Investigate in Efficiency of Vacuum Tube Photovoltaic/Thermal (PV/T) Roof

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Abstract— *This research was designed to test the efficiency of vacuum tube Photovoltaic/Thermal (PV/T) roof, as well as to analyze the economic viability of the (PV/T) roof. The PV/T roof consists of the solar panel assembly with polycrystalline Silicon solar cells, there was 5 row of 70 Modules of 2 watts solar cells and the thermal vacuum tube including with the four 64 mm diameter: 1,800 mm length vacuum borosilicate glass tubes to produce hot water at a temperature of 50 degrees Celsius in a 60-liter water tank. As the result of the experiment, the average solar radiation intensity throughout the test period was 826.68 watts per square meter on 18th February 2017, 848.68 watts per square meter on 19th February 2017 and 875.76 watts per square meter on 20th February 2017. The average electrical power during the test was 117.99 Watts on 18th February 2017, 116.92 Watts on 19th February 2017 and 123.47 Watts on 20th February 2017. The battery charge capacity was 0.93 on 18th February 2017, 0.96 on 19th February 2017 and 0.94 on 20th February 2017. The heat was supplied to the water in the tank of the vacuum tube Thermal (T) roof was 7,295.43 kJ on 18th February 2017, 7,976.24 kJ on 19th February 2017 and 7,968.70 kJ on 20th February 2017. The average efficiency of hot water was 0.37 on 18th February 2017, 0.40 on 19th February 2017 and 0.38 on 20th February 2017. The vacuum tube Photovoltaic/Thermal (PV/T) roof can reduce the total amount of electricity cost by 12.10 x 365 = 4,416.5 baht/year. The vacuum tube Photovoltaic/Thermal (PV/T) roof payback period is 4.87 years.*

Keywords— **Vacuum tube, Photovoltaic/Thermal, Roof, solar energy.**

1. INTRODUCTION

Energy is a key factor in order to meet the basic needs of the people. Therefore, energy must be provided in sufficient quantity in good quality to meet the needs of the users. There were about 1.6 billion people in the world who lived without electricity and about 0.9 billion lived in Asia [1]. In Thailand, there were about 290,000 households in remote areas who have no access to electricity [2]. Thailand has a very high demand for electricity in order to meet the basic needs of the people sufficiently. In 2016, the total net energy generation requirement of the Electricity Generating Authority of Thailand (EGAT) system was 188,999.64 million kilowatt-hours (kWh). The electricity purchased from private power producers and abroad was 121,233.72 million kWh representing 64.14 percent [3]. This was very high compared to the total electricity produced by the country. EGAT's energy sales totaled 185,046.51 million kWh including electricity distribution to the power of Laos, Malaysia, and Cambodia. It could be seen that electricity sales were close to the total of electricity production [4]. Another important factor was that the population in Thailand was growing. The demand for electricity for daily activities increased because the rise and expansion of housing. Meanwhile, tariffs were also rising. It needed to increase the production rate to meet the demand. Most of the fuel used for electricity was the non-renewable resources such as oil, coal and natural gas. These fossil fuel reserves are declining as the consumption becomes higher and higher everyday. Demand contrasts to supply, leads fossil fuel to rise in prices, and that makes production more expensive for businesses and industries. In addition, this consumption of fuel also affected the environment, causing global warming, because of the carbon dioxide emissions in large quantities. It is necessary to find renewable energy. The sun is an important source of energy and does not cause any impact on the environment. It is suitable to use as a source of renewable energy in the country. Solar energy is the most important renewable energy in the world. It is natural and have enormous amount of energy. Moreover, it is clean and non-polluting energy to the environment and not harmful to human as well. At present, the problem of global warming has occurred due to the use of non-renewable energy. Therefore, solar energy is ideal for renewable energy. It will be used to reduce the carbon dioxide emissions from burning fossil fuels. In Thailand, the use of Photovoltaic is adopted in the significant numbers and sizes of solar farm and the publication of a solar roadmap [5]. In 2016, the Department of Alternative Energy Development and Efficiency (DEDE) studied the potential of solar energy and created the data that provided the map of solar power of Thailand . The analysis included satellite data and the ground survey data in Thailand. It showed the solar radiation intensity distribution by area. In each month, Thailand is influenced by the northeast monsoon and the southwest monsoon. Most areas of Thailand receive

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maximum solar radiation between April and May. The calculation of the annual average daily solar radiation across the country was 18 MJ/ m^2-day [6]. The Photovoltaic Stand-Alone System is suitable for any utilization, which its annual energy consumption is less than 1 MWh [7]. Under normal operation, during daytime when there is adequate solar insolation, the load is supplied with DC power while charging the battery, simultaneously [8].The results showed that Thailand has a relatively high solar energy potential. The usage of solar energy can be classified into 2 types. The first solar usage type is heat and the second solar usage type is electricity power.

