

Design and Analysis of Solar Space Heating System in Iraq

Abdulrahman Th. Mohammad

Baqubah Technical Institute, Middle Technical University (MTU), Baghdad, Iraq

Abstract

This paper describes the design and analysis of space heating system with solar evacuated tube collector using a TRNSYS simulation within the weather data of Baghdad city-Iraq for the period between 1st of November and 31th of March. The first objective summarized in select the main parameters of collect cycle (solar collectors and storage tank) and the main parameters of radiating cycle (fan coil units and pump). The second objective deals with the estimation of the system performance in terms of heat collected by the solar collector, solar fraction in solar cycle and the heat gain in radiating cycle with whole efficiency. The results of simulation show that the maximum radiating heating energy was investigated in December about 985 MJ with solar fraction 0.55 and whole efficiency 35.75%.

Keywords: *Solar collector, evacuated tube, TRNSYS.*

1. Introduction

Generally, the solar space heating system consist of two cycles, the first cycle is energy collection cycle includes: solar collectors and storage tank. The second cycle is an energy radiating cycle includes: fan coil units and pump. During the energy collection cycle, the water is circulated through an array of solar collector and then after heated is stored in a storage tank, while during the radiation cycle, the hot water circulated through the fan-coil units making a cross flow configuration with air enter the space heating. The solar collector is the main component in energy collection cycle and includes different types: flat plate and evacuated tube collectors. The flat plate collector is characterized by its simplicity while, the evacuated tube collector is characterized by high cost and very promising as a solution to increase the performance of the solar system. A forced circulation solar heating system was built by Ayompe et al. [1] to predict the collector performance in terms of outlet temperature, heat collected and heat delivered to the load. Prasad et al. [2] used a C-language program to produce and design optimum cost of flat plate collector for solar water heater system. The program takes in consideration the effect of location and time of the day on the performance of collector. Matrawy and

Farkas [3] developed a new derivations and analyses to compare between parallel plate collectors (TPPC) with parallel tubes collectors (PTC) and serpentine tube collectors (STC). The efficiency results show that the efficiency of (PTC < STC < TPPC). Zambolin, and Del Col [4] compared between flat plate and evacuated tube collectors in steady-state and quasi-dynamic test methods. The test was performed in several conditions to investigate different uses; hot water, space heating and solar cooling. Dupeyrat et al. [5] designed, built, and tested a prototype of hybrid collector (Photovoltaic-Thermal) to investigate the thermal and electrical performance. This type of collector reaches the highest efficiency than the standard Photovoltaic panel. The main objective of this study is to estimate the performance of the solar space heating system in terms of heat collected by the solar collector, solar fraction in solar collect cycle and the heat gain of radiating cycle.

2. Solar Collection Cycle

The solar energy is collected and transmitted to a water storage tank through an internal coil in the storage tank. The tank is assumed to be very well insulated, and the heat losses are considered. The water in the tank is supposed to be mixed fully, and, therefore, the stratification is not considered. The total solar radiation on the tilted surface at any time can be defined as [6]:

* Corresponding author. Abdulrahman Th. Mohammad

Tel.: +9647723482910

E-mail: abd20091976@gmail.com

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DOI: 10.5383/ijtee.13.01.006

$$S = I_b R_b (\tau \alpha)_b + I_d R_d (\tau \alpha)_d \left(\frac{1 + \cos \beta}{2} \right) + \rho g (I_b + I_d) \left(\frac{1 - \cos \beta}{2} \right) \quad (1)$$

Where: S : Absorbed radiation (W/m^2), I_b : Beam radiation (W/m^2), I_d : Diffuse radiation (W/m^2), α : Absorptance of the absorber plate, τ : Transmittance of the cover, ρ : Diffuse reflectance of the surface, $\frac{1 + \cos \beta}{2}$: View factors from the collector to the sky, $\frac{1 - \cos \beta}{2}$: View factors from the collector to the ground. The general equation describes the useful energy from a solar collector for near normal incidence angle of the solar radiation can be written as [5].

