**Faculty of Mechanical Engineering**

# DESIGNING A SOLAR COLLECTOR USING F-CHART METHOD FOR DOMESTIC HOT WATER IN MALAYSIA

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**Master of Mechanical Engineering (Energy Engineering)**

**2018**

# DESIGNING A SOLAR COLLECTOR USING F-CHART METHOD FOR DOMESTIC HOT WATER IN MALAYSIA

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

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2018**

# DECLARATION

I declare that this thesis entitled "Designing a solar collector using f-chart method for domestic hot water in Malaysia" is the result of my own research except as cited in the references. The thesis has not been accepted for any master degree and is not concurrently submitted in candidature of any other master degree.

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| Name | : | ……………………………… |
| Date | : | ……………………………… |

**APPROVAL**

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering (Energy Engineering).

Signature     :     ………………………….

Name         :     ………………………….

Date          :     ………………………….

# DEDICATION

I would like to dedicate this project to my beloved parents and family.

# ABSTRACT

The solar energy system converts solar energy into useful energy. The performance system depends on the weather that changes over period of time. This make it difficult to analyse accurately the solar system performance by simply referring to the short-term or average weather conditions. To overcome this problem, researchers often do experiments and software such as TRNSYS, Simulink, MATLAB and more. In this study, the f-chart method was used to predict the solar collector system. The f-chart method is one of the empirical frameworks that use metric standards to characterize the long-term performance of the solar system. Nowadays, many researchers use the f-chart method because of its simple analysis formula. In addition, the f-chart method is the easiest method to determine the size of the solar collector. The f-chart method considered value of x and y throughout the year to determine the annual fraction of the load supplied by solar energy. A total of 3 varied sizes of solar collectors were used in this study. Residential areas in Bangi have been selected in this study to design hot water heating systems using solar energy and data for ambient temperature and average solar radiation in 2013 have been used to make this study possible. After doing this study, the load given by the solar collector for 3 varied sizes is not the same as 0.38, 0.66 and 0.84. This shows that 0.84 is the highest and shows that 84% of the load is supplied by solar energy. The monthly average domestic heating in Malaysia is 1.22 GJ. Meanwhile, the total domestic heating temperature in Malysia is 14.66 GJ.

# ABSTRAK

Sistem tenaga solar menukarkan tenaga suria menjadi tenaga berguna. Prestasi sistem ini bergantung kepada cuaca yang seringkali berubah terhadap masa. Ini menjadikannya sukar untuk menganalisis prestasi sesebuah sistem suria dengan tepat dengan hanya merujuk kepada keadaan cuaca jangka pendek atau purata. Bagi mengatasi masalah ini, penyilidik sering melakukan eksperimen dan perisian seperti TRNSYS, simulink, MATLAB dan pelbagai lagi. Pada kajian ini, kaedah *f-chart* telah digunakan bagi meramal sistem pengumpul suria. Kaedah *f-chart* adalah salah satu rangka kerja empirikal yang menggunakan metrik standard untuk mencirikan prestasi jangka panjang sistem solar. Pada masa kini, banyak penyelidik menggunakan kaedah *f-chart* kerana rumusan analisisnya yang mudah. Selain itu, kaedah *f-chart* adalah kaedah paling mudah untuk menentukan saiz pengumpul suria. Kaedah *f-chart* mengambil kira nilai x dan nilai y sepanjang tahun untuk dipadankan dengan kupayaan pengumpul. Sebanyak 3 jenis saiz penugmpul suria yang berbeza telah digunakan didalam kajian ini. Kawasan kediaman di Bangi telah dipilih dalam kajian ini untuk merancang sistem pemanasan air panas menggunakan tenaga suria dan data untuk purata suhu ambien dan purata solar radiasi pada tahun 2013 telah digunakan untuk menjayakan kajian ini. Setelah melakukan kajian ini, didapati beban yang diberikan oleh pengumpul suria untuk 3 saiz yang berbeza juga adalah tidak sama iaitu 0.38, 0.66 dan 0.84. Ini menunjukkan bahawa 0.84 adalah nilai yang paling tinggi dan menunjukkan 84% daripada beban tahuan adalah dibekalkan oleh tenaga solar. Purata bulanan pemanasan domestik di Malaysia ialah 1.22 GJ. Sementara itu, jumlah suhu pemanasan domestik di Malaysia ialah 14.66 GJ.

