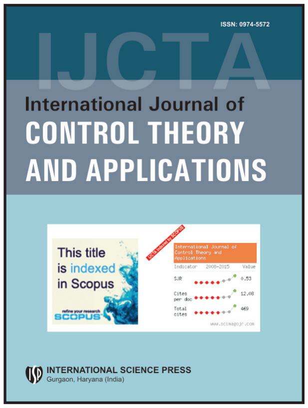


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# Stand Alone Hybrid Photovoltaic/Thermal System

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***Abstract:*** Solar is one of the clean, renewable and sustainable sources of energy which has to be harvested everywhere on the earth special places which have extended the sunshine around the year like Malaysia. They involve low-scale accommodation designed with minimal environmental impact. The industry's rapid growth is stressing on the increase in the energy demand, especially in small island developing states where low impact energy sources such as hydroelectricity are often available only in restricted quantities. This research work is aligned with the environmentally sustainable energy which its goals encompass the transformation of existing solar technologies into electrical and thermal energy in an efficient and reliable method. These goals were to address some of the emission, carbon reduction and climate change issues that the world is confronting now. This paper presents the hybrid Photovoltaic Thermal (PVT) systems and their contribution to the sustainable tourism development of Malaysia. The considered system includes PV array, thermal collectors, controller, Supervisory Control and Data Acquisition (SCADA) system, MPPT and storage tank with heat exchange unit. The effectiveness of the proposed scheme will be evaluated through modeling of both PVT system and by available simulation software such as Multisim and Matlab program. This implementation on the selected area to arrive at a low-cost and vigorous solution is aimed towards the sustainable development in terms of energy conservation and utilization in an optimal mode. Two different fluids, water, and Nanofluid will be used and experimentally tested as a heat transfer. The data will be collected with the precision equipment such as data loggers and will be further analyzed. The end result will be obtained from the setup system and data obtained from the thermal system and PV array will be further compared and evaluated with the expected value by the simulation software.

***Keywords:*** Hybrid; Photovoltaic; thermal; nanofluid.

## 1. INTRODUCTION

Energy is one of the most important components in a human life. It is used for cooking, communication, traveling from one location to another and numerous more. There are various ways to obtain energy, ranging from fossil fuel to harvest solar energy using PV cells. The environmental side effect of using the fossil fuel is disastrous. Advanced countries are among the top list of contributors to the environmental issues caused by using fossil fuel as a source of energy. New research done at Concordia University suggests that more than 60 percent of the anthropogenic global warming that occurred before 2005 was generated by just seven countries [1].

The researchers reported that the US is the uncontested leader in contributing to global warming, which alone is responsible for a global temperature increase of 0.15 degrees Celsius, a change that amounts to 20 percent of observable global warming. China and Russia contributed 8 percent each, India and Brazil provided 7 percent and the UK and Germany contributed around 5 percent each. Other nations made up the remaining 40% [1]. Table 1 shows the contribution of different emissions to the global warming.

**Table 1**
**Contribution to total temperature change between 1800 and 2005 for each type of emissions [1]**

| *Category of emissions* | *Warming (°C)* |
|---|---|
| Fossil fuel $CO_2$ | 0.5 |
| Land-use $CO_2$ | 0.25 |
| Methane | 0.25 |
| Nitrous Oxide | 0.09 |
| Aerosols | –0.4 |
| Total warming | 0.7 |

