Feasibility Study of a Solar Flat Plate Collector for Domestic and Commercial Applications under Iraq Climate

H. K. Jobair, O. I. Abdullah, Z. M. Atyia
University of Baghdad, College of Engineering, Energy Department, Baghdad-Aljadria 47024, Iraq

Husseinkhalaf82@gmail.com

Abstract. Experimental study had been accomplished to evaluate the performance of flat plate collector according to Iraq climate to find the practical benefit and to transform the idea into reality and to apply it for domestically and commercial field. The study had been achieved for a typical flat plate collector. The dimensions of the flat plate collector, solar intensity, ambient temperature and angles relating to this study have been practically applied and all of these information mentioned in this study. This study approved the feasibility of using the hot water as heating purposes for domestic and commercial applications instead of using the electricity for heating the water. This method will reduce the consumption of the electric power obtained from the national network. The reduction of consumption for the national network electric power is approved by comparing three models of houses that is using the electric power for heating water with the same houses models which are using a flat plate collector for heating purposes.

1. Introduction
Global warming, the greenhouse effect, climatic change, ozone layer depletion and acid rain are all accidental consequences of the extensive fossil fuel exploitation in almost all human activities. These phenomena are caused by the emission of carbon dioxide into the atmosphere. All these phenomena and causes that are harmful to the environment and reflected on human life led to the opening of the mind of humans to how to deal with other types of energy-friendly environment and how to exploit them in a way that serves humanity and the lack of impact on the environment. Among the environmentally friendly types of energy, solar energy is the most important source of renewable energy sources due to the abundance of energy obtained from the sun. Since Iraq receives a large amount of solar energy, it is necessary to use this energy to serve the region rather than the traditional sources of energy that Iraq relies on to save energy for humans like oil. One of the most important applications that use solar energy as an energy source is the flat plate collector. Flat plate collector is the simplest and one of the cheapest means of collecting solar energy for use in system that require thermal energy at low temperature (< 100°C). Flat plate collector requires a minimum amount of material per square meter of collector and thus provides for the possibility of lower costs. Domestic hot water is the second-highest energy cost in the typical household in all over the world. In fact, for some homes it can be the highest energy expenditure. Solar water heating can reduce domestic water heating costs by as much as 70%. It is easy to install and almost maintenance free.
Yousef and Adam [1] investigated the effect of several parameters theoretically to the performance of a flat plate collector. Mass flow rate, flow channel depth and collector length on the system thermal performance and pressure drop through the collector with and without porous medium had been studied for a single and double flow rate of a flat plate collector. The results showed that at the same configuration and parameters for both single and double flow rate, the efficiency of the thermal system increases by 10-12% in double flow mode than single flow due to the increased of heat removal, and increase by 8% after using porous medium in the lower channel as a result of the increase of heat transfer area. The study also showed that the pressure drop increased and all collectors show improved efficiency when the collector operates at relatively high flow rates, and at relatively low collector temperature rise since the collector losses will be less in low temperature difference. Amrutkar et al. [2] evaluated the performance of FPC with different geometric absorber configuration. This study have been accomplished under laboratory conditions (as per IS standard available for the flat plate collector testing). The results of this study showed that with the same collector space higher thermal efficiency or higher water temperature can be obtained. Thus, cost of the FPC can be further bringing down by enhancing the collector efficiency. Chaji et al. [3] fabricated and tested a small flat plate solar collector (FPSC). The study had been achieved by using nanoparticle concentrations of TiO in water as base fluid. Different flow rates and concentration ratios was employed in this study. Ameen et al. [4] investigated experimental and numerical the heat transfer enhancement of flat plat collector (FPC) using three types of twisted tapes (single twisted tape (ST), double twisted tape (DT) and mixed twisted tape (SDT)) then compared with plain tube with twist ratios (TR=2). The study was considered under fully developed turbulent flow with solar radiation heat gain is changing with time. Experimental study showed that the DT are more efficient than ST and SDT and the temperature of outlet water from mixed twisted tape collector is higher than the other type of plain tube collector by 10°C. Numerical analysis of this study was base on finite volume numerical techniques to solve the governing partial differential equations in three dimensions, using ANSYS FLUENT commercial CFD software. The comparison between the experimental and numerical results shows a high agreement. Mankhi et al. [5] designed a number of solar systems that are fit for work in the atmosphere of the city of Basra. The study demonstrated the feasibility of obtaining temperatures in these systems may sometimes up to 90 degrees Celsius even in the coldest days. Basim et al. [6] investigated the experimentally and numerically the effect (ZnO-water) nano fluid on heat transfer flat plate solar collector. The experiment part is conducted in Karbala with the latitude of 32.6 0 N. The numerical part is applied by ANSYS 15software. a good agreement between the experimental and CFD results for outlet temperatures where the maximum error was (8.4%).