Over the past years, the solar power market has been greatly growing every year. Solar cell in the panel can convert sunlight to electricity up to 10-20% [9]. Even though Hybrid PV-thermal (PVT) systems have been around for several decades [10], there have not been many commercial successes. Currently, there is a renewed interest in the development and application of PVT systems in the Netherlands, the main focus is on uncovered or add-on PVT systems, which are used in combination with a heat pump [11]. In number of researches, the use of solar panels have been installed on roof of many places, even football stadium, for the purpose of reducing dependence on fossil fuels [12]. The main purpose of this research is to focus on generating electricity for residential use, especially in lighting and water heating system. The researcher has designed and built the roof which made of resin and coated with natural colors as a prototype roof, also built the resin roof that looks like commercial roman roof tile because most households install roman roof tile which makes it convenient for people to replace with customized roof tile. In comparison to commercial roman roof tile, the resin roof tile of this research is able to generate electricity and produce hot water with enough amount for household use. More resin roof tiles can be added if the need for electricity increases. This roof tile needs the space of 4 m^2 for installation and can replace 8 commercial roman roof tiles. It can generate electricity and produce hot water by itself without using any other solar cell panel or water heating system. The power generated is enough to supply lighting and water heating system by itself which already covers the basic need of electricity in household and then minimizing energy bill and dependency on fuel fossil energy. This is the most cost-effective and cost-effective use of space. In this research, there was two types of solar energy that can be used to produce both hot water and electricity for household usage. The design can install on the roof of the house, and as a model of the resin roof that molded by natural colors. It can paint any needed colors. For this reason, the researcher designed an environmentally friendly solar roof. It responds to alternative energy needs and solves a shortage problem of energy. It also responds to government support programs. It also encourages communities to produce their own electricity and reduce household energy consumption. It is a model roof that can be used as a source of energy in the form of thermal energy and electricity. The community can apply it self-made in the household.

2. METHODOLOGY

Principle of the Vacuum Tube Photovoltaic/Thermal (PV/T) Roof

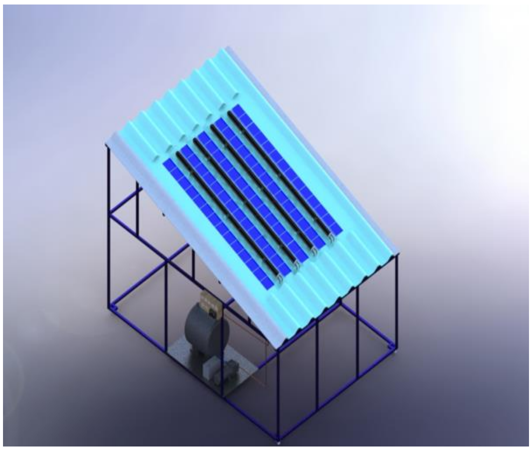

Fig. 1: Vacuum Tube Photovoltaic/Thermal (PV/T) Roofs model.

Fig. 1 shows Principle of the Vacuum Tube Photovoltaic/Thermal (PV/T) Roof. In this research had design and constructed the eco-friendly solar roof. The purpose was to test the efficiency of electricity production and the efficiency of hot water production and analyze the economic value of the Vacuum Tube Photovoltaic/Thermal (PV/T) Roof. The research was divided into two parts. The first part was the production of electricity by solar cells. There were 2 watt 70 polycrystalline silicon solar panels were connected to a series circuits in each row and connected in parallel circuits between rows as assembly of solar panels. The principal begins when sunlight hits the solar cell on the roof. The negative and positive elementary charge is created, namely electrons and holes respectively. The absorption of a photon, therefore, leads to the creation of an electron-hole pair. The p-n junction creates the electric field within the cell to transfer electrons to cathode and transfer hole to the anode. A piece of p-type silicon is placed in close contact with a piece of n-type silicon, then a diffusion of electrons occurs from the region of high electron concentration (the n-type side of the junction) into the region of low electron concentration (p-type side of the junction). This diffusion of carriers does not go on indefinitely because charges build up on either side of the junction and create an electric field. It connects to a set of capacitors to charge the 12-volt battery and takes electrical power from charged battery to inverter for lighting system. The second part was to produce hot water with vacuum tube solar radiation. In this research, it was designed to be installed with 4 tubes on the roof. All of the tubes have a U-shaped copper tube for pumping water from a vacuum vessel in a glass vacuum tube. A temperature control set was installed at 60 °C using 60 liters of water, which was contained in a heat insulated container. The vortex pump was heated by a vacuum tube to increase the water temperature to 60 °C to heat up the water for household usage without any more installation of water heating system.

Development and experiment of Photovoltaic/Thermal Vacuum Tube (PV/T) Roof

First of all, Fig. 2 shows the structure of the Vacuum Tube Photovoltaic/Thermal (PV / T) roofs was designed. The framework used the 25 mm x 25 mm steel boxes to cut and connect together into a cage equipped with 4 wheels.

