Modeling and Simulation of a Solar Thermal System for Domestic Space Heating Using Radiators Low Temperature

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Received: 11.12.2014 Accepted: 26.01.2015

Abstract- This article presents the study of the thermal behavior of a solar heating system at low temperature for an old individual home built in the 1990s, on one hand, a traditional fluid heating boiler is replaced by a storage tank heated by a set of solar panels and on the other hand, the existing conventional radiators (75° C/65 °C) are replaced by radiators at low temperature (50° C/45 °C). The numerical model is used to evaluate temperature changes of each part of the system (collection, storage, distribution and indoor air of the room).Comparing these results with those obtained by a home heated by radiators at high temperature associated with a traditional boiler.
The simulation input parameters include climatic conditions concerning the site of Adrar (27.10 N, 0.17 E, Altitude: 279 m) in Algeria, for four successive days, on January, where the average minimum and maximum temperatures are respectively about 4 ° C and 19 °C. The results show that the integration of solar heating using low temperature of radiators in an old individual home provides adequate comfort conditions while minimizing the energy consumption of 20%. Furthermore, this heating technique helps to decrease each year 20% of carbon emissions and reduce energy costs.

Keywords—Solar collector, Stratified tank, Low temperature heating, Water radiator, Solar heating.

1. Introduction

Today, the world of building enters a new era. The energy consumption of buildings in Algeria represents about 46% of the produced energy and it is responsible for over 25 % of greenhouse gas emissions which must be reduced by economic and environmentally friendly energy solutions [1]. For that, to improve the building envelope is by a reinforcing insulation, so it is the better treatment of thermal bridges which introduce a reduction in thermal requirements in air-conditioning and heating that should be considered. Furthermore, the research should focus on effective heating systems of the building to control the living environments at a lower energy cost [2].

Technological development in the field of current heating needs to go in the direction of reducing the environmental impact by using renewable energy sources to ensure the security of our energy supplies from the exhaustion of fossil sources of energy. Many studies are currently underway to make this field of building an example of energy. The thermal performance of building envelopes has improved significantly and therefore the heating load decreased significantly. This will reduce the heat transfer areas and therefore a decrease in the temperature of the heating medium. This last option very interesting from the perspective of sustainability, because it makes possible to apply an alternative heat source such as heat pumps, solar collectors. Such systems have greater efficacy if they provide heat to the lower temperature level (heated floors, radiators low temperature).

Research has been done in this field by many authors, Ala Hasan and Jarek Kurnitsk [3] have developed a new system of combined water heating at low temperature which uses radiators at low temperature in rooms and heating floors in bathrooms. The results showed that this combined heating system can maintain a comfortable temperature inside the home. Vitanen and Ala [4] have encouraged the use of heating systems at low energy that minimizes energy consumption. The work of Marek Brand [5] have shown that renewable sources can be integrated with the urban heating system and heat at low temperature an individual house built in the 1970s with a forwarding temperature of 50°C.

In our country, 75 % of buildings are old and poorly isolated, they require a high quantity of energy, and they use traditional heating at high temperature (75 ° C / 65 ° C). The integration of solar heating systems in old homes involves to replace on one hand a traditional boiler fluid heating in a storage tank heated with a plurality of solar panels and on the other hand, the existing conventional radiators with radiators at low temperature (50 ° C / 45 ° C). Due to a lower supply temperature, a calculation of the system performance is made to avoid the discomfort of residents. In this context, we conducted this study to evaluate the temperature inside an old home heated by oversized radiators which the energy input is provided by solar collectors.

The studied solar heating consists of solar collectors for collecting thermal energy, a storage tank that transmits this energy to the distribution system which in turn will transfer the heat to the radiators at low temperature. A detailed simulation of the entire system based on the calculation of the heat balances in the elements of the system was conducted to evaluate the temperature changes of each part of the system, assembling, storage and distribution. In addition, the economic and environmental impact of the solar system will be examined.

2. System Description

Our study focuses on an old individual home, built in 1990s, type F3, with a surface area of 90 m^2, heated by radiators low temperature which the energy input is provided by the solar collectors.

The characteristics of the building are:
- The exterior walls are double-walled with hollow bricks and an air gap.
- The roof is a hollow-core slab.
- The low floor is a concrete slab.
- The glazing is simple, with a thickness of 4 mm, with a conductance without surface resistance of 5 W/ m^2K and a solar factor of 0.85 with a wooden frame.
- The number of occupants of the building is five, the other internal charges are: equipment and lighting.

The used solar heating system (Fig.1) consists of two solar panels with a surface area of 3 m^2 oriented towards the south with an inclination of 45 °, and a mass flow of 0.03 kg /s, a vertical storage tank without heat exchanger, a 300 l with a ratio (L / D = 1.6) with a glass-wool insulation of 50 mm thickness. Two valves, one at the input of cold water and the other at the output of hot water, two pumps for circulating the fluid in the primary circuit between the collector and the tank on the one hand, in the secondary circuit between the storage tank and the distribution system on the other hand [6], That is composed of hot water radiators at low temperature and thermostatic faucets to control the flow completing the installation. An auxiliary gas system completely independent of the storage tank "constituting a low temperature boiler" that is used as an auxiliary heating.