2. Solar Radiation in Iraq

The monthly average of solar radiation measured in Baghdad city, reported by NASA, is shown in figure 1. The annual averaged of energy received daily from the sun in Iraq ranges between 4.5 – 5.4 KWh/m². For horizontal surface, more insulation is available during summer rather than winter. If the surface is tilted, the available insolation can be increased due to focusing of the incident radiation to the optical area.
Because of geographical location and favourable climatic conditions, most parts of Iraq receive very high solar insolation about 2000 KWh/m²/year. It is therefore necessary to go to the solar energy options to reduce the consumption of fossil fuel. Therefore, there is the possibility for converting a proportion of that solar energy into useful heat and electricity and subsequently solar thermal technology is commonly used to harness the sun's energy.

3. Collector Formulation

The first law of thermodynamics plays an important role in the performance calculations of the solar flat plate collector. Energy balance applied to a flat plate collector for computing the useful energy absorbed. For a simple flat plate collector computations, several assumptions which is acceptable for evaluating the energy gain. Steady state energy transfer condition was assumed and the energy exchanging occurred for a collector area Ac. The useful energy absorbed in flat plate collector is the difference between the absorbed solar radiation and thermal losses [8]:

Useful energy gain \( Q_u \) = energy absorbed by the collector – heat loss to the surroundings,

\[
Q_u = A_c [S - U_L (T_i - T_a)]
\]  

where \( A_c \) represented Collector area in m², \( S \) is absorbed solar radiation in J/m², \( U_L \) is heat transfer loss coefficient in J/m²°C, \( T_i \) is the mean absorber plate temperature in °C and \( T_a \) is the ambient temperature in °C. Equation (1) is an extremely useful equation and applies to essentially all flat-plate collectors. To improve the performance of solar collector it is necessary either to reduce the overall energy loss coefficient or reduce area from which energy is lost. That is the maximum possible useful energy gain (heat transfer) in a solar collector occurs when the whole collector is at the inlet fluid temperature. Heat losses to the surroundings are then at a minimum. The above equation is correct and applicable if the actual useful energy gain of the collector is equal to the useful gain, which is mean that the heat removal factor \( F_R \) is unity. In equation 1, \( S \) represents the absorbed radiation and it is equal to:

Figure 1. Monthly averaged insolation incident for year 2016 on a horizontal surface in Baghdad, adopted [7].
In equation 2, \((1 + \cos \beta / 2)\) and \((1 - \cos \beta / 2)\) are the view factors from the collector to the sky and from the collector to the ground, respectively. \(\beta\) represents a flat plate collector tilt angle from the horizontal. The subscripts \((b, d, g)\) represent beam, diffuse, and ground, respectively. \(\tau \alpha\) is transmittance and absorption product. \(R_b\) is the ratio of beam radiation on the tilted surface to that on a horizontal surface at any time. \(\rho_g\) represents the ground reflectance. When measurements of incident solar radiation \(I_t\) are available, instead of equation (2), the following relation can be used [9]:

\[
S = (\tau \alpha)_{av} I_t 
\]

(3)

\((\tau \alpha)_{av}\) can be obtained from,

\[
(\tau \alpha)_{av} = 0.96 (\tau \alpha)_{b} \]

(4)

The overall heat loss coefficient is a complicated function of the collector construction and its operating conditions, given by the following expression. In equation (1) \(U_L\) is the collector overall loss coefficient and it is equal to the sum of the top, bottom, and edge loss coefficients.

