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Energy Consumption Enhancement of a Solar Under Floor Heating System in a Small Family House Located in Mosul City, Iraq

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ABSTRACT

This paper deals with simulating a solar assisted under floor heating system during the three coldest months (i.e., December, January, and February) for a building of 100 m² area in Mosul city, Iraq. The simulations are conducted using TRNSYS18 software. The main components of the heating system under consideration, simulated using TRNSYS18 software, are a flat plate collector a storage tank, under-floor heating pipes. and an auxiliary heater which used when there is no enough solar potential. This work presents the indoor temperature and accessory loads by using variable collector area and volume of the storage tank. The results indicate that the heating system efficiently warms the indoor air in the building under study with an optimum collecting area of (24 m²) and optimum storage tank volume of (1.0 m³) to reduce the consumption of auxiliary energy to a very low level.

Keywords:

Under-floor heating, Heating load, Energy Consumption, Flat plate collector, Solar energy

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1. INTRODUCTION

Residential building loads account for about 35% of energy consumption worldwide [1]. The majority of the energy consumed in building is for heating and cooling. In addition, the substantial energy that is used in covering the needs of the construction sector leads to a considerable consumption of fossil fuels, consequently resulting in a significant impact on the environment. Hence, many previous studies discussed the use of solar energy in buildings for heating [2]. Moreover, solar energy can be stored as sensible heat, latent heat, or a combination of the two [3]. One of the most crucial challenges associated with using solar energy is its continuity and fluctuation, which can be overcome through the effective utilization of a thermal energy storage system. On the other hand, under-floor heating systems, a technology started in Germany in1970s, were employed in heating commercial buildings [5]. Nowadays, most European buildings adopted this technology [6] because the under- floor heating systems can reduce the heating energy by 18% [7] and enhance the indoor air temperature, which in turn improves the thermal comfort conditions [8]. Many studies have been done in this area. For instance, E. Bellos et al. [9] analyzed an underfloor heating system operated by solar energy for heating a typical building and concluded that this system is able to efficiently heat abuilding using (30) m² solar collecting area and (2.5) m³ storage tank volume. In their interesting work, Heba and Hussen [10] explored a solar-assisted floor heating system and they found that their theoretical results are agreed very well with the experimental outcomes. Another theoretical and experimental investigation for an underfloor heating system driven by solar collector or solar ponds was conducted by Ali and Mohammed [11]. The results demonstrated that the efficiency of the solar collector system is higher than that of the system of solar pond system by about 7%. In a different study, Sarvenaz and Ugur [12] employed a compound parabolic concentrating (CPC) solar collector instead of the traditional flat plate solar collector (FPC). Their results showed that a 2 m^2 CPC collector array can leads to match the function of a 8 m^2 FPC array to get the same required circulating temperature of water in the slabs.

In this paper, a solar energy-assisted underfloor heating system, figure (1), will be examined for a house with an area of 100 m^2 in Mosul city, Iraq. The objective of this work is to reduce the consumption of electric energy and fossil fuel in heating residential buildings. Furthermore, the present work aims to achieve comfortable conditions inside the considered building by integrating under floor heating with the use of latent heat storage system (LHSS).

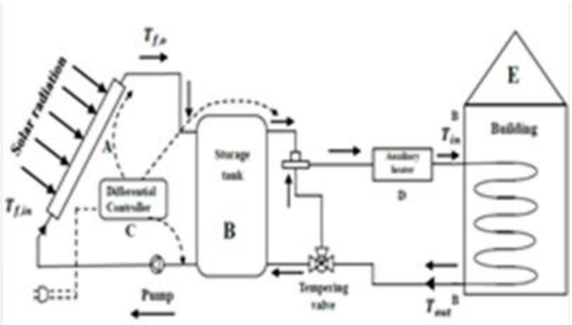

Fig. 1 Flow diagram solar-assisted floor heating system

Table 1 Buildings Parameters [15]