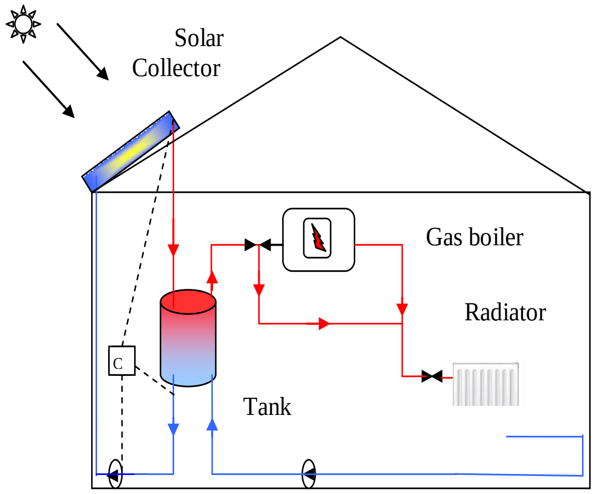

Fig.1. Schematic diagram of a solar low heating system

The water heated by solar collectors and stored in the water tank is used to supply the radiators and meet heating needs during the period from November to April. When the water temperature at the outlet of the tank is less than the supply temperature of the heating system of about 50 ° C system, the water moves towards the booster, so it can be heated and then to the radiators, on the other side, if the temperature is over 50 ° C, the water in the storage is directly used to meet the heating demand and go directly to the radiators [7].

3. Mathematical Modelling

The numerical model is established by adopting the following assumptions:
- The temperature in the tank is homogeneous in a section (layers).
- The Thermo-physical properties of the building envelope are assumed to be independent of the temperature.
- The internal temperature of the building is considered uniform.
- The temperature of the fluid in the radiator varies in a single direction, length of the radiator.
- The mode is transitional.

2.1. Solar Collector

The developed thermal model is based on the energy transfer phenomenon in the various components of the collector, The simulation is done by dividing the transversal section [8] collector into six isothermal regions: the glass cover, the air layer, the top half of the absorber, the water layer, the bottom half of the absorber and the insulation, therefore, we propose to dividing the length collector into ten sections in order to take into account the temperature distribution of the working fluid inside the collector [9] .

For each node, according to the Kirchoff's law [9]:

$$\left(\delta\,\rho\,Cp\right)_i \frac{\partial T_i}{\partial T} = \sum q_{ij}\,(T_j - T_i) + p_i \qquad (1)$$

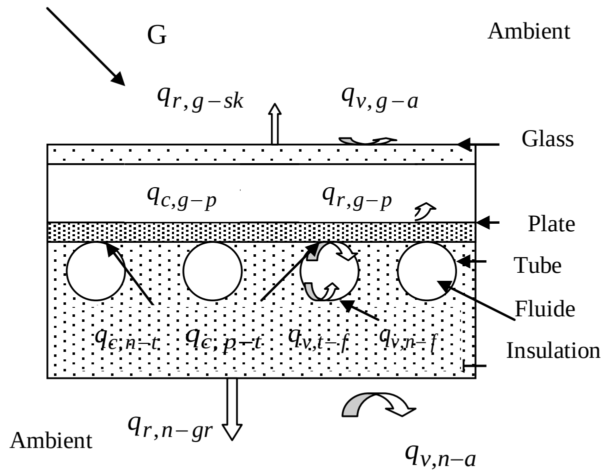

Fig. 2. Solar collector

- Glass

$$\left(\delta\,\rho\,Cp\right)_g \frac{\partial T_g}{\partial t} + q_{v,g-a} + q_{r,g-sk} = q_{r,g-p} + q_{c,g-p} + G\alpha_g \qquad (2)$$

where $q_{v,g-a}, q_{v,g-p}$ are respectively the quantities of heat exchanged by convection between the glass–ambient and the glass–plate absorber. $q_{r,g-sk}, q_{r,g-p}$, are respectively the quantities of heat exchanged by radiation between the glass–sky and the glass–plate absorber.

- Plate absorber

$$(\delta\,\rho Cp)_p \frac{\partial T_p}{\partial t} + q_{v,p-g} + q_{r,p-g} = q_{c.p-t} + G(\alpha\tau)_P \qquad (3)$$

where $q_{c,p-t}$ is the heat quantity exchanged by conduction between plate absorber and tubes.

- Tubes

$$(\delta\,\rho Cp)_t \frac{\partial T_t}{\partial t} = -q_{c,p-t} - q_{v,t-f} - q_{c,.n-t} \qquad (4)$$

where $q_{v,t-f}$ is the heat quantity exchanged by convection between the tubes and the fluid and $q_{c,n-t}$ is the heat quantity exchanged by conduction between the tubes and insulation.

- The fluid

$$\dot{m}cp_f\,(T_f - T_f^*) + s_t.q_{v,n-f} = s_{if}.q_{v,t-f} \qquad (5)$$

with, $\dot{m}$: Flow mass rate of fluid. $q_{v,n-f}$ is the heat quantity exchanged by convection between the insulation and fluid, T_f^* the fluid temperature of the preceding section.

- Insulation

$$(\delta\,\rho Cp)_n \frac{\partial T_i}{\partial t} + q_{v,n-a} + q_{r,n-gr} = q_{v,n-f} + q_{c,n-t} \qquad (6)$$

where $q_{v,n-a}$ is the heat quantity is exchanged by convection between the insulation and the ambient temperature and $q_{r,n-gr}$ is the heat quantity exchanged by radiation between the insulation and the ground.

