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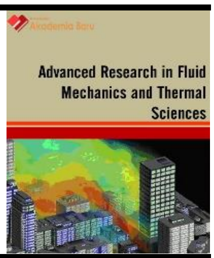


# F-Chart Method for Design Domestic Hot Water Heating System in Ayer Keroh Melaka

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**ABSTRACT**

Renewable energy is an alternative approach of energy supply that meets the needs of the present generations without compromising the ability of future generations to meet their own needs. One type of renewable energy is solar energy. Solar energy systems convert solar energy into useful energy. In designing a solar collector, there are predictable and unpredictable parameters that are considered. Predictable parameters include performance characteristics of collector and mainly concern weather data such as solar radiation, ambient temperature, wind speed, direction, and other parameters is performance characteristics of collectors. This work analysed the use of the f-chart method in design liquid solar heating systems due to its simplicity and ability to estimate the fraction of total heating load supplied by the solar heating system. This method is very commonly used in designing for both active and passive solar heating systems, especially in selecting sizes and type of solar collectors that provide the hot water and heating loads. In this research, the data of the project is analysed to calculate based on the f-chart graph. The results show that the area in Melaka around the vicinity of Ayer Keroh is suitable for the installation of the flat-plate solar collector. The total annual heating load of domestic hot water in Melaka is 9.55 GJ and the annual fraction of the load supplied by solar energy is 78.42% which is suitable for implementation and installation in Ayer Keroh, Melaka.

***Keywords:***
F-chart method, Solar energy, Water heating system



## 1. Introduction

Solar energy is energy produced by the sun in the form of radiant energy to the earth surface. The free and available resources make the sun the most promising option to explore intensively. Since the depletion of non-renewable energy resources such as oil per barrel, liquid petroleum gas (LPG), charcoal and higher demand and supply over the years, the study of the potential of available

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renewable energy resources become vital. This is due to the higher cost of energy and the harmful effect on the environment.

Only a fraction of this energy gets to the earth surface. Solar energy systems convert solar energy into two ways which used thermal and electrical energy [1]. Such systems can either be passive or active systems. According to Okafor and Akubue [2], in order to collect, restore and convert solar energy, the passive system does not require mechanical power to distribute the heat while active system requires mechanical power such as pumps or fans. In 2015, the population in Malaysia is estimated at about 30.7 million. In the next year, the current population is estimated to increase from 30.7 million to an approximation of 31.2 million, which leads to an increase in electricity demand in time being [3].

In this study, the assessment of the solar collector was conducted to produce hot water under low thermal application. The investigation of the system under a hot and humid climate considerably low thus give the motivation to get the possible application range of application. Using the available commercial solar collector helps to determine the current performance which indicates the possible use of the system in Malaysia. Knowing the range and configuration of the solar collector will be beneficial to the designer to estimate the potential of storing the hot water for domestic application.

Proper design of a solar water heating system is important to assure maximum benefit to the user, especially for a large system. Designing a solar water system involves appropriate sizing of different components which are based on predicted solar isolation and hot water demand. There are three general categories for design methods of solar water heating system which are utilizability method, f-chart method, and SOLCOST method.

According to Duffie and Beckman [4], the first category applies to a system in which collector operating temperature is known or can be estimated and critical radiation levels are able to be determined. For example, the utilizability method which falls in the first category is able to obtain the fraction of the total month's radiation that is above the critical level by utilizing an analysis of hourly weather data. The second category includes the correlations of the result of a large number of detailed simulations, for instances the f-Chart method. The third category involves short-cut simulation in which simulations are done using meteorological data for representative days; for example, SOLCOST method.

Besides that, there is another category of design method, which is software as shown in Table 1. They are useful for early design studies. The most popular software programs that are well-known for modelling and simulation are TRNSYS, WATSUN, and Polysun applied in solar energy system modelling and prediction [11].