Parameter	Value
City	Mosul
Area	100 m^2
Height	3 m^2
South glass	1.5 m^2
West glass	3 m^2
Shading coefficient	70%
Specific light	5 W/m^2
Infiltration rate	0.8 ACH
Persons in the building	5
U-value for wall	0.709 $W/m^2.K$
U-value for window	1.4 $W/m^2.K$
Roof U-value	0.74 $W/m^2.K$
Floor U-value	0.885 $W/m^2.K$
Ventilation rate	0.5 ACH

2. MATERALS AND METHODS:

2.1 Building description

As shown in figure (2), the layout of the studied building is divided into four zones, each with four walls The structure of these walls consists of multiple layers as follows: a 0.025m plaster, 0.15m concrete, 0.025m insulation, 0.15m concrete, and 0.025m plaster. Meanwhile, the structure of the roof includes four layers, namely, 0.025m plaster, 0.04m insulation, 0.2m concrete, and 0.045m cement. Finally, the floor is composed of the following layers: 0.01m ceramics, 0.06m concrete, the active layer for heatin 0.06m concrete, 0.03m insulation layer, and 0.2m beton layer. It is worth mentioning that the building is oriented toward the south. All other building parameters are listed in table (1).

The modeling of radiant system is performed using an "active layer", which is embedded into the floor, and it is called "active" because it contains a set of pipes filled with fluid that exchange heat with the surface. The important parameters of these layers, as shown in figure (3). are the specific heat coefficient of water (4.19 kJ/kg.K), the spacing between pipes (0.1 m), the pipe outside diameter (0.02m) , the pipe wall thickness (0.002 m) and the wall thermal conductivity of the pipe is (0.35 W/m.K).

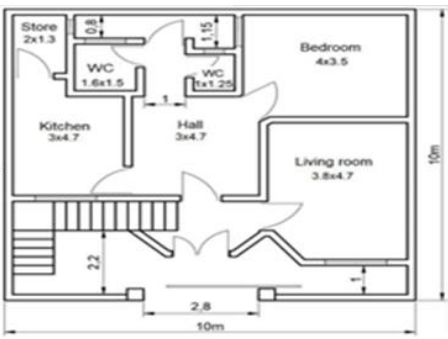

Fig. 2 Plan of floor building

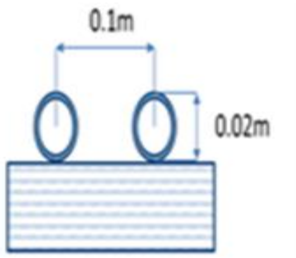

Fig. 3 Parameters of pipes of the active layer

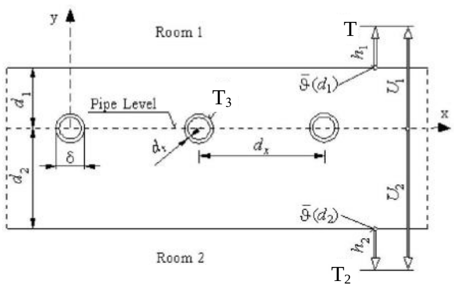

Fig. 4 Structure of the thermo active construction element system.

Table 2 Component types in TRNSYS

Components	Types in TRNSYS
Building	56
FPC	1b
Storage Tank	4c
Water pump	3d
Auxiliary heater	138
Controller	970
Differential controller	165
Tee-Piece	11h
Tempering valve	11b
Weather data	15-2
Online plotter	65d
Printer	25c

2.2. Mathematical formulation

The mathematical equations for the tested system are presented in this section. These equations are necessary to obtain the results from the TRNSYS models.

2.2.1: Flat Plate Collector

The ratio of the useful heat (q_u) to the solar energy (q_s) is called the thermal efficiency (η) which, can be calculated from the following equation [13]:

$$\eta = \frac{q_u}{q_s} \quad \text{….. (1)}$$

where q_u represents the useful heat form the flat plate collector and can be obtained from:

$$q_u = m_c . Cp .(T_{f,o} – T_{f,i}) \quad \text{….. (2)}$$

while q_s is the available solar energy reached the top of the collectors and can be calculated as follows:

$$q_s = A_c .G \quad \text{….. (3)}$$

2.2.2: Storage Tank

To evaluate the energy balance for storage tank, the following equation can be employed [13]:

$$q_u + q_{aux} = q_{st} + q_{load} + q_{loss} \quad \text{….. (4)}$$

where

q_u : The useful energy from the collectors

q_{load} : The heat required to heat the indoor air of the building

q_{loss} : The heat losses from the building by radiation.

