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Influence of the auxiliary system in the determination of the optimal collecting areas for domestic solar heating installation

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Abstract

The purpose of this work is to study the influence of the auxiliary system on the collector of a solar water heater installation of a school canteen. The canteen serves 200 meals per day and is built on an area of 40 m2 located in the city of Algiers. A mathematical model was derived for the studied system and a Matlab code was developed to determine the solar fraction by the F-Chart method. The solar fraction is directly related to the auxiliary energy; so we can calculate the corresponding surface of the collector field. The obtained results demonstrate that more the implantation space for solar collectors is big the more the collector field big and therefore the use of the energy of the auxiliary system is minimal or even null beyond a certain surface.

Keywords: *Auxiliary system, collector field, school canteen, F-chart method, Matlab code*

1- Introduction

The water heating consumes a significant amount of energy that could be replaced with free and abundant solar energy. In Algeria growth for solar water heaters installations is very low; hence the need to target all public institutions. The purpose of this article is to study a solar water heater installation for a school canteen in Algiers. The school has 200 students who all are entitled to a meal at 12pm. Assuming, an average hot water requirement of 5 l / meal [1], the daily needs are of 1,000 liters. Therefore, the installation has a storage tank of 1500 liters for which the loss coefficient is of 7.5 W / C [2], with a heat exchanger immersed inside it with an efficiency of 0.7 [3]. The used collectors are produced in Algeria with a surface of 2 m^2, an estimated optical performance of 0.6 and a coefficient of total losses of 6.5 W / m^{2}K. A mathematical model was derived for the studied system and a Matlab code was developed to determine the solar fraction by the F-Chart method. The solar fraction is directly related to the auxiliary energy. So we can calculate the corresponding collector surface.

2- Mathematical Modélisation

The energy balance of the system can be given by [4]:

$$(\mathrm{Mcp})_s \frac{\mathrm{d}T_s}{\mathrm{dt}} = Q_u' + \mathrm{Q_{aux}} - (\mathrm{Q_s} + \mathrm{Q_l}) \quad (1)$$

Qu': Energy transmitted to the stored fluid,
Q_{aux} : Auxiliary energy
Q_s : Heat loss from the storage tank to the atmosphere,
Q_l : the use of water

The useful energy collected by the solar collector Q_u:

$$\mathrm{Q_u} = \mathrm{A_c F_r}\left[(\tau\alpha)_e \mathrm{I_g} - \mathrm{U_g}(\mathrm{T_i} - \mathrm{T_a})\right]^+ \quad (2)$$

After solving the above equation, the variation of storage temperature as a function of time is [5]:

$$\mathrm{T_s}^+ = \mathrm{T_s} + \frac{\mathrm{dt}}{(\mathrm{Mcp})_s}\left\{\mathrm{A_c F_r}'\left[(\tau\alpha)_e \mathrm{I_g} - \mathrm{U_g}(\mathrm{T_i} - \mathrm{T_a})\right]^+ - (\mathrm{UA})_s(\mathrm{T_s} - \mathrm{T_a}) - \varepsilon(\dot{\mathrm{m}}\mathrm{cp})_s(\mathrm{T_s} - \mathrm{T_r})\right\} \quad (3)$$

The variation of storage temperature depends on the daily variation of the ambient temperature and solar irradiance, but remains strongly linked to the characteristics of solar collectors characteristics Fr (τα) ,Fr Ug and the fluid flow ṁ.

2-2- Determination of the solar fraction F using f-chat method

The main variables in this method are the collector surface, the collector type, the storage capacity, the fluid flow and the size of the load and the heat exchanger.

The solar fraction f of the thermal load for the desired duration of calculation provided by solar energy is function of two dimensionless parameters X and Y. [5]

$$f = \frac{1}{L}\int_{\Delta t} A Fr \left[(\tau\alpha)_e I_g - U_g (T_e - T_a)\right]^+ dt \quad (4)$$

This equation can be divided into two non dimensional parts [5]:

$$Y = \frac{A\,Fr}{L}\int_{\Delta t} (\tau\alpha)_e \; I_\beta \, dt = \frac{A\,Fr}{L}\overline{(\tau\alpha)}_e \; H_\beta \; N$$
$$X = \frac{A\,Fr}{L}\int_{\Delta t} U_g \left(T_{ref} - T_a\right)dt = \frac{A\,Fr}{L} U_g \left(T_{ref} - \overline{T_a}\right)\Delta t \qquad (5)$$

Under the following operation conditions:

