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Studying, Testing and simulating floor heating solar system

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Abstract:

In this research a floor heating solar system had been studied and installed in renewable energy lab in the Mechanical and Electrical Engineering Faculty-Damascus University.
The ssystem was simulated by using Trnsys program, and experimental results were compared with theoretical results given by Trnsys .Results were so close considering thermal losses and measuring faults.
Finally project's feasibility was calculated in order to get saving rate and payback period were calculated

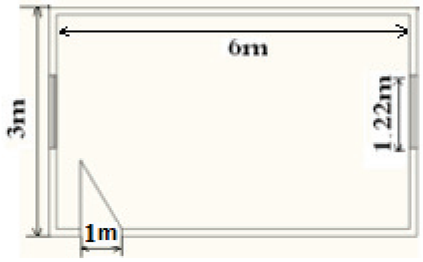

Fig .1 The study room.

Introduction

By process of time , and increasing demand for fossil ,a tendency towards renewable energy started for different uses , the most important of which is : power generation , and water heating ,by using solar power .Since , mostly, the average temperature for heating water given by solar power is [50C^0],and radiators heating need water of [70-90 C^0],temperature , as such floor heating is suitable in thermal applications .
Radiant-floor heat is commonly designed for residential applications, where ventilation requirements are often met by operable windows, and cooling is not mandatory. Other applications include large open buildings, such as airplane hangars, where providing heat at the floor is much more cost-effective than heating the entire volume of air in the space. Water in the radiant-floor loop is often around [45C°], depending on the floor finish. This is a lower

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temperature than forced hot-air systems, and reduces the energy required toheat the building. Buildings that have high ceilings, large windows, or high infiltration rates or that require high air change rates can save additional energy by using radiant-floor heat.

1. Advantages of floor heating:

1.provides required temperatures up to the height of human being in the position of standing .such advantage is quite feasible upon using it in the places of high ceilings such as mosques, churches, museums ….etc

2. Investment costs are low because water's temperature about (40-50 C^0), while temperature in other systems about [70-90 C^0].

3. Spreading thermal power in homogeneous way, as well as distributing it in the whole area, where floor heating push heat upward. This provides thermal relief.

2. Disadvantages of the floor heating:

1 - Difficult maintenance.

2 - hot air rising from the earth carries with it dust particles, which affects breathing.

3. Calculating heating load:

There are two conditions should be taken into consideration when calculating the heat load in floor heating circuit:

1-heating load is calculated for the height of two meters, and not for the whole height of the ceiling, because in traditional heating systems, the difference between the temperature of the hot air coming from the radiator and place where the person is standing leads to a difference in air density and thus the heat is transferred by Convection ,while in floor heating systems there is homogeneity in the temperature of hot air rising from the ground because every point of the ground gives the same degree. Therefore, the heat convection currents are very weak and the heat is transferred to the person by Radiation as if he were standing on the radiator [2] .

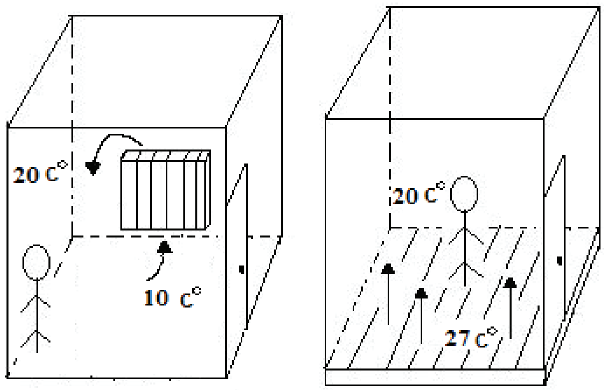


Fig .2 thermal distributions in the floor heating and traditional systems

2-heat leakage through the floor and the ceiling is not taken into consideration, because the floor is isolated by foam boards and thermal reflector and we already considered the ceiling height is two meters

After taking into account the direction of the place and

Accordingly, the heat load was calculated according to the following conditions:[3]

- outside temperature [- 2 C °] and.
- Designed internal temperature of the place [20 C °] and.
- number of ventilation times per hour.