# ACKNOWLEDGEMENT

First and foremost, I wanted to pray to Allah S.W.T for giving me chances to perform this project and for helping and guiding me to complete this report successfully. I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr. Mohd Afzanizam Bin Mohd Rosli from the Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his informative supervision toward me from the beginning to the end of this project really helps me to complete this project successfully. Furthermore, a huge thanks to Naziatul Fazilah, postgraduate student who give me guidance, advices, cooperation, and generously sharing her knowledge and experience to me regarding this project. Special thanks to all my peers, my beloved parents and siblings for their moral support in completing this master's degree. Lastly, thank you to everyone who had been to the crucial parts of realization of this project.

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# LIST OF SYMBOLS

$A_c$     -     Area of solar collector ($m^2$)

$F'R$     -     Collector-heat exchanger efficiency factor (%)

$FR$     -     Collector heat removal factor (%)

$UL$     -     Collector overall energy loss coefficient (w/$m^2$ °C)

$\Delta t$     -     Total number of seconds or hours in the month

$T_a$     -     Monthly average ambient temperature (°C)

$L$     -     Monthly total heating load for space heating and hot water (GJ)

$HT$     -     Monthly averaged, daily radiation incident on collector surface per unit area (MJ/$m^2$)

$N$     -     Number of days in the month

$(\tau\alpha)$     -     Monthly average transmittance-absorptance product

$(\tau\alpha)_n$     -     Normal transmittance-absorptance product (%)

$T_{ref}$     -     Reference temperature (100 °C)

$C_p$     -     Specific heat of water

$\rho$     -     Density of water

$h_w$     -     Hot water daily consumption

$T_w$     -     Required hot water temperature

$T_m$     -     Mains water supply temperature

# CHAPTER 1

# INTRODUCTION

## 1.1    Introduction

The main goal of this project is to identify optimum size of the solar collector that can provide the highest solar fraction for domestic hot water in Malaysia by f-chart method. This chapter will cover the research background, problem statement, objectives and scope of the research. A further explanation also will be included here to provide more understanding about this project.

## 1.2    Background

Along the decade, researchers have proposed some various methods to represents the solar system analysis and design program. The researcher suggested a method for estimating performance for passive solar systems became available called the Solar Load Ratio (SLR) method (Colle and Vidal 2004). Besides, previous researcher has been studying an experiment method. Because by doing an experiment it will take a longer time, cost a lot of money and vary parameters to see their effect on the system performance (Duffie and Beckman 2013).

The method called f-charts is one of the empirical frameworks that uses standardised metrics to characterise the long-term performance of solar system. Nowadays many researchers are using F-chart method because of its simple analytical formulation, as

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opposed to an annual full- time transient simulation performed in codes such as TRNSYS (Koussa 2014). Other than that, f-chart method is the simplest method to determine the size of the solar collector (Koussa and Djohra 2014).

## 1.3    Problem Statement

Nowadays, designing solar collectors is being used around the world as well as here in Malaysia. Solar collectors transform solar radiation into heat and transfer that heat to a medium (water, solar fluid, or air). Then solar heat can be used for heating water, to back up heating systems or for heating swimming pools. In this case study the solar collector is used to provide heat to domestic hot water system. From this study we are able to identify the size of the solar collector. Besides, we also can determine the annual energy performance of domestic hot water system in Malaysia. To achieve the objectives of this case study, a suitable method should have been used.