**Table 1**
Advantages and disadvantages of Simulation program

| Software | Advantages | Disadvantages |
|---|---|---|
| TRNSYS | Interconnecting system components in any desired manner | Advantages of compound equations are not available |
| WATSUN | Allow user to monitor the simulation data file | Hard to use |
| Polysun | Provides catalog which contains characteristic of various components | - |

Recently, there is research work regarding f-chart in Malaysia for this project in Nilai, Negeri Sembilan. There were three flat-plate solar collectors selected in the market and analysed in term of thermal performance of efficiency slope ($F_R U_L$), intercept [$F_R(\tau\alpha)_n$], the ratio of the monthly average to normal incidence transmittance-absorptance product $\left(\frac{(\overline{\tau\alpha})}{(\tau\alpha)_n}\right)$ and area of collector $A_c$ (m²) [4]. This research leads to the output of solar sizing based on the solar irradiance and the efficiency of the solar collector to load which is 88 percent from solar energy [4]. This method was also used in other countries such as Nigeria, Calicut in India, Hyderabad in Telangana, India and Rome [2,19-21].

According to Rosli *et al.,* [6], to determine the thermal efficiency of solar collector system, the $F_R$ parameter is important. The equation below is the basis of the standard test methods [4,5,10];

$$n = F_R \tau \alpha - F_R U_L \left( \frac{T_i - T_a}{G} \right) \tag{1}$$

## 2. Design of the system

### *2.1 F-chart Method*

F-chart method is the most popular solution method for its characteristics being a simple process, user-friendly and precise. F-chart method is developed by Klien and Beckman [4]. F-chart method is used for estimating the annual thermal performance of active heating systems for buildings (using either liquid or air gas the working fluid) where the minimum temperature of energy delivery is near 20$^{\circ}$C.

The F-chart method provides a means for estimating the fraction of a total heating load that will be supplied by solar energy for a given solar heating systems. There are three variables that should be taken in f-chart; primary design variable is collector area; secondary variables are collector types, storage capacity, fluid flow rates, and collector heat exchanger sizes. The resulting correlations give the fraction of the monthly heating load (for space heating and hot water) supplied by solar energy (*f*), as a function of two dimensionless variables; X: ratio of collector losses to heating loads and Y: ratio of absorbed solar radiation to heating loads.

### *2.2 System Works*

Figure 1 shows a standard heating system using liquid heat transfer fluids covered by the f-chart method. This system normally uses water or an antifreeze solution as the collector heat transfer fluid. The collector may heat either air or liquid. If the collector heat transfer fluid is not water, a heat exchanger is used between the collector and the tank. In this system, energy collector loop is transferred from the collector fluid to the preheat storage tank directly or via an external heat exchanger.

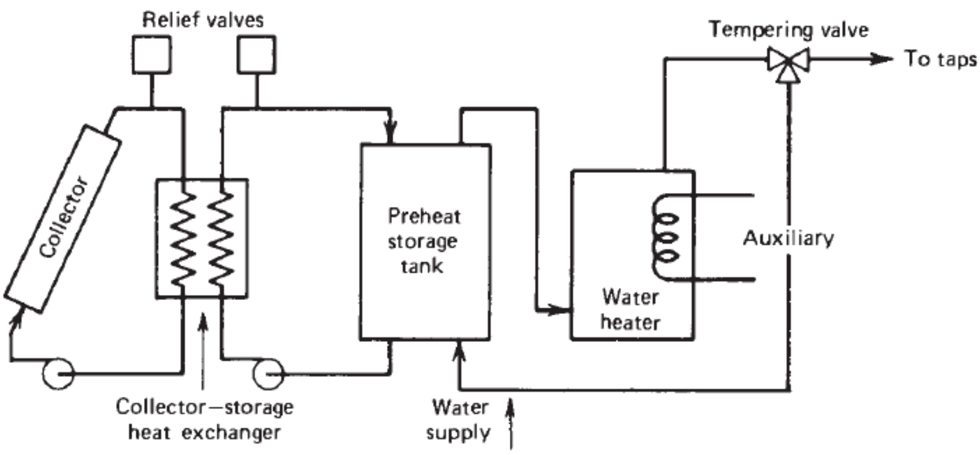


**Fig. 1.** Standard configuration for water heating only [4]

## 3. Methodology
### *3.1 Process Flow for F-Chart Analysis*

Figure 2 show the methodology to determine the f-chart in Ayer Keroh, Melaka. It refers to the yearly date in 2016 which are global irradiance, tilt irradiance and average temperature.