Place heat load was calculated without insulation:

Direction	A	A_d	A_w	Δt	U	U_d	Uw	$\boldsymbol{Q_0}$	$\boldsymbol{Q_w}$	$\boldsymbol{Q_d}$	$\sum Q$	Ps1	Pz	Qt	V	Qv	Qtot
North	12	-	-	10	1.5	1.5	5.7	180	361.15	30	1192.65	5%	20%	1550.44	36	264	1814.45
South	10	2	-	10	1.5			150									
East	4.56	-	1.44	22	3.2			321									
west	4.56	-	1.44	22	1.5			150.5									

Table .1 Room heat load without isolation

Where:

[A] wall area [m]

[V] Place size. [m^3].

$[A_w]$ Windows area [m]

$[A_d]$ Doors area [m]

$[\Delta t]$ Temperature difference between inside and outside [C○].

$[U]$ walls's Transfer coefficient $[\frac{W}{m^2 C^0}]$.

$[Uw]$ windows's Transfer coefficient $[\frac{W}{m^2 C^0}]$.

$[U_d]$ doors's Transfer coefficient $[\frac{W}{m^2 C^0}]$.

$[\boldsymbol{Q_d}]$ Heat loss from doors [w]

$[\boldsymbol{Q_w}]$ Heat loss from windows [w]

$[\boldsymbol{Q_{tot}}]$ Total heat loss. [w]

Ps1, Pz Special factors for the direction of the place

After isolating the room the results were as in the following table:

Direction	A	A_d	A_w	Δt	U	U_d	Uw	$\boldsymbol{Q_0}$	$\boldsymbol{Q_w}$	$\boldsymbol{Q_d}$	$\sum Q$	Ps1	Pz	Qt	V	Qv	Qtot
North	12	-	-	10	1.5	1.5	5.7	74.4	361.15	30	637.92	5%	20%	797.4	36	264	1061.4
South	10	2	-	10	1.5			54									
East	4.56	-	1.44	22	3.2			64									
west	4.56	-	1.44	22	1.5			54.17									

Table .2 heat load to the room without the studied isolate

Fig .3 Thermal insulation boards for walls

Compared with the previous table, we find that the thermal insulation provided about [753w] , therefore the ratio of saving about 40%

3.1 **Process calculating stages:[5]**

To calculate the process we need:

1.Thermal resistance of the floor cover

$$U = \frac{1.85}{0.02} + \frac{1.4}{0.04} + \frac{1.05}{0.015} = 197.5 W / m^2 .k \quad \text{equ[1]}$$