Coal is the most abundant fossil fuel in the world. In the USA alone coal is used to produce over 50% of the electricity [2]. In addition to electricity production, coal is sometimes used for heating and cooking in less developed countries and in rural areas of developed countries. The burning of coal results in significant atmospheric pollution. The sulfur contained in coal forms the sulfur dioxide when burned. The toxic ash residual after coal burning is also an environmental concern and is usually disposed into landfills. Harmful nitrogen oxides, heavy metals, and carbon dioxide are also released into the air during coal burning [3]. Among other side effects of using fossil fuel or fossil, coal is global warming, acid rain, drought and the greenhouse effect which is a worldwide environmental issue, yet lacking a proper solution. These side effects are mainly caused by carbon emission from human activities such as energy production, which depends highly on fossil fuel [4]. A source from U. S. Energy Information Administration (EIA) stated that Malaysia emitted 191.4441 million tons of carbon dioxide in the year 2011 from fossil fuel consumption [5]. The concerned issue mentioned above open the doors for the researchers, scientist, and engineers to seek for a better alternative source of energy. Renewable energy technologies have accounted for 13.3% of the world primary energy needs [6]. One of the elite source to obtain clean, free, abandon and renewable energy source is the Sun. Due to abundant solar irradiation on the surface of the earth, solar energy harvesting is becoming essential and yet expensive for homes and industries. There are 3 types of solar panel in the market which are a monocrystalline, polycrystalline and thin film. Among the three, the polycrystalline is the cheapest and the process of making it is simpler. The efficiency of such solar panel is ranging from 13% to 16% [7]. However, the claimed efficiency is at a temperature of 25°C. The rising temperature of the PV beyond 25°C will drop the efficiency of the PV modules [8]. The efficiency of a solar panel, are generally below 20% as stated earlier, which is low compared to other alternative energy source such as coal, hydropower, and wind. But, the source of energy, which is the Sun, gives out a large amount of energy, about 3.850 x1024 joules at Earth's surface per year. This makes the Sun the highest energy provider compared to wind, biomass, and fuel, which encourages engineers to create a better way to harvest the energy from the Sun.

Based on Malaysia Meteorological Department, Malaysia receives about 6 hours of the sunshine per day on average, which basically this solar radiation is constant throughout the years [9]. One of the ways to maximize the potential of a PV based system is to combine it with another system like thermal. This project focuses on a PVT system, whereby it is a combination of a solar panel with a thermal collector. The thermal collector plate, place under the solar panel to absorb the heat from the solar panel. The heatsinks are attached to the bottom of the thermal collector plate and are submerged in the fluid which is in a thermal box unit under the solar panel. The heatsinks collect the heat from the thermal plate and transfer it further to the fluid. The fluid will be directed to the thermal tank via a water pump through a rubber tube and circulated around the heat exchanger unit located in the center of the thermal tank and back to the thermal box unit as a close loop system. The heat exchanger unit transfers the heat to the water in the tank raising its temperature. The purpose of this work is to examine the hybrid PVT solar systems and their contribution to the sustainable tourism development of Malaysia. A hybrid PVT system is a combination of photovoltaic and solar thermal components incorporated into one system that is able of producing together electrical and thermal energy concurrently. The concept and design of a PVT system were being developed not only to utilize the wasted heat energy, but also to improve the electrical efficiency of a photovoltaic component at high temperature more than 25°C. Solar energy can cover a significant percentage of tourism infrastructures, which the hybrid PVT systems can contribute to thermal energy and electrical energy demand. The proposed system includes a PV array, MPPT, a novel controller system for optimized thermal energy harvesting, heat exchanger and thermal collector unit. The tourism industry's rapid growth is stressing on the increase in the energy demand, especially in small island developing states where low impact energy sources, such as hydroelectricity are often available only in restricted quantities, and where sea water desalination can consume significant amounts of fuel [10]. Ecotourism focuses on ecologically sustainable tourism, which contributes about 10% revenue of tourism industry in Malaysia and is the fastest growing form of tourism [11]. One of the ways to sustain the rapid need is to possibly turn solar energy systems into a driver for tourism development and consequently for local economic development [12]. Several authors examined different methods to extract the heat from the PV system and convert it to a usable energy. Zondag and Helden in their research explained a number of diverse methods to remove heat from the PV system for domestic thermal collector system usage, such as Covered Water Collector (CWC), Uncovered Water Collector (UWC), and the combination of each mentioned system [13]. It is worth to note that correct design and selecting the right elements in order to construct a PVT system plays an important role in the PVT system's overall performance. Aneta Hazi and colleagues write in their paper that there are few things which affect the efficiency of a given PVT system. It is said that, if the number of solar panel increases, the electric efficiency of a PVT system increases proportionally [14]. As the number of panel increases, the area of "capturing" solar energy is larger which yields to a higher electrical energy output. At the same time, heat also increases due to the increase of solar radiation on the panels. The light intensity is also a factor for the electric and thermal efficiency of the PV system, that is the more intense the solar irradiation the higher the efficiency of the PVT system. On a different note, a researcher concluded that energy efficiency is higher in a hybrid photovoltaic module than in an isolated system for producing heat and electricity [15].