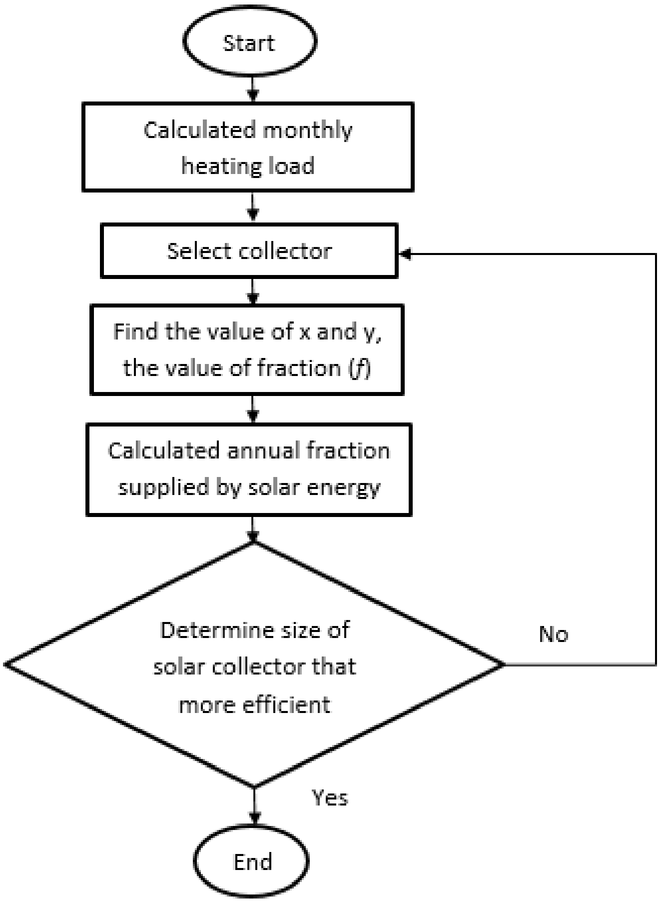


**Fig. 2.** Overall methodology of the analysis

### *3.2 General Information*

F-chart method requires two values to describe the solar collector which is the solar collector thermal performance curve slope ($F_R U_L, W.m^2.°C^{-1}$) and intercept ($F_R(\pi\alpha)_n, \%$). In this study, a flat-plate solar collector was selected to be analysed. The water heating collector characteristics are $F_R U_L$ = 4 W/m$^2$ which refers to the collector efficiency on the top, bottom and edges surface of collector, $F_R(\pi\alpha)_n$= 0.74 and $(\pi\alpha)/(\pi\alpha)_n$= 0.96 and the collector heat exchanger correction factor $F'_R/F_R$ = 0.97 as determined from standard collector tests. A solar heating system is to be designed in Ayer Keroh, Melaka (Latitude of 2.1944° N, Longitude of 102.2491° E, elevation above sea level 6 m). Table 2 and Figure 3 showed the range of variable collectors and the estimation pattern of the performance of selected solar collectors respectively.

**Table 2**
Range of design variables used in developing f-chart for liquid and air systems [4]

| Parameter | Value |
|---|---|
| Transmittance-absorptance product at normal incidence- $(\pi\alpha)_n$ | 0.6 - 0.9 |
| Product of heat removal factor with heat exchanger and collector area - $F'_R A_C$ | 5 – 120 $m^2$ |
| Collector heat loss coefficient - $U_L$ | 2.1 – 8.3 $W/m^2$°C |
| Collector slope from horizontal - β | 30 - 90° |
| Overall energy loss coefficient and area product for a building used in a degree day space heating load - $(UA)_h$ | 83- 667 W/°C |