\[
U_L = U_{top} + U_{bottom} + U_{edge} 
\]

(5)

Equation 5 represents the overall loss coefficient \(U_L\). Energy diagram of typical flat collector is shown in figure 2. 92% of the total sunshine reaches to the copper absorber, 8% of the total sunshine is reflected from glass, 5% of the sunshine is emitted from the panel, 12% is lost through convection and conduction.
The basic method of measuring collector performance is to expose the operating collector to solar radiation and measure the fluid inlet and outlet temperatures and the fluid flow rate. The useful gain is:

\[ Q_u = A_c [S - U_L (T_i - T_a)] = \dot{m}C_p(T_o - T_i) \]  

(6)

Where \( \dot{m} \) is mass flow rate of working fluid, \( C_p \) is specific heat of working fluid and \( T_o, T_i \) represent outlet and inlet temperature of the working fluid, respectively. The instantaneous efficiency can be defined as

\[ \eta = \frac{\dot{m}C_p(T_o - T_i)}{A_c I_t} \]  

(7)

\( I_t \) represents the total incident radiation to the flat plate collector.

4. Orientation of Flat Plate Collector

For maximizing the performance of flat plate collector, they should be orientated and tilted properly. The collectors should be oriented directly toward the equator, facing south in the Northern Hemisphere and north in the Southern Hemisphere. The optimum tilt angle of the collector is equal to the latitude of the location, with angle variations of (10° to 15°) more or less, depending on the application [9]. If the application is solar cooling, then the optimum angle is latitude (-10°) so that the sun will be perpendicular to the collector during summertime, when the energy will be mostly required. If the application is space heating, then the optimal angle is latitude (+10°); whereas for annual hot water production, it is latitude (+5°), to have relatively better performance during wintertime, when hot water is mostly required.

\[ H_G = H_b \frac{\sin(\alpha_a + \beta)}{\sin\alpha_a} + H_d \]  

(8)

Where \( H_G \) is the monthly average of the global radiation in kWh/m², \( H_b, H_d \) are beam and diffuse monthly average solar radiation respectively in kWh/m². \( \alpha_a \) is the monthly average altitude angle at noon. The total flux falling on the collector over the year is obtained by summing over all months,

\[ H_G = \sum_{i=1}^{12} H_b \frac{\sin(\alpha_a + \beta)}{\sin\alpha_a} + H_d \]  

(9)

For this annual flux to be a maximum, it can be shown that the optimum tilt angle \( \beta \) is given by:

\[ \beta_{opt} = \tan^{-1} \left[ \frac{\sum_{i=1}^{12} H_b \tan(\delta - \theta)}{\sum_{i=1}^{12} H_b} \right] \]  

(10)

Where \( \delta \) is declination angle which is the angle made by the line joining the center of the sun and the earth with its projection on the equatorial plane, \( \theta \) is the latitude of the location (degree). The optimum tilt angle would be different if the nature of the energy demand is different. For example, for an application like space heating, demand may be high in the winter months of November, December, January and February. On the other hand, if solar energy were to be used for running an absorption refrigeration plant, the duty would be highest in months like May, June, July and August have high ambient temperature. In such case, it would be obviously be desirable to use a tilt greater than the latitude for wintertime applications and the reverse for the summer applications.
### Table 1. Solar angles of flat plate collector in Baghdad city for year 2016