## 2. EXPERIMENTAL MODEL AND THE CONSTRUCTION OF THE SYSTEM

After verifying the system design by Multisim simulation and Matlab program, the construction of the system begins. The model primarily had three stages, design, development, and analysis. The design stage covered the design of the PV module set up due to the incompatible output voltage of each single PV module, a thermal system with controller, SCADA system using WiFi and designing MPPT. Development stage consists of the fabrication of the entire system, including thermal system, SCADA, controller, and MPPT. The analysis stage, analysis the data obtained both for electrical efficiency and thermal efficiency of the system for two fluids, water and Nanofluid. The flow chart of the proposed system is shown in Figure 1.

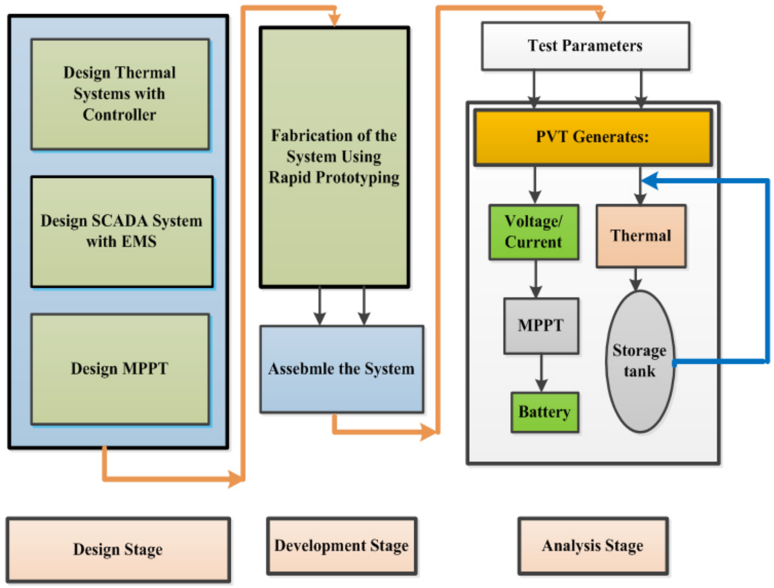


**Figure 1: PVT system design flowchart**

The PV module produces electrical power while the thermal unit which consists of insulated container unit to hold the fluid under the PV, thermal collector, heatsinks, heat transfer fluid, heat exchanger, thermal storage tank, pump, and controller system to produce thermal energy.

The entire structure of the PVT system is shown in Figure 2, which shows the communication and interaction of each the unit.

