OPTIMIZATION OF INTEGRATED SOLAR PHOTOVOLTAIC THERMAL (PVT) AND AIR SOURCE HEAT PUMP (ASHP) FOR HOT WATER AND ELECTRICITY GENERATION IN HEALTHCARE FACILITY

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Abstract— **Photovoltaic Thermal System (PVT) has become an important research area due to concern of global crisis on utilization of energy resources such as oil and gas. One interesting and potential application of PVT technology is for healthcare facility where both energy output of PVT are highly in demand. Healthcare facility is a highly energy intensive facility due to the intensity of medical equipment and air conditioning system requirements. One of the barrier to wide spread application of this new technology is life cycle cost which is relatively high compared to conventional PV and thermal collector system. In order to aid successful market penetration of PVT system, optimization of PVT system is indeed needed which reduces the overall life cycle cost of the system. In this paper, optimization of PVT system in health care facility has been carried out using the actual hot water demand in one of the leading hospital in Malaysia. PVT system integrated with Air Source Heat Pump (ASHP) hot water plant has been simulated and optimized. By series integration of PVT system with existing ASHP system, ASHP will act as auxiliary heater for PVT system and thus reducing the energy input for ASHP as well as generating electricity for hospital consumption. Dynamic simulations results and optimization using TRNSYS simulation tools of the proposed plant are presented and outlined.**

Keywords: Photovoltaic Thermal Collector, Renewable Energy, Hot Water, Air Source Heat Pump.

I. INTRODUCTION

Concerns for negative environmental impacts of conventional fossil fuels, has been the main factor driving the transition towards renewable energy technologies. Researches and policy makers all around the world are actively looking for ways to reduce the greenhouse emissions from their operations with a major focus on the use and installation of sustainable renewable energy systems. Abundant solar energy is the most promising source of renewable energy with its abundance in most part of the world, readily available to generate electricity and thermal energy. Malaysia has great potential to utilize solar energy as a renewable source of energy due to its equatorial location and high solar energy potential with the daily average solar radiation of 4000–5000Wh/m^2. The average sunshine duration was found to be in the range of 4–8 h/day [1].

Two type of solar energy derivatives are available, namely electricity from the solar Photovoltaic Collector (PV-Collector) and thermal energy from Solar Thermal Collector (ST-Collector). In building with both demand for electricity and thermal energy exists such as in hospitals and hotels, options are available whether to have two separate systems for PV-Collector and ST-Collector or a single system integrating both collectors using a hybrid Photovoltaic-Thermal Collectors (PVT-Collector). PVT collector has many advantageous compared to independent collectors. Well-designed PVT collector system can achieve better PV performances, and decrease the rate of cell degradation with time, resulting in maximization of the life span of photovoltaic modules and space saving compared to two separated systems [2]–[4].

A typical PVT collector contains a flat plate collector with various configuration laminated with PV panel acts as a thermal absorber. Apart from generating electricity directly by absorption of solar radiation onto PV panel , part of the energy will converted into thermal energy and absorbed by flat plate collector, simultaneously reducing the operational temperature of the photovoltaic cells and increasing its efficiency. Every 1°C surface temperature rise of the PV module causes a reduction in efficiency from 0.2% to 0.5% depending on type of PV-collector [5], [6].

PVT technology as with others renewable energy technologies are mainly faced with economic barrier that limits its full wide spread application rather than technical barrier. Installation of a PVT system could easily become more affordable than that of the two solar technologies separately [3]. Nonetheless, the capital cost is still relatively high compared to importing electricity from the grid and conventional heating system. As such, optimization of the design of PVT system is thus required as one of the measures to alleviate its economic barrier.

In typical hospitals in Malaysia, demand for electricity is far exceeds the Domestic Hot Water (DHW) heating demand. Thermal energy on the other hand is required for sterilization, hydrotherapy, cleaning, dehumidification and other related services. Application of PVT in hospitals is thus highly potential with its 24 hours demand of electricity and thermal energy. In lieu, with this, this research paper will focused on optimizing the design of PVT system to serve both thermal energy and electricity demand in Serdang Hospital, Selangor, Malaysia.