so the thermal resistance will be

$$R = \frac{1}{U} = 0.006 m^2 .k / w \qquad \text{equ[2]}$$

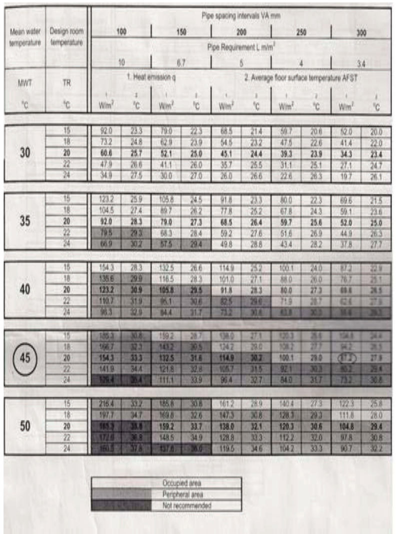
Therefore P = 300 mm = 30cm

2.design room Temperature: $t_R = 20C^0$

3.water temperature : $t_{mw} = 45C^0$

4.Specific heat flow

$$q = \frac{Q_{tot}}{A} = \frac{1061.4}{18} = 60 w / m^2 \qquad \text{equ[3]}$$



Mean water temperature	Design room temperature	Pipe spacing intervals VA mm									
		100		150		200		250		300	
		Pipe Requirement L m/m²									
		10		6.7		5		4		3.4	
MWT	TR	1. Heat emission q				2. Average floor surface temperature AFST					
		1	2	1	2	1	2	1	2	1	2
°C	°C	W/m²	°C	W/m²	°C	W/m²	°C	W/m²	°C	W/m²	°C
30	15	92.0	23.3	79.0	22.3	68.5	21.4	59.7	20.6	52.0	20.0
	18	73.2	24.8	62.9	23.9	54.5	23.2	47.5	22.6	41.4	22.0
	20	**60.6**	**25.7**	**52.1**	**25.0**	**45.1**	**24.4**	**39.3**	**23.9**	**34.3**	**23.4**
	22	47.9	26.6	41.1	26.0	35.7	25.5	31.1	25.1	27.1	24.7
	24	34.9	27.5	30.0	27.0	26.0	26.6	22.6	26.3	19.7	26.1
35	15	123.2	25.9	105.8	24.5	91.8	23.3	80.0	22.3	69.6	21.5
	18	104.5	27.4	89.7	26.2	77.8	25.2	67.8	24.3	59.1	23.6
	20	**92.0**	**28.3**	**79.0**	**27.3**	**68.5**	**26.4**	**59.7**	**25.6**	**52.0**	**25.0**
	22	79.5	29.3	68.3	28.4	59.2	27.6	51.6	26.9	44.9	26.3
	24	66.9	30.2	57.5	29.4	49.8	28.8	43.4	28.2	37.8	27.7
40	15	154.3	28.3	132.5	26.6	114.9	25.2	100.1	24.0	87.2	22.9
	18	135.6	29.9	116.5	28.3	101.0	27.1	88.0	26.0	76.7	25.1
	20	**123.2**	**30.9**	**105.8**	**29.5**	**91.8**	**28.3**	**80.0**	**27.3**	**69.6**	**26.5**
	22	110.7	31.9	95.1	30.6	82.5	29.6	71.9	28.7	62.6	27.9
	24	98.3	32.9	84.4	31.7	73.2	30.8	63.8	30.0	55.6	29.3
45	15	185.3	30.8	159.2	28.7	138.0	27.1	120.3	25.6	104.8	24.4
	18	166.7	32.3	143.2	30.5	124.2	29.0	108.2	27.7	94.2	26.5
	20	**154.3**	**33.3**	**132.5**	**31.6**	**114.9**	**30.2**	**100.1**	**29.0**	**87.2**	**27.9**
	22	141.9	34.4	121.8	32.8	105.7	31.5	92.1	30.3	80.2	29.4
	24	129.4	35.4	111.1	33.9	96.4	32.7	84.0	31.7	73.2	30.8
50	15	216.4	33.2	185.8	30.8	161.2	28.9	140.4	27.3	122.3	25.8
	18	197.7	34.7	169.8	32.6	147.3	30.8	128.3	29.3	111.8	28.0
	20	**185.3**	**35.8**	**159.2**	**33.7**	**138.0**	**32.1**	**120.3**	**30.6**	**104.8**	**29.4**
	22	172.9	36.8	148.5	34.9	128.8	33.3	112.2	32.0	97.8	30.8
	24	160.5	37.8	137.8	36.0	119.5	34.6	104.2	33.3	90.7	32.2

☐	Occupied area
▨	Peripheral area
■	Not recommended

Table .3 calculating the process in accordance with reference [5]

4. Components of the floor heating circuit

1.Surrounding insulator
2. Floor thermal insulation
3.Thermal Reflection sheets
4.Water heating pipes
5.Expansion joints
6.Concrete mixture
7.Surface coverage