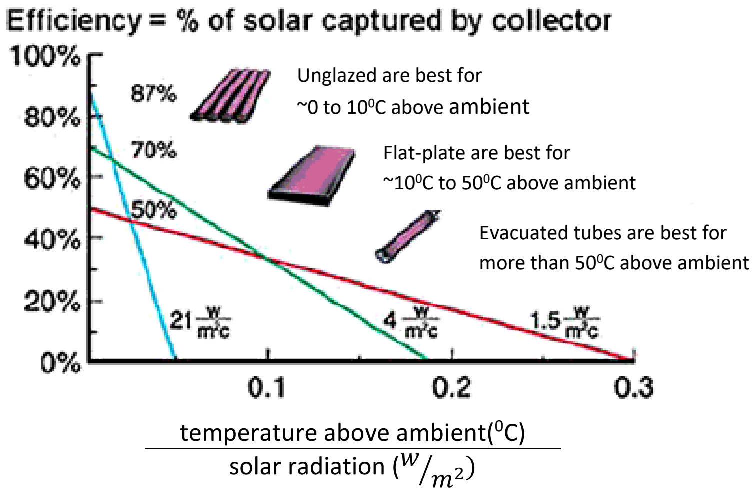


**Fig. 3.** Efficiency of common collector types by Walker [18]

Melaka was chosen because of the solar radiation acceptance by this state is enough for the implementation of the solar collector and design the suitable solar collector area. In addition, an 8MW Kompleks Hijau Solar farm project was started functioning at the end of December 2014. This project is one of the largest solar park installation in Malaysia which will be able to generate approximately 10,120 MWh of clean electricity for average electricity consumption of approximately 1800 typical residential homes in Malaysia [7].

### *3.3 F-chart Calculations Method*

For liquid heating system, the system performance is determined in term of *f* which is the fraction of the total heating load supplied by solar energy. In order to find the monthly and annual performance of solar collector chosen, the calculation is as follows as refers to [4]. The monthly total heating load for hot water (L);

$$L = c_p \rho h_w (T_w - T_m) N \tag{2}$$

The collector losses variables;

$$X = F_R U_L \text{ x } \frac{F'_R}{F_R} \text{ x } (T_{ref} - T_a) \text{ x } \Delta t \text{ x } \frac{A_c}{L} \tag{3}$$

The incident solar variables;

$$Y = F_R(\pi\alpha_n) x \frac{F'_R}{F_R} x \frac{(\pi\alpha)}{(\pi\alpha)_n} x H_T x N x \frac{A_c}{L} \quad (4)$$

The monthly solar fraction, $f$ can be determined from the following relation with X and Y;

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3 \quad (5)$$

The annual load heating supplied by solar energy;

$$F = \frac{\sum f_i L_i}{\sum L_i} \quad (6)$$

## 4. Results

### *4.1 F-chart*

According to Okafor and Akubue [2], the f-Chart method has been validated in two ways. First, the performance predictions of f-Chart have been compared with Transient System Simulation Program (TRNSYS). The standard error between the TRNSYS simulations and the f-Chart results was about 2.5%. Secondly, it had also been compared with experimental data results which are now available since the f-Chart method was developed. They concluded that a good agreement between experimental and predicted performance is obtained for systems having the configurations assumed in the development of the f-Chart method. Other studies have also shown a good agreement between experimental results and the f-Chart predictions. Table 3 summarized the required load provided by the solar thermal system with a size area of 2.06 m$^2$ (by applying the f-chart method).

