014.

[8] J. Guo, S. Lin, J. I. Bilbao, S. D. White and A. B. Sproul, A review of photovoltaic thermal (PV/T) heat utilisation with low temperature desiccant cooling and dehumidification, *Renewable and Sustainable Energy Reviews*, vol.67, pp.1-14, 2017.

[9] M. Beccali, M. Cellura, S. Longo and F. Guarino, Solar heating and cooling systems versus conventional systems assisted by photovoltaic: Application of a simplified LCA tool, *Solar Energy Materials and Solar Cells*, vol.156, pp.92-100, 2016.

[10] S. Bahria, M. Amirat, A. Hamidat, M. El Ganaoui and M. El A. Slimani, Parametric study of solar heating and cooling systems in different climates of Algeria – A comparison between conventional and high-energy-performance buildings, *Energy*, vol.113, pp.521-535, 2016.

[11] M. Hasanuzzaman, A. B. M. A. Malek, M. M. Islam, A. K. Pandey and N. A. Rahim, Global advancement of cooling technologies for PV systems: A review, *Solar Energy*, vol.137, pp.25-45, 2016.

Application of photovoltaic-thermal (PV-T) Power for cooling systems - syafar uddin.pdf

ORIGINALITY REPORT

5%	2%	4%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	M. Hasanuzzaman, A.B.M.A. Malek, M.M. Islam, A.K. Pandey, N.A. Rahim. "Global advancement of cooling technologies for PV systems: A review", Solar Energy, 2016 Publication	1%
2	docplayer.net Internet Source	1%
3	www.icicelb.org Internet Source	1%
4	Juwel Chandra Mojumder, Wen Tong Chong, Hwai Chyuan Ong, K.Y. Leong, Abdullah-Al-Mamoon. "An experimental investigation on performance analysis of air type photovoltaic thermal collector system integrated with cooling fins design", Energy and Buildings, 2016 Publication	1%
5	www.spacepac.com.au Internet Source	<1%

6	Syafaruddin, Salama Manjang, Wahyu H. Piarah. "Photovoltaic system powering automatic control of air circulation", The 2nd IEEE Conference on Power Engineering and Renewable Energy (ICPERE) 2014, 2014 Publication	<1%
7	www.orientjchem.org Internet Source	<1%
8	Ali H.A. Al-Waeli, K. Sopian, Hussein A. Kazem, Miqdam T. Chaichan. "Photovoltaic/Thermal (PV/T) systems: Status and future prospects", Renewable and Sustainable Energy Reviews, 2017 Publication	<1%
9	www.cder.dz Internet Source	<1%
10	M. Tripathy, S. Yadav, S.K. Panda, P.K. Sadhu. "Performance of building integrated photovoltaic thermal systems for the panels installed at optimum tilt angle", Renewable Energy, 2017 Publication	<1%
11	A.H. Elsheikh, S.W. Sharshir, Mohamed E. Mostafa, F.A. Essa, Mohamed Kamal Ahmed Ali. "Applications of nanofluids in solar energy: A review of recent advances", Renewable and Sustainable Energy Reviews, 2018	<1%

Publication

12 Yongqiang Luo, Ling Zhang, Jing Wu, Zhongbing Liu, Zhenghong Wu, Xihua He. "Dynamical simulation of building integrated photovoltaic thermoelectric wall system: Balancing calculation speed and accuracy", Applied Energy, 2017 <1%
Publication

13 conference.unhas.ac.id <1%
Internet Source

14 Mohammad Alobaid, Ben Hughes, Dominic O'Connor, John Calautit, Andrew Heyes. "Improving Thermal and Electrical Efficiency in Photovoltaic Thermal Systems for Sustainable Cooling System Integration", Journal of Sustainable Development of Energy, Water and Environment Systems, 2018 <1%
Publication

15 Farideh Yazdanifard, Mehran Ameri. "Exergetic advancement of photovoltaic/thermal systems (PV/T): A review", Renewable and Sustainable Energy Reviews, 2018 <1%
Publication

Exclude quotes	On	Exclude matches	< 5 words
Exclude bibliography	On		