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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

ANALYSIS OF PHOTOVOLTAIC THERMAL USING F-CHART METHOD FOR DOMESTIC HOT WATER

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Master of Mechanical Engineering (Energy Engineering)

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ANALYSIS OF PHOTOVOLTAIC THERMAL USING F-CHART METHOD FOR DOMESTIC HOT WATER

MUHAMMAD HASIF BIN JAMIL

A thesis submitted
in fulfilment of the requirement for the degree of Master of
Mechanical Engineering (Energy Engineering)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitles "Analysis of Photovoltaic Thermal Using F-Chart Method for Domestic Hot Water" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this thesis is sufficient in terms of scope and quality as a partial fulfilment of Master of Mechanical Engineering (Energy Engineering).

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Date : 1/2/2019.

DEDICATION

To my beloved family

ABSTRACT

Integration of photovoltaic thermal technology in the household water heating system explore the possibility of lowering energy consumption for the domestic market. However, its lower thermal efficiency characteristics compared with conventional solar thermal collector remains the barrier in practical application. The purpose of this study is to investigate the feasibility of photovoltaic thermal collector for domestic water heating application in Malaysia. A theoretical F-chart method adopted in evaluating the performance of the photovoltaic-thermal water heating system for a typical family house with four occupants. Preliminary analysis conducted in Ayer Keroh, Malacca shows the optimal tilt angle of location obtained at 30 degrees with the average solar radiation of 18.35 MJ/m^2 per month. Based on feasibility analysis, the proposed photovoltaic thermal system capable meeting 85% of annual water heating load demand under the surface area of 5.66 m^2. The total heating energy generated by the photovoltaic thermal system ranges between 2,284 to 2,376 kWh per year. In summary, the integration of photovoltaic thermal collector is suitable for meeting domestic water heating demand in Malaysia.

ABSTRAK

Integrasi teknologi fotovoltan-terma dalam sistem pemanas air rumah meneroka kemungkinan menurunkan penggunaan tenaga untuk pasaran domestik. Walau bagaimanapun, kecekapan haba yang rendah berbanding dengan pengumpul haba konvensional kekal sebagai penghalang dalam aplikasi praktikal. Tujuan kajian ini dijalankan adalah untuk mengkaji kesesuaian pengumpul suria fotovoltan-terma bagi aplikasi pemanasan air domestik di Malaysia. Kaedah F-chart digunakan untuk menilai prestasi sistem pemanas air fotovoltan-terma bagi sebuah rumah dengan empat penghuni. Analisis awal yang dijalankan di Ayer Keroh, Melaka menunjukkan sudut kecondongan optimum bagi lokasi adalah 30 darjah dengan purata radiasi solar sekitar 18.35 MJ / m^2 sebulan. Berdasarkan analisis yang telah dijalankan, sistem fotovoltan-terma yang dicadangkan mampu memenuhi 85% permintaan tenaga pemanas air setahun dengan keluasan permukaan 5.66 m^2. Jumlah tenaga pemanasan yang dihasilkan oleh sistem fotovoltan-terma antara 2,284 hingga 2,376 kWj setahun. Ringkasnya, pengintegrasian pengumpul suria fotovoltan-terma sesuai digunakan untuk memenuhi keperluan pemanasan air domestik di Malaysia.

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CHAPTER 1

INTRODUCTION

1.1 Background

Solar energy is part of nature sustainable energy sources besides wind, ocean wave, hydro and geothermal. The technology converts incoming solar radiation of the sun into useful electric and thermal energy. The solar collector is the main equipment used in harvesting the incoming radiation received by the earth. It is available in thermal, photovoltaic and photovoltaic-thermal form factor. In general, the thermal collector transforms solar radiation into useful heat while photovoltaic panel converts it into electric energy. Introduction of photovoltaic thermal collector combined both solar thermal and photovoltaic panel design. Two in one design helps the photovoltaic thermal collector produce electricity and thermal energy simultaneously. This innovative design is seen as a viable option to fulfil the domestic and industrial energy demand, especially for water heating application.

Latest review on photovoltaic thermal technology by Brahim and Jemni (2017) found more than half of solar energy harvested by collector transformed into heat while less than 20% converted into electricity. High heat generated from solar radiation is useful for water, space and industrial heating application. Detail comparison of various photovoltaic thermal collector concludes the typical thermal efficiency range between 40% to 80% depending on the design and heat transfer medium (Joshi and Dhoble, 2018). The flat plate collector is one of most commercialised design used in domestic application due to its lower payback period than evacuated tubes (Loginov et al., 2015; Asyar, 2017). Reviews past four decades found the location solar insolation and ambient temperature remain as two main factors influencing the performance of the photovoltaic thermal system (Das, Kalita and Roy, 2018).