2.2. Storage Tank

The storage system considered in this analysis is a vertical cylinder of diameter D and length L, completely filled with water with a ratio (L / D = 1.6). The volume of water is divided into N horizontal sections of equal height I, treated with a uniform temperature $T_{s,i}$ [10]. These sections are numbered from 1 to *N* from top to bottom (Fig. 3). Water is injected from the collector into the tank at the first node and exits the tank towards the collector at the last node. Water temperatures of the sections are always divided increasingly from the bottom to the top of the tank [11, 12].

The energy equation takes into account of the energy gain from the collector, energy lost to surrounding, and energy utilized by the load [14], which results in a set of N differential equations that can be solved to obtain the temperatures of the N nodes as a function of time [15]. In order to correctly model the tank, a large number of nodes (layers) are considered to ensure a stable solution of the temperature. In our study the tank is divided into 100 nodes.

The energy balance of the i^{th} node is [12]:

$$(mCp)_{s,i}\frac{dT_{s,i}}{dt} = \beta_c^i\,\dot{m}_h\,Cp_i\left(T_c - T_{s,i}\right) + \beta_l^i\,\dot{m}_l\,Cp_i\left(T_l - T_{s,i}\right) + (UA)_{s,i}\left(T_a - T_{s,i}\right) + \lambda_{s,i}A_{s,i}\Delta x\frac{\partial^2 T_{s,i}}{\partial x^2} + Q_{\text{int}} \qquad (7)$$

β_c^i is a collector control function, which can be defined to identify which node receives water from the collectors.

$$\beta_l^i = \begin{cases} 1 & if \quad T_{s,i} \rangle T_l \rangle T_{s,i+1} \\ 0 & other \end{cases} \qquad (8)$$

β_l^i is a load return control function, which can be denoted to identify which node receives water returning from the radiators heating system.

$$\beta_c^i = \begin{cases} 1 \quad if \quad T_{s,i-1} \rangle T_c \rangle T_{s,i} \\ 0 \quad other \end{cases} \tag{9}$$

Q_{int} : Power generated by the fluid flow from the neighboring nodes. It is given by the following formula [13, 14]:

$$Q_{\text{int}} = \begin{cases} \gamma_i Cp_i \left(T_{s,i-1} - T_{s,i}\right) \; si \;\; \gamma_i \rangle 0 \\ \gamma_i Cp_i \left(T_{s,i} - T_{s,i+1}\right) \; si \;\; \gamma_i \langle 0 \end{cases} \tag{10}$$

γ_i is a parameter that controls the exchange between internal nodes

$$\gamma_i = \dot{m}_h \sum_{j=1}^{i-1} \beta_c^i - \dot{m}_l \sum_{j=i+1}^{N} \beta_l^i \tag{11}$$

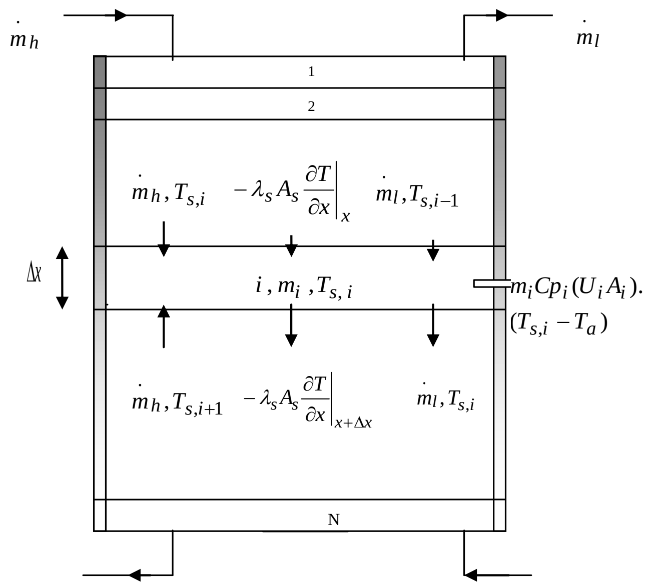

Fig. 3. Stratified water storage tank.

2.3. Loads

The heating power is the energy needed to provide a reference and comfort temperature in the room or building to be heated. This power depends on a calculation of the needs or losses taking into account the contributions from the walls, gains by sunlight, as well as contributions due to people and renewal of air [15]. The calculation is performed in extreme conditions from an outdoor base temperature. In our study we used the equations contained in the regulatory technical document, 'DTR 3-2 C' according to the Algerian regulation [16].

The total losses Q_{los} for an accommodation, containing several thermal volumes are:

$$Q_{los} = \sum Q_{losses,j} (T_b - T_a) \tag{12}$$

The total losses $Q_{losses,j}$ of a j volume are the amount of losses by transmission and the amount of air renewal.

$$Q_{los,j} = (Q_{tra})_j + (Q_{air})_j \tag{13}$$

Where Q_{tra} is the heat loss due to transmission; Q_{air} is the heat losses by air renewal.