Fig. 4. (a) Thermal Insulation; (b) Surrounding insulators

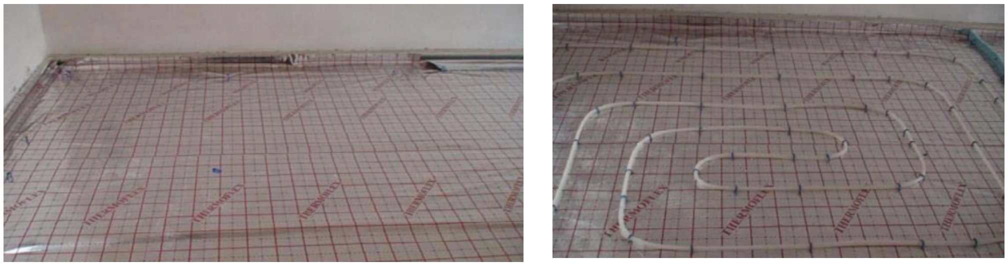


Fig. 5. (c) thermal reflectors ; (d) floor heating pipes

Fig 6.(e) concrete mixtures ;(f) expansion joints

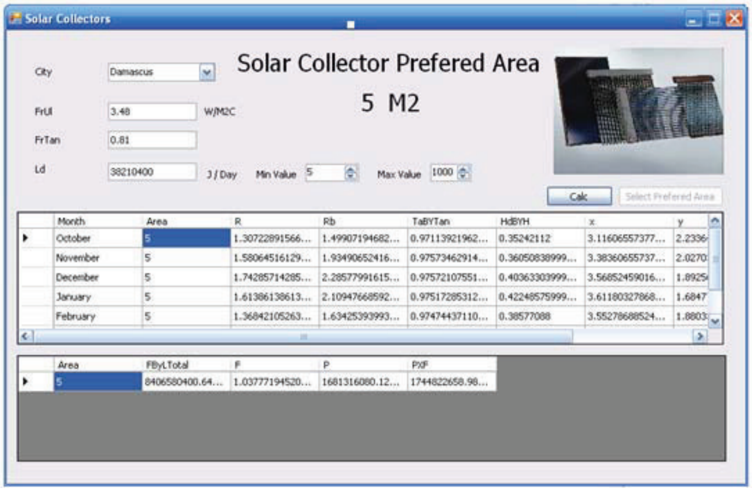
Fig .7 surface coverage

5.The area of the collectors:[7]

Collectors area was calculated using a program depends on F-CHART method .
Collector area is calculated by using a program depending on F-chart
Used collector is (Vitosol 100 sv1) from (Viessmann) with technical specifications:
$F_RU_L = 3.48$[w/m^{2}c] , $F_R(\tau\alpha)_n$ = 81 %, A= 2.5 [m^2]) .
(τα)n: outcome of permeative coefficient of collector covers multiplied by uptake of sucking panel for the vertical radiation on collector surface .
τ / τn : percentage of monthly average of sucking permeative in normal case, to the same percentage in case of regular incoming

Where:

F_R : efficiency coefficient of the heat exchanger between the collectors circuit and used water circuit .
U_{L} : Total heat loss coefficient [w/ m^2. C ^{0}] A: collector area.



City: Damascus

FrUl: 3.48 W/M2C

FrTan: 0.81

Ld: 38210400 J / Day Min Value 5 Max Value 1000

Solar Collector Prefered Area

5 M2

Month	Area	R	Rb	TaBYTan	HdBYH	x	y
October	5	1.30722891566...	1.49907194682...	0.97113921962...	0.35242112	3.11606557377...	2.2336
November	5	1.58064516129...	1.93490652416...	0.97573462914...	0.36050838999...	3.38360655737...	2.0270
December	5	1.74285714285...	2.28577991615...	0.97572107551...	0.40363303999...	3.56852459016...	1.8925
January	5	1.61386138613...	2.10947668592...	0.97517285312...	0.42248575999...	3.61180327868...	1.6847
February	5	1.36842105263...	1.63425393993...	0.97474437110...	0.38577088	3.55278688524...	1.8803

Area	FByLTotal	F	P	PXF
5	8406580400.64...	1.03777194520...	1681316080.12...	1744822658.98...

Fig .8 the window of the program appears on the computer

The program shows that the optimum area is (Ac = 5 m2) and the number of required collectors is two.

