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Thermal Collector for Water and Space Heating System in Egypt

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Abstract. Solar energy for water and space heating is one of the effective methods to reduce conventional energy requirements for remote area buildings. In winter, a heating system for building is needed to compensate the heat loss, to maintain the comfortable temperature and to provide hot water for inhabitant. This report proposed and devolves a typical water and space heating system. This system is composed of a solar collector and biogas fuel which are designed to provide the suggested building (i.e hospital building) with the required thermal energy to obtain hot water and suitable hot air to make building warmer during winter season. A stand alone photovoltaic (PV) system is designed to supply the different electrical loads of the heating system.

Keywords
Solar energy, solar collector, radiator, water heater

1. Introduction

Today, solar heating is becoming more important than ever before. Natural gas and oil, which are burned to heat our building and water, are limited. As reserve of gas become more expensive. If more people began using solar heating systems, fossil fuels such as oil and gas would become less expensive and last longer. Burning natural gas and oil in our heating systems also causes air pollution. Even electric

water and space heaters cause air pollution indirectly, because coal and natural gas are burned to produce electricity in large power plants. If more people use solar energy to heat the air and water in their buildings, our environment would be cleaner. Space heating generally refers to the provision of comfort heating in an occupied building during winter seasons. It is accomplished by the use of special equipments called radiators. Solar water heating system is used to transfer the energy from the sun into the domestic water [1,2]. In this paper we introduce the basic concepts of the proposed water and space heating system. In this system, solar energy as a form of electricity is utilized to supply the proposed electrical loads of the hot water and space heating system with the required power. While solar and biomass energies as a form of heat are used to provide the building with the required thermal energy for water and space heating. In this context, the proposed work presents and design a thermal collector hot water and space-heating system to operate in emergency hospital building in a remote area in Egypt .

2. The Proposed Thermal Collector Hot Water And Space Heating System Components

The block diagram of the the hot water and space heating system is shown in Fig.1. Where, in this case, the heating process is accomplished in a remote site of Sante Catherine, which is far from the national grid of Egypt.

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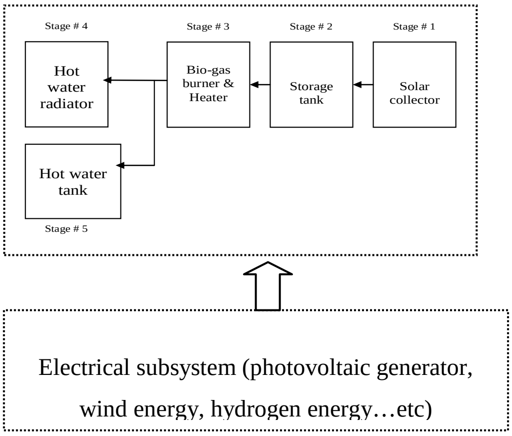


Fig. 1 Block diagram of the global heating system.

This thermal subsystem of the hot water and space heating system consists mainly of components or stages. Stage # 1 represents the main source of heating in the thermal system. Where, in this stage a clean source of energy, which is a solar collector, is used to directly utilize the sun's energy. In this way the thermal energy from the sun can be transferred to the heat transfer fluid, which is chosen to be the water. In stage # 2 the thermal energy of the water gained from stage # 1 is stored in a suitable storage tank. The output water from the tank carries certain amount of thermal energy with a specified temperature. Stage # 3 represents the auxiliary source of heating the water, through using a bio-gas burner and heater. Where, this stage will be effective only when the outlet temperature of the water from the tank is lower than a predetermined value; and this usually occurs during the periods of clouds or during the night period. Therefore, stage # 3 will be considered as a conventional pipe, if the outlet temperature of the water from the tank is greater than or equal to the required hot value. While, in stage # 4 a hot water radiator is utilized to transfer a certain amount of the thermal energy of the hot water to the building. In stage # 5 a hot water tank is used to supply the hot water to the hospital building.

The electrical subsystem of the hot water and space heating system is utilized to supply the required electrical energy to the heating system. This subsystem can contain any type of renewable energy resources (i.e. photovoltaic generator, wind energy, hydrogen energy…etc). in this work, the PV generator is considered to be the main source of electrical energy of the subsystem, while the lead acid battery is considered to be the auxiliary source and at the same time is the storage medium of the electrical energy

3. System Design

The design and the selection of each component of the thermal collector hot water and space heating system plays an important role in the system reliability, safety, cost and maintenance. Size, type and material of each component are the most important parameters, which should be considered .