2.2.3: Auxiliary Heater

The auxiliary heater is used to add heat to flow stream at a rate equal to or less than $q_{aux,max}$. The set point T_{set} is 45°C, and the outlet flow temperature is maintained lower than the set point T_{set}. The equations that describe the operation of auxiliary heater are [14]:

$$q_{aux} \le q_{aux,max} \quad \text{….. (5)}$$

$$q_{aux} = \min(q_{aux,max} , m_{hs} .Cp .(T_{set} – T_l)) \quad \text{….. (6)}$$

2.2.4: Building Energy Demand

The building heating load can be given as [13]:

$$q_h = m_{hs} . Cp . (T_{in}^B – T_{out}^B) \quad \text{….. (7)}$$

where Cp represents the water specific heat capacity (4.19 kJ/kg.°K), while the solar coverage (F) can be calculated from the equation below [13]:

$$F = 1 - \frac{q_{aux}}{q_h} \quad \text{….. (8)}$$

The required energy from the floor heating system is [16]:

$$E = q_h * t \quad \text{….. (9)}$$

where (t) is the running time.

Figure (4) represents the construction of the active layer and the heat transfer from the floor to the indoor air can be written as [15]:

$$q=\phi U_1(T_3-T_1)+(1-\phi)[(U_1U_2)/(U_1+U_2)] (T_2-T_1) \text{…(10)}$$

2.3. Description of the tested system

In this study, the simulation for the considered problem has been conducted using a well-known software in the field of renewable energy engineering called TRNSYS 18, which stands for Transient System Simulation. The results were gathered for the coldest months in Iraq, i.e., December, January, and February. The simulated heating system consists of storage tank and flat plate collector, pipes of under floor heating and auxiliary heater. The required heat has been provided by auxiliary heaters and solar collectors.

In Fig. 5, the tested system in this work is illustrated. In this figure, the red lines represent the hot water supplied by the flat plate solar collector while the blue lines indicate the cold water returned from the building. The hot water exiting the collector enters the storage tank, then passes through the tee-piece, and after that it carries through the auxiliary heater to the floor pipes the house to warm it. At the tee-piece, the hot water is mixed with some of the cold return water to avoid the destruction of the pipes due to the very high temperature of the water coming from the collector. All the component types utilized in the current TRNSYS simulation are listed in Table [2].

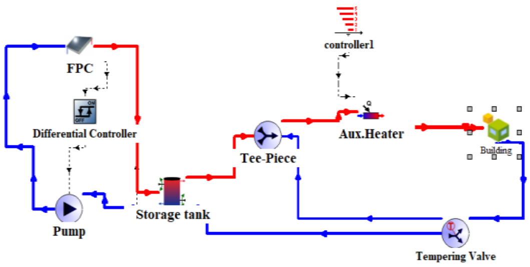

Fig. 5 The basic components of the examined system.

One of the aims of the present simulation is to find the values of the collector area and the volume of storage tank that minimizes the energy consumed by the auxiliary heater during the winter season.

Table 3: Values of the System Parameters

Parameter	Value
Collector area Ac	14-30 m^2
Slope angle of the collector	45˚
Collector thermal loss coefficient factor	4 $W/m^2.K$
Optical efficiency factor	0.8
Collector mass flow rate [mc]	1200 kg/h
Heating system flow rate	1200 kg/h
Fluid specific heat [Cp]	4.19 W/kg.K
Tank volume	1.0 -2.5 m^3
Auxiliary heater power	1 kW
Heater thermostat temperature	21-22˚C

3. RESULTS AND DISCUSSIONS

3.1 Heating Load Calculations

The results of simulation are depicted in Figures (6-9) for the monthly heating requirements for each zone of a typical building in Mosul city, Iraq. Several factors affect the heating load for any building, such as its size, characteristic, and orientation. Notably, the current results reveal that the living room and kitchen show the maximum heating demand. In the following subsections, the results of each zone will be discussed in some details. The statistical analysis indicates that the highest demand for each zone occurs in January. For example, the hourly change in heating load for the bedroom, Figure (6), is about (6601 KJ/h), while for the kitchen, Figure (9), it reaches (7846 KJ/h).