- Mass flow : 0.015 kg / m ^{2}s
- Storage capacity : 75 kg/m^2 of collector surface
- Heat exchanger efficiency

$$1 < \frac{\varepsilon \, C_{\min}}{U\,A} < 5$$

Therefore, the solar coverage is obtained using the equation below [4]:

$$f = 1.029\,Y - 0.065\,X - 0.245\,Y^2 + 0.0018\,X^2 + 0.0215\,Y^3 \qquad (6)$$

with:

$0 < Y < 3$ et $0 < X < 18$

The need in hot water should usually be stable through a year. To take into consideration this fact, a correlation of the variable X has been introduced [5]:

$$\frac{X_c}{X} = \frac{11.6 + 1.18T_s + 3.86T_r - 2.32\overline{T}_d}{100 - \overline{T}_d} \qquad (7)$$

With : Tr : grid temperature,
Ts : Storage temperature,
Td : mean daily temperature

The energy of auxiliary is given bellow[5]:

$$Aux = (1-f)*L \qquad (8)$$

3- Results and discussion

The following assumptions are used in our calculation

- The daily needs of hot water are of 1 m^3 at 45 °C,
- The storage capacity is 1.5 m^3,
- The used solar collector has the following characteristics: a surface of 2 m^2, an optical performance of 0.6 and un a global loss coefficient of 6.5 W/m^2K,
- The flow of the coolant liquid is of 0.02 $kg/s.m^2$,
- The efficiency of the exchanger is of 0.7,
- Electric energy : 16 kW,
- Reference month: December,
- Use of hot water (from 9.00 am to 1.00 pm),
- The various losses in the piping is about 5%,
- No variation in the optical performance as well as in the global loss coefficient throughout the day,
- The loss coefficient of the storage tank is of 7.5 W/C,
- No antifreeze in the primary circuit,
- The time step is 1 hour,
- Configuration: 2 sensors in series.

We choose the weakest month of the year in terms of solar radiation and heat load which is the reference month of December. We plot the variation of solar fraction and the electric auxiliary energy as a function of the collecting area. It is shown on figure.1.

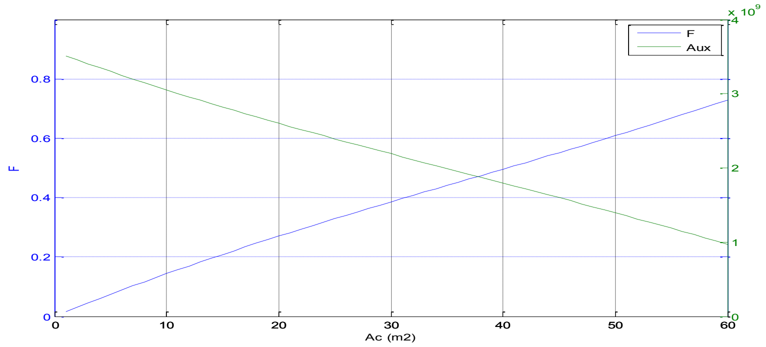

Fig. 1- Variation of the solar fraction and the auxiliary energy as a function the collector surface Reference month (December)

If we take a satisfaction rate of 0.4 this month (which is reasonable regarding to a limited area 40 m^2), then the collector area needed is of 30 m^2 which is considered as the minimum area which must be the same to be used for the calculation of the contribution of the auxiliary energy for the rest of the months of the year.

We will determine the contribution of the auxiliary energy as a function of the surface for the representative months of the four seasons. After running simulation with Matlab, the following graphs are obtained:

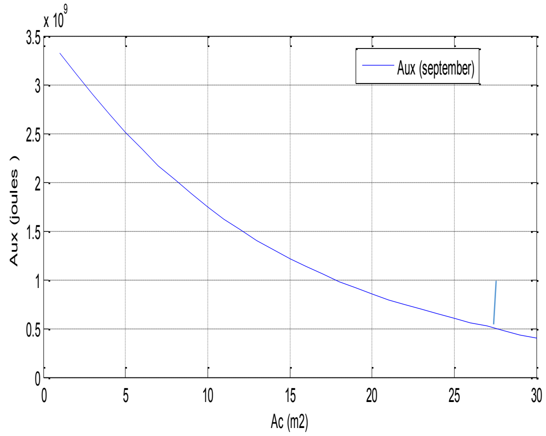

Fig. 2- Variation of the auxiliary energy as a function of the surface (September)