Losses by transmission of an i volume occurs through walls, ceilings, thermal bridges, and windows, external and it can be expressed by the equation:

$$(Q_{tra})_i = (Q_{wal})_i + (Q_{lin})_i + (Q_{flo})_i + (Q_{su})_i \tag{14}$$

Q_{wal} the heat loss transmission through vertical walls in contact with outside, is calculated as :

$$Q_{wal} = K_{wal} . A_{wal} \tag{15}$$

Q_{lin} the heat loss due to linear thermal bridging given by :

$$Q_{lin} = K_l . L \tag{16}$$

Q_{flo} the heat loss transmission through floors.

$$Q_{flo} = K_{sol} A_{sol} \tag{17}$$

Q_{su} the heat loss transmission through surfaces in contact with non-heated zones given by :

$$Q_{su} = T_{au} \left(\sum (K_{su} A_{su}) + \sum (K_{lin} L) \right) \tag{18}$$

The heat loss by air renewal of building is [17]:

$$Q_{air} = 0.34 \times \left(Q_{ven} + Q_{\text{inf}}\right) \tag{19}$$

where 0.34 is the air volume heat (W h/m^3 K); Q_{ven} is the specific flow caused by ventilation due to natural ventilation through open windows or doors and mechanical ventilation by fans is defined as:

$$Q_{ven} = Max\left(0.6 \times V_h, Q_{vref}\right) \tag{20}$$

where V_h is the volume of room, Q_{vref} is the flow Reference extract.

$$Q_{vref} = \frac{5 Q_{v\min} + Q_{v\max}}{6} \tag{21}$$

where $Q_{v\max}$ and $Q_{v\min}$ are respectively the maximum and minimum debit extract of reference.

$Q_{\inf}$ the additional flow caused by infiltration ; uncontrolled airflow through all the little cracks and openings in building is calculated as :

$$Q_{\inf} = \sum \left(e_{vi} . \left(\sum p_{oj} . A_j \right) \right) \quad (22)$$

where e_{vi} is the coefficient of exposure to the wind assigned to the wall i, p_{oj} is the surface permeability to the air of the panel j and A_j the surface of the panel j.

heat provided by solar radiation entering, directly or indirectly (after absorption in building elements), into the building through windows, opaque walls through processes commonly known as passive solar heating , which contributes to significantly reduce the heating period .

The solar gain through transparent elements and opaque walls are respectively:

$$Q_{s.w} = \alpha_w \sum_{i=1}^{M} \tau_w A_w I_w \quad (23)$$

$$Q_{s.wal} = \sum_{i=1}^{NM} \alpha_{wal} \, F_{wal} \, A_{wal} \, I_{wal} \quad (24)$$

Where I_w, I_{wal} are respectively the values of solar radiation (including the effect of shading) on the i^{th} transparent element and opaque walls; F_{wal} is the Shading factor.

People, electrical devices and lighting produce thermal wastes that reduce heating needs.

The people gains depend on the number of people and activity level is given by [15]:

$$Q_{peo} = N_p . (q_{s.peo} + q_{L.peo}) \quad (25)$$

The heat gain due to electric appliances is given by [18, 19]

$$Q_{app} = \sum (q_{s.app} + q_{L.app}) \quad (26)$$

Lighting can have a significant impact on the heating of a building, is calculated as [18]:

$$Q_{li} = \sum \left(W_n . C_{me} . C_{cr} \right) \quad (27)$$

Where W_n the nominal power of the bulb; C_{cr} Percentage of residual heat.

From the calculation of losses, it is possible to determine the energy requirements of a home for heating. Heating needs are then equal to the difference between heat losses and heat gaining [18, 20]:

$$Q_h = Q_{los} - \eta . Q_i \quad (28)$$

$$Q_i = Q_{s.w} + Q_{s.wal} + Q_{peo} + Q_{app} + Q_{li} \quad (29)$$

By assuming that all heated parts of the room are heated at a uniform indoor temperature at all times, the room can be modeled as a single heat capacity element. A differential equation is then written relating the heat flow to the room to time derivative of the indoor temperature and the room heat capacity. The indoor temperature of room is calculated by [21, 22]

$$C_b \frac{dT_b}{dt} = \dot{m}_r \, Cp \, (T_{re} - T_{rs}) - K_b (T_b - T_a) \quad (30)$$

2.4. Radiators

A studied individual home is equipped with hot water radiators at low temperature to meet the heating needs. These radiators use a low water starting temperature, usually between 45° and 50 ° C, however, these days, all manufacturers of radiators made in countries of the European Union define their heat output according to the European standard EN 442 Delta T equal to 50 ° C 75/65/20 ° C. Due to a lower supply temperature, the exchange surface of radiators at low-temperature with ambient air must be larger.

The heat emitted from oversized radiators is given by [25]:

$$q_r = q_{rn} \left(\Delta T_{\log} \big/ \Delta T_{\log\, nom} \right)^n \quad (31)$$

Where q_{rn} is the nominal heat emission from radiator; n is the constant describing the type of radiator.

The water return temperature through radiators based on actual heat emission and inlet water temperatures is calculated by:

$$C_r \frac{dT_{rs}}{dt} = \dot{m}_r \, Cp (T_{re} - T_{rs}) + (UA)_r (T_b - T_{rs}) \quad (32)$$

The heat capacity of a hot water radiator depends on the logarithmic mean temperature difference is calculated by equation [24]:

$$(UA)_r = \frac{q_{rn} \left(\dfrac{\Delta T_{\log}}{\Delta T_{\log\, nom}} \right)^n}{(T_{rs} - T_b)} \quad (33)$$

The logarithmic mean temperature difference is [25]

$$\Delta T_{\log} = \frac{T_{re} - T_{rs}}{\ln \left(\dfrac{T_{re} - T_b}{T_{rs} - T_b} \right)} \quad (34)$$

4. Numerical Computation

The system is modeled after the nodal method which is based on the calculation of heat balances of each element constituting the solar heater. The discretization of transfer equations is carried out by using the finite difference method. The equation system is solved by a numerical approach based on the LU method. A calculation code is set up and developed in Fortran language for the resolution of the thermal balance equations for different elements. The program calculate every minute the temperature at the outlet of the solar collector, the storage tank and the radiators as well as the energy demand of the room, its inner temperature.

