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EVALUATION OF ENERGY AND CO_2 SAVINGS OF AN INSTITUTIONAL COLLECTIVE SOLAR WATER HEATING SYSTEM IN PALESTINE

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ABSTRACT

The collective solar water heater (SWH) system of the main cafeteria of Birzeit university - Palestine is evaluated in this paper in terms of utilized energy and the corresponding CO_2 savings. The system is equipped with required sensors and data logger which is scanned remotely by telephone line using tele-monitoring system.

The utilized energy using the collective solar SWH system and the environmental protection offered by this most widely renewable energy application is presented. The results show that by using solar energy considerable amounts of greenhouse polluting gasses are saved.

The effectiveness of the system is calculated and it is found to be highly dependent on the consumption rate of water with other factors. The consumption rate is low compared to the capacity of the system which consequently degrades the efficiency. This is approved in the presented case study of a Crown Plaza Hotel- Amman which showed a higher CO_2 savings with fewer collectors area.

Keyword: collective solar water heater (SWH), environmental impacts, CO_2 savings , tel-monitoring system .

1 INTRODUCTION

The shortage and high prices of energy sources have become a major obstacle to economic growth in Palestine. The imported fossil fuels and electricity continue to be one of the main problems to Palestinian economy. Palestine imports all its needs of petroleum products from Israeli market and about 92% of electrical energy from the Israeli Electric Corporation [PCBS 1999].

Solar water heaters (SWH) are extensively used in the residential sector in Palestine, in which 68.2% of households use solar family systems. Whereas, it is limited in the service and industry sectors. The existing installed capacity in all sectors is totaled to 1,533,000 m² of which 7100 m² in the service sector. This can produce 650 GWh annually with corresponding CO_2 savings of 395,000 tons per year [PEC 2007].

The energy consumption in service and building sector in Palestine and in all other developing countries represents a major part of energy bill, approximately equal to 75% [PEA 2010], in which hot water production and space heating have the maximum share. The electric water heating consumes the most electric power and emits the most pollutants during its life cycle [Taborianski and Prado 2004].

Palestine lies on the western edge of the Asian continent on the eastern extremity of the Mediterranean sea, between 34°20'– 35°30' E and 31°10'– 32°30' N. The population of Palestine in 2009 was 3,935,249 inhabitants [PCBS 2010].

About 99.8% of the Palestinian population has access to grid electricity [PCDB 2008], with a small percentage is electrified by decentralized diesel generators. Few PV systems (70 kWp) were installed to provide electricity for some rural houses and street lighting including schools, clinics, mosques and some small communities.

Fig.1 illustrates Total primary Energy Supply (TPES) in the period between 1995 - 2004.

Fig.1 here

Total Final Energy Consumption (TFEC) by fuel type and sector for the year 2004 is presented in Fig. 2.

Fig.2 here

The monthly average solar energy of three different locations in Palestine is shown in Fig.3 (Ibrik 2007).

Fig. 3 here

This paper is arranged as follows: Section 2 describe the collective SWH system of Birzeit university . Section 3 presents the measured data and discussion. Sections 4 and 5 calculates the utilized energy and corresponding environmental benefits, respectively. The conclusion is presented in section 6.

2. DESCRIPTION OF COLLECTIVE SWH SYSTEM

The collective SWH system provides the main cafeteria of Birzeit university with hot water. An auxiliary boiling system is installed to compensate the deficiency of water temperature in case of low radiation . The cafeteria serves around 7000 students. The system layout is shown in Fig.4.

Fig.4 here

The collective SWH system is south-facing 45˚ slant with 148 m^2 total collectors area, with 5 well- insulated 3000 Liters storage tanks each. The connection steel pipes are 2 inch diameter. An external flat plate heat exchanger is used.

A tel-monitoring unit was installed in the above described system by Palestinian Energy Center (PEC) sponsored by European Commission under MEDA project. The data were collected remotely using a special data logger connected with telephone lines. The data logger was installed on the solar system in addition to required measuring sensors.

The data is scanned every 10 minutes, it can record and store data for the last 10 days. Then data is processed by a special software programmed for this kind of application [MEDA project 2001].

Components of the data logger system are illustrated in the Fig. 5:

Fig.5 here

Positions of the various sensors are illustrated in Fig.4. The measured data: solar radiation (W/m^2), cold water temperature (TEF-°C), solar tank outlet temperature (TSS-°C), collector outlet temperature (TSC-°C). or heat exchanger inlet temperature on the primary circuit, back up solar temperature (TSA-°C), flow rate (Liter /10 min), primary and secondary pump operation.