| Month | $H_b$ (kWh/m$^2$) | $\delta$ (Degree) | $\phi - \delta$ (Degree) | $H_b \tan(\phi - \delta)$ (kWh/m$^2$) | $\beta_{opt.}$ (Degree) |
|-------|------------------|-------------------|-------------------------|---------------------------------|---------------------|
| Jan.  | 2.96             | -20.7             | 54.63                   | 4.078                           | 54.02               |
| Feb.  | 4.03             | -12.3             | 45.63                   | 4.119                           | 45.62               |
| Mar.  | 4.98             | -1.8              | 35.13                   | 3.503                           | 35.12               |
| Apr.  | 5.39             | 9.7               | 23.63                   | 2.358                           | 23.62               |
| May   | 6.48             | 18.8              | 14.53                   | 1.679                           | 14.52               |
| Jun.  | 7.56             | 23.0              | 10.33                   | 1.377                           | 10.32               |
| Jul.  | 7.00             | 21.2              | 12.13                   | 1.504                           | 12.12               |
| Aug.  | 6.71             | 13.7              | 19.63                   | 2.393                           | 30.23               |
| Sep.  | 5.55             | 3.09              | 30.24                   | 3.235                           | 30.23               |
| Oct.  | 3.98             | -8.45             | 41.78                   | 3.556                           | 41.77               |
| Nov.  | 2.98             | -18.1             | 51.43                   | 3.736                           | 51.44               |
| Dec.  | 2.62             | -22.8             | 56.13                   | 3.903                           | 56.12               |
| $\Sigma$ | 60.24         |                  | 35.441                 |                                | $\beta_{opt.}$ Annualy: 32.87 |

### Table 2. Specification of flat plate collector

| Specification                              | Value |
|--------------------------------------------|-------|
| Length of the absorber plate, L [m]        | 2m    |
| Thermal conductivity of insulating material | 0.055 W/m.k |
| Width of the absorber plate, W [m]         | 1m    |
| Density of insulating material              | 200 Kg/m$^3$ |
| Plate thickness                             | 0.005m |
| Material of collector tray                  | mild steel |
| Material of absorber plate                 | Copper |
| Thermal conductivity of collector tray      | 53.6W/m.k |
| Glass cover transmissivity                 | 0.92  |
| Density of collector tray                  | 7833 Kg/m$^3$ |
| Tilt angle of collector                     | 33°   |
| Specific heat of fluid                     | 4200 J/Kg.k |

### Table 3. Experimental results of a flat plate collector

| Time (hr) | $I_r$ (w/m$^2$) | $T_i$ (°C) | $T_o$ (°C) | $\dot{m}$ (kg/s) | $\eta$ |
|-----------|----------------|------------|------------|------------------|-------|
| 10:00 AM  | 900            | 16         | 29         | 0.0157           | 0.474 |
| 11:00 AM  | 1000           | 21         | 39         | 0.0157           | 0.591 |
| 12:00 PM  | 1200           | 32         | 59         | 0.0157           | 0.739 |
| 1:00 PM   | 1150           | 40         | 62         | 0.0179           | 0.716 |
| 2:00 PM   | 1050           | 47         | 66         | 0.0183           | 0.68  |

5. Experiment Analysis of Flat Plate Collector

This section presents the details of the experimental work using a typical flat plate collector installed in Baghdad city. Table 2 gives the dimensions of the flat plate collector and all the relevant properties. Table 3 lists the measured values of the incident solar intensity, inlet temperature, outlet temperature, mass flow rate and efficiency of flat plate collector according to Iraq climate on 4th of May 2016.
6. Results and Discussions
The discussion consists of two parts, the first part reveals a brief results of the measurements obtained from the experimental work, which is explained in figures 3 and 4. Figure 3 represents the variation of the flat plate collector efficiency with the local time. The value of the efficiency starts to increase during of time proceeding. It reaches the maximum value at the midday, then begins to fall. This is because of the decreasing in the incident solar radiation that strikes the flat plate collector.

This decreasing in the incident solar radiation striking the flat plate collector appears in figure 4, which represents the variation of incident solar radiation with respect to time. The obtained heat gain in flat plate collector having the same pattern of incident flat plate collector, but in less values.

The second part of discussion presents the Statistics derived from the use of solar water heating instead of electrical heating to determine the obtained economic feasibility. Table 4 shows the fuel used based on economic surveys related to the availability of household fuel for various purposes. The proper design and implementation of buildings, the use of efficient appliances and energy systems improve the performance of buildings. In addition, the rationalization of energy consumption and the improvement of the efficiency of use in the building sector depend on the procedures and actions of the users of these buildings and the management of energy in them, hence the importance of finding suitable opportunities for rationalizing energy consumption and improving the efficiency of its use in buildings. To find the actual benefit from the use of solar collectors and compensate them for devices used to heat water with electricity. Three models were taken for household consumption and how to distribute consumption according to the device used. The models were putted according to the classification of the Ministry of Electricity in Iraq [12].