A. Design of the Thermal Subsystem

This section presents the design of the thermal subsystem in the following steps:

- Determine the space heating load required for each room in the hospital building.
- Calculate the radiator heating area and the radiator dimensions.
- The hot water consumption in the hospital building is used to determine the hot water load and the water capacity.
- The value of the total heat load (space heating load + water heating load) is used to calculate the mass flow rate of the solar thermal collector and area.

B .Space heating load calculation

Before designing a heating system, one must estimate the amount of heat which is lost from the building. There are two sources of heat loss from a building fabric heat losses and ventilation heat losses. Fabric heat losses are losses directly through the walls, windows, doors, floors and ceiling of the room. For ease of calculation, it is assumed that these losses are at a uniform rate through each surface. Fabric heat losses can be calculated from the following equation [3,4]

$$Q_f = A_s * (t_i - t_o) * 'U' \qquad (1)$$

Where

Q_f Fabric heat loss rate (k .cal / hr).

A_s Area of each individual surface (m_2).

$(t_i - t_o)$ The design temperature difference(^oC).

'U' The heat transfer coefficient (k .cal/ hr.m_2 . ^oC).

Ventilation heat losses are caused by the air flowing through a building. Ventilation rates are usually quoted in air changes per hour which is defined as the volume of the air flowing through the room in one hour divided by the actual volume of the room itself. This air clearly needs to be heated by the space heating system and the heat required (Q_v) is calculated as follows [3]:

$$Q_v = C * ACH * (t_i - t_o) * HCA \qquad (2)$$

where

Q_v The Ventilation heat losses (k .cal / hr).

C The volume of the room m^3.

ACH The air change rate.

HCA The heat capacity of air (k .cal / hr .m^3 .^oC).

C . Design of radiators

There are different types of radiators (i.e cast iron, steel and aluminum radiators). A summary of typical ratings for different types of radiators for a temperature difference, water to air, of 60 oC is included in Table.1. These ratings may be recalculated using Table 2 for 30 oC as in case of our application. The most commonly used type is the steel radiators. Steel is more susceptible to corrosion than cast-iron. The particular merits of steel radiators result from their small mass and their comparatively narrow waterways: they are light to handle on a building site and respond quickly to temperature control. Two types are selected to be used in our application, the radiant panel type for small rooms and a tubular type for medium and large rooms as shown in Fig. 2.The space heating load curves for the hospital building is shown in Fig. 3.

Table 1 Emissions from radiators for a temperature difference air to mean water of 60 ^oC .

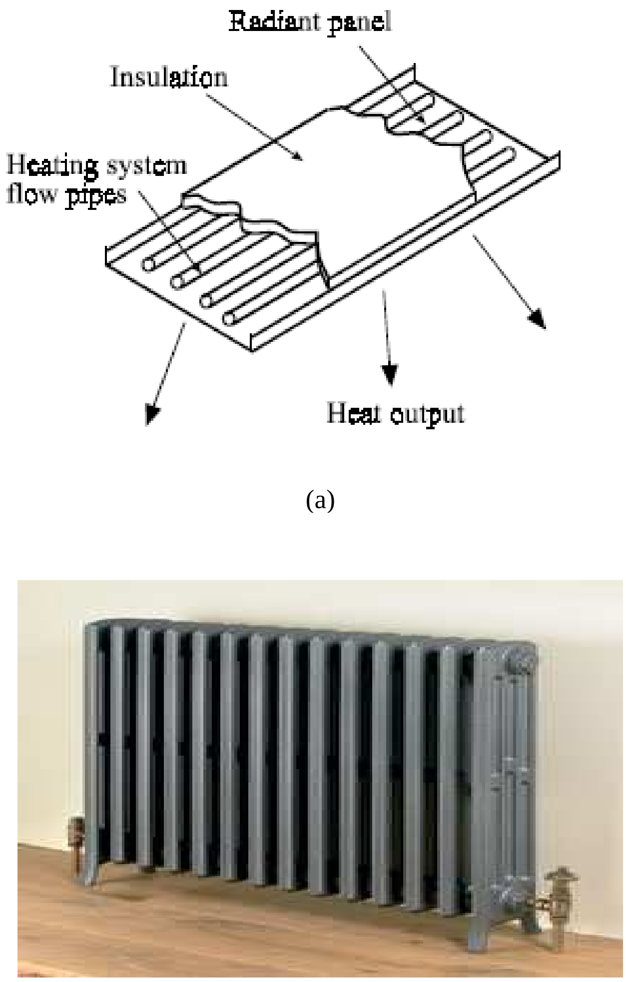
Radiator		Dimensions (mm)		Range of emissions of elevation (k.cal/hr .m^2)*10^3
Type	pattern	Depth	Range of heights	
Cast iron sectional (open)	2- column 4- column 6- column	70 160 250	430- 980 430- 980 280	1.61-1.80 2.93-3.08 4.67
Cast iron sectional (flat front)	2- column 4- column 6- column	71 161 251	430- 980 430- 980 280	1.97-1.99 3.45-3.5 5.17
Radiant panel		35	500- 900	0.99-1.04
Steel tubular with headers	40 mm crs for elements 60 mm crs for elements	98 166 98 166	400- 1000 400- 1000 400- 1000 400- 1000	2.52-2.68 4.44-4.55 1.68-1.8 2.95-3.04
Aluminum sectional with flat panel front	Open top Closed top	95 160	430- 690 285- 435	3.89-4.0 5.74-5.79
Aluminum finned unit in casing	With damper at base	30	300- 750	2.51-2.55