$$Q_u = F_R A_C [\tau \alpha . S - U_C (T_i - T_a)] \quad (2)$$

Where: Q_u is the useful energy gain (W), S is the incident solar radiation on the collector (W/m^2), A_C is the used collector area (m^2), F_R is heat removal efficiency factor and U_C is the overall collector heat loss ($\text{W}/\text{m}^2 \cdot ^\circ\text{C}$). T_i is the inlet temperature ($^\circ\text{C}$) and T_a is the ambient air temperature ($^\circ\text{C}$). The useful energy gain from the solar collector can be written as:

$$Q_u = \eta_c A_C S \quad (3)$$

Whereas: the A_C is the aperture area of the collector (m^2), S is the incident radiation (W/m^2), and η_c is the collector efficiency. The efficiency of the collectors is calculated by using the following formula [7]:

$$\eta_c = \eta_0 - a_1 T_m - a_2 T_m^2 \quad (4)$$

$$T_m = (T_i - T_a) / S \quad (5)$$

Where: η_0 is the intercept (maximum) of the collector efficiency, a_1 is the first-order order efficiency coefficient ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$), a_2 is the second-order efficiency coefficient ($\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-2}$), these coefficients are delivered from the company according the thermal test of the product.

3. Radiating Cycle

As shown in figure 1, the calculation the temperature of water inside the storage tank at any instant of time t :

$$\frac{dT}{dt} = \frac{N \cdot \dot{m}_w \cdot (T_{w2} - T)}{M} \quad (6)$$

Where N is the number of fan-coil, \dot{m}_w is the water mass flow rate circulates through the fan-coil units, T_{w2} is the water temperature after it has passed through the fan-coil units, T is the temperature of water inside the tank at instant time t and M is the mass of hot water in the full storage tank.

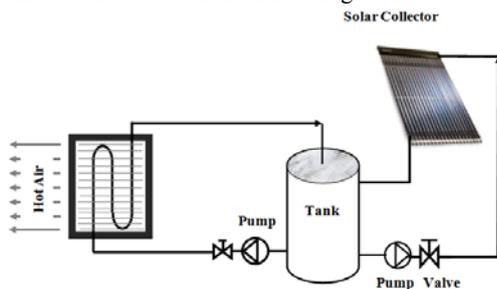


Fig.1. Solar heating system design

The heat balance during the heat exchange process defines as [8]:

$$\dot{m}_w \cdot C_w \cdot (T - T_{w2}) = \dot{m}_a \cdot C_a \cdot (T_{a2} - T_a) \quad (7)$$

As the hot water exchanges heat with air that is blown over the fan coil unit, the temperature of the air increases from ambient temperature T_a to T_{a2} . Where \dot{m}_a is the air flow rate blown over the fan-coil, C_a is the specific heat of air, and C_w is the specific heat of water.

The actual heat exchanged:

$$Q_{ac} = \dot{m}_a \cdot C_a \cdot (T_{a2} - T_a) \quad (8)$$

And the maximum heat that could be exchanged:

$$Q_m = \dot{m}_w \cdot C_w \cdot (T - T_a) \quad (9)$$

The ratio of actual heat exchanged to the maximum heat can be represented as two parameters R and ϵ , where:

$$R \equiv \frac{\dot{m}_a \cdot C_a}{\dot{m}_w \cdot C_w} \quad (10)$$

$$\epsilon \equiv \frac{T_{a2} - T_a}{T - T_a} \quad (11)$$

Combining equations (6), (7), (10), and (11), get

$$\frac{dT}{dt} = - \frac{N \cdot \dot{m}_w \cdot R \cdot \epsilon \cdot (T - T_a)}{M} \quad (12)$$

This equation has the solution as:

$$(T - T_a) = (T_0 - T_a) \exp \left(- \frac{N \cdot \dot{m}_w \cdot R \cdot \epsilon \cdot t}{M} \right) \quad (13)$$

Where T_0 is the temperature of water inside the tank at $t=0$.