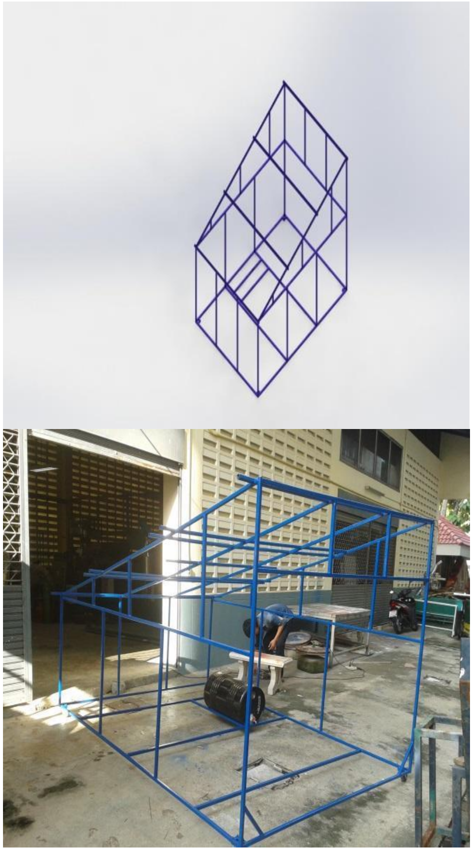

Fig. 2: Structure of Vacuum Tube Photovoltaic / Thermal (PV/T) Roof.

Fig. 3 shows the modeling for roofing uses a commercial roof, the Roman tile roof, as the mold. Then cut the fiberglass to the size of the roof and assemble it to the top of the roof. The fiberglass was pressed down and cut the edges to equal to the Roman tile roof mold. After that, the resin mixed with hardener and food coloring powder. The colors could be selected as needed. In this research, the researchers selected green because it is the closest to natural color.

Secondly, the resin was put on a prepared roof and left it dried for a day. When the roof was completely dry, then gradually removed the roof sheet from the mold. The roof model shows in Fig. 4.

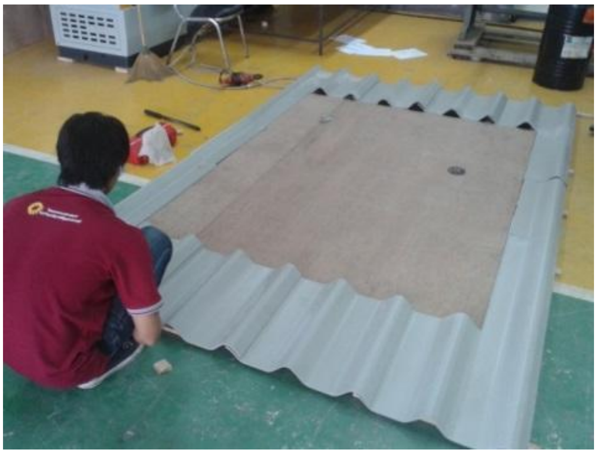

Fig. 3: Roof mold.

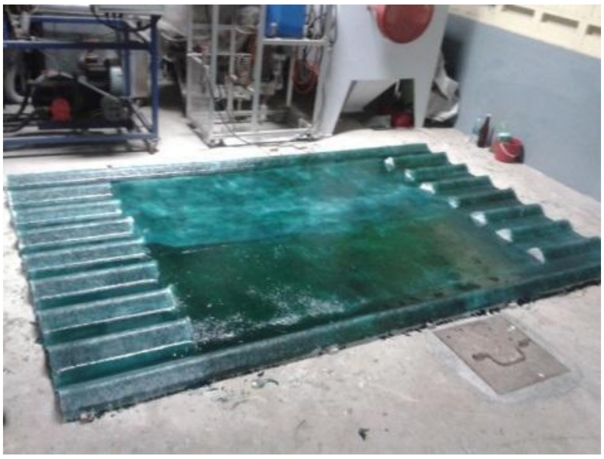

Fig. 4 formed roof model.

Fig. 5 shows the thermal vacuum tube including with the four 64 mm diameter: 1,800 mm length vacuum borosilicate glass tubes. Fig. 6 shows the 2 core of 10 mm diameter copper tube that weld 90 degrees in U-shape. The copper tubes was strengthened by welding four small pipe every 450 mm pipes between the two copper tubes. Fig. 7 shows the tube was covered with epoxy.

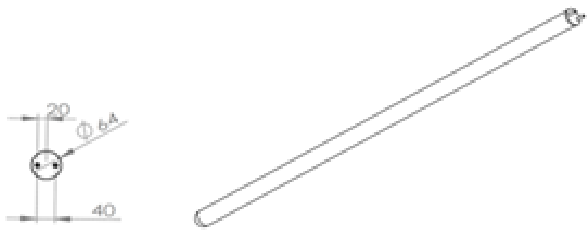

Fig. 5: The thermal vacuum tube.

Fig. 8 shows the hot water tank, there was a 60-liter tank to drill three holes. The first two holes supported the water pump inlet and outlet. The thermometers were set up to record the temperature of the water inlet and outlet from the tank. The insulation was covered with one layer of fiberglass and one layer of foam rubber. The water pump was a 12-volt 60W pump that had 5 liters per minute flow rate. The water flow system was heated through the copper tube inside the four connected thermal vacuum tubes. The thermostat controlled the water temperature from the tank. When the water temperature reaches 60 degree Celsius, the thermostat stopped the water pump working.

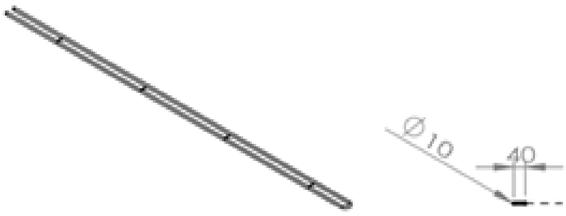

Fig. 6: The copper tubes in the thermal vacuum tube.