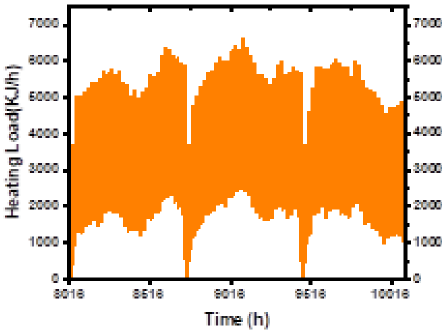

Fig. 6 Simulation heating load for bedroom

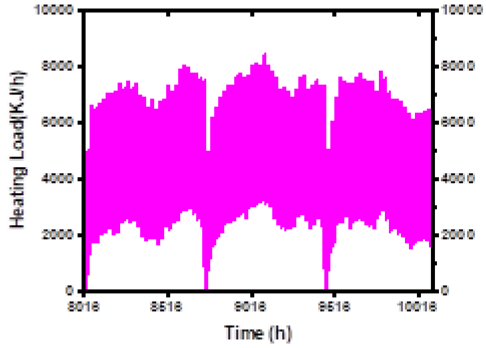

Fig. 7 Simulation heating load for living room

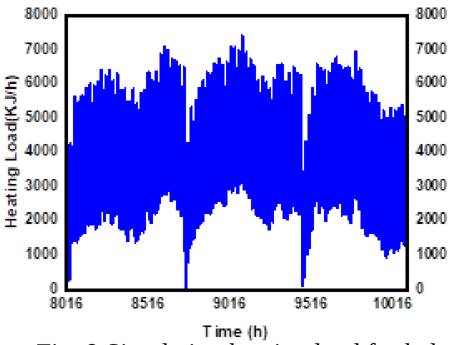

Fig. 8 Simulation heating load for hal

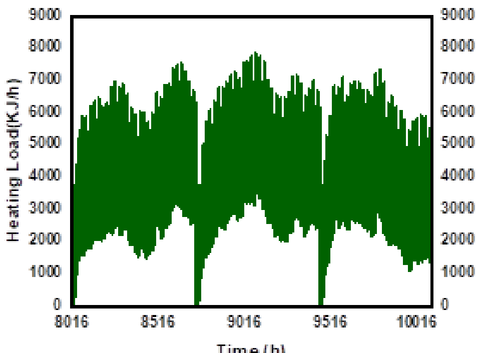

Fig. 9 Simulation heating load for kitchen

3.2. Zone temperature

The indoor temperatures for all building zones were extracted from the simulation of the current case for January and are depicted in Figures (10 and 11). The minimum recorded temperature was (20 °C), while the temperature variation ranged from 20°C to 28 °C, which falls within the limits of thermal comfort.

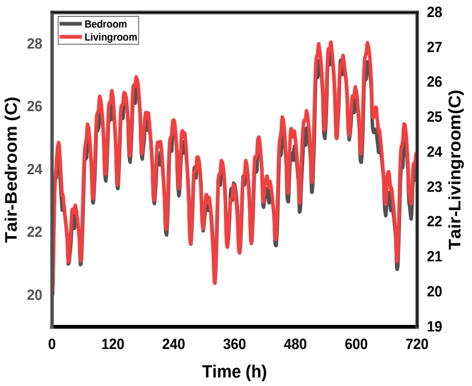

Fig. 10 Indoor temperature of bedroom and living room.