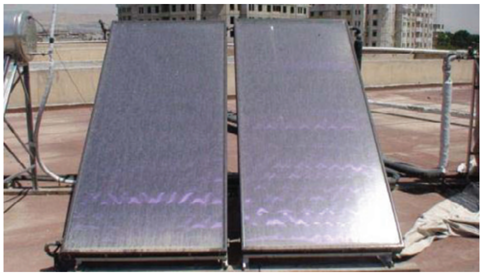


Fig. 9 the used collectors

6. System situations:

6.1. The first situation:

in the days where the intensity of solar radiation is sufficient , valves 1-2 opened and all other valves are closed , so the water will be heated by solar energy until water reach [$45C^0$],which is the temperature of which water should enter floor heating circuit , then the water goes out from the circuit to return to the thermal storage tank and make up the temperature drope and becomes [$45C^0$]again.

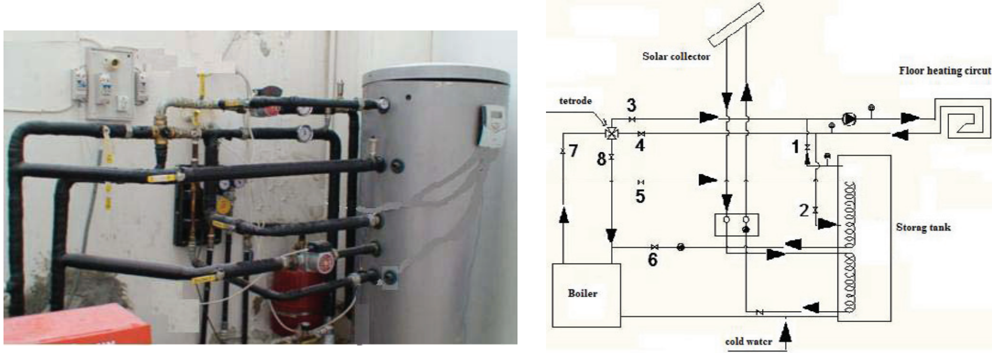


Fig .10(j) used thermal storage tank ;(k) system chart

6.2 The **Second situation:**

Sometimes when the intensity of solar radiation is low because of the clouds the solar energy will not be sufficient to make the water temperature [$45C^0$], for that assistant heater is used to raise the water temperature to the required temperature. For example, if solar collector raises water temperature to [$30C^0$], the assistant heater will raise it to [$45C^0$], so it raises it [15] degrees .To do so all valves will be closed except valves 1-2-5-6

6.3. The third situation:

When the intensity of solar radiation is very low or at night, the assistant heater is used, to do so all valves will be closed except valves 3-4-7-8, and assistant heater will heat water, which will go directly to the floor heating circuit without passing through the thermal reservoir.

7. The system output: [9]

After taking into account the thermal losses in pipes and the yield of the thermal storage tank, the maximum system output was about [18%] at 14:00pm

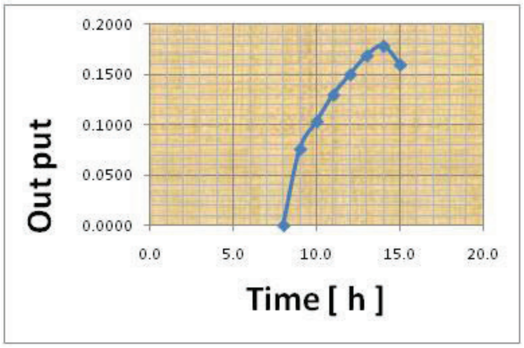


Fig .11 the highest system output18%   at 14:00

Temperature degrees were confirmed by using special Measuring Instruments to measure inlet and outlet water temperature from the collector tank. Also , temperature of room surface, as well as heating pipe s temperature were measured by infra-red camera .

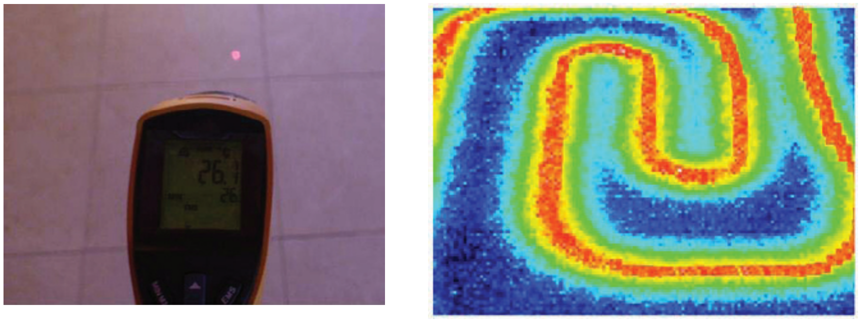


Fig .12. (m) Water temperature in the heating pipes under the ground. (n) Measuring the temperature of the floor surface