**Table 3**
Monthly and Annual Performance of Liquid Heating System in Ayer Keroh, Melaka

| Month | $H_T$ (MJ/$m^2$) | $T_a$ (°C) | L (GJ) | X | Y | f | fL (GJ) |
|---|---|---|---|---|---|---|---|
| Jan | 17.83 | 27.78 | 0.8131 | 1.90 | 0.96 | 0.67 | 0.54 |
| Feb | 20.38 | 27.32 | 0.7673 | 1.89 | 1.09 | 0.74 | 0.57 |
| Mar | 24.04 | 28.87 | 0.7961 | 1.85 | 1.33 | 0.87 | 0.69 |
| Apr | 20.21 | 29.46 | 0.7615 | 1.91 | 1.13 | 0.76 | 0.58 |
| May | 18.76 | 29.17 | 0.7914 | 1.91 | 1.04 | 0.71 | 0.56 |
| June | 17.80 | 28.26 | 0.7796 | 1.90 | 0.97 | 0.67 | 0.52 |
| July | 17.87 | 28.02 | 0.8093 | 1.90 | 0.97 | 0.67 | 0.54 |
| Aug | 19.37 | 28.34 | 0.8043 | 1.91 | 1.03 | 0.71 | 0.57 |
| Sep | 19.00 | 28.05 | 0.7828 | 1.90 | 1.07 | 0.73 | 0.57 |
| Oct | 16.74 | 27.75 | 0.8135 | 1.90 | 0.87 | 0.61 | 0.50 |
| Nov | 13.98 | 26.77 | 0.8021 | 1.89 | 0.77 | 0.54 | 0.43 |
| Dec | 14.77 | 26.71 | 0.8297 | 1.89 | 0.76 | 0.53 | 0.44 |
| Total | | | 9.5507 | | | | 6.51 |

By referring to f-chart in Figure 4, the value of f-chart in January is 0.67 as shown above. It shows that the solar collector is capable to provide 67% thermal energy for area of 2.06 m$^2$ based on chosen solar collector characteristics. The highest thermal energy that the solar collector capable to provide is in March with 0.87 while the lowest is in December with 0.53. Roughly, the monthly average daily total solar radiation on tilted surface $H_T$ is between 13.98 to 24.04 MJ/$m^2$.

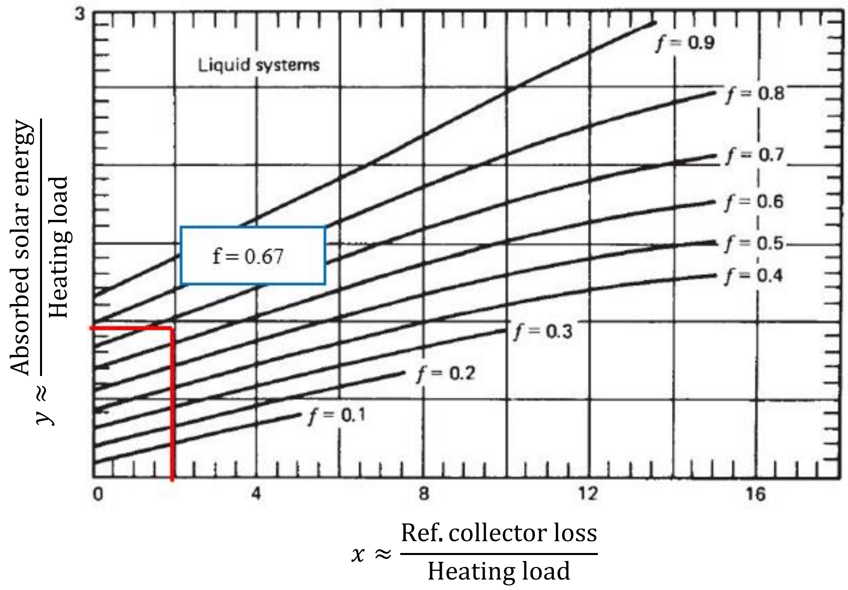


**Fig. 4.** The F-chart for systems using liquid heat transfer and storage media

According to Mekhilef, S. *et al.,* [8], on average, Malaysia receives about 17 MJ/$m^2$ of solar radiation per day. Over time, solar radiation increases to around 20 MJ/$m^2$. Furthermore, throughout the year, the temperature range is between 22°C and 33°C while average daily temperature is 26.5°C. Nowadays, in September 2018, the maximum and minimum temperature in Melaka is 31.0°C and 27°C while the average temperature is 29°C [17].