II. DESCRIPTION OF SERDANG HOSPITAL HOT WATER AND ELECTRICITY CONSUMPTION

A 129,000 square meters, Serdang Hospital is located in Serdang, Selangor provides medical services to approximately 570,000 residents in Serdang, Putrajaya, Kajang and Bangi areas. Serdang Hospital is a government hospital that operates as a reference hospital with 620 beds equipped with a variety of up-to-date facilities. The hospital provides medical services and treatments according to current needs for internal and external patients, as well as a teaching hospital for Universiti Putra Malaysia (UPM) medical students. Current hot water demand is served from Centralized Air Source Heat Pump (ASHP) plant. A total of four unit of ASHP are installed with a capacity of 42kW each providing hot water at 60^{o}C to all hot water fittings distributed throughout the hospital. Four (4) number of 5,000 liter calorifier were also provided for storage purposes.

A. Thermal Energy Demand

Fig. 1 shows the recorded hot water consumption and resulting thermal power demand for a week in Dis 2017 with total average daily consumption of 80m^3. Peak consumption was recorded in the morning around 9.00 a.m with hourly consumption of 7.1 m^3/hr. Hot water set point temperature was set at 60^{o}C ±4^{o}C. Average make-up water from main roof storage tank was at 27^{o}C. Maximum thermal power output from Centralized Air Source Heat Pump (ASHP) plant is 274 kW and daily thermal energy demand of 2,984 kWh per day. This excludes heating energy demand for dehumidification purposes which are extensively used in Air Handling Unit (AHU) and Fan Coil Unit (FCU) throughout the hospital. At presence, all dehumidification processes utilize cooling coil dehumidification and electrical reheater for that purpose.

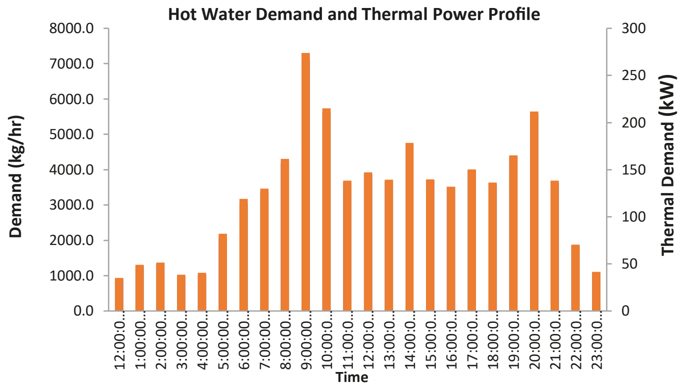

Fig. 1. Average daily hot water demand and thermal power profile for Serdang Hospital

B. Electrical Energy Demand

Total electricity consumption and maximum demand for Serdang Hospital obtained from monthly electricity bill is shown in Figure 2. Maximum consumption occurred in month of May amounting to 2,481,678 kWh whereas maximum demand of 4167 kW was recorded on June. Currently all electrical energy is fed from Tenaga Nasional Berhad national grid.

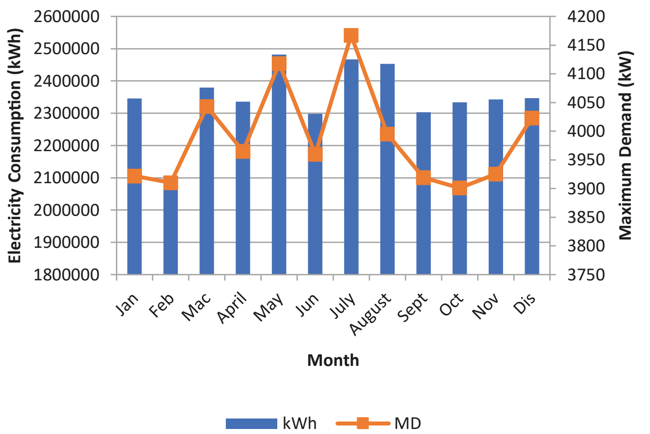

Fig. 2 Monthly electricity consumption and maximum demand

2.3 Total Energy Sources

Demand for electricity is far above the thermal energy demand for water heating. Electricity demand constitutes up 96% of the total energy demand for the hospital followed by 4% for thermal energy demand.