Fig. 7: heat exchanger of the thermal vacuum tube on the roof.

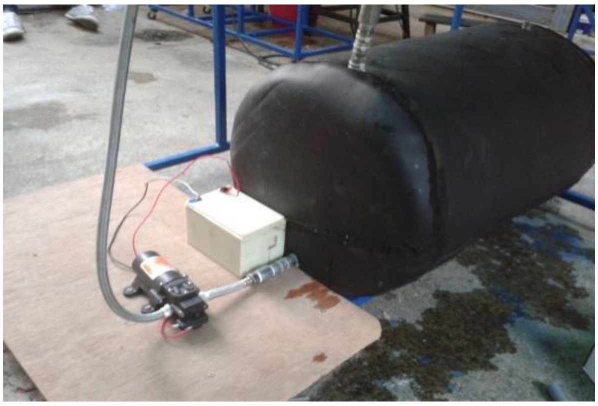

Fig. 8: The insulated hot water tank.

Fig. 9 shows the solar panel assembly with polycrystalline Silicon solar cells. There was 5 row of 70 two watts solar cells. Each row was connected with 14 cells in the series circuit. The first two rows were connected in parallel circuit and call set number 1. The rest three rows were connected in parallel circuit and call set number 2. Set number 1 connected with set number 2 in the parallel circuit. The overall voltage was 12 volt and the overall power was 140 watts.

Fig. 9: Connection of a 2-watt solar panel with 70 cells.

Fig. 10 shows the process of assembling all the components. The thermal vacuum tube that includes the copper pipe was installed on the roof. The hot water tank, water pump, charge controller and battery were installed under the roof. There were 5 positions of thermometer that were at inlet and outlet of the vacuum tube, in the hot water tank, at the center of under the solar roof and outdoor position to measure ambient temperature.

This research was tested in 2017 by recording the test results every month from January to December, 3 days a month. The average number from every result was used to analyze the effect of seasons on the amount of generated electricity and produced hot water. The records were done every 20 minutes from 8.00 am to 16.00 pm. This research will show the results in February because this month had the highest number in generated electricity. The results show the temperature results at all 5 position from the thermometer. The solar intensity recorded from the Solar Power Meter. The voltage, electric current from solar panels, charge control devices and batteries, recorded by the multimeter.

In this research, when assembling all, Fig. 11 shows the components together, the solar roof is efficiency. The solar energy used in the form of heat water and electricity. It can be used as a model for the community to install at household to generate electricity and hot water.

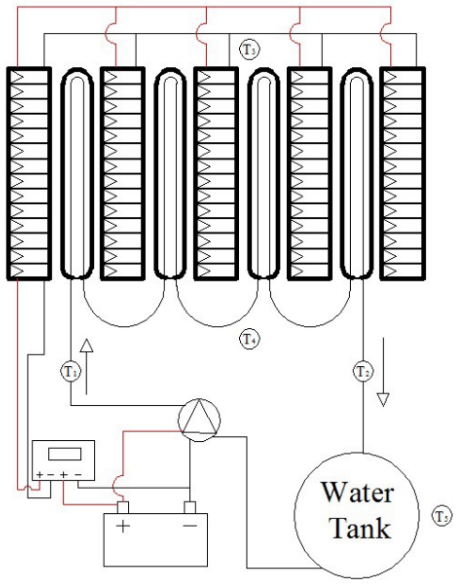

Fig. 10: System diagram of the vacuum tube (PV/T) roof.

Fig. 11: set up all assembly of Vacuum Tube Photovoltaic/Thermal (PV/T) Roof.

3. ANALYSIS OF THE TEST RESULTS

This study analyzed data from the recording parameters shown in the equation.

1. To analyze the Battery Charge efficiency are evaluated as follow:

Battery Charge efficiency = Pout/Pin = $P_{battery} / P_{PV}$

where P_{out} is Power is charged to the battery (W), P_{in} is Power produced by the solar roof (W).

2. To analyze the efficiency of hot water with solar roof are evaluated as follow:

$$Eff_T = \frac{[mC_p(T_o - T_i)]/S}{I_T A_c}$$

where Eff_T is the efficiency of Vacuum Tube Thermal (T) Roofs**;** *m* is the Mass of water (kg); C_P is the specific heat capacity of water(kJ/kg.K); T_O is the outlet temperature of the thermal vacuum tube (^oC); T_i is the inlet temperature of the thermal vacuum tube (^oC); I_T is the solar intensity(W/m^2); A_C using vacuum glass tube solar collector area (m^2) = 0.754 m^2; *S* is time for test period (second)

3. To analyze the Simple payback period of the Vacuum tube (PV/T) roofs are evaluated as follow:

Simple payback period = Initial Investment/Annual Saving

where

Initial Investment = Investment cost(Baht), Annual Savings = Annual operating return (Baht)

In this research, the simple payback period was used in the analysis as a method for evaluating the initial payback period. To assist in decision making in the design and construction of solar roofs.