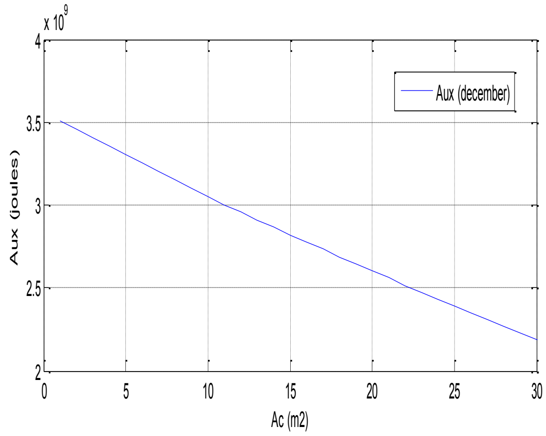

Fig. 3- Variation of the auxiliary energy as a function of the surface (December)

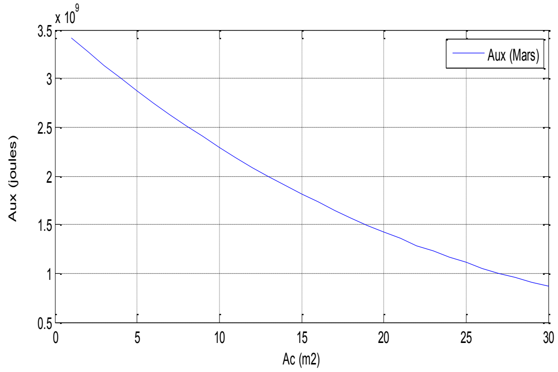

Fig. 4- Variation of the auxiliary energy as a function of the surface (March)

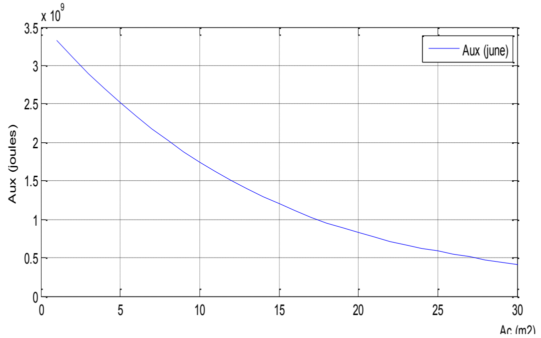

Fig.5- Variation of the auxiliary energy as a function of the surface (June)

We deduce from the graphics that the contribution of the electric energy decreases when the collector area increases, except that this contribution varies from one season to another. For 30 m^2 collector area, the necessary input for September is $0.4\ .10^9$ J (Figure 3), for the month of March it is of the order of $0.8.10^9$ J (figure 5), but in June it reaches the $0.3.10^9$ J (figure6), a value corresponding to a high solar potential. In the other hand, for the winter season the contribution of auxiliary energy reached a maximum with a value of $2.4.10^9$ J (Figure 4), when the solar potential is at its minimum. We plot in the following figure, the average solar fraction and average auxiliary energy as a function of the sensor surface for the whole year.

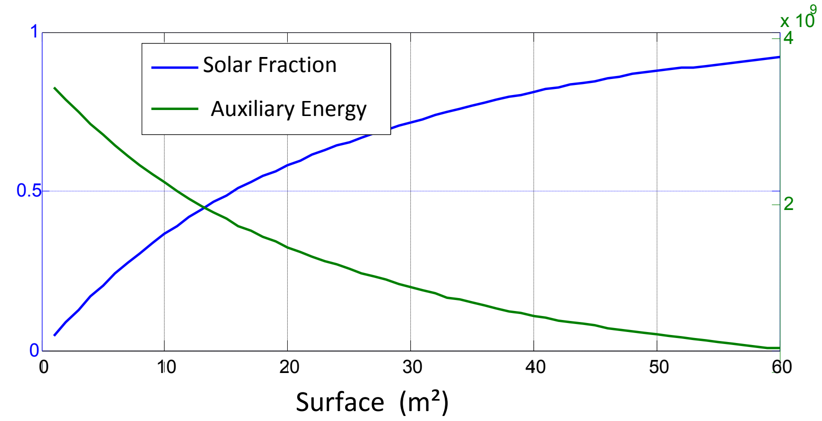

Fig. 6- Annual variation of the solar fraction and the electric as a function of collector surface

We can conclude from this plot that the more collector surface is high the more the intake in electric energy decreases until it becomes zero when reaching the surface of 60 m^2.

4- Conclusion

In a solar water heater installation, it is important for the implantation surface to be known in order to choose the corresponding solar fraction, for a certain need, to determine the collector surface.

The more the implantation space of collectors is important the less the use of extra energy is needed or even null for a certain area. In this case it is true that water is heated only with solar radiations but in the other hand the installation would be oversized and the investment cost would be greater. Hence, a good design is very important for such installations.

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