Several methods have been proposed in order to reach the goal of this case study. But solar energy system exhibits nonlinear dependence on weather and this makes it difficult to accurately analyse their performance. Due to the nonlinear dependence of these systems, its require an examination of their performance over a long period of time. Experiments are very expensive and time-consuming and difficult to vary parameters to see their effect on the system performance.

In order to overcome the difficulties of the experimental methods, this case study has proposed to use f-chart method to design the solar collector for domestic hot water system. The f–chart method provides a means of easily determining the thermal performance of active solar heating systems (using either liquid or air as the working fluid) and solar domestic hot water systems. Other than that, it also provides a quick and robust estimate of system performance using collector parameters and average monthly radiation and temperature data.

**1.4    Objectives**

The objectives that will be accomplished by fulfilling the case study are:

    i.   To determine solar fraction for selected solar collector using f-chart method.

    ii.  To determine month and annual performance of domestic hot water in Malaysia.

    iii. To determine the storage capacity for selected solar collector.

**1.5    Scope of Study**

The scope below should be emphasized in order to achieve the objectives of the project:

1)     F-chart method is the only way that being used in the procedure of this case study.

2)     The area that involve in this case study is only in Malaysia.

3)     The annual energy performance that need to be calculated is based on the average data in Bangi, Selangor, Malaysia.

4)     Using flat plate collector (FPC)

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# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

The literature review of this project comprises from the journal on the internet, paper proceedings and research, books and lectures. The literature review is done to investigate cases of the projects that may arise to overcome it. The literature review gives a broad knowledge on the fundamentals of the project.

## 2.2 Method to Design Domestic Hot Water System

Domestic hot water heating often requires higher temperature water than space heating does. This is due to the fact that heat is being transferred to a 49ºC or greater sink rather than the 21ºC air in a space heat application. There are several ways to configure a domestic water heating system. The two most common are storage recharge and instantaneous. There is also the possibility of using the geothermal water directly as makeup to the domestic hot water heater if the water chemistry permits.

### 2.2.1 Transient System Simulation Tool (TRNSYS)

TRNSYS is a transient systems simulation program that has been commercially available since 1975 is currently maintained by an international collaboration from the United States (Thermal Energy System Specialists and the University of Wisconsin-Solar Energy Laboratory), France (Centre Scientifique et Technique du Bâtiment), and Germany (TRANSSOLAR Energietechnik) (Asim and Kanan 2016). TRNSYS can be used to simulates all sectors of an energy-system except the transport sector because it is an open modular structure with open source code.

Overall TRNSYS can simulate all thermal and renewable generation except nuclear, wave, tidal and hydro power. TRNSYS has been used extensively to simulate solar energy applications, conventional buildings, and even biological processes. These include analysing the performance of prototype solar-thermal system, optimising the operation of a solar thermal system, analysing the thermal performance of buildings and modelling a hybrid PV-thermal solar system.

Kalogirou and Tripanagnostopoulos (2006) designed domestic hot water applications both passive (thermosyphonic) and active by using TRNSYS simulation results for hybrid PV/T solar systems. Hybrid PV/T system was modeled and simulated based on the environmental conditions by using TRNSYS simulation program. Based on the authors the system can satisfy part of the thermal and electrical needs of a family of four persons. It was found that the optimum water flow rate value was 4.9 l/h m² in the previous studied in which an active PV/T system was modelled. So, for the low value of flow rate, they found that the system could be used a thermosyphon mode.