Table1. Input parameters of the simulation

Location	Latitude (North)	27°.54
	Longitude (West)	0°.17
Load	area	90 m²
	Hot water demand temperature	50°C
Collector		
	Total collector area	3m²
	Optical efficiency	0.76 %
	Number of collectors	2
	Tilt angle	45°
	Mass flow rate	0,03 Kg / s
Glass	Thickness	0.003m
	Emissivity	0.88
Plates	Thickness	0.001m
	Emissivity	0.95
	Mass density	24 Kg/ m³
Storage tank		
	Height	1 m
	Diameter	0.65 m
	Capacity	300 l
	Conductivity	204 W/m.K
Insulation	Density	2700 Kg/m ³
	Thickness	0.05 m
	Conductivity	0.045W/m.K
Radiators	Material—iron	
	Supply temperature	50°C
	Number of elements	8
	Number of columns	4
	Power of elements	119 W
	Masse flow rate	108 l/h
Boiler	Efficiency	0.75 %

The input parameters for the simulation of the heating system of the site of Adrar are shown in the Table 1. The measured values of the total solar irradiance and the exterior temperature were conducted from January 3 to 6, 2013 and recorded, using a mini weather station in each minute (Fig4).

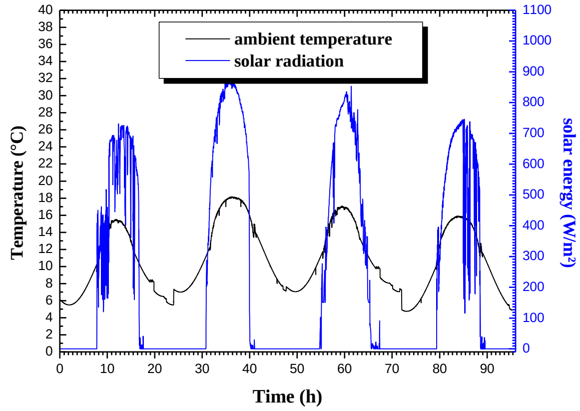

Fig. 4. Solar radiation and ambient temperature for fore consecutive days.

5. Results and Discussion

The use of solar heating requires us to replace the traditional fluid heating boiler by a storage tank of 300l disposed within the home, so that all the heat lost from the tank will be acquired by the house. The tank is heated by two solar panels of 3m². The existing conventional radiators are replaced by radiators low-temperature. In our study, the length and height of conventional radiators are maintained while the depth is changed, this way, the replacement of radiators low temperature is done without any piping modification. An additional gas consisting of a low temperature boiler heating the water of the heater circuit with a temperature between 35 ° C and 50 ° C is used as an auxiliary heater when the water temperature at the outlet of the tank is less than the supply temperature.

Before using the solar heating we left the collector system tank operating without water withdrawal for one week to increase the temperature of the water inside the tank (water heating supply). The variation of the inlet and outlet temperature of the collector and the temperatures of the upper and lower layers of the storage tank hot water for the last two days of the week (fifth and sixth day) are illustrated in the Fig. 5. The curves examination of this figure similar to that found in literature [27, 28] allows to note that the outlet temperature of the collector reaches 64 ° C, we also notice a difference between the temperature at the top of the tank (63 ° C) and bat the bottom of the tank (59 ° C) due to stratification.

Moreover a variation of the inlet temperature of the collector is observed early in the day and after 13 h, probably resulting from functioning interruptions of the circulation pump. Indeed, when the tank temperature is higher than the collector, the regulator stops the pump. When the water inside of the collector is more (a few degrees) to that of the solar tank, the circulation pump is switched on.

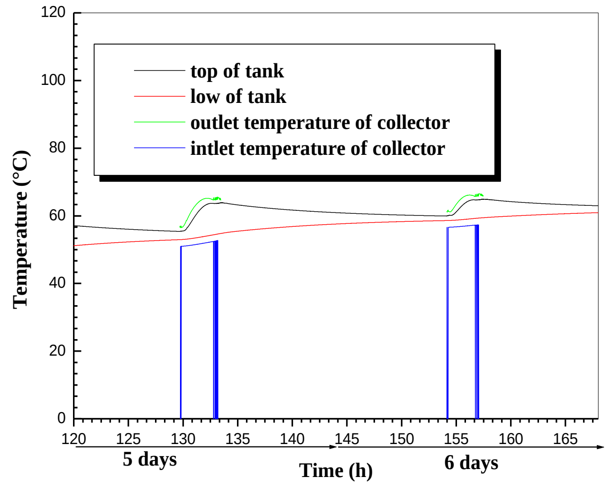

Fig. 5. Variation of outlet and inlet temperature of the collector and the tank.

To design a heating system, it is necessary to estimate the amount of heating requirements of each room of the home, the room we chose in our study is a room on the East and North facades of a home with a surface of 20 m² with a panel of 1.5 meters heated by the radiator.

The variation of losses and external inputs (solar) and the heating needs during the chosen four days is shown in Fig. 6. It is clear that the inputs have a maximum value between 12.00 h and 14.00 h, unlike of losses which have minimum values in this period. Therefore, sunlight greatly minimizes the need for heating.