In order to know the amount of electricity consumed to all of country. We must know the population of Iraq. The last census was recorded indicating that the population of Iraq almost (37 880 000) [13]. So the consumption is equal to approximately (37 880 000) × (0.0017×10^6) = (6.4×10^10 MWh). By making some assumptions to find the percentage of consumption the electric power for heating water demands. The assumptions were based on dividing the population into families with different members. Each family lives in a separate house. Three types of families have been adopted. A family of five people, a family of six people, and the last assumption is a family of seven people. Iraq families
were divided into three groups as mentioned below. Each family assumed to be living in each three models (see Tables 5-7) of houses to find the value of electricity consumption by heating water. Table 8 represented the statistic of consumption the electric power by heating water. This statistic is Acceptable to a high extent with an error percentage of (±2%).

Table 8 shows the quantity of electric power which was consumed to heat water in three selected models of houses in Iraq for one hour. The average heat gain from flat plate collector is roughly to (1301 w.h). Table 9 represents calculations about the reduction in consumption of electrical power from the national network.

From table 9, flat plate collector reduces the consumptions of electrical power of heating water from 100%. Which means there is no ever consumptions of electrical power to heating water, to 25% which represents the electrical power consumed to heat the water reduced by 25% when using flat plate collector for each house.

**Figure 4.** Variation of incident solar radiation on the collector and heat gain with local time

| Consumption Type | Electricity | Gas  | Kerosene | Others | Total |
|------------------|-------------|------|----------|--------|-------|
| Cooking          | 2.2         | 82.7 | 11.2     | 3.9    | 100   |
| Lighting         | 98.4        | 0.1  | 1.5      | -      | 100   |
| Heating          | 13.9        | 0.9  | 81.0     | 4.2    | 100   |
| Water heating    | 60.2        | 11.3 | 23.3     | 5.3    | 100   |

**Table 4.** Distribution of resources domestic consumption % [11]
Table 5. Model (1) of calculation the electricity according to the domestic consumption

| Elec. Instruments | Quantity | Elec. Power (W) | Average daily operating hours | Daily consumption (kWh) | Monthly consumption (kWh) (%) |
|-------------------|----------|-----------------|-------------------------------|-------------------------|-------------------------------|
| 1 Fluorescent lamp | 5        | 40              | 8                             | 1.6                     | 48                            | 9.6                          |
| 2 Flash lamp       | 5        | 60              | 8                             | 2.4                     | 72                            |
| 3 Refrigerator     | 1        | 200             | 8                             | 1.6                     | 48                            | 10.6                         |
| 4 frozen           | 1        | 350             | 8                             | 2.8                     | 84                            |
| 5 TV               | 1        | 400             | 8                             | 3.2                     | 96                            |
| 6 Radio            | 1        | 60              | 2                             | 0.12                    | 3.6                           |
| 7 Washing machine  | 1        | 200             | 1                             | 0.2                     | 6                             | 10                           |
| 8 Iron             | 1        | 1250            | 0.5                           | 0.625                   | 18.75                         |
| 9 Fan              | 5        | 100             | 10                            | 5                       | 150                           | 26.4                         |
| 10 Air cooler      | 2        | 300             | 10                            | 6                       | 180                           | 7                            |
| 11 Water heater    | 1        | 3000            | 6                             | 18                      | 540                           | 43.3                         |
|                    |          |                 |                               |                         | Total                         | 41.545                       | 1246.35                      | 100                          |

Table 6. Model (2) of calculation the electricity according to the domestic consumption