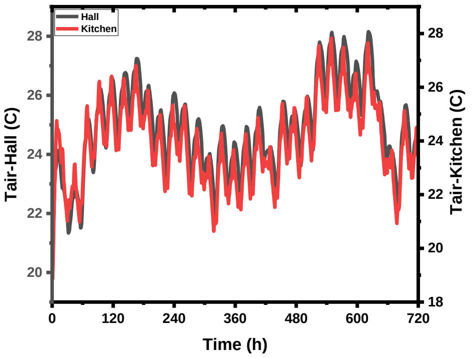

Fig. 11 Indoor temperature of hall and kitchen

Figure 12 illustrates the variations in global solar radiation on horizontal surface and ambient temperature over time for a typical day in winter under Mosul's climate conditions. Upon careful examination of the figure, it can be concluded that, on a typical winter day, ambient temperatures fluctuated between -3.65 °C and 2.25 °C, while solar radiation varied between 0 W/m^2 and 692W/m^2.

Furthermore, the useful energy of the collector is presented in Figures (13-a, b, c, and d) for various collector area and for different sizes of the thermal storage tank. It has been observed that increasing the area of the collector leads to a noticeable enhancement in the useful heat production.

The auxiliary heater load was evaluated for different collector area and various storage tank volumes, as shown in Figure (14). The higher collector area leads to the lower consumption of auxiliary energy, attributed to the high production of useful heat from solar field. It also has been observed that when the volume of the storage tank is at its maximum, this leads to the greatest demand for the auxiliary heater energy. Therefore, the optimal design is achieved with the lowest volume of storage tank at 1.0 m3.

In the current work, the useful energy of the collector and the energy consumed by the auxiliary heater have also been studied, and their results for a typical day in January are presented in Figure 15. It is clear that during periods of minimal solar radiation, the heating system relies on the auxiliary heater to meet the required heat demand. This implies that when the useful energy is at its lowest, the energy consumption

Moreover, the results of the simulation regarding solar coverage for different collector areas and storage tank volumes are present in Figure 16. This figure shows that the solar coverage increases with increasing the collector area, driven by the necessity to reduce the heating requirement for the building.

To compare the fluctuation in indoor temperatures relative to the ambient temperature, the results for each zone in the studied building are depicted in Figure (17) for the period from 1st December to 21st February. The data indicates that the indoor temperatures are higher than the ambient temperature, close to the thermal comfort limits.

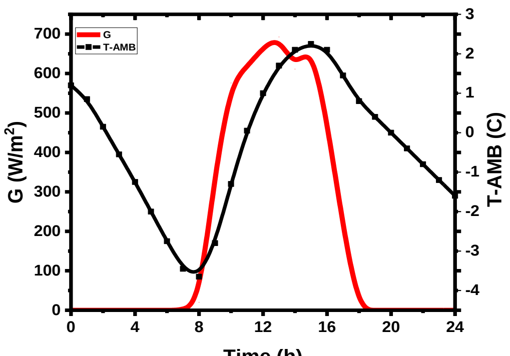

Fig. 12 Variations of hourly solar radiation on horizontal surface and ambient temperature for one typical winter day.

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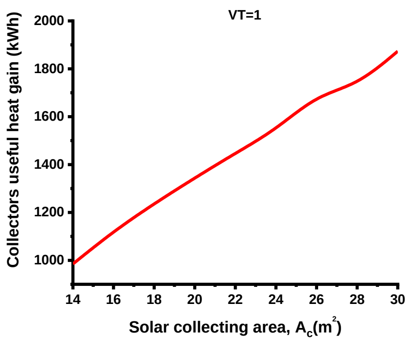
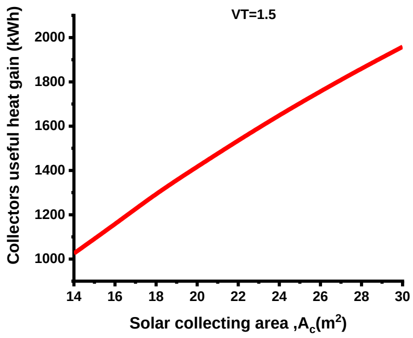
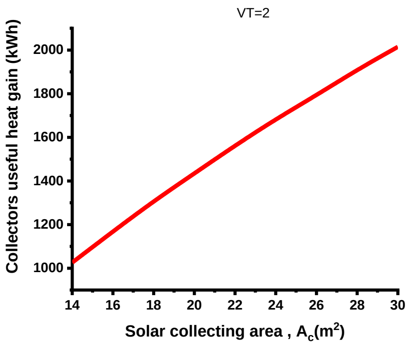