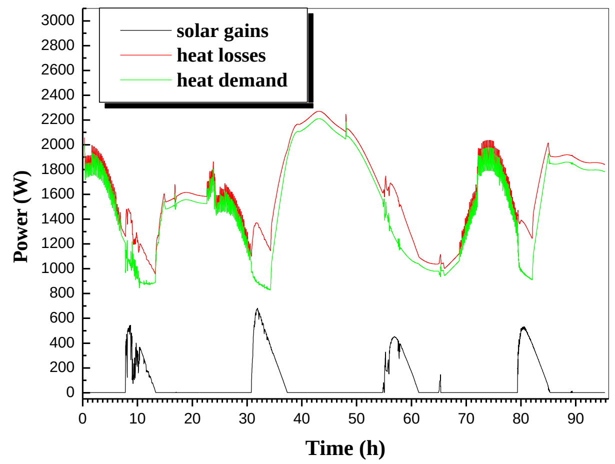

Fig. 6. Variation of solar gain, Heat losses and heat demand for fore consecutive days.

After one week of heating without withdrawal, we use the tank water as supply water of radiators heating at low temperature (the supply temperature is set to 50 ° C).

The curves of Fig. 7 illustrate the changes in temperature at the outlet of the tank and at the inlet and outlet of the radiator, which allows observing that when the water temperature at the outlet of the tank is lower than the supply temperature, water goes to the booster to be heated then to the radiators. This case occurs when the solar radiation is not sufficient to heat the water of the tank, during the morning, the evening and on cloudy days. If the temperature is over 50 ° C the storage water will go directly to the radiators. A control system is necessary to regulate the flow of the system and prevent the overheating of the room because at this time there are lower heating needs.

Furthermore, we can observe that the difference between the temperature of the inlet and the outlet of the radiator is about 6 to 8 °C, this difference is due to the heat exchange with the atmosphere of the room.

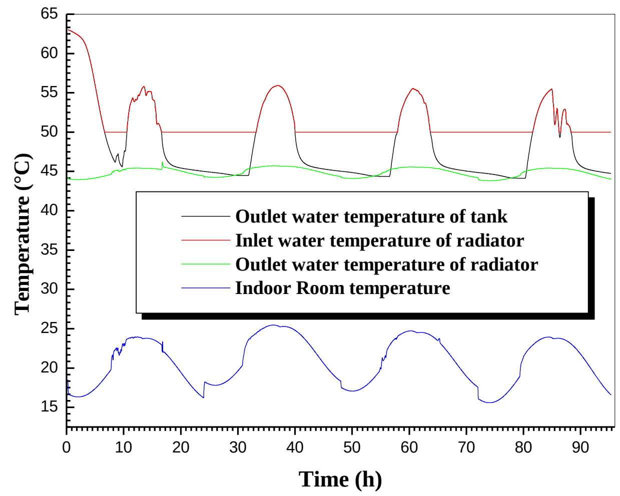

Fig. 7. Variation of the water temperature of the radiator and the tank.

For the radiator low temperature, which is the subject of this study the length and height of the conventional radiators are kept, only the depth is exchanged. The previously used conventional radiators are in cast iron with two columns and eight elements, while the low temperature radiators are of the same type with four columns and eight elements [28]. The flow of the system is set to 108 l / h. Table 2 gives the characteristics of the two types of radiators.

Table 2. Configuration parameters of the Radiators

Radiators	Number of columns	Height mm	Thickness mm	Length mm	Weight Kg	Power ΔT50° C Watt
Conventional	2	630	65	65	3.77	68.5
Low temperature	4	630	142	65	6.62	119

The variation of the temperature at the inlet and the outlet of the radiator water and the power emitted by the two types of radiators during the selected four days are shown in Figs. 8, 9 we can observe that the inlet and outlet temperature of the conventional radiator water are respectively about 75 ° C and 65 ° C. The power ranges from 550W (at night) and 440W (day), whereas the low-temperature radiator, the temperature varies between 50 ° C and 41 ° C and the power between 500 W and 360W, which leads to the conclusion that despite the difference in the starting temperatures of the two radiators they provide almost the same power.

The observation of the Fig. 10 allows us to observe that the room temperature during the four studied days, varies between 14° C (at night) and 24° C (daytime), in the case where the solar heating is used while it is 20 ° C (night) and 29 ° C (daytime) for conventional heater. This temperature difference between day and night is due to the flow of the used heating system which is set to 108l / h. To solve this problem it is necessary to use a regulator to control the flow of water in radiators. The curves have the same shape found in that of the literature [29].

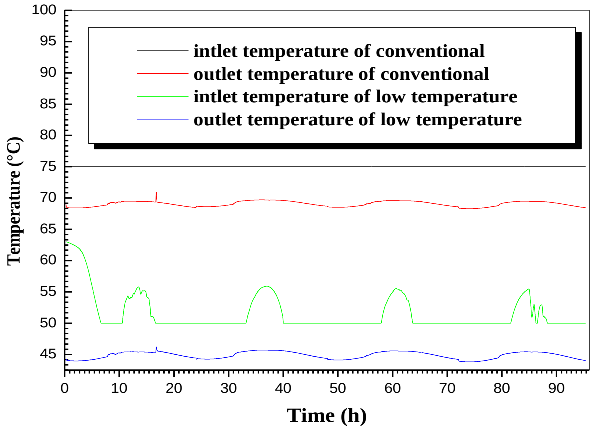

Fig. 8. Variation of the water temperature at the outlet and the inlet of the radiator. (Low temperature, conventional)

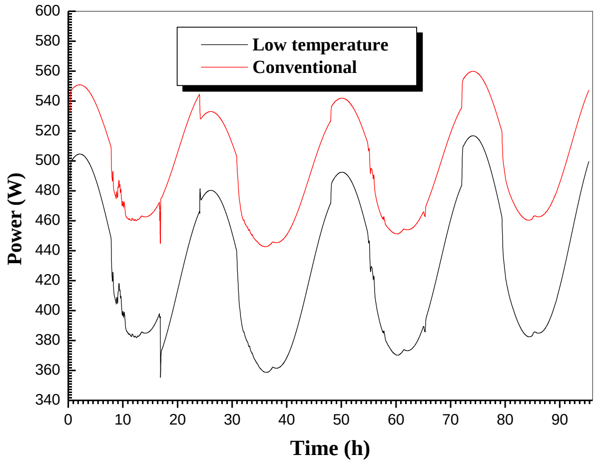

Fig. 9. Variation of radiator heat emission.