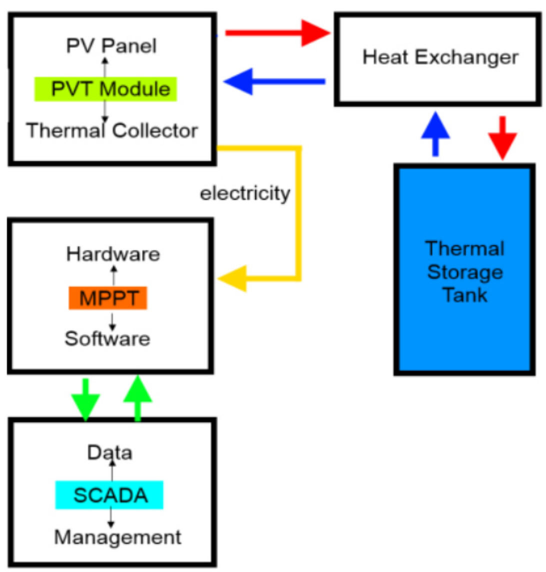


**Figure 2: Overview of the System implementation**

As mentioned above the thermal unit extract thermal energy from PVT which consists of insulated container units, heat transfer fluid, heat exchanger, thermal storage tank, and a pump. The thermal collector that is an aluminum plate was attached to the PV panels in order to absorb the heat from the PVs, and heatsinks attached to the thermal collector in order to transfer the heat from the thermal collector into the fluid. In order to increase the rate of heat transfer, Equation (1) is taken as a reference.

$$q = UA\Delta Tm \quad (1)$$

where, $q$ is the rate of heat transfer (W), U is an overall heat transfer coefficient which is directly proportional to the rate of heat transfer ($W/m^2K$), A is Surface area ($m^2$) and $\Delta Tm$ is mean temperature difference (K). The area is directly proportional to the rate of heat transfer. In order to maximize heat transfer, the thermal collector and the heat transfer fluid should have maximum contact area. The heatsinks were connected to the aluminum heat conductive plate as shown in Figure 3.

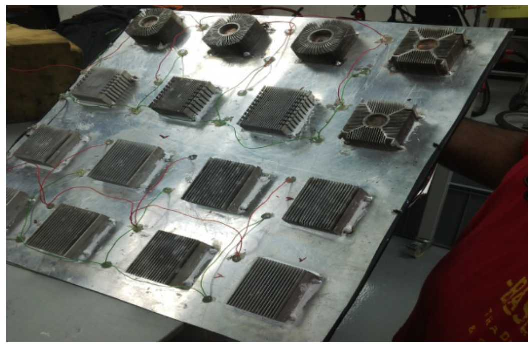

**Figure 3: Assembly of thermal conductive plate and heatsinks**

It should be noted that the choosing of material is extremely vital for the heat transfer as stated in Equation (1) above. The side view of the thermal system, including PV module, heat conductive plate, heatsinks, and heat transfer fluid is shown in Figure 4 below.

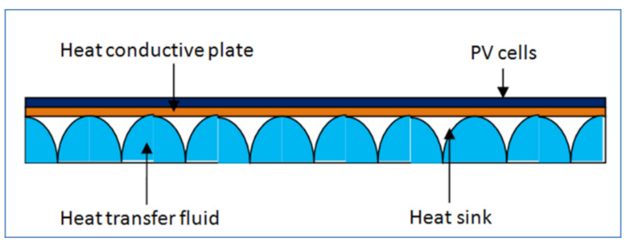


**Figure 4: Heat collection design system**

The mediums are important elements for overall heat efficiency of the thermal system. The respective overall heat transfer coefficients of the possible materials are tabulated in Table 2.

**Table 2**
**A rough estimation of heat transfer coefficient with water on both surfaces**

| *First Surface Fluid* | *Material* | *Second Surface Fluid* | *Overall Heat transfer coefficient, U ($W/m^2K$)* |
|---|---|---|---|
| Water | Copper | Water | 401 |
| Water | Mild Steel | Water | 370 |
| Water | Cast iron | Water | 260 |
| Water | Aluminium | Water | 205 |

From Table 2, it can be noticed that the copper and mild steel both have high overall heat transfer coefficient. In the final design, aluminum was chosen as Iron has one major disadvantage which is oxidation or rust especially when contact with water. Since aluminum has moderate heat transfer rate, light weight, resistance to corrosion and the heatsinks used were made of aluminum, it was selected. Matlab software was employed for simulating equation 1, the surface area was varied from 1 $m^2$ to 10 $m^2$ in step of 1 $m^2$. It can be seen that the rate of heat transfer is directly proportional to the surface area. Thus, the surface area of the heatsinks that contact with fluid should be maximized. A controller adjusts the speed of the pump according to the temperature difference between the tank water and the fluid under the PV. The higher the difference of the temperature, the faster the speed of the pump is in order to transfer more heat to the thermal tank as shown in Figure 5.