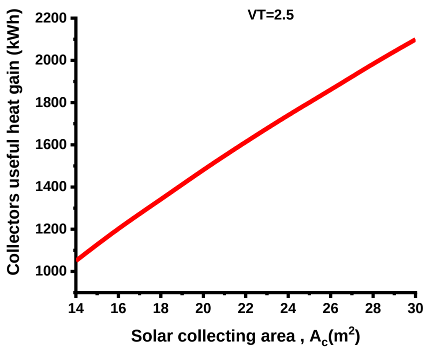
(a)



(b)

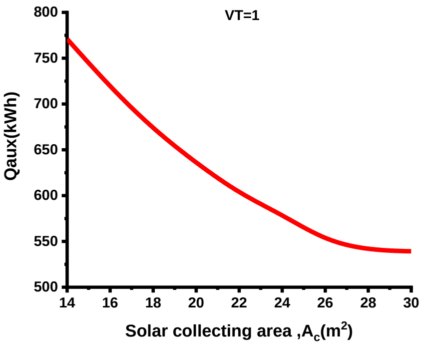


(c)

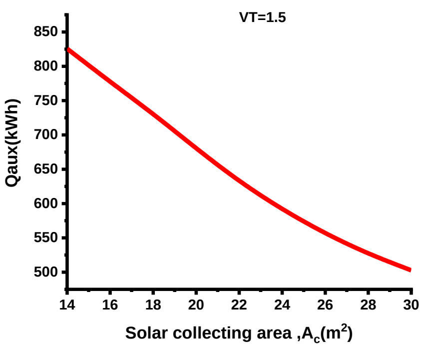


(d)

Fig. 13 The useful energy of collector for variable collecting areas at a volume storage tank of a: 1.0 m^3, b: 1.5 m^3 , c: 2.0 m^3 , d: 2.5 m^3



(a)



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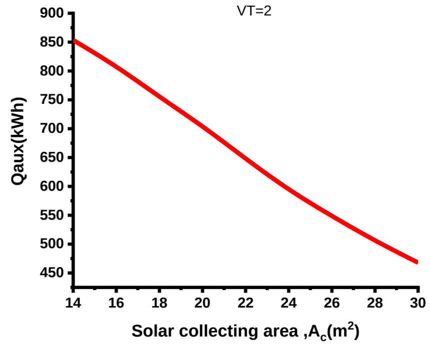

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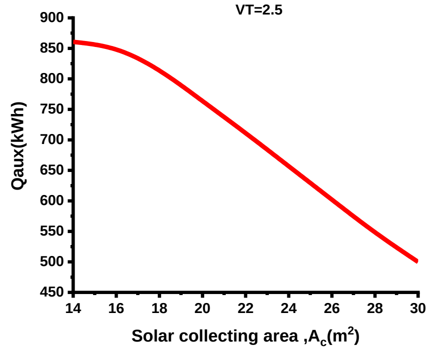


(d)

Fig. 14 The auxiliary energy variable collecting areas at storage tank volume a: 1.0 m^3, b: 1.5 m^3, c: 2.0 m^3 and d: 2.5 m^3.