4. RESULTS AND DISCUSSION

Research results of electricity from the vacuum tube Photovoltaic/Thermal (PV/T) roof

After recording the test results throughout the year in 2017 by recording 3 days a month, the average amount of generated electricity and produced hot water was highest in February then it was found that solar radiation intensity from the vacuum tube Photovoltaic/Thermal (PV/T) roof on 18th-20th February 2017 in Nakhon Sawan province for 8 hours since 8:00 am to 4:00 pm. On February 18 th, 2017, the maximum hourly solar radiation intensity of the test was 1,102 watts per square meter and the lowest was 442 watts per square meter. The average solar radiation intensity throughout the test period was 826.68 watts per square meter. On February 19 th, 2017, the maximum hourly solar radiation intensity of the test was up to 1,089 watts per square meter and a minimum of 398 watts per square meter. The average solar radiation intensity was 848.68 watts per square meter. On February 20th, 2017, the maximum hourly solar radiation intensity of the test was up to 1,084 watts per square meter and a minimum of 482 watts per square meter. The average solar radiation intensity was 875.76 watts per square meter. The average of the solar intensity throughout the three-day test period was different as shown in Fig. 12.

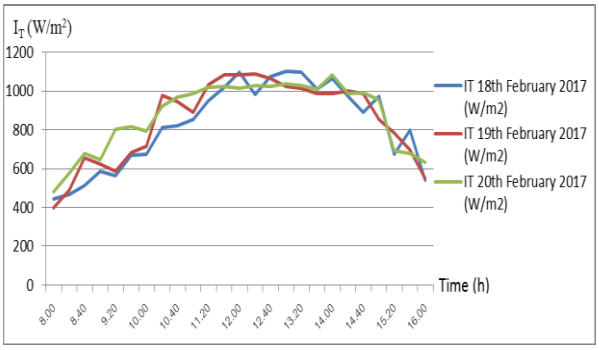

Fig. 12: The hourly solar intensity from 18th-20th February 2017.

The results of voltage from the solar panel on the vacuum tube Photovoltaic (PV) roof on 18 th -20 th February 2017 in Nakhon Sawan province for 8-hour test period since 8:00 am - 4:00 pm. On February 18 th, 2017, the maximum hourly voltage of the test was 15.21 Volts and the lowest was 11.84 Volts. The average voltage during the test was 13.23 Volts. On February 19 th, 2017, the maximum hourly voltage for the test was 15.32 Volts and the lowest was 11.72 Volt. The average voltage during the test was 12.99 Volts. On February 20th, 2017, the maximum hourly voltage of the test was 15.65 Volts and the lowest was 11.80 Volts. The average voltage during the test was 13.54 Volts. It was found that the average voltage over the three-day test period was different as shown in Fig. 13.

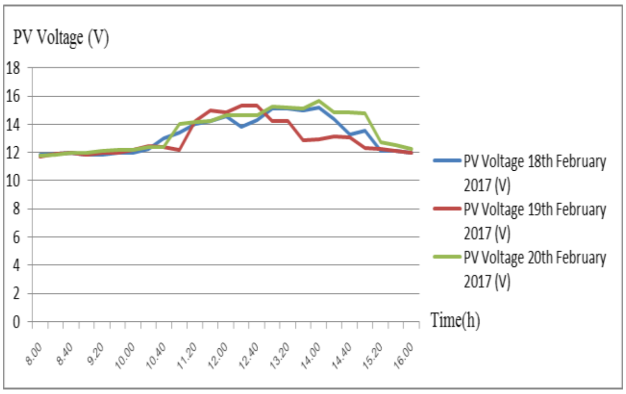

Fig. 13: the hourly voltage between 18 th -20 th February 2017.

The results of electrical current from the solar panel on the vacuum tube Photovoltaic (PV) roof on February 18-20, 2017 in Nakhon Sawan province for 8-hour test period since 8:00 am - 4:00 pm. On February 18, 2017, the maximum hourly power of the test was 10.01 Ampere and the minimum was 7.81 Amperes. The average electric current during the test was 8.89 Amperes. On February 19, 2017, the maximum hourly electrical current of the test was 9.65 Ampere and a minimum of 7.69 Amperes. The average electrical current during the test was 8.96 Ampere. On February 20, 2017, the maximum hourly electrical current of the test was 9.66 Amperes and the minimum was 7.80 Amperes. The average electrical current during the test was 9.07 Amperes. It was found that the average of electrical current during the 3-day test period was different as shown in Fig. 14.

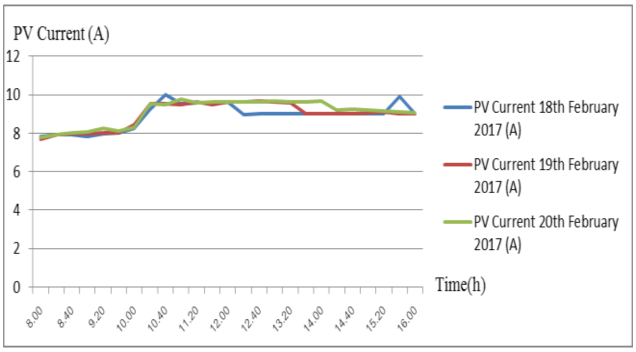

Fig. 14: shows the hourly electric current between 18 th -20 th February 2017.