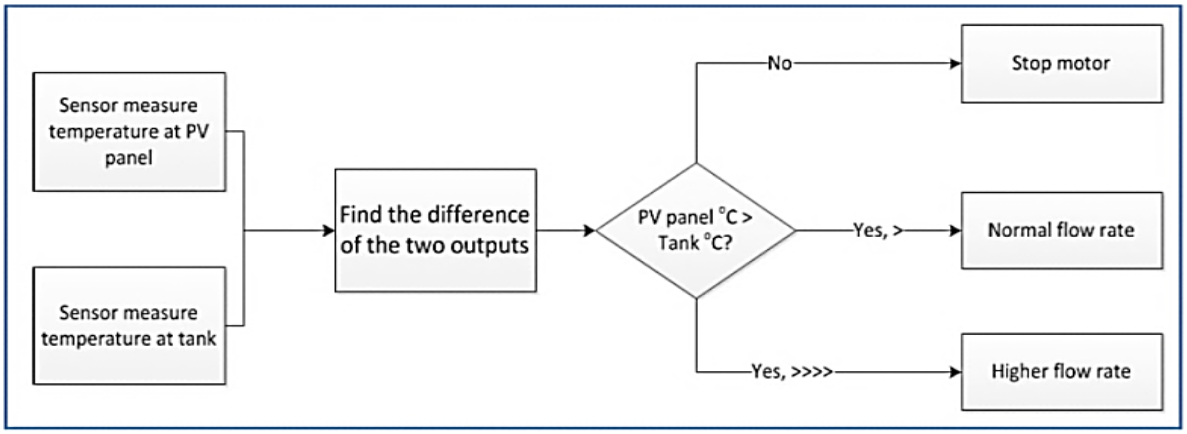


**Figure 5: Controller Algorithm**

It is crucial in the design stage as to ensure the maximum heat transfer from the PV panel into a thermal storage tank. Supervisory Control & Data Acquisition (SCADA) system has a major role in designing a good functional solar panel project. The SCADA system project integrated with the other two projects; PVT system and MPPT. The PVs should be continuously monitored and controlled for their health condition in order to maximize the output power efficiency. There were two elements in the SCADA application [16]. The SCADA is responsible for extracting its data and monitoring the power output of the PV modules. The project becomes more successful by using xively.com website which displays the value of temperature and luminance as well. The SCADA project is not just monitoring the parameter's value only, but it can be improved by controlling the parameter's value when there is a fault or the parameter value was not in the working range. Arduino GSM plays a major role in the data presentation because of its ability to connect the Internet by using GPRS network connectivity. Utilizing a mobile phone SIM card which has the capability to connect to the internet and GSM, the xively.com website was used to monitor the voltage and the temperature of the PV module online in the real time. The operator or technician can be alerted when there is a fault in the solar panel circuit as voltage value is not in the working range as expected by the PVs, therefore, sending an alert text to handphone or an e-mail by the GSM. Since the Sun irradiance at the surface of the earth during the day varies, it will cause undesired fluctuation voltage produced by PV. The voltage produced by PV needs to be regulated and ensure the maximum obtained electrical power. MPPT employs a DC-DC converter and work in tandem with a microcontroller to stabilize and optimize the output from the PV arrays which produces a better output [17]. The basic component of the MPPT structure is shown in Figure 6.

Weather conditions, such as cloudy day can hinder the power output PV system. The role of the MPPT is to provide an optimized output, meaning near constant at maximum efficiency.

## 3. RESULTS AND DISCUSSION

The small scale of the proposed PVT system which consists of 4 segments, including PV system, thermal system, SCADA system and MPPT system has been successfully constructed and tested [see Figure 7].