From above equation can estimate that the temperature of the tank fall exponentially with the time, at the same way, using the above equations, can determine how the temperature of the hot air changes with time.

$$(T_{a2} - T_a) = \epsilon \cdot (T_0 - T_a) \exp \left(- \frac{N \cdot \dot{m}_w \cdot R \cdot \epsilon \cdot t}{M} \right) \quad (14)$$

This equation shows that the air temperature will also fall exponentially with time. By defining another parameter $a \equiv \frac{N \cdot \dot{m}_w \cdot R \cdot \epsilon}{M}$ can simplify equation (13) as:

$$(T - T_a) = (T_0 - T_a) \exp(-a \cdot t) \quad (15)$$

Therefore equation (14) becomes

$$(T_{a2} - T_a) = \epsilon \cdot (T_0 - T_a) \quad (16)$$

4. TRNSYS Modeling

TRNSYS is quasi-steady states program consists of many components stored in a big library and connecting graphically in the simulation studio. It is utilized to validate the domestic hot water systems, buildings and their equipment, control strategies, and alternative energy systems. In this simulation, solar space heating system suggested with heat storage tank supported with auxiliary heater and evacuated tube collector. On the other side, an energy radiating cycle consisted of fan coil units and pump is added to the system as shown in figure 2. Number of insert equations in TRNSYS used to program set equations for solving the performance of the system. The main components of the TRNSYS model are summarized in table 1. Table 2 shows the main design parameters values of the system components in the TRNSYS model.

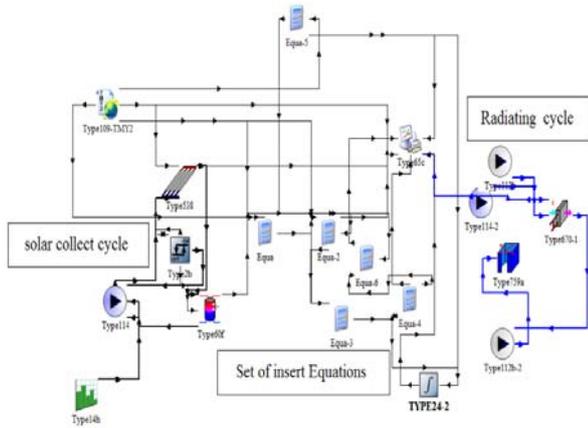


Fig.2 .The system represented in TRNSYS components

Table 1. The Main components and their symbols in TRNSYS library

| Name of components in TRNSYS library | Symbols |
|---|-----------|
| Weather data (TMY): Typical Meteorological Year of Baghdad city | Type 109 |
| Evacuated tube collector | Type 538 |
| Vertical storage tanks with 2 inlet and 2 outlet and with non-uniform losses | Type 60 f |
| Heating coil with hot-side bypass to keep air-side outlet below its set point | Type 670 |
| Two single speed pumps | Type 114 |
| Forcing functions | Type 14 h |
| Single speed fan | Type 112 |
| ON/Off differential controller outputs | Type 2b |
| Quantity integrator | Type 24 |
| Online plotter | Type 65c |
| Online printer | Type 25 c |
| ON/OFF Differential Controller; Old Control Strategy | Type 2b |
| Simple lumped capacitance multi-zone building model component | Type 759a |
| Time Dependent Forcing Function | Type 14 h |

Table 2. The values of main parameters in system

| Evacuated tube collector | | |
|--------------------------|-------|----------------|
| Parameters | Value | unit |
| Number in parallel | 1 | |
| Collector area | 10 | m ² |
| Intercept efficiency | 0.7 | |
| Inlet flow rate | 500 | Kg/hr |
| Collector slope | 35 | degree |
| Thermal storage tank | | |
| Volume | 0.3 | m ³ |
| Height | 1.25 | m |
| Flow rate at inlet | 500 | Kg/hr |
| Flow rate at inlet | 500 | Kg/hr |
| Pumps | | |
| Inlet flow rate | 500 | Kg/hr |
| Efficiency | 0.9 | |
| Heating coil | | |
| Effectiveness | 0.9 | |
| Fluid flow rate at inlet | 500 | Kg/hr |
| Air flow rate at inlet | 200 | Kg/hr |
| Fan | | |
| Air flow rate at inlet | 200 | Kg/hr |

5. Results and Discussion

The period between 1st of November and 31th of March is very cold in Iraq so, the demand of space heating will be more needed. According to the weather data of Baghdad in TRNSYS simulation, the maximum hourly values of ambient temperature is (26, 20, 15, 16 and 21 °C) in November, December, January, February and March respectively as shown in figure 3. While, the minimum value along this period is recorded in January about (-1.5 °C). The maximum hourly values of solar radiation are ranges between 295 W/m² in November and 550 W/m² in March (figure 4).