From Table 3, the fraction of the annual heating load supplied by solar energy;

$$F = \frac{6.51}{9.5504} = 68.16\%$$

Table 4 showed that the annual load supplied by solar energy after size correction is 78.42%. It shows that the efficiency of solar collector in absorbing the solar energy to supply to the consumer is 78.42% after increasing the area of solar collector. In time being, Malaysia receives about 17 $\mathrm{MJ/\ m^2}$ of solar radiation per day [8]. Besides that, Malaysia is located at the equatorial region with an average solar radiation of 400 - 600 MJ/$m^2$ per month and abundant sunshine for about 12 hours per day [8]. In addition, Malaysia’s climate has relatively high levels of temperature and humidity. This factors could increase the total received solar radiation along with the large surface area of the solar collector.

From Table 4, the new fraction of the annual heating load supplied by solar energy;

$$F = \frac{7.49}{9.5507} = 78.42\%$$

**Table 4**
The annual fraction of the load supplied by a collector size correction from 2.06 m$^2$ to 2.50 m$^2$

| Month | L (GJ) | X | Y | f | fL |
|---|---|---|---|---|---|
| January | 0.8131 | 2.1 | 1.17 | 0.76 | 0.62 |
| February | 0.7673 | 2.30 | 1.32 | 0.84 | 0.64 |
| March | 0.7961 | 2.32 | 1.61 | 0.97 | 0.77 |
| April | 0.7615 | 2.33 | 1.37 | 0.86 | 0.65 |
| May | 0.7914 | 2.33 | 1.27 | 0.81 | 0.64 |
| June | 0.7796 | 2.31 | 1.18 | 0.76 | 0.59 |
| July | 0.8093 | 2.31 | 1.18 | 0.76 | 0.62 |
| August | 0.8043 | 2.31 | 1.24 | 0.88 | 0.71 |
| September | 0.7828 | 2.31 | 1.30 | 0.83 | 0.65 |
| October | 0.8135 | 2.30 | 1.09 | 0.72 | 0.59 |
| November | 0.8021 | 2.30 | 0.93 | 0.62 | 0.50 |
| December | 0.8297 | 2.29 | 0.92 | 0.62 | 0.51 |
| Total | 9.5507 | | | | 7.49 |

## 5. Conclusion

F-chart method provides a means of easily determining the thermal performance of solar energy heating systems (using either liquid or air as a working fluid). This work had analysed the use of f-Chart method in designing liquid solar heating systems due to its simplicity and ability to estimate the fraction of total heating load supplied by solar heating system. According to this method, the *f* value is calculated monthly and annually by two dimensionless variables as X and Y. The meteorological data such as average solar radiation, ambient temperature and tap water changing between 13.98 and 24.04 MJ/m$^2$. As a conclusion, based on 2016 temperature data in Ayer Keroh, Melaka and the results in Table 3, the annual load that supplied by solar energy for the chosen collector is 68.16%. The results show that Ayer Keroh have the average monthly heating load of domestic hot water in Melaka which is 0.80 GJ. Lastly, the total annual heating load of domestic hot water in Melaka is 9.55 GJ and the annual fraction of the load supplied by a collector size correction from 2.06 m$^2$ to 2.50 m$^2$ is 78.42% based on the solar collector chosen. Thus, it is suitable to be implemented and installed in Ayer Keroh, Melaka. A normal efficiency for flat-plate solar collector is around 70% based on ambient temperature categories in f-Chart.