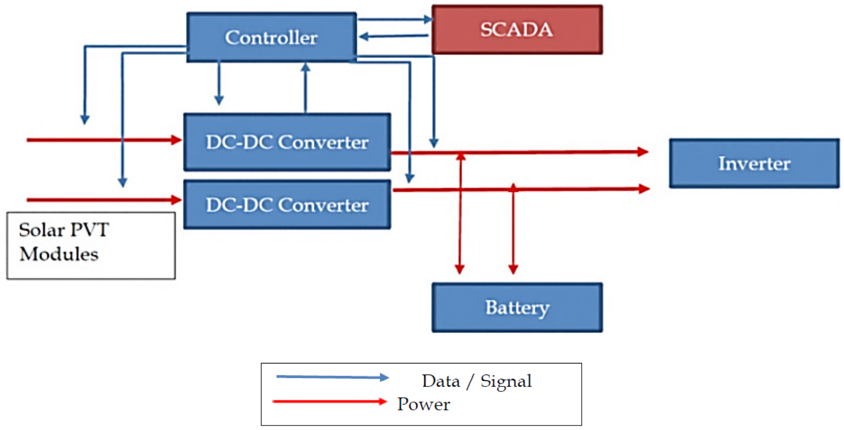


**Figure 6: Basic components of MPPT (blue color)**

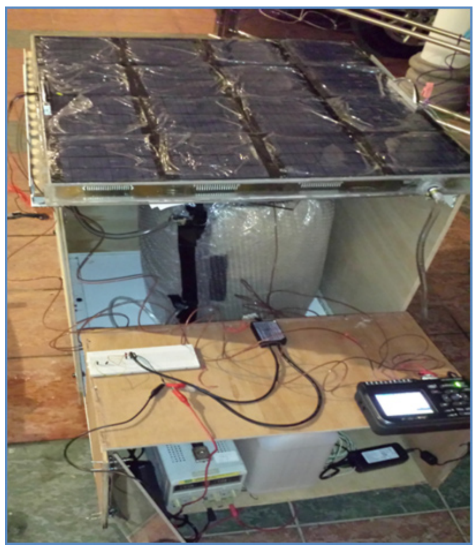

**Figure 7: Photovoltaic thermal system**

The temperature of the water in the thermal tank and the fluid under the PVs along the ambient temperature were collected by an accurate data logger. Water was initially used as a transfer medium and the later Nanofluid CNT was used. The fluid used for heat transfer would need to fulfill these characteristics: high thermal conductivity, low viscosity (resistance to fluid flow), low cost, nontoxic, chemically inert, would not cause corrosion.

Nanofluid are a stable dispersion of nanoparticles in a base fluid such as water, ethylene glycol, or engine oil. Nanoparticles are a modern material with sizes less than 100 nm. These particles have excellent mechanical, electrical, thermal and optical properties compared to their parent material. Examples of Nanoparticles are $Al_2O_3$, CuO, $TiO_2$, Cu, Fe, and Carbon Nanotube (CNT). Nanofluid has a higher thermal conductivity enhancement. The CNT has higher thermal conductivity than the water and many other materials and liquid [18]. In this experiment two different fluids, water and CNT have been selected in order to analyze the thermal transfer efficiency of each fluid. In this work, CNT is prepared according to our previous work [19]. The desired result of the peak temperature of 40°C was achieved. The result is tabulated in Table 3 and shown in the Figure 8. It can be clearly noticed from Table 3 and Figure 8 that the data obtained from the test performed in the 2 days showed that weather does affect the amount of heat collected. By comparing the results of the 2 days, it can clearly be seen that the temperatures of the thermal collector were higher when the sky is clearer than hazy weather.