Figure 5 shows variations of maximum average hourly temperature coming-out of storage tank ($T_{out-tank}$) and air load temperature ($T_{airload}$) from November to March. The variation of ($T_{out-tank}$) is marked in pink color while the variation of $T_{airload}$ is marked in blue color. The temperature coming out of storage tank fluctuated between 48°C in December and 55 °C in March. Generally It increases during the morning hours to reach a maximum value at 2pm and then starts to decrease until 30 °C. As a result, the maximum $T_{airload}$ is recorded in March period with value about 44 °C , while the minimum value is recorded in December 40 °C.

As shown in Fig. 6, the monthly solar fraction values are fluctuating from 0.54 to 0.58 and the maximum value was found to be 0.58 in November. From Fig.7, we can observe that the requirements of auxiliary energy was needed during December with maximum value 1240 MJ/month while the minimum value was recorded during November 850 MJ/month. As shown in figure, the total energy was recorded in December was 2775.5 MJ/month. The performance of the radiating cycle is traditionally defined as benefit energy divided by the energy consumed in the process. The radiating energy and whole efficiency of the cycle can be described graphically as shown in Figures 8 and 9. These figures show that the maximum radiating energy was 985 MJ during December with efficiency 35.75%, whereas the maximum whole efficiency of the system was 37.7% during November.

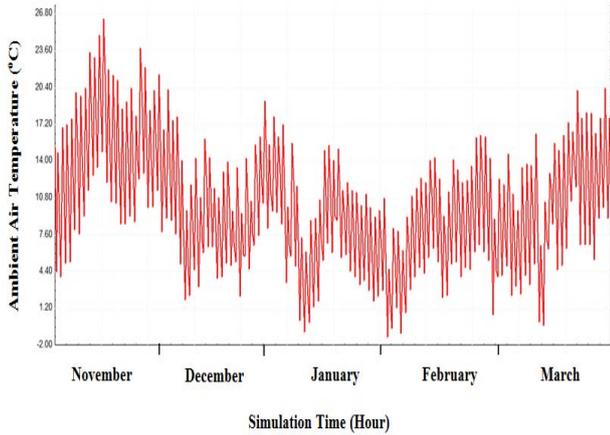


Fig.3. Ambient temperature for the period between 1st of November and 31th of March

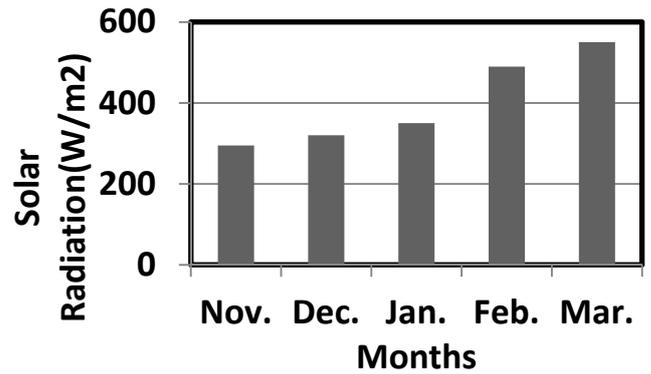


Fig 4. Maximum solar radiation in each month for the period between 1st of November and 31th of March