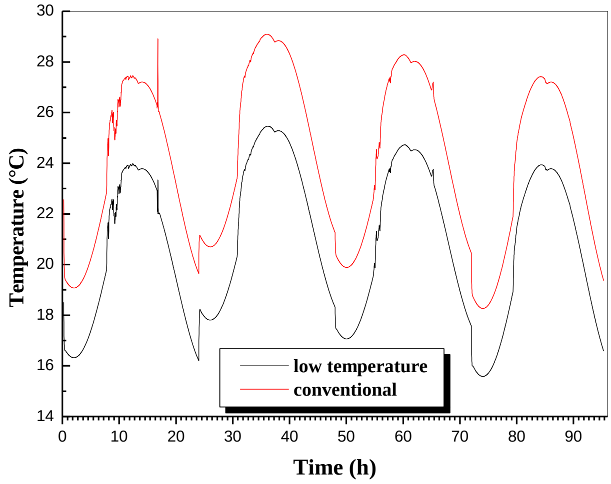

Fig.10. Variation of indoor room temperature.

Fig. 11 which illustrate the variation of the booster power in the four selected days, allows us to observe that on the first day, solar heating at low temperature is supplied by water that comes directly from the storage tank. Thereafter, as the water temperature of the tank is less than 50 ° C the booster is started between generally the periods from 6.00 h until 9.00 h. during 9.00 h until 6.00 h. The heating circuit is supplied by water coming directly from the tank and therefore the backup system stops. The curves obtained by simulation have the same shape as those found in the literature [30].

The influence of isolation on the annual performance of solar heating was also studied. Two types of construction, HB1 a poorly isolated conventional home and HB2 with the same architecture and the same surface area as the previous one but differing from the latter by using insulating materials.

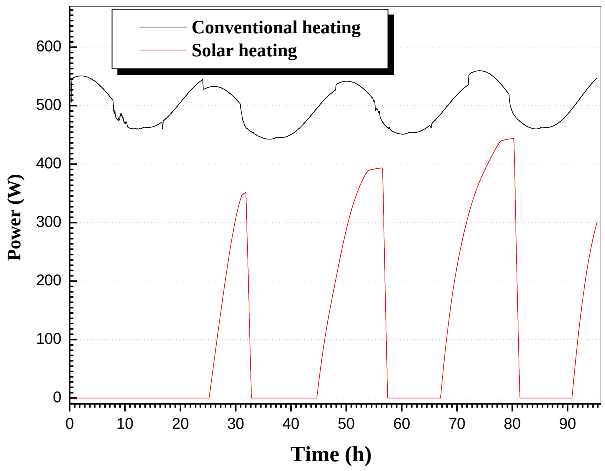

Fig.11. Variation of auxiliary power.

A calculation of the annual heating needs, the fuel needs and the available solar power, based on the principle of the method of heating degree-days, the monthly average value of the solar radiation and the ambient temperature of the studied site is performed using the available long-term data of NASA (meteorology of surface and solar energy) [31].

The energy needs of the two building types HB1 and HB2 are shown in Fig. 12 .It is easy to note that the annual heating needs for HB1 estimated at about 17884 kWh / year are more important than those for HB2 which are only 8050 kWh / year, a saving of nearly 50% resulting from the insulation that can significantly reduce heat loss.

In Fig. 13 we can remark that the use of solar heating helps to cover almost 20% of the annual heating needs for a home with type HB1. In this case the boiler only provide 205250 kWh / year instead of 23845 kWh / year, a saving of 20% of energy .In the case of home with type HB2 containing a solar heating, total saving is 45%.

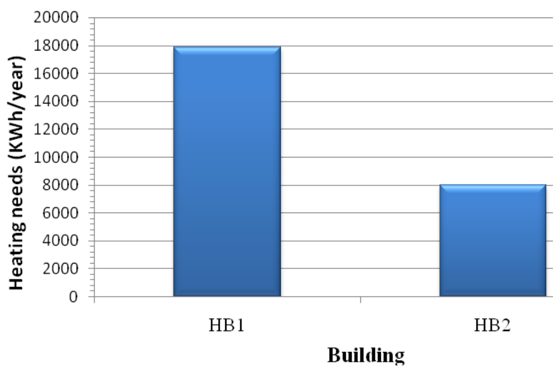

Fig.12. Annual heating needs.