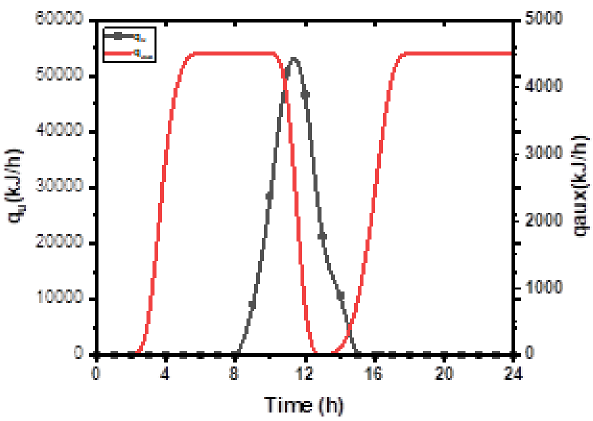
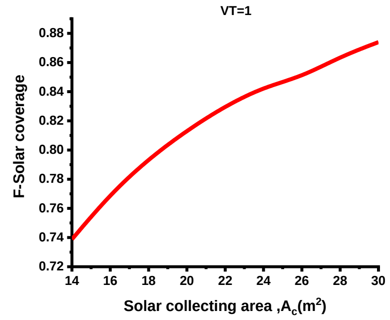


Fig. 15 Variation of hourly FPC useful energy and auxiliary heater energy.



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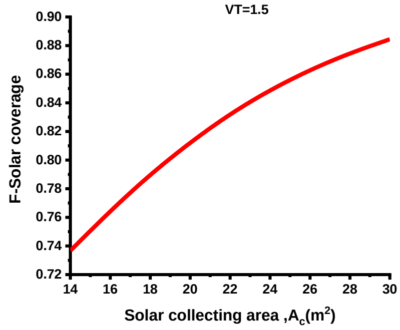

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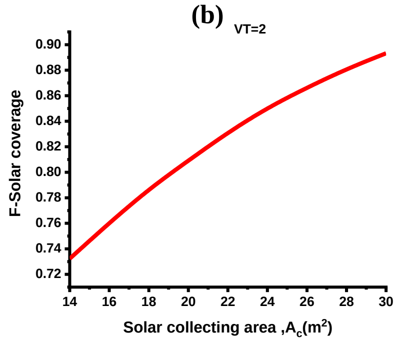

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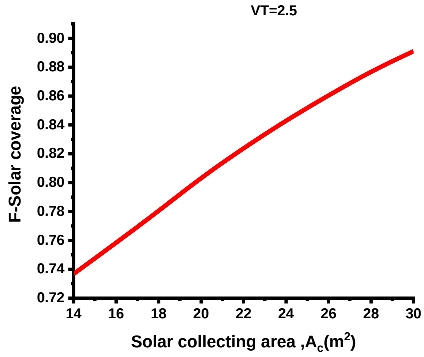

(d)

Fig. 16 The solar coverage for variable area of collectors at storage tank volume a:1.0 m^3, b:1.5 m^3, c: 2.0 m^3 and d: 2.5 m^3.

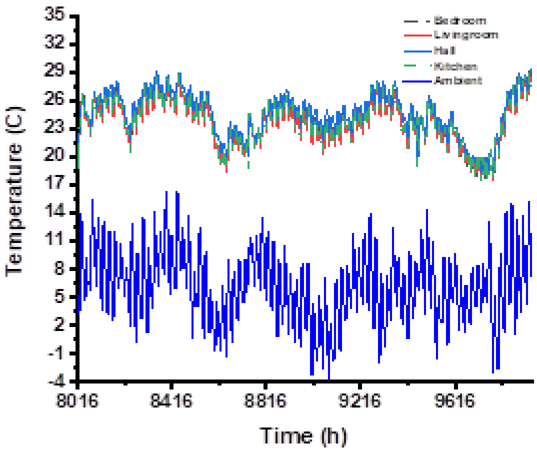

Fig. 17 Indoor temperature's fluctuation with FPC system during the winter period in Mosul.

4. DISCUSSION

The current work involves an investigation of a solar-assisted underfloor heating system small family house located in Mosul City, Iraq. The building under examination exhibits a lower heating load, attributed to the effective insulation integrated into structural components. The results presented in section (2.4.1) show the heating load demand for each zone in the building, revealing the maximum demand observed in the bedroom and kitchen.