TRNSYS Type 45 model is being used for simulation of the thermosyphon system. By dividing the thermosyphon loop into a number of segments normal to the flow direction and applying Bernoulli's equation for incompressible flow to each segment to analyse the thermal performance of the system. Figure 2.1 shows the flow diagram of the large hot water system application which the units are modelled by combining a number of components. In this case study the system is assumed to be active system. From this case study, we can conclude that the results give an account of the energy and cost benefits of the studied PV/T systems with thermosyphon and forced water flow by using derived TRNSYS.
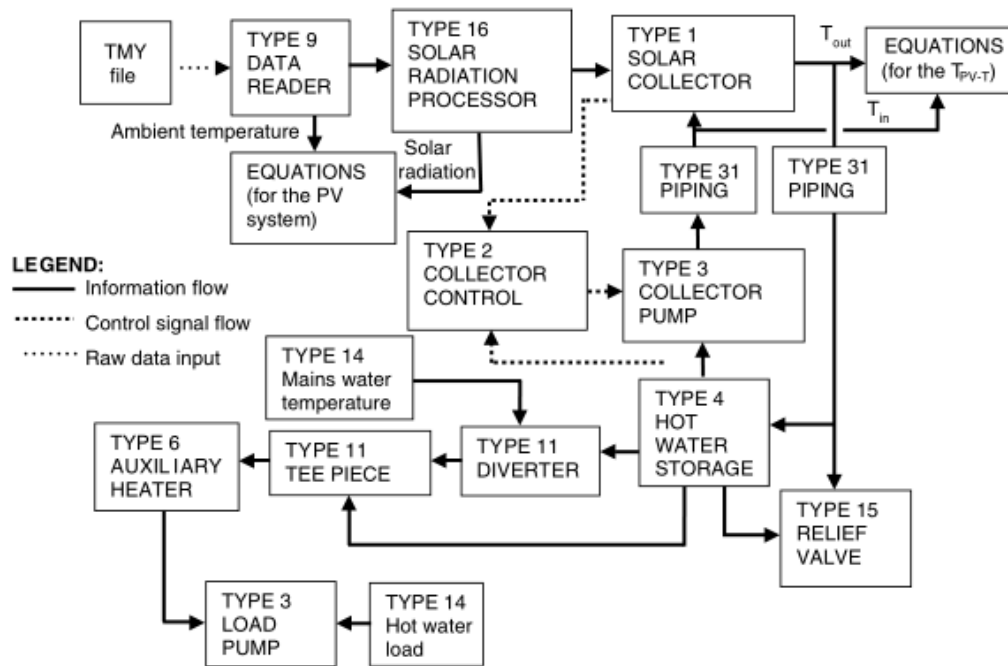


Figure 2.1: Information flow diagram for the large hot water system application (Kalogirou and Tripanagnostopoulos 2006)

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TRNSYS was used to simulate the ideal solar thermal system by using equivalent components from the simulation studio platform. Results that gained from the calculated system models were used as the operating requirements and parameters for the simulation and the simulation was performed for over one-year period. Over one-year period of simulation the temperature and useful energy gain distribution graph shows the bell shape which was expected of a solar energy system (Mbakwe 2016).