Table 2 Correction factors for power emitted from radiators .

Δ t(°C)	0	1	2	3	4	5	6	7	8	9
30	0.41	0.43	0.44	0.46	0.48	0.49	0.51	0.53	0.55	0.57
40	0.59	0.61	0.63	0.65	0.67	0.69	0.71	0.73	0.75	0.77
50	0.79	0.81	0.83	0.85	0.87	0.9	0.92	0.94	0.96	0.98
60	1.00	1.02	1.04	1.07	1.09	1.11	1.13	1.16	1.18	1.2
70	1.23	1.25	1.27	1.30	1.32	1.34	1.37	1.39	1.41	1.43
80	1.45	1.48	1.50	1.52	1.55	1.57	1.59	1.62	1.65	1.67

1 Temperature difference air to mean water.

2 Correction factor at temperature difference (Δ t) =43 ^oC



(a)

(b)

Fig.2. Steel type radiator: (a) Radiant panel. (b) Steel tubular with headers.

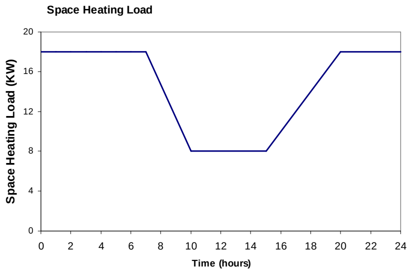


Fig. 3 Space heating load for the hospital building.

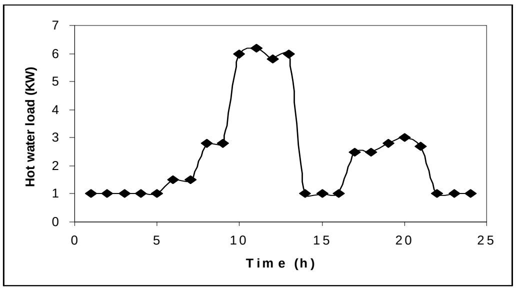


Fig. 5 Hot water heating load in hospital

D. Design of water heating system

A small steel heat exchanger inside a stainless steel tank, as shown in Fig. 4 transfers heat from the collector side to the domestic hot water. The tank consists of steel cylindrical vessel insulated by a layer of 7 cm of glass wool and the other casing cover is aluminum. Water heating load level, is shown in Fig. 5, depends on the dimensions of the stainless steel tank, the user activities and the habits (for how long, how much water one use). Table 3 shows the hot water consumption for the hospital building and the corresponding maximum heat load.

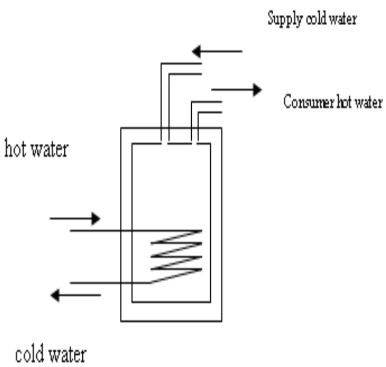


Fig. 4. Water heater.

Table 3 Daily hot water consumption for the hospital building.