The performance of the solar water heating system varies depending on the climate and ambient temperature of the location. A feasibility study measures the effectiveness of the domestic water heating system under local ambient temperature and solar insolation. In the conventional water heating system, analysis under temperate climate shows the system capable meeting 64% to 78% of annual water heating load demand (Şerban et al., 2016). Another study by Vieira et al. (2017) shows the maximum solar fraction of subtropical climate improved significantly up to 98%. A similar pattern also observed for the photovoltaic thermal collector although it has lower thermal efficiency than the conventional solar thermal collector. A study conducted by Herrando and Markides (2016) found the photovoltaic thermal system covers 36% of the annual water heating load under temperate climate. Analysis conducted in Tengchong, China shows the annual solar fraction increased up to 86% under the subtropical climate (Ouyang et al., 2017). The tropical zone located close to earth equator where the location received 12 hours sunlight throughout the year. Malaysia is one of the countries under the tropical climate which obtained average solar radiation of 4 to 5 kWh/m² per day (Belhamadia et al., 2013; Aziz et al., 2016). Parametric studies conducted by Daghigh et al. (2015) analysed the solar fraction of active water heating system using two types of the photovoltaic-thermal collector. The simulated result indicates the photovoltaic thermal system fulfil 63.0% to 65.2% of the annual solar fraction for unglazed design and 95.4% to 96.4% under the glazed collector (Daghigh et al., 2015). Reviews conclude the photovoltaic thermal system in theory capable of accommodating the location water heating load thus reduce energy demand for the domestic sector.

Although low in thermal efficiency compared with the conventional collector, the long-term review indicates the water-based photovoltaic thermal system is more promising for future investment (Rosli et al., 2014). The combined electric and thermal energy produced by the photovoltaic thermal collector is higher than the conventional solar thermal water heating system. A study under low ambient temperature and solar radiation showed the photovoltaic-thermal system capable covering 51% of annual household electricity demand in London (Herrando and Markides, 2016). Another study examined the system effectiveness under various heating mode found the overall result of photovoltaic thermal still considerable than the conventional solar thermal system (Zhang et al., 2017). In summary, optimising the configuration of the photovoltaic thermal system helps improve the amount of energy generated thus explore its adaptability in future.

1.2 Problem Statement

In Malaysia, the evaluation of solar water heater leans towards the domestic application. The F-Chart, simulation, mathematical modelling and experiment are four main approaches frequently used in evaluating the effectiveness of solar water heating system. Review of studies found most information available for the conventional solar thermal system which employs evacuated tube and flat plate collector (Naghavi et al., 2014; Sulaiman and Fauzi, 2014; Sabiha et al., 2015; Rahman et al., 2018; Din and Azlan, 2018; Kumar et al., 2018; Fayaz et al., 2018). However, limited reference is available for the photovoltaic thermal collector. In the photovoltaic thermal evaluation, most of the studies utilised simulation and experiment method (Daghigh et al., 2015; Al-Waeli et al., 2017). The mathematical modelling and F-Chart are two types of evaluation method categorised in the numerical approach which remains unexplored in Malaysia. Both methods utilise the mathematical formula in evaluating the performance of the solar water heating system. The mathematical modelling generates detail result with higher accuracy. However, the analysis process is much complex than the F-Chart method. Detail study shows the F-Chart method is easy to use with its simplified equations. Hence, the F-chart method suggested as the project approach in assessing the feasibility of the solar water heating system using the photovoltaic thermal collector in Malaysia.

1.3 Objectives

The general aim of the project is to determine the feasibility of the domestic water heating system using the photovoltaic thermal collector in Malaysia by employing the F-Chart method. The city of Ayer Keroh, Malacca selected as the location for conducting the case study analysis. Preliminary analysis of location solar radiation is necessary since insufficient data available for references. The main objectives of the project summarised as follows.

i. To analyse the tilt angle radiation of Ayer Keroh, Malacca using isotropic model.
ii. To evaluate the solar fraction of the photovoltaic-thermal water heating system using the F-Chart method.
iii. To compare the solar fraction and surface area of photovoltaic thermal with the conventional solar thermal collector.
iv. To recommend the optimal surface area for the photovoltaic-thermal collector under the specified configuration.

1.4 Scope of Study

The scopes of study consist of several assumption and limitation for the domestic solar water heating system utilising photovoltaic thermal collector summarised as follows.