Cichy *et al.* (2016) focuses on the detailed analysis of different control concepts of buildings and heating, ventilation and air conditioning (HVAC) engineering in this case study. To simulate thermal and electrical energy flows in buildings dynamically and in detail, it requires a simulation tool. There are numerous programs available for the dynamic thermal modelling of buildings, including EnergyPlus, Modelica, IDA-ICE or TRNSYS. Tools for heating, ventilation and air conditioning (HVAC) design and analysis can be categorized with respect to the problems they are meant to deal with. For this case study, the best simulation tool that can be used is TRNSYS 17 in combination with the TRNSYS 3D-Plugin for Google SketchUp. Figure 2.2 below shows a schematic overview of the used HVAC components. The Building and the heating, ventilation and air conditioning (HVAC) system were modelled in TRNSYS 17.1.
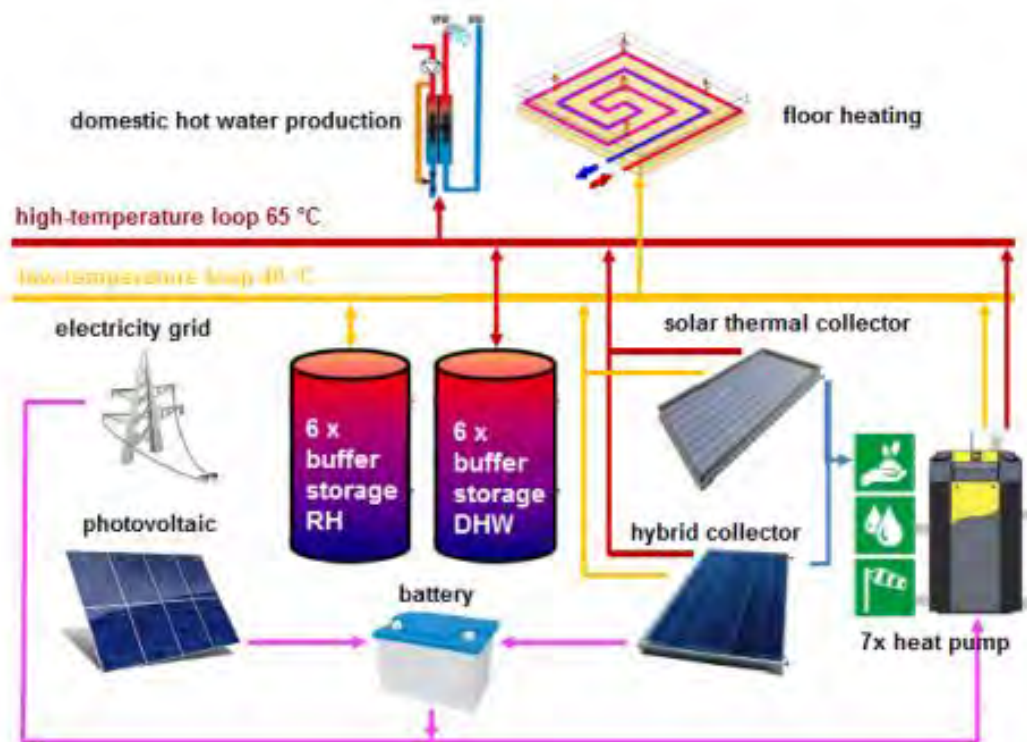
Figure 2.2: Schematic overview HVAC components (Cichy *et al.* 2016)

### 2.2.1.1 Advantages and Disadvantages of TRNSYS

Fuentes *et al.* (2017) states that TRNSYS contains of several components to simulate the daily domestic hot water consumption profiles with timesteps lower than an hour based on different technical standards. To provide performance ratings for complete solar thermal systems, the program applies computer modelling which is TRNSYS. The software adopts an approach where a system is reduced to a set of interconnected subsystems modelled as TYPES (Haurant *et al.* 2015). TRNSYS has the capability of interconnecting system components in any desired manner, solving the system differential equations, and producing information output (Asim and Kanan 2016).

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There are disadvantages by using TRNSYS which are standard input data not available, operational mode checks required, designing and setting up of individual components are tedious and time consuming. As studied by  (Shrivastava *et al.* 2017), advantages of compound equations are not available in the TRNSYS. Defining the connections and keeping all of the inputs and outputs organized became a frightening task for the more advanced projects (Duffy *et al.* 2009).

## 2.2.2  MATLAB/SIMULINK

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment. MATLAB usually uses in math and computation, algorithm development, modelling, simulation, and prototyping, data analysis, exploration, and visualization, scientific and engineering graphics and application development, including graphical user interface building. The MATLAB system consists of five main parts which are the MATLAB language, the MATLAB working environment, handle graphics, the MATLAB mathematical function library and the MATLAB Application Program Interface (API).

Based on Mendaza *et al.* (2013), MATLAB/Simulink was used to carry out the data analysis and the profile generation task. For this case study, to analyse the space heating (SH) and domestic hot water (DHW) consumption data, Statistics Toolbox of MATLAB has been used. According to Mendaza *et al.* (2013) domestic hot water (DHW) is more instantaneous than by nature in its consumption compare to space heating (SH).