Building	No. of persons	Hot water consumption / person (L/day)	Total consumption (L/day)
Hospital	30	30	900

E. Design of solar thermal collector

This type of a solar water heating system consists of a flat-plate solar collector, and a vertical storage tank. There are two gate valves one at the cold water inlet and the other at the hot water outlet. A small pump is used to force water to realize a closed loop. The flat-plate collector consists basically of an absorbing surface, an insulation layer, anodized aluminum section casing and a transparent cover.

The mass flow rate of hot water circulating in the collector heating system can be calculated from the heat load equation[5].

$$Q = m_w * \Delta T_W * 500 \qquad (3)$$

where

Q Heat load (BTU / hr) (= 24KW = 24 * 10^3 * 3.4122 BTU / hr).

m_w Water mass flow rate (Gal / min).

ΔT_W Water temperature difference in (^oF) (= 30 ^oC = 34 ^oF).

Table 4 shows the technical data of the solar collector .

Table 4 Technical specification of solar collectors.

Number of rows	Number of collectors in the row	Net absorbing area		Optimal flow rate		Total pressure drop ΔP across the collectors row water H_2O head			Main pipes on the roof inside diameter inch
		M^2	Ft^2	Lit / min	GPM	cm	inch	PSI	
1	1	2.1	22.6	2.1	0.55	0.1	0.04	0.001	1/2
1	2	4.2	45.2	4.2	1.10	0.51	0.2	0.007	1/2
1	3	6.3	67.8	6.3	1.66	1.00	0.39	0.014	1/2
1	4	8.4	90.4	8.4	2.21	2.82	1.11	0.04	1/2
1	5	10.5	113.0	10.5	2.77	6.60	2.6	0.094	1/2
1	6	12.6	135.6	12.5	3.30	13.05	5.14	0.19	1/2
1	7	14.7	158.2	14.7	3.88	20.9	8.23	0.30	1/2
1	8	16.8	180.8	16.8	4.43	30.8	12.13	0.44	3/4
1	9	18.9	203.4	18.9	4.99	44.0	17.32	0.63	3/4
1	10	21.0	226.0	21.0	5.55	60.5	23.80	0.86	3/4
1	11	23.1	248.6	23.1	6.10	79.2	31.20	1.13	3/4
1	12	25.2	271.2	25.2	6.65	104.5	41.14	1.49	1
1	13	27.3	293.8	27.3	7.21	132.0	52.00	1.88	1
1	14	29.4	316.4	29.4	7.76	165.0	65.00	2.35	1
1	15	31.5	339.0	31.5	8.32	198.0	78.00	2.82	1
1	16	33.6	361.7	33.6	8.87	242.0	95.30	3.44	1
1	18	37.8	406.9	37.8	9.98	381.0	150.00	5.42	1 1/4
1	20	42.0	452.1	42.0	11.09	528.0	208.20	7.51	1 1/4
1	22	46.2	497.3	46.2	12.20	707.0	278.30	10.05	1 1/4
1	24	50.4	542.5	50.4	13.31	922.7	363.00	13.10	1 1/4
1	26	54.6	587.7	54.6	14.42	1168.5	460.00	16.63	1 1/4
1	28	58.8	632.9	58.8	15.53	1476.0	581.10	21.00	1 1/4
2	56	117.6	1266.0	117.6	31.07	1514.0	596.1	21.54	2
3	84	176.4	1899.0	176.4	46.60	1552.0	611.0	22.10	2
4	112	235.2	2532.0	235.2	62.14	1590.0	626.0	22.63	2 1/2
5	140	294.0	3165.0	294.0	77.67	1628.0	641.0	23.17	3
6	168	352.8	3798.0	352.8	93.21	1666.0	656.0	23.71	3
7	196	411.6	4430.0	411.6	108.74	1704.0	671.0	24.25	3

IV. RESULTS AND DISCUSSIONS

The Specifications of different components of the thermal collector hot water and space heating system are illustrated. The complete dimensions of the selected radiators needed in each room, the area of the collector and the corresponding heat load in the hospital building are shown in Table 5 . The different specifications of the water heater are included in Table 6. The specification parameters of the flat-plate solar collector have been tabulated in Table 7. From table4 the area of collector according to the calculated value of mass flow rate is equal to 58.8 m^2. The absorbing surface is made of aluminum. It is painted by a black color, and insulated from bottom and sides by 4 cm polyurethane insulation layer to reduce heat losses to the surroundings. Also to minimize the heat losses from the upper collector surface due to the re-radiation and convection, an absorber plate is provided with a transparent cover. This cover must be capable of transmitting almost all solar radiation as possible. A glass sheet with 3 mm thickness is fixed 3 cm above the absorber. The storage tank consists of steel cylindrical vessel of 44.6 cm diameter and 132 cm height. It's insulated by a layer of 7 cm of glass wool and the other casing cover is aluminum. The complete dimensions of the tank are shown in Fig. 8. Different specifications of the storage tank are included in Table 8.