3. MESUREMENTS AND DISCUSSION

Figs. 6-a, 6-b, 7-a and 7-b show the experimental results of a ten days obtained during March 25 at local time 12:10 PM until April 3,2006 at local time 11:58 PM.

Fig.6-a here

Fig.6-a show the values of temperature at different position of collective SWH system in addition to hot water consumption and duration time of primary pump in the periods extends from 25 March until 30 March.

Fig. 6-b here

Fig. 6-b shows the corresponding solar radiation of the same period with the solar tank (TSS) and collector exit (TSC) temperatures. Those temperature values are already shown in Fig. 6a and they are re-shown in Fig.6-b to illustrate the relationship between them and the solar radiation which is clear from the consequence of both dips in collector exit temperature (TSC) and solar radiation.

In fact the cold water (TEF) and the solar tank temperatures are the most important values that determine the amount of heat energy that can be utilized from the sun.

Fig. 6-b shows the amounts of solar radiations each 10 minutes for a 5 days. In general the solar radiation distribution follow the average values of Palestine as can be indicated from Fig.3.

Fig.7-a here

Fig.7-b here

Figs. 7-a and 7-b resemble the Figs. 6-a and 6-b, respectively. But the formers describe the experimental data of the period extends from 30 March until 3 April.

This study analyzes only the data from 8:00 AM to 4:00 PM, because it is mostly the effective period for any SWH system in Palestine as well as this is the working period of our field study.

4. ENERGY UTILIZED FROM COLLECTIVE SWH

The collective SWH system is used as a pre heater to electric/diesel boiler. This study is based on both energy sources of boiler.

The input energy in solar collectors can be calculated equation (1).

$$E_{in} = I.\Delta t.A_{tot}/1000 \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where:

E_{in}: Solar energy input to collector, kWh;

I: Solar radiation, W/m^2

Δt: The time, hours;

A_{tot}: Total area of the collectors, m^2.

The energy utilized from collective SWH can be calculated from equation (2):

$$E_{collect} = \Delta T C_p \dot{m}\, \Delta t = (T_{TSS} - T_{TEF}) C_p \dot{m} \Delta t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

$E_{collect}$: solar water heater Energy, kWh;

ΔT: Temperature gradient, °C;

T_{TSS} : Solar tank temperature, °C;

T_{TEF}: Cold water temperature, °C;

Cp: Specific water heat, kJ/kg °C;

$\dot{m}$: hot water flow rate, kg/h.

The total energy utilized to heat the water is calculated using equation (2) and it is found to be 1158 kWh for the period of ten days at the specified working hours (8:00AM - 4:00PM) . The energy consumed by primary pumps are already subtracted from the total utilized energy. The total solar radiation energy input of collectors is calculated using equation(1) and it is found to be 6523.322 kWh.

Figs 8-a and 8-b illustrate the relation between the energy produced from solar collectors and the input solar energy. A great difference between the solar energy absorbed by the sun collectors and the utilized energy in heating water.

Fig.8-a here

Fig.8-b here

In general, the instantaneous effectiveness of solar system can be calculated from the following relation:

$$\eta = \dot{m}\, C_p \frac{(T_{SS} - T_{EF})}{A_{tot} G_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots. \quad (3)$$

Where G_t is the instantaneous solar radiation in W/m^2.

It is clear from the above discussion that the amount of water consumption has a great effect on the effectiveness of the system. This effect is depicted in Fig.9 which illustrates part of the experimental results of the case study. It shows the strong dependence of the system effectiveness on the hot fluid mass flow rate. The maximum values of effectiveness are approximately 50% which are reached when the water consumption rate higher than 170 kg/10 min.

Fig. 9 here

The input solar energy depends only on the solar radiation as the total area of the collectors is constant. The energy produced by the collectors depends on the amount of energy produced from the sun as well as on the temperature difference between the cold water and the solar tank temperature. This variation in temperature doesn't depend only on the solar energy, but also conversely depends on the rate of water consumption.

5. ENIVRONMENTAL BENFITS

In fact, measuring or evaluating the financial impact resulted from the huge burning of conventional energies is simple when they affect tradable goods; but this is complicated when it comes to non-tradable goods like human health and ecosystems [Kalogirou 2009].

This study, estimates the environmental impacts from the operation of collective SWH system in Birzeit university without estimating the manufacturing impacts. Therefore, it is assumed that the gas emissions produced from the operation of solar system is zero, because this study estimates the gas emissions produced in case the utilized solar energy is delivered from electric and diesel boilers.

To investigate the environmental benefits of utilizing solar energy instead of conventional sources of energy, air pollution saved derived from the reduction in consumption of electricity and/or diesel, conventionally used for water heating in Palestine, are to be evaluated.