**Table 3**
**The temperature of water in thermal collector recorded.**

| *Time* | *T(°C) (Hazy)* | *T(°C) (Clear Sky)* |
|---|---|---|
| 8 am | 26.5 | 27.9 |
| 9 am | 27.4 | 29.3 |
| 10 am | 29.8 | 33.6 |
| 11 am | 32.1 | 36.2 |
| 12 pm | 34.6 | 37.4 |
| 1 pm | 35.6 | 41.5 |
| 2 pm | 34.9 | 40.4 |
| 3 pm | 34.2 | 38.9 |
| 4 pm | 33.4 | 38.2 |
| 5 pm | 32.9 | 36.5 |
| 6 pm | 32.4 | 35.8 |

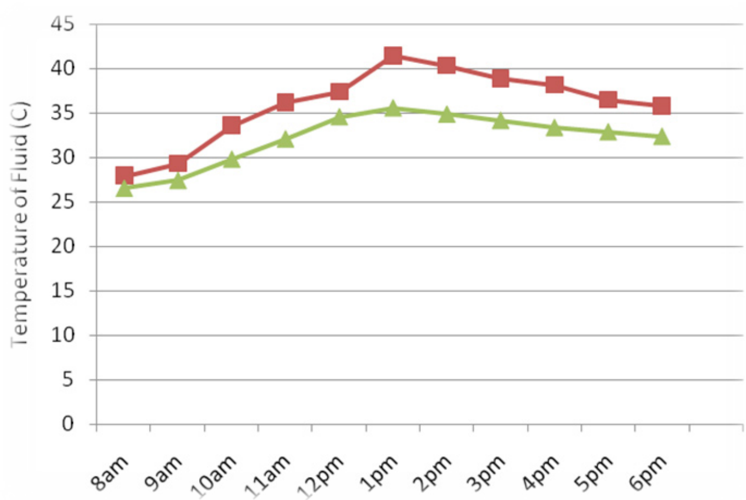


**Figure 8: The temperature of Water in Thermal Collector from 8 a.m. to 6 p.m**

Besides, both days have achieved a peak temperature at 1 p.m. This tells that the hottest hour in a day is about 1 p.m. This study also compares the obtained results of CNT Nanofluid and Water. The data obtained shown in Table 4 clearly show that nanofluid has a higher heat transfer rate than water.

**Table 4**
**Peak and lowest temperature using water vs. nanofluid**

| *Part* | *Peak Temperature (°C)* | | *Lowest Temperature (°C)* | |
|---|---|---|---|---|
| | *Water* | *Nanofluid (CNT)* | *Water* | *Nanofluid (CNT)* |
| Thermal Conductive Plate | 41.2 | 42.5 | 27.3 | 27.4 |
| Heat Transfer Fluid | 40.0 | 40.0 | 27.6 | 27.7 |
| Thermal Storage Tank | 35.9 | 38.6 | 28.2 | 28.3 |

The electrical efficiency of the system is found to be 14.44% based on average radiation. The data obtained is within the range of the data claimed in [7] which is 13% to 20%. The thermal efficiency of the PVT system using water as heat transfer fluid is 24.52%. The thermal efficiency of the PVT system using Nanofluid is

33.03%, which is 8.51% higher comparing with water. The overall efficiency of the system including electrical and thermal using water as heat transfer fluid is 14.44% + 24.52% = 38.92% and the overall efficiency of the system including electrical and thermal using Nanofluid as heat transfer fluid is 14.44% + 33.03% = 47.47%.

## 4. CONCLUSION

In conclusion, the system was built as expected and 2 different fluids, water and CNT were used as the heat transfer medium and analysis were done on each for their performance and efficiency. The test done on the performance of the system using these two fluids showed that the CNT nanofluid performed better than water in heat transfer thus better thermal efficiency. The heat lost in the system, which comprises the heat transfer exist and can be improved and further reduced by using better and more efficient parts. A better designed thermal tank can hold the heat for a longer time, which will further improve the efficiency of the system. Many parameters can be changed to find the optimum output, but at the same with a trade-off of electrical or thermal output. The extraction of PV thermal energy not only is a good free source of energy but also improves the efficiency of the PV output by lowering down the temperature of the PV module. These combinations of energy, electrical and thermal are a clean, abundant and sustainable source of energy which aligned with the concept of ecotourism philosophy. Since the ecotourism is naturally in a remote location using hybrid photovoltaic/ thermal system energy further contributed to the sustainable tourism development in Malaysia and protected the nature against increasing $CO_2$ and as a result, contributes to reducing the global warming.

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