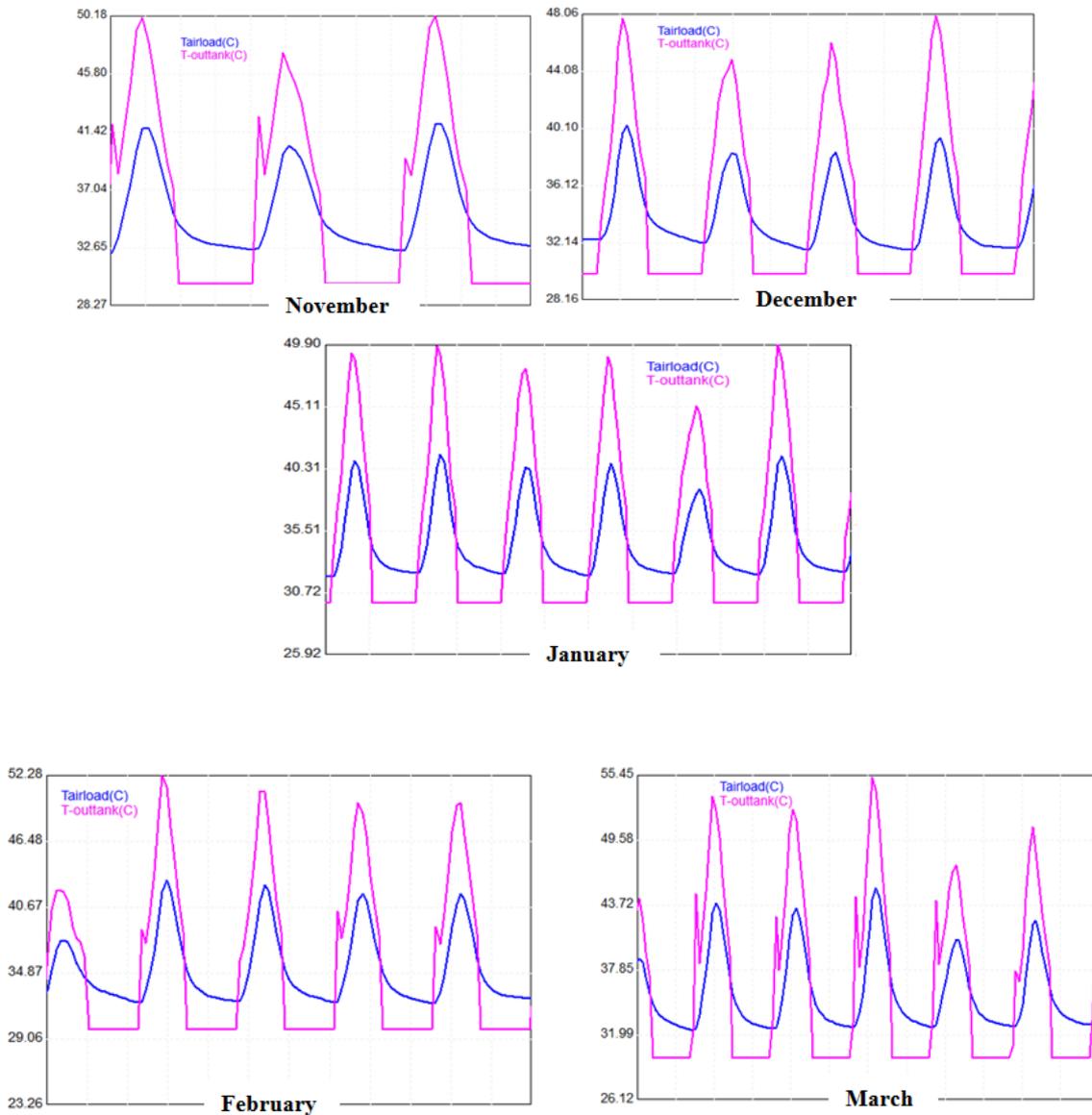


Fig. 5. Maximum hourly variations of tank outlet temperature and air load temperature