The results of the electrical power of solar panels on the vacuum tube Photovoltaic (PV) roof at 18 th -20 th February 2017 in Nakhon Sawan province for 8-hour test period since 8:00 am - 4:00 pm. On February 18 th, 2017, the maximum hourly electrical power of the test was 139.97 Watt and the minimum was 92.59 Watt. The average electrical power during the test was 117.99 Watts. On February 19 th, 2017, the maximum hourly electrical power of the test was 147.68 Watt and the minimum was 90.13 Watts. The average electrical power during the test was 116.92 Watts. On February 20th, 2017, the maximum hourly power of the test was 147.16 Watt and the minimum was 92.04 Watts. The average power during the test period was 123.47 Watts. It was found that in the period of high solar intensity affected the maximum electrical power on 19 th February 2017 and 20 th February 2017 was higher than 140 Watt. The average electrical power over the 3-day test period was different as shown in Fig. 15.

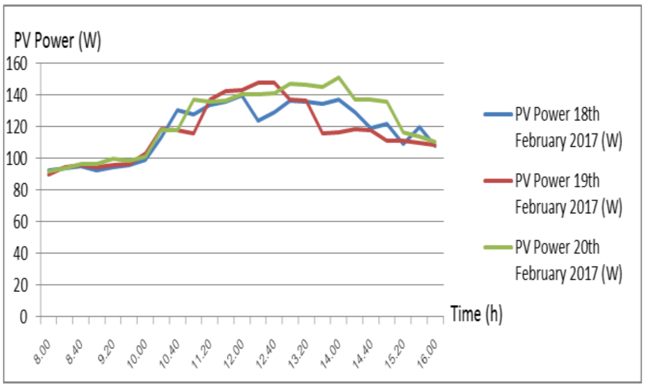

Fig. 15: The hourly electrical power between 18 th -20 th February 2017.

The table 1 shows the battery charge performance test from the solar panel on the vacuum tube Photovoltaic (PV) roof and the charging capacity of the battery was measured from the multimeter on 18 th -20 th February 2017 in Nakhon Sawan province for 8-hour test period since 8:00 am - 4:00 pm. On February 18 th, 2017, the battery charge capacity was 0.93. On February 19 th, 2017, the battery charge capacity was 0.96. On February 20 th, 2017, the battery charge capacity was 0.94.

Table 1. Battery charge performance test

Date	Average solar intensity (W/m^2)	Average power from solar panels (W)	The average battery power is charged to the battery (W)	Battery Charge efficiency
18th February 2017	826.68	117.99	110.54	0.93
19th February 2017	848.68	116.92	112.42	0.96
20th February 2017	875.76	123.47	116.52	0.94

The production of hot water result from the vacuum tube Photovoltaic/ Thermal (PV/T) roof

Table 2 shows the results of the test of hot water production of the vacuum tube Thermal (T) roof on 18th - 20th February 2017 in Nakhon Sawan province for 8-hour test since 8:00 am to 4:00 pm. On February 18 th, 2017, the production of hot water heated by the thermal vacuum tube on the roof was 60 liters. The specific heat of water(kJ/kg.K) was 4.187. The inlet temperature of thermal vacuum tube was 22.23 degree Celsius at 8:00 am. It could be heated to the outlet temperature of the thermal vacuum tube at 51.27 degree Celsius at 4:00 pm. During the test period, the heat was supplied to the water in the tank of the vacuum tube Thermal (T) roof was 7,295.43 kJ. The average efficiency of hot water was 0.37.

Table 3 shows the results of the test of hot water production of the vacuum tube Thermal (T) roof on 18 th -20 th February 2017 in Nakhon Sawan province for 8-hour test since 8:00 am to 4:00 pm. On February 19th, 2017, the production of hot water heated by the thermal vacuum tube on the roof was 60 liters. The specific heat of water(kJ/kg.K) was 4.187. The inlet temperature of thermal vacuum tube was 20.89 degree Celsius at 8:00 am. It could be heated to the outlet temperature of the thermal vacuum tube at 52.64 degree Celsius at 4:00 pm. During the test period, the heat was supplied to the water in the tank of the vacuum tube Thermal (T) roof was 7,976.24 kJ. The average efficiency of hot water was 0.40.

Table 4 shows the results of the test of hot water production of the vacuum tube Thermal (T) roof on 18th-20th February 2017 in Nakhon Sawan province for 8-hour test since 8:00 am to 4:00 pm. On February 20th, 2017, the production of hot water heated by the thermal vacuum tube on the roof was 60 liters. The specific heat of water (kJ/kg.K) is 4.187. The inlet temperature of thermal vacuum tube was 21.23 degree Celsius at 8:00 am. It could be heated to the outlet temperature of the thermal vacuum tube at 52.95 degree Celsius at 4:00 pm. During the test period, the heat is supplied to the water in the tank of the vacuum tube Thermal (T) roof was 7,968.70 kJ. The average efficiency of hot water was 0.38.

Table 2. test results for hot water with the vacuum tube thermal (T) roof on February 18, 2017.