III. METHODOLOGY

Detail simulation was carried out in TRNSYS 17 by using the actual hot water demand data and existing heat pump plant coefficient of performance (COP). A hybrid PVT collector system was annexed to the hot water plant system to preheat the incoming feed water to the calorifers. PVT collector area and pre-heat water tank volume were optimized and the effects on solar fraction, overall PVT collector efficiency were carried out.

IV. PVT COLLECTOR

The proposed PVT collector module is an un-glazed PVT collector with the following parameters;

TABLE 1. PVT COLLECTOR PARAMETERS

Parameters	Value
Type	Unglazed Flat plat solar collector
PV efficiency at STC	12%
Temperature coefficient	0.5%/°C
Absorber plate thickness	0.002 m
Collector tilt	14°
Flow configuration	Direct
Water flow rate (kg/hr.m^2)	50 kg/hr.m^2

Optimal water flow rate is set at 50kg/hr per each square meter of PVT collector area[7].

PVT collector overall efficiency consists of both thermal and photovoltaic components as describe below;

$$\zeta_{pvt} = \zeta_{th} + \frac{\zeta_{pv}}{\zeta_p} \quad (1)$$

The term ζ_{pv}/ζ_p represents the pv efficiency normalized by the typical efficiency of power plant (ζ_p) in Malaysia. This efficiency term represents the energy output of the PV cell in terms of primary energy. This approach enables us to make fare comparison with thermal energy output of the PVT collector. Efficiency of power plant (ζ_p) in Malaysia was taken as 38% as reported in Malaysia's National Energy Balance 2015.

Solar fraction (f) defined as the ratio of thermal energy output of PVT collector (Q_{pvt}) and total thermal energy demand of the hot water system (Q_{dhw}) is also used as a performance indicator of the PVT.

$$f = \frac{Q_{pvt}}{Q_{dhw}} \quad (2)$$

V. SIMULATION RESULTS AND DISCUSSION

A. *Energy Analysis*

Energy analysis was carried out in TRNSYS by varying PVT collector area and water storage volume. Solar collector areas were varied from 400 m^2 to 2000 m^2. 1st stage optimization was carried out by determining the optimum water storage volume for each collector area that will result in the highest solar fraction. Result of 1st stage optimization is shown in Fig. 3. Each PVT collector area has its own optimum water storage volume ranging from 0.02 to 0.2 m^3/m^2 of PVT collector area.

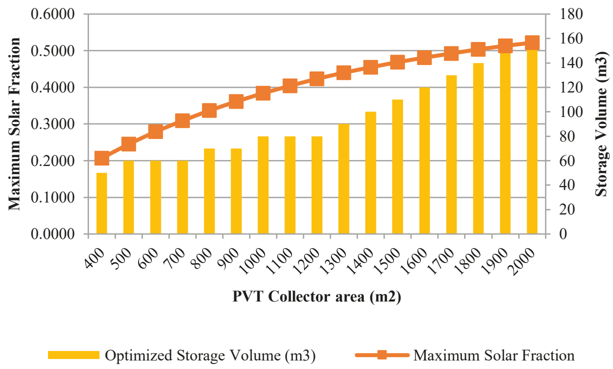

Fig. 3 Effect of storage volume on solar fraction with different PVT collector area

Simulations were run for each set of optimized water storage volume and associated PVT collector area to determine the resulting solar fraction and overall PVT efficiency as shown in Fig. 4. Overall PVT efficiency decreases with collector area and this is consistent with other studies carried out in the same context. Higher number of PVT collector areas will result in lower overall efficiency [8]. Solar fraction on the other hand increases with PVT collector areas. PVT collector area of 400 m^2 resulted in solar fraction of 0.21 and increased to 0.54 with 2000 m^2 PVT collector area. In this study, maximum solar collector area was limited to 2000 m^2 due to site constraints.