8. Simulate the system using TRNSYS Software:[10]

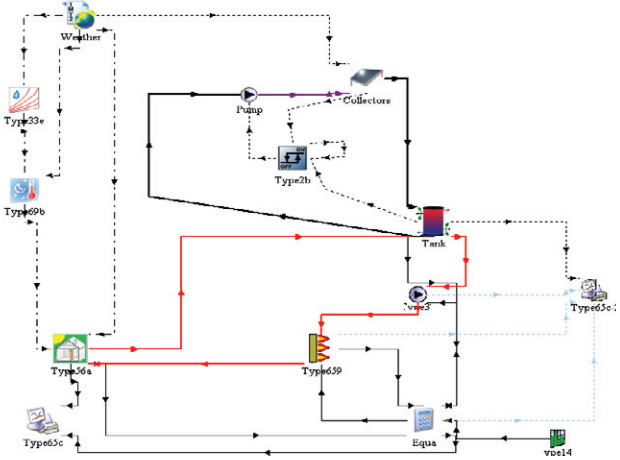


Fig.13 the link between the Types before showing the results

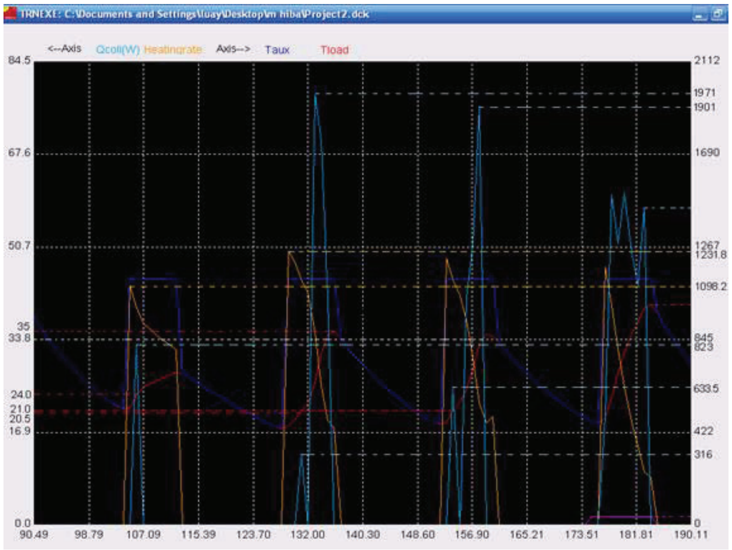


Fig.14 simulation for several days of January

TRNSYS deals with the time as hours only. The heating period extending from November 15 and until April15. For explanation, a period of January was studied.At the beginning of the fourth day the intensity of solar radiation was weak and

Where:

Tload: water temperature.

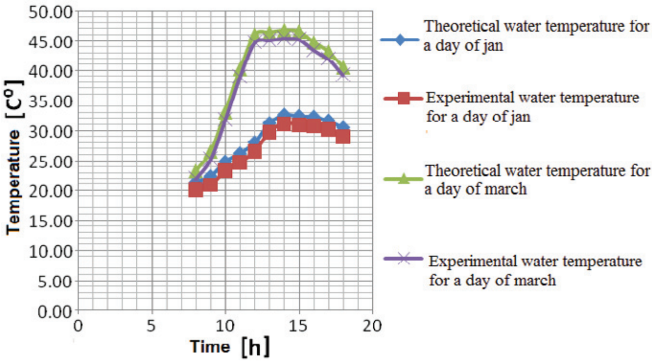
Taux: the temperature that water reaches by using auxiliary heater.

Fpump: pump capacity.