Table 5 Typical space heating load and radiator specifications for hospital building.

Room Description	Room area (m^2)	Estimated heat load (kcal/hr) $*10^3$	Design heat load (kcal/hr) $*10^3$	Radiator Type	Heater Area (m2)	Radiator Dimensions (mm)		
						Depth	Length	Height
Reception	6*4.2	1.388	1.376	Steel tubular with headers	1.312	98	1312	1000
Sterilization and Reviving rooms	6*4.2	1.138	1.118	Steel tubular with headers	1.066	98	1066	1000
Surgery room	6*6	1.587	1.548	Steel tubular with headers	1.476	98	1476	1000
Intensive care room	4.2*4.8	1.108	1.118	Steel tubular with headers	1.066	98	1066	1000
Nursing room and kitchen	3*4.8	0.581	0.602	Steel panel with coil	1.449	35	1610	900
Patient room1	4.8*6	1.372	1.376	Steel tubular with headers	1.312	98	1312	1000
Patient room2	4.8*6	1.303	1.290	Steel tubular with headers	1.230	98	1230	1000
Pharmacy	5.4*4.8	1.2	1.204	Steel tubular with headers	1.148	98	1148	1000
Bath rooms 1 &2	3*4.8	0.635	0.602	Steel panel with coil	1.449	35	1610	900
Execution room	4.2*4.8	0.982	0.946	Steel tubular with headers	0.902	98	902	1000
Stores 1&2	2.4*2.4	0.279	0.258	Steel panel with coil	0.621	35	690	900
Main corridor	3*18.6	2.421	2.408	Steel tubular with headers	2.296	98	2296	1000
Secondary corridor	2.4*22	1.586	1.548	Steel tubular with headers	1.476	98	1476	1000
Entrance	3.6*4.8	0.585	0.602	Steel tubular with headers	0.574	98	574	1000

Table 6 Specifications of different constituents of the water heater.

Item	Specification
a- Hot water tank	
- Material	Stainless steel
- Volume	900 liter
- Dimensions	225 cm * 75 cm
b- Insulation	
- Type	Glass wool
- Thermal conductivity	0.034 W/Mk
- Thickness	7 cm
- Density	13 Kg/m^3
c- Heat exchanger	Steel

Table 7 Specification of different components of the flat plate solar collector.

Item	Specifications
a-Absorber plate:	
material	Aluminum
Mechanical process	Roll-bond absorber
Dimensions	1m * 2 m
Number of channels	5 tubes
Thermal conductivity	237 W / mk
b-Coating	
Type	Selective coating
Absorbitivity	90%
Emissivity	20%
c-Back and side insulation	
Type	Polyurethane
Density	14 Kg / m^3
Thickness	4 cm
Thermal conductivity	0.0245 W / m k
d- Transparent cover	
Type	Thermal glass
Properties	Shatter resistance
Transmittance	75 %
Thickness	3 mm
Air gap	3 cm
e- Casing	
Type	Anodized aluminum sec

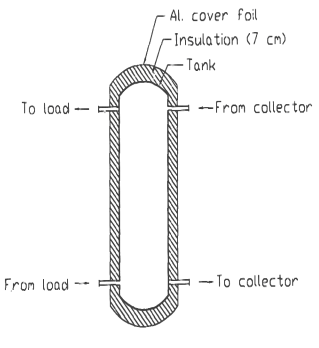


Fig. 8 The storage tank

Table 8 Specifications of different constituents of the storage tank.

Item	Specifications
Storage tank -a	
- Material	Coated steel
- Volume	2000 liter
- Dimensions	300 cm * 100 cm
Insulation -b	
- Type	Glass wool
- Thermal conductivity	0.034 W / mK [37]
- Thickness	7 cm
- Density	[37] ^{2} 13 Kg / m

4. Conclusion

The thermal collector hot water and space heating system is the best and clean system to satisfy the energy needs in remote area buildings. We conduct a design analysis of the thermal collector heating system components and apply to a hospital building in a remote site of Sante Catherine in Egypt as a case study. The design parameters and specifications of each component are determinated.

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