Time (h)	Mass of hot water 18th February 2017 (kg)	Ti (°C) 18th February 2017	To (°C) 18th February 2017	Specific heat of water (KJ/kg.K)	mCp(To - Ti) 18th February 2017	ITAc 18th February 2017	Eff (T) 18th February 2017
8.00	60	22.23	22.75	4.187	130.63	333.27	0.33
8.20	60	22.75	22.84	4.187	22.61	350.61	0.05
8.40	60	22.84	24.12	4.187	321.56	386.05	0.69
9.00	60	24.12	24.98	4.187	216.05	444.11	0.41
9.20	60	24.98	25.20	4.187	55.27	425.26	0.11
9.40	60	25.20	26.50	4.187	326.59	505.18	0.54
10.00	60	26.50	27.23	4.187	183.39	509.70	0.30
10.20	60	27.23	28.29	4.187	266.29	612.25	0.36
10.40	60	28.29	29.43	4.187	286.39	619.79	0.39
11.00	60	29.43	31.20	4.187	444.66	643.92	0.58
11.20	60	31.20	33.21	4.187	504.95	717.81	0.59
11.40	60	33.21	35.11	4.187	477.32	769.08	0.52
12.00	60	35.11	37.34	4.187	560.22	828.65	0.56
12.20	60	37.34	39.54	4.187	552.68	741.94	0.62
12.40	60	39.54	41.24	4.187	427.07	810.55	0.44
13.00	60	41.24	43.12	4.187	472.29	830.91	0.47
13.20	60	43.12	45.21	4.187	525.05	828.65	0.53
13.40	60	45.21	46.35	4.187	286.39	763.05	0.31
14.00	60	46.35	48.57	4.187	557.71	804.52	0.58
14.20	60	48.57	49.14	4.187	143.20	735.15	0.16
14.40	60	49.14	50.13	4.187	248.71	671.06	0.31
15.00	60	50.13	50.21	4.187	20.10	732.89	0.02
15.20	60	50.21	50.46	4.187	62.81	508.20	0.10
15.40	60	50.46	51.25	4.187	198.46	601.69	0.27
16.00	60	51.25	51.27	4.187	5.02	408.67	0.01

Table 3. test results for hot water with the vacuum tube thermal (T) roof on February 19th, 2017

Time (h)	Mass of hot water 19th February 2017 (kg)	Ti (°C) 19th February 2017	To (°C) 19th February 2017	Specific heat of water (KJ/kg.K)	mCp(To - Ti) 19th February 2017	ITAc 19th February 2017	Eff (T) 19th February 2017
8.00	60	20.89	20.92	4.187	7.54	300.09	0.02
8.20	60	20.92	21.32	4.187	100.49	370.97	0.23
8.40	60	21.32	22.45	4.187	283.88	496.13	0.48
9.00	60	22.45	24.15	4.187	427.07	472.00	0.75
9.20	60	24.15	24.98	4.187	208.51	441.84	0.39
9.40	60	24.98	25.34	4.187	90.44	514.23	0.15
10.00	60	25.34	26.67	4.187	334.12	539.86	0.52
10.20	60	26.67	27.56	4.187	223.59	738.17	0.25
10.40	60	27.56	28.98	4.187	356.73	712.53	0.42
11.00	60	28.98	29.87	4.187	223.59	670.31	0.28
11.20	60	29.87	31.24	4.187	344.17	779.64	0.37
11.40	60	31.24	32.56	4.187	331.61	818.84	0.34
12.00	60	32.56	34.89	4.187	585.34	817.34	0.60
12.20	60	34.89	36.12	4.187	309.00	821.11	0.31
12.40	60	36.12	37.89	4.187	444.66	803.01	0.46
13.00	60	37.89	39.21	4.187	331.61	772.10	0.36
13.20	60	39.21	41.97	4.187	693.37	765.31	0.75
13.40	60	41.97	44.58	4.187	655.68	744.20	0.73
14.00	60	44.58	46.24	4.187	417.03	745.71	0.47
14.20	60	46.24	47.93	4.187	424.56	755.51	0.47
14.40	60	47.93	49.31	4.187	346.68	744.20	0.39
15.00	60	49.31	50.42	4.187	278.85	642.41	0.36
15.20	60	50.42	51.42	4.187	251.22	592.64	0.35
15.40	60	51.42	52.36	4.187	236.15	526.29	0.37
16.00	60	52.36	52.64	4.187	70.34	413.19	0.14

Table 4. test results for hot water with the vacuum tube thermal (T) roof on February 20th, 2017

Time (h)	Mass of hot water 20th February 2017 (kg)	Ti (°C) 20th February 2017	To (°C) 20th February 2017	Specific heat of water (kJ/kg. K)	mCp(To - Ti) 20th February 2017	$I_T A_c$ 20th February 2017	Eff (T) 20th February 2017
8.00	60	21.23	21.45	4.187	55.27	363.43	0.13
8.20	60	21.45	21.78	4.187	82.90	435.81	0.16
8.40	60	21.78	22.14	4.187	90.44	511.97	0.15
9.00	60	22.14	23.21	4.187	268.81	486.33	0.46
9.20	60	23.21	24.26	4.187	263.78	605.46	0.36
9.40	60	24.26	25.48	4.187	306.49	614.51	0.42
10.00	60	25.48	26.14	4.187	165.81	599.43	0.23
10.20	60	26.14	27.82	4.187	422.05	695.94	0.51
10.40	60	27.82	28.78	4.187	241.17	729.12	0.28
11.00	60	28.78	29.89	4.187	278.85	745.71	0.31
11.20	60	29.89	31.08	4.187	298.95	769.83	0.32
11.40	60	31.08	33.14	4.187	517.51	771.34	0.56
12.00	60	33.14	35.27	4.187	535.10	765.31	0.58
12.20	60	35.27	36.15	4.187	221.07	777.37	0.24
12.40	60	36.15	38.12	4.187	494.90	772.10	0.53
13.00	60	38.12	39.92	4.187	452.20	782.65	0.48
13.20	60	39.92	41.16	4.187	311.51	775.87	0.33
13.40	60	41.16	43.05	4.187	474.81	763.80	0.52
14.00	60	43.05	45.95	4.187	728.54	817.34	0.74
14.20	60	45.95	48.89	4.187	738.59	744.20	0.83
14.40	60	48.89	51.12	4.187	560.22	749.48	0.62
15.00	60	51.12	52.14	4.187	256.24	719.32	0.30
15.20	60	52.14	52.78	4.187	160.78	524.03	0.26
15.40	60	52.78	52.79	4.187	2.51	511.21	0.01
16.00	60	52.79	52.95	4.187	40.20	476.53	0.07