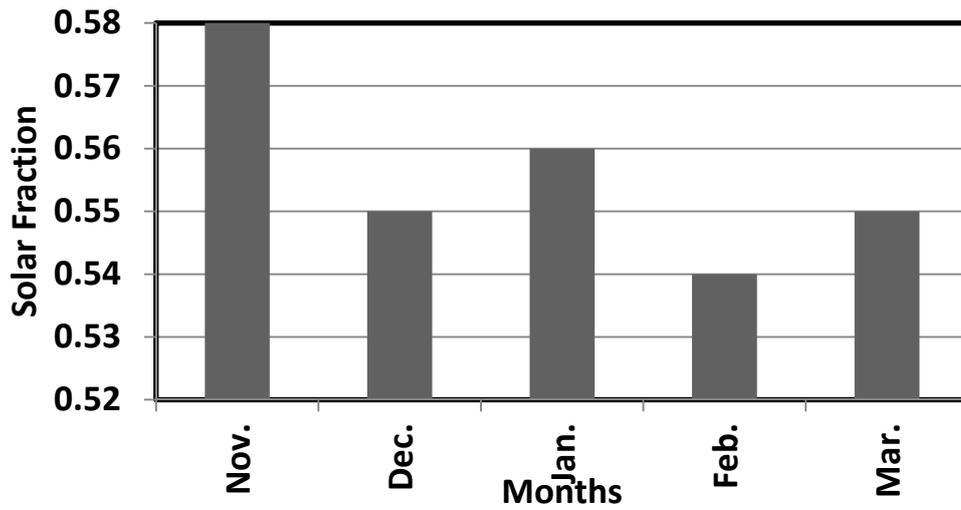


Fig. 6. Solar fraction in each month

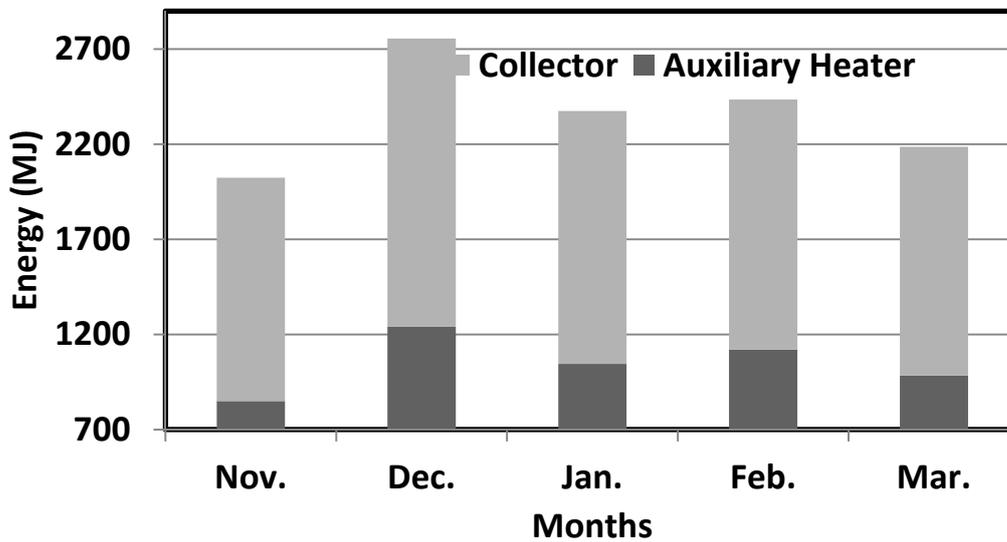


Fig. 7. Energy of solar collector and auxiliary heater

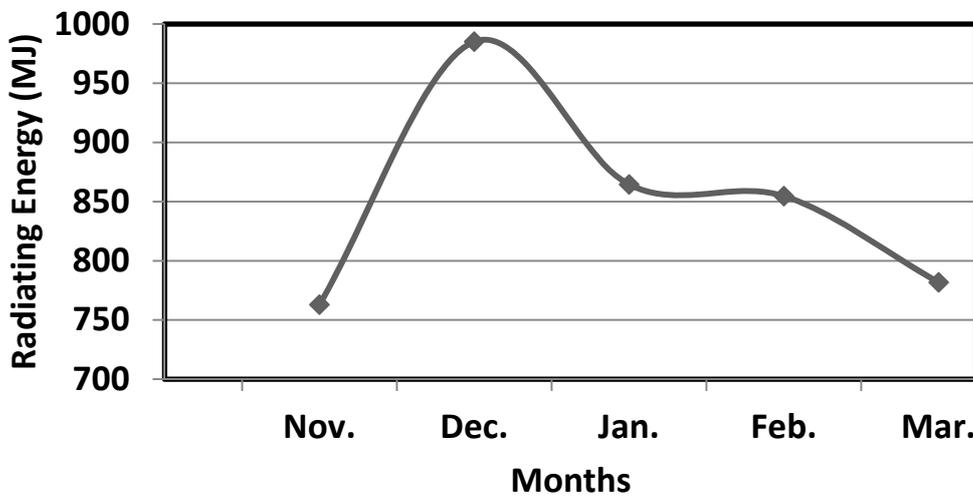


Fig. 8. Energy of radiating system

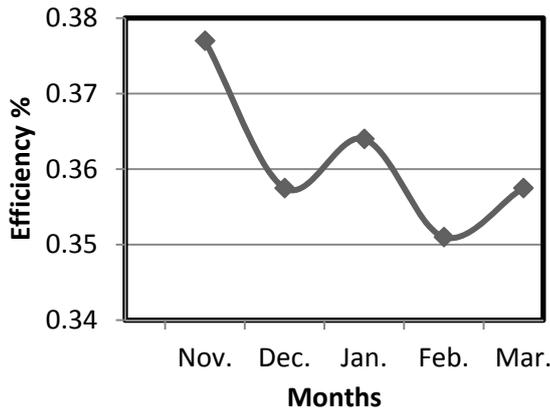


Fig. 9. Efficiency of the system

6. Conclusions

TRNSYS simulation within the weather data of Baghdad city-Iraq was used to analysis the space heating system for the period between 1st of November and 31th of March. The main objective deals with the estimation of the system performance in terms of heat collected by the solar collector, solar fraction in solar cycle and the heat gain in radiating cycle with whole efficiency. The simulation results show that the main conclusions were:

- Auxiliary energy was needed during December with maximum value 1240 MJ/month.
- The total energy was recorded in December was 2775.5 MJ/month.
- The maximum radiating heating energy was investigated in December about 985 MJ.
- The maximum whole efficiency of the system was 37.7%.

Nomenclature

| | |
|-------------|--|
| A_C | The used collector area (m^2) |
| a_1 | The first-order order efficiency coefficient ($W \cdot m^{-2} \cdot K^{-1}$) |
| a_2 | The second-order efficiency coefficient ($W \cdot m^{-2} \cdot K^{-2}$) |