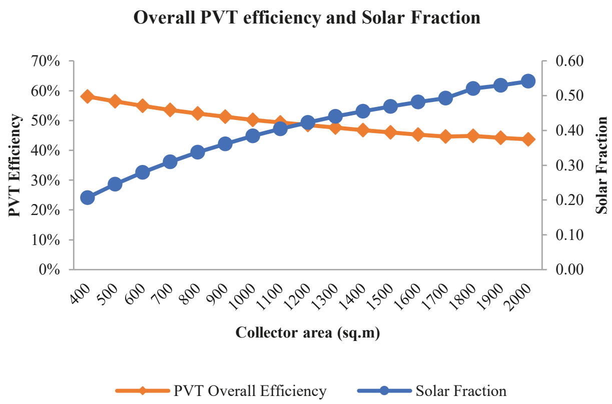

Fig. 4 PVT efficiency and solar fraction for different PVT collector area

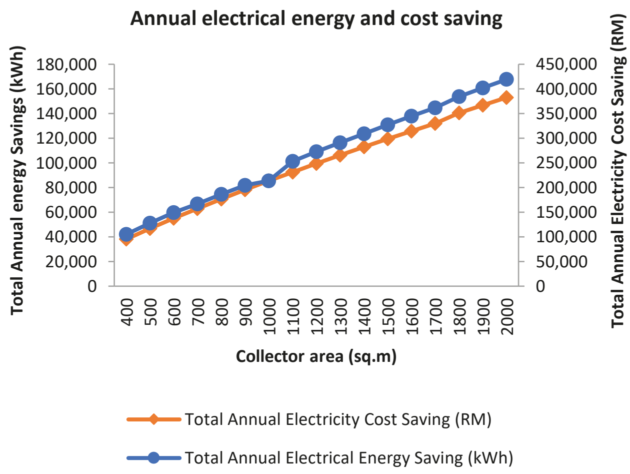

Fig. 5 Total annual electrical energy and cost saving to existing hot water plant

B. *Economic Analysis*

Economic analysis was carried out to determine the most cost effective solution of PVT system integration with existing hot water plant. Economic calculation criteria are as shown in Table 2.

TABLE 2 PVT ESTIMATED COST AND TNB TARIFF

PVT System Cost

PVT collector (RM/m^2)	2,000
Supports & electrical works (RM/m2)	300
Pumps, storage tank and pipeworks (RM/m2)	500
Total Works (RM)	2,800

TNB Tariff C2	MD	45.1	RM/kW
	kWh	0.365	RM/kWh

Simple payback period (SPB) method was used as a quick estimate of the economic viability of the system proposed. The result of analysis is shown in Fig. 6. Minimum SPB calculated is 29 years for 400 m^2 collector area with RM 38,048 annual cost saving and RM 1,120,000 million capital cost.

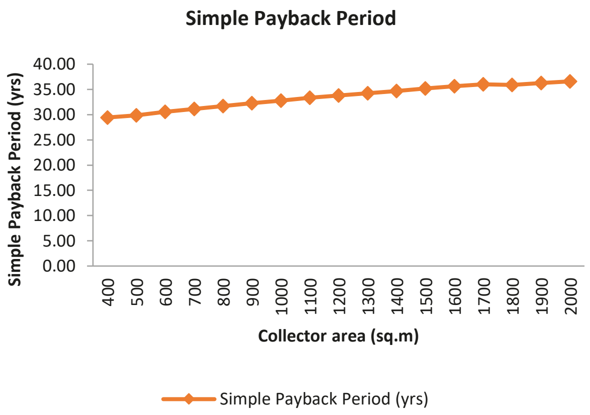

Fig. 6 Simple payback period

VI. CONCLUSIONS

Optimization of the proposed PVT collector system integrated with existing heat pump driven hot water plant have been carried out to determine the optimized PVT collector area and storage volume that will result in lowest overall system Simple Payback Period (SPB). 400 m^2 PVT collector area, with 50 m^3 storage volume has been found to be the most economically viable configuration with 0.21 solar fraction and overall PVT efficiency of 58%. Future study will include more detail economic assessments, taking into account subsidized feed in tariff rate and cost structure that will result in shorter payback period, making it more attractive to building owners.

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