| Elec. Instruments | Quantity | Elec. Power (W) | Average daily operating hours | Daily consumption (kWh) | Monthly consumption (kWh) (%) |
|-------------------|----------|-----------------|-------------------------------|-------------------------|-------------------------------|
| 1 Fluorescent lamp | 6        | 40              | 8                             | 1.92                    | 57.6                          | 6.6                          |
| 2 Flash lamp       | 6        | 60              | 8                             | 2.88                    | 86.4                          |
| 3 Refrigerator     | 2        | 200             | 8                             | 3.2                     | 96                            | 8.2                          |
| 4 frozen           | 1        | 350             | 8                             | 2.8                     | 84                            |
| 5 TV               | 2        | 400             | 8                             | 6.4                     | 192                           |
| 6 Radio            | 1        | 60              | 2                             | 0.12                    | 3.6                           |
| 7 Washing machine  | 1        | 200             | 1                             | 0.2                     | 6                             | 10.9                         |
| 8 Iron             | 1        | 1250            | 1                             | 1.250                   | 37.5                          |
| 9 Fan              | 6        | 100             | 10                            | 6                       | 180                           | 49.5                         |
| 10 Air cooler      | 2        | 300             | 10                            | 6                       | 180                           |
| 11 Air Conditioner | 1        | 3000            | 8                             | 24.0                    | 720                           |
| 12 Water heater    | 1        | 3000            | 6                             | 18                      | 540                           | 24.7                         |
|                    |          |                 |                               |                         | Total                         | 72.77                        | 2183.1                       | 100                          |
Table 7. Model (3) of calculation the electricity according to the domestic consumption

| Elec. Instruments | Quantity | Elec. Power (W) | Average daily operating hours | Daily consumption (kWh) | Monthly consumption (kWh) | (%) |
|-------------------|----------|----------------|-------------------------------|-------------------------|---------------------------|-----|
| 1 Fluorescent lamp | 8        | 40             | 8                            | 2.56                    | 76.8                      | 5.2 |
| 2 Flash lamp      | 8        | 60             | 8                            | 4.84                    | 115.2                     |     |
| 3 Refrigerator    | 2        | 200            | 8                            | 3.2                     | 96                        | 7.1 |
| 4 frozen          | 2        | 350            | 8                            | 5.6                     | 168                       |     |
| 5 TV              | 2        | 400            | 8                            | 6.4                     | 192                       |     |
| 6 Radio           | 1        | 60             | 2                            | 0.12                    | 3                         |     |
| 7 Washing machine | 1        | 200            | 1                            | 2.5                     | 75                        | 8.3 |
| 8 Iron            | 1        | 1250           | 1                            | 1.25                    | 37.5                      |     |
| 9 Fan             | 6        | 100            | 10                           | 6                       | 180                       |     |
| 10 Air cooler     | 1        | 300            | 8                            | 2.4                     | 72                        | 64.9|
| 11 Air conditioner| 3        | 3000           | 8                            | 72                      | 2160                      |     |
| 12 Water heater   | 1        | 3000           | 6                            | 18                      | 540                       | 14.5|

Total of consumption: 123.87 kWh

Table 8. Statistic of consumption the electric power with typical houses models

| Number of houses | Power consumptions model (1) | Power consumptions model (2) | Power consumptions model (3) |
|------------------|------------------------------|------------------------------|------------------------------|
| Family of five people | 7576000                      | 3680.5                       | 2099.5                       | 1232.5                      |
| Family of six people | 6313333                      | 4416.6                       | 2519.4                       | 1479                        |
| Family of seven people | 5411428                     | 5152.7                       | 2939.3                       | 1725.5                      |

Table 9. Percentage reduction in consumption of electrical national network

| Number of houses | Reduction % in Elec. consumption, model (1) | Reduction % in Elec. consumption, model (2) | Reduction % in Elec. consumption, model (3) |
|------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|
| 7576000          | 35%                                         | 62%                                         | 100%                                        |
| 6313333          | 29%                                         | 52%                                         | 88%                                         |
| 5411428          | 25%                                         | 44%                                         | 75%                                         |

7. Conclusions
Experimental study supported by a numerical calculation had been accomplished to determine the economical feasibility of using flat plate collector technique. The study assumed there is a singular flat plate collector for each house in Iraq. The population were divided into three different models of houses, different in terms of electricity consumption and the consumption of electricity to heat the water. By using these assumptions, the electrical power consumptions appear to be decreased by a
(25% to 35%) from the total electric power consumptions in the case of using the electric power for heating water. The study had been achieved on 4th of May 2016. This month have the same properties for several months. This study could be achieved in June, July, August, September and April. By using this technique with these months, the consumption of electrical heating will be decreased by a large amount and this is helps to store electrical energy for using in another useful work.

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