Analysis of economic value

1) The Investment cost building of the vacuum tube Photovoltaic/Thermal (PV/T) roof 21,500 baht.

2) From the test results of electricity and hot water production from The vacuum tube Photovoltaic/Thermal (PV/T) roof in 2017 by recording the results every month, 3 times a month. The average numbers of electricity production and thermal energy in hot water each month in 2017 are shown in table 5.

From table 5, the test resuts show the average electricity production from The vacuum tube Photovoltaic/Thermal (PV/T) roof in 2017 is 112.92 W and 6,601.48 kJ/28,800 s for average number of thermal energy in hot water which results to 229.22W for electric power. After calculating it with produced electricity, it was found that, the vacuum tube Photovoltaic/Thermal (PV/T) roof was able to produce energy up to 342.14 W. Accordingly, In 1 cycle of test, the produced electricity can be calculated into electricity bill as (342.14 W x 8 H)/1,000 x 4.42 baht = 12.10 baht/day (1 kWh of 4.42 baht tariff: PEA, 2016)[13]

3) The payback period of the vacuum tube Photovoltaic/Thermal (PV/T) roof is 4.87 years. The Investment cost to build a vacuum tube Photovoltaic /Thermal (PV/T) roof is 21,500 baht. The vacuum tube Photovoltaic /Thermal (PV/T) roof to produce electricity amount of 2.74 kWh/day, compared to the use of electric power to be equivalent to 12.10 baht/day. The vacuum tube Photovoltaic /Thermal (PV/T) roof can reduce the total amount of electricity 12.10 x 365 = 4,416.5 baht/year.

Table 5. shows the average numbers of electricity production and the numbers of thermal energy in hot water

Months (2017)	Average numbers of produced electricity (W)	Thermal energy in hot water (kJ)
January	116.48	7,682.67
February	119.46	7,746.79
March	119.42	7,735.65
April	118.89	7,745.68
May	109.42	5,998.62
June	102.48	5,479.25
July	103.45	5,535.62
August	107.85	5,795.72
September	111.54	6,012.23
October	113.78	6,124.75
November	116.87	6,785.90
December	115.42	6,574.86
average	112.92	6,601.48

5. CONCLUSION

This research can be concluded that the prototype roof is able to generate electricity and produce hot water. Furthermore, its design that looks similar to commercial roman roof tile proves how effective and convenient it is to replace the old ones which do not require more work to the roof. The prototype roof takes 4 m2 of space or 8 tiles of normal roman roof tile that cannot generate electricity. For that reason, if there is more need for electricity and hot water, with enough roof space, more of the roof can be installed to meet with the demand. The power generated from the roof converts from DC to AC through power inverter then supplies to the lighting system.

The major conclusions about the production of electricity and hot water from the present study are summarized as follows:

1) The average solar radiation intensity throughout the test period was 826.68 watts per square meter on 18th February 2017, 848.68 watts per square meter on 19th February 2017 and 875.76 watts per square meter on 20th February 2017.

2) The average voltage during the test was 13.23 Volts on 18th February 2017, 12.99 Volts on 19th February 2017 and 13.54 Volts on 20th February 2017.

3) The average electric current during the test was 8.89 Amperes on 18th February 2017, 8.96 Ampere on 19th February 2017 and 9.07 Amperes on 20th February 2017.

4) The average electrical power during the test was 117.99 Watts on 18th February 2017, 116.92 Watts on 19th February 2017 and 123.47 Watts on 20th February 2017.

5) The battery charge capacity was 0.93 on 18th February 2017, 0.96 on 19th February 2017 and 0.94 on 20th February 2017.

6) The heat was supplied to the water in the tank of the vacuum tube Thermal (T) roof was 7,295.43 kJ on 18th February 2017, 7,976 kJ on 19th February 2017 and 7,968.70 kJ on 20th February 2017.

7) The average efficiency of hot water was 0.37 on 18th February 2017, 0.40 on 19th February 2017 and 0.38 on 20th February 2017.

8) The vacuum tube Photovoltaic/Thermal (PV/T) roof can reduce the total amount of electricity cost as 12.10 x 365 = 4,416.5 baht/year. The vacuum tube Photovoltaic/Thermal (PV/T) roof payback period is 4.87 years.

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