Heating rate: the energy provided from the auxiliary heater

Qcoll: energy provided by the solar collector.

energy resulting value was [823W], and water temperature was [24 C^0], so the auxiliary heater raise the temperature from [24 C^0] to[45C ^{0}] , while on the fifth day the intensity of solar radiation was unstbale , at the beginning of the day at hour number [130] the intensity of solar radiation was low and the value of resulting energy [316W]water heated by solar energy until[24 C^0] so the auxiliary heater raise the temperature to[45C] then at about [132] solar radiation increasing suddenly and the energy was [1917W] and that was enough to make the water temperature [45C ^{0}] .



. Fig.15 experimental and theoretical temperatures for 20/01/2009 and 22/03/2009

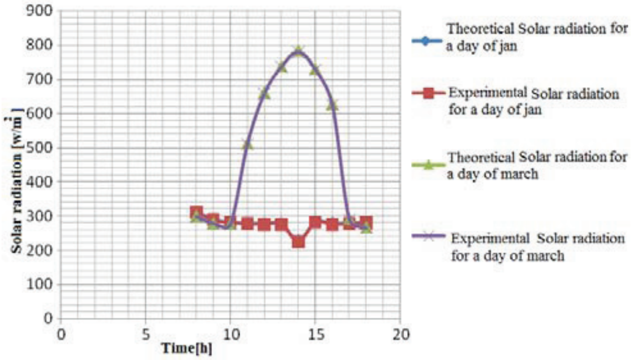


Fig .16 experimental and theoretical solar radiation for 20/01/2009 and 22/03/2009

By comparing the charts we find that theoretical and experimental results are close and this indicates that the implementation is correct, taking into consideration the losses and measuring errors.

9. Economic study for the solar thermal system

9.1. Establishing costs for the solar system: [9]

Name of the material	Used amount	unit price [s.p]	Total price [s.p]
Solar collector	2	20000	40000
Boiler	1	35000	35000
Pump	2	3800	7600
Thermal insulated tank	1	45000	45000
Tubes	60	100	6000
Valves	8	700	5600
T-valve	20	100	2000
Non-return valve	1	700	700
Installation fees		10000	
Total		141900 [sp]	

Table .4 the basic elements of the solar system with the approximate price of each.

9.2. Constituent costs for the traditional systems:

Name of the material	Used amount	unit price [s.p]	Total price [s.p]
Boiler capacity	1	40000	40000
Burner 3[kg/h]	1	16000	16000
Diesel tank 500[lit]	1	5000	5000
Electricity Panel	1	6000	6000
Chimney	1	35000	35000
Installation fees		12000	12000
Non-return valve	1	1500	1500
Accessories		6000	
Total		121500	

Table .5 elements of the traditional system and the approximate price of each.

9.3 investment costs for the solar system: [10]

It includes the cost of annual maintenance and the cost of energy provided by the auxiliary heater when it works during the weak solar radiation in addition to the electric power consumed by the pump So, the investment cost of the solar system is :

Csola=300+ 3000 +444 = 3744 [sp/year]

9.4 The investment costs of traditional systems: [9]

The investment costs include annual maintenance costs , the price of the electricity consumed by the burner ,and the Price of the fuel used during the period of heating .

Ctr-inv= 3000 + 2145+8000 = 13145 [sp / year]

9.5. Pay back period:

By using the solar system, we get savings in investment cost, which is estimated by the difference between the costs of two systems and calculate savings as follows:
Annual savings in investment cost = investment cost of the traditional system - investment cost of the solar system.
S=13145 - 3744 = 9401 [sp / year]

Payback period = (the difference between the establishing costs of the solar and traditional system) / annual savings.
Pp= (141900-121500) / 9401 = 2.1[year]
we notic that the payback period is about two years.

Conclusions:

1. Considering the height of the ceiling as two meters , a lot of energy is saved
2. In this research, practical and theoretical results were close, indicating the validity of the study and implementation
3. We've noticed that the thermal insulation has saved about [40%] of consumed fuel annually.

Recommendations:

1 - Increase citizen's awareness about the importance of solar energy environmentally and economically.

2 - Reduction the price of solar energy equipments through the reduction of customs duties and taxes imposed on it.

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