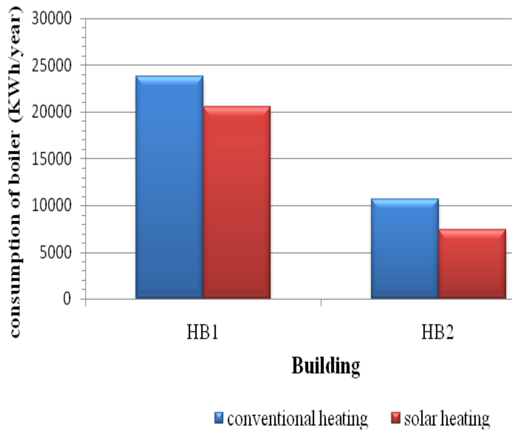

Fig.13. Annual consumption of the boiler.

The economic analysis of solar heating system is shown in Fig. 14. It is easy to note that_the annual energy invoice estimated at 12,000 DA (150 €) for an HB1individual home and reduced to 7000 DA (90 €) in the case of an HB2 home, to be only the small value of 65 € in case the solar heating is used. The low values of the cost of heating bills in our country due to the price of gas are estimated at € 0.006 / kWh. This price is considered as symbolic compared to other countries.

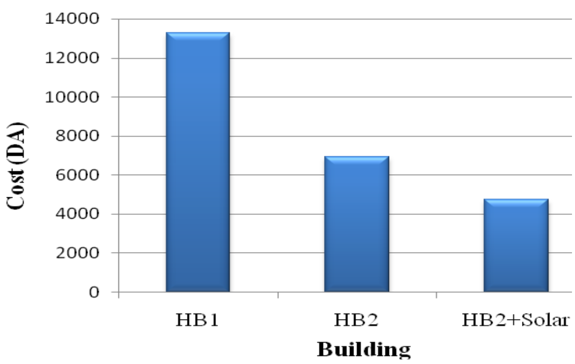

Fig.14. Annual economic analysis.

In addition, the environmental impact is not insignificant. It appears clearly in Fig. 15, that the amount of CO_2 emitted in the case of a conventional home (HB1) is about 6000 Kg / year and it is reduced by more than half in the case of a new well isolated home and it is only 2/3 in the case of a solar heating.

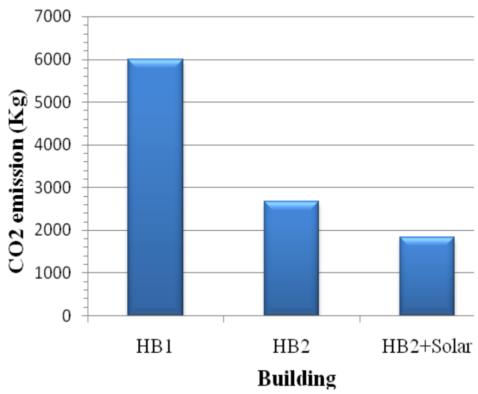

Fig.15. Annual environmental analysis.

6. Conclusion

The simulation of a solar heating for an old individual home, which the energy input is provided by solar collectors connected to central heating radiators was undertaken as part of this work. The temperature evolution of the various elements constituting the system was determined by a transitional system during successive four days.

Simulation results show that this technique of solar heating not only provides the same heat comfort generated by conventional radiators but also reduces emissions of greenhouse gas emissions by 20% while saving nearly 20% of energy, and thus reducing energy costs.

The improving of the overall balance of the old home (renovation of the envelope by isolation) has reduced heat demands and saved 45% of energy, in the case of a well isolated home containing a solar heating, the total energy savings increases by 60%.

It is obvious that in order to heat the home by radiators directly connected to the storage tank it should be used, on one hand an extra heater to provide a constant supply temperature of heating and on the other hand a regulator to control the tank temperature and the flow of water in radiators.

Finally, this technique of solar heating radiators low temperature is suitable if we cannot or do not want to install heating floors which can be difficult or too expensive to implement in renovation.

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Nomenclature

Symbols

A	area, m²
C	heat capacity, J /°C
Cp	specific heat, J/(Kg. °C)
G	global solar intensity, W/m²
K	overall heat-transfer coefficient, W/(m².°C)
K_b	building heat loss factor, W/°C
m_h	water mass flow rate of the tank inlet, Kg/s
m_l	water mass flow rate of the tank inlet, Kg/s
N_P	number of people
Q_{ven}	specific flow the ventilation, m^3/h
Q_{inf}	additional flow by infiltration, m^3/h
Q_{air}	air renewal heat losses, W/°C
Q_{tra}	transmission heat losses, W/°C
Q_{los}	total heat losses, W
Q_i	heat sources for heating, W
Q_h	building energy need for heating, W
Q_{peo}	heat gain of occupants, W
Q_{app}	heat gain from equipment , W
Q_{li}	heat gains from lights, W
q_s	sensible heat gain, W
q_l	latent heat gain, W
q	quantity of heat exchanged,W/m²
t	time, s
T_c	temperature of collector return flow, °C
T_l	temperature of load return flow, °C
T_{rs}	water supply temperature, °C
T_{re}	water return temperature, °C
T_b	indoor temperature, °C
UA	loss coefficient-area product, W /°C
$\Delta T_{\log}$	logarithmic temperature difference, °C
$\Delta T_{\log\, nom}$	logarithmic temperature difference nominal conditions, °C

Greek

γ_i	Boolean function
ρ	mass density, kg/m³
δ	thickness, m
η	dimensionless gain utilization factor
α	absorption coefficient
τ	transmittance coefficient
λ	heat conduction coefficient, W/(m .°C)

Subscript

a	ambient temperature
b	building
f	fluid
g	glass
n	insulation
i	*i*th node in the stratified storage tank
t	tubes
r	radiator
s	tank
p	plate absorber
w	window
wall	walls