| F_R | Heat removal efficiency factor |
| I_b | Beam radiation (W/m^2) |
| I_d | Diffuse radiation (W/m^2) |
| M | Mss flow rate in storage tank (Kg) |
| \dot{m}_a | Air flow rate (Kg/s) |
| \dot{m}_w | Water flow rate through fan coil (Kg/s) |
| N | Number of fan coil |
| Q_u | The useful energy gain (W) |
| Q_{ac} | Actual heat exchange (W) |
| Q_m | Maximum heat exchange (W) |
| R_b | Tilt factor for daily beam radiation |
| R_d | Tilt factor for daily diffuse radiation |

| | |
|----------|--|
| S | Absorbed solar radiation (W/m^2) |
| T_a | Ambient temperature ($^{\circ}C$) |
| T_{a2} | Outlet temperature from fan coil ($^{\circ}C$) |
| T_{w2} | Temperature after pass fan coil ($^{\circ}C$) |
| T_i | Inlet water temperature ($^{\circ}C$) |
| U_c | The overall collector heat loss ($W/m^2 \cdot ^{\circ}C$). |

Greek symbols

| | |
|-------------------|---|
| α | Absorptance of the absorber plate |
| $(1 + \cos\beta)$ | View factors from the collector to the sky |
| $(1 - \cos\beta)$ | View factors from the collector to the ground |
| ρ | Diffuse reflectance of the surface |
| τ | Transmittance of the cover |
| η_c | The efficiency of the collector |
| η_o | The intercept (maximum) of the collector efficiency |

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