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## References
[1] Rosli, Mohd Afzanizam Mohd, Yap Joon Ping, Suhaimi Misha, Mohd Zaid Akop, Kamaruzzaman Sopian, Sohif Mat, Ali Najah Al-Shamani, and Muhammad Asraf Saruni. "Simulation Study of Computational Fluid Dynamics on Photovoltaic Thermal Water Collector with Different Designs of Absorber Tube." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 52, no. 1 (2018): 12-22.
[2] Okafor, I. F., and G. Akubue. "F-chart method for designing solar thermal water heating systems." *International Journal of Scientific & Engineering Research* 3, no. 9 (2012).
[3] United Nations, Department of Economic and Social Affairs, Population Division. "Worldometers." (2018): 1–4.
[4] Duffie, John A., and William A. Beckman. *Solar engineering of thermal processes*. John Wiley & Sons, 2013.
[5] Rahman, Fatiha Binti Abdul, Mohd Afzanizam Bin Mohd Rosli and Danial Shafiq Bin Mohd Zaki. "Designing a Solar Collector Using F-Chart Method for Domestic Hot Water in Malaysia." (2018).

[6] Rosli, M. A. M., S. Misha, Kamaruzzaman Sopian, Sohif Mat, M. Yusof Sulaiman, and E. Salleh. "Parametric analysis on heat removal factor for a flat plate solar collector of serpentine tube." *World Applied Sciences Journal* 29, no. 2 (2014): 184-187.
[7] Yingli Solar. "8Mw Kompleks Hijau Solar Farm." (2017).
[8] Mekhilef, S., A. Safari, W. E. S. Mustaffa, R. Saidur, R. Omar, and M. A. A. Younis. "Solar energy in Malaysia: current state and prospects." *Renewable and Sustainable Energy Reviews* 16, no. 1 (2012): 386-396.
[9] Sujith, K. "Design Of Active Solar Water Heating System Using F-Chart Method." *Energy Engineering and Management, Department of mechanical engineering National Institute of Technology, Calicut, Kerala, india-673601* (2013).
[10] Caretto, Larry. "The F-Chart Method for Solar Collectors Heat Exchangers Compact Heat Exchangers III Shell-and-Tube Exchanger ME 483 Alternative Energy Engineering II F-Chart Method Shell and Tube Passes II Shell and Tube Passes III Effectiveness-NTU Meth." (2010): 1–10.
[11] Kalogirou, Soteris A. *Solar energy engineering: processes and systems*. Academic Press, 2013.
[12] Kocer, Abdulkadir, Ibrahim Atmaca, and Can Ertekin. "A comparison of flat plate and evacuated tube solar collectors with f-chart method." *ISI BILIMI VE TEKNIGI DERGISI-JOURNAL OF THERMAL SCIENCE AND TECHNOLOGY* 35, no. 1 (2015): 77-86.
[13] Agbo, S. N., and G. O. Unachukwu. "Design and Performance Features of a Domestic Thermosyphon Solar Water Heater for an Average-Sized Family in Nsukka Urban." *Trends in Applied Sciences Research* 2, no. 3 (2007): 224-230.
[14] The Green Mechanics. "Annual solar radiations in different cities in Malaysia." (2003).
[15] Klevinskis, Andrius, and Vytautas Bučinskas. "Analysis of a flat-plate solar collector/Plokščiojo saulės kolektoriaus tyrimas." *Mokslas–Lietuvos ateitis/Science–Future of Lithuania* 3, no. 6 (2011): 39-43.
[16] Jamil, Basharat, Abid T. Siddiqui, and Naiem Akhtar. "Estimation of solar radiation and optimum tilt angles for south-facing surfaces in Humid Subtropical Climatic Region of India." *Engineering Science and Technology, an International Journal* 19, no. 4 (2016): 1826-1835.
[17] Online, World Weather. "Melaka Monthly Climate Averages." (2018).
[18] Walker, Andy. "Whole Building Design Guide (Solar Water Heating)." (2016):11-16.
[19] Sujith, K. "Design Of Active Solar Water Heating System Using F-Chart Method." *Energy Engineering and Management, Department of mechanical engineering National Institute of Technology, Calicut, Kerala, india-673601* (2013).
[20] Deepika, Dasari, M. Ahmed Ali Baig, A. Raji Reddy, and D. Maneaih. "Utilization of f-Chart Method for Designing Solar Thermal Heating System."
[21] Poles, S, and M Venturin. n.d. "Design and Modelling The Φ - F Chart Method for Active Solar."