In section (2.4.2), the outcomes demonstrate that an increase in collector area led to a reduction in auxiliary heater energy consumption, however, this effect was noticeable after reaching (24 m^2). The results also reveals that the reduction in the energy consumption of auxiliary heater was limited. Furthermore, the optimal collector area was found to be (24 m^2). Additionally, it was observed that a smaller storage tank size correlated with lower auxiliary energy consumption, and the optimal volume was (1.0 m^3).

5. CONCLUSIONS

In this paper, a solar assisted heating system for under floor heating in a building in Mosul city, Iraq, is studied. The system components include a storage tank, a collector of flat-plate collector, and an auxiliary heater. The analysis was implemented using TRANSYS software for the three coldest months in winter. The following conclusions can be drawn:

1. The examined system can efficiently heat the four zones in the building with a heating demand of 28 kWh.
2. Larger collector area exhibits lower auxiliary heater energy consumption, with an optimum collector area of (24 m^2).
3. It is also found that an increase in storage tank volume leads to an increase the energy demand, and the optimum volume of storage tank is identified as (1.0 m^3).
4. It has also been concluded that as the collector area increases, the solar coverage also increases.
5. Furthermore, the present system can operate without using an auxiliary heater, maintaining thermal comfort conditions at a high level inside the building if the solar collecting area is increased to 35 m^2.

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NOMENCLATURE

u	Thermal transmittance	W/m2.K
q	Heat rate	kW
Q	Energy	kWh
T	Temperature	C°
T_1	Indoor air temperature(side1)	C°
T_2	Indoor air temperature(side2)	C°
T_3	Surface temperature of the pipe	C°
VT	Storage tank volume	m^3
m	Mass flow rate	Kg/h
A_C	Collecting area	m^2
G	Solar irradiation on titled surface	W/m^2
F	Solar coverage	
U1 and U2	Coefficient of thermal transmittance	$W/m^2.K$
	Greek symbols	
η	Efficiency	%
ϕ	Correction factor	
	Abbreviations	
FPC	Flat plate collector	
LHSS	Latent heat storage system	
ACH	Air change per hour	
	Subscripts and superscripts	
u	Useful	
s	Solar	
c	Collector	
f,in	Fluid in	
f,out	Fluid out	
st	Stored	
aux	Auxiliary	
max	Maximum	
min	Minimum	
AMB	Ambient	
hs	Heating system	
h	Heating	
B	Building	
L	Load	

تعزيز استهلاك الطاقة لنظام تدفئة تحت الأرض بالطاقة الشمسية في منزل عائلي صغير يقع في مدينة الموصل – العراق

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الخلاصة:
يهتم هذا البحث في اجراء محاكاة لنظام التدفئة تحت الأرضية والذي يعتمد على النظام الشمسي خلال ثلاثة أشهر الاكثر برودة وهي (كانون الاول وكانون الثاني وشباط) لمبنى مساحته 100 متر مربع في مدينة الموصل (العراق). تم إجراء عملية المحاكاة باستخدام برنامجTRNSYS18 . يتكون نظام التسخين من أجزاء رئيسية كالمجمعات من نوع اللوح المسطح وخزان التخزين وأنابيب التدفئة تحت الأرضية وسخان إضافي يستخدم عند عدم وجود إمكانات شمسية كافية. يقدم هذا العمل درجة الحرارة الداخلية وأحمال الملحقات باستخدام تغيير مساحة المجمع وتغيير حجم خزان التخزين. أظهرت النتائج أن نظام التدفئة يمكنه تسخين المبنى بكفاءة وأن مساحة التجميع المثلى التي تقلل من استهلاك الطاقة المساعدة هي (24 م مربع) وبعد هذه القيمة يكون التقليل منخفضًا جدًا. كما أن الحجم الأمثل لخزان التخزين هو (1.0 م مكعب) ، والذي يتميز بأقل استهلاك للطاقة بالنسبة للسخان الإضافي.

الكلمات المفتاحية:

التدفئة تحت الارضية ، حمل التدفئة ، استهلاك الطاقة ، مجمع مستوي ، الطاقة الشمسية