It is easy to translate the amounts of energy saved into the corresponding amounts of air pollution saved by using special equations designed to each specific type of pollutants [Kalogirou 2004].

Table 1 illustrates the average energy utilized from solar water heater in 10 days measurements and the corresponding energy required from diesel/electric boiler.

Table 1 here

This amount of energy in case it is taken from diesel or electric boiler could save significant quantities of gas emissions mainly carbon dioxide (CO_2) which is considered the main player of greenhouse gases. The CO_2 saved emissions by utilizing collective SWH is shown in Fig.10

Fig.10 here

Fig.11 shows the amounts of saved emissions of other pollutants types.

Fig.11 here

From the above results, the capacity of system is overestimated if it is compared with the load. To explain this point, the results of a case study implemented by [NERC 2004] to evaluate the energy and air pollution saved from a 10 days utilization of collective SWH of Crown Plaza Hotel in Amman is shown up.

This hotel includes more than 180 rooms distributed out of 12 floors and several restaurants. The demand for hot water consumption is more than $50m^3$/day. The collectors area of the system is 92 m^2 and south oriented at 30˚slant with fuel oil auxiliary heating. The case study was held on July 2004.

Table 2 illustrates the amounts of energy that can be utilized in 10 days from SWH in additions to the amounts of energy needed in case energy is taken from diesel and electric boiler.

Table 2 here

The CO_2 saved emissions by utilizing collective SWH is shown in Fig.11, while Fig.12 shows the amounts of saved emissions of other types of pollutants.

Fig. 12 here

Fig. 13 here

6. CONCLUSION

The utilized heat energy from the Birzeit university collective SWH system in 10 days, measurements period, is 1158 kWh and the corresponding savings in CO_2 emissions are 585 and 1163 kg in case of using diesel and electric boilers, respectively.

The energy utilized from the collective solar water heater system of Birzeit university case study is not big enough compared to the capacity of the system and this is mainly due to low hot water consumption and to some extent to the location of the system and. This explains the lower amounts of utilized energy than that of Crown Plaza Hotel (2038.86 kWh/10days) case study which has less collectors area.

Collective SWH systems have a good potential to reduce gas emissions which are considered an important factor to evaluate the performance of any energy system. The results show that by using solar energy, considerable amounts of greenhouse polluting gasses are saved.

The investigated system give positive and very promising performance and financial characteristics. Therefore, utilizing the collective solar heating are efficient, cost effective and friendlier to the environment.

The reduction of greenhouse gasses pollution is the main advantage of utilizing solar energy. Therefore, solar energy systems should be employed whenever possible in order to achieve a sustainable future.

Collective SWH systems technology usage is very limited in service sector in Palestinian due to the lack of awareness within consumers about the significant profit that could be gained in energy saving and gas emissions reduction.

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LIST OF TABLES

Table 1: Energy utilized in ten days measurement- Birzeit university,Palestine

Energy utilized / needed	Kwh/10days
Energy utilized From SWH	1158
Energy needed from Diesel boiler with 80% efficiency	1447
Energy needed from electric boiler with 90% efficiency	1286

Table 2: Energy utilized in ten days measurement – Crown Plaza Hotel, Amman

Energy utilized / needed	Kwh/10days
Energy utilized From SWH	2038.86
Energy needed from Diesel boiler with 80% efficiency	2265.4
Energy needed from electric boiler with 90% efficiency	2265.4

LIST OF FIGURES

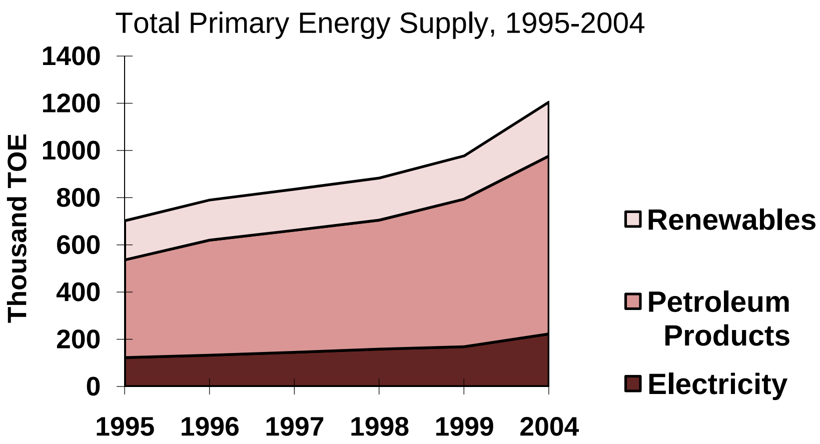


Fig. 1: Total primary energy supply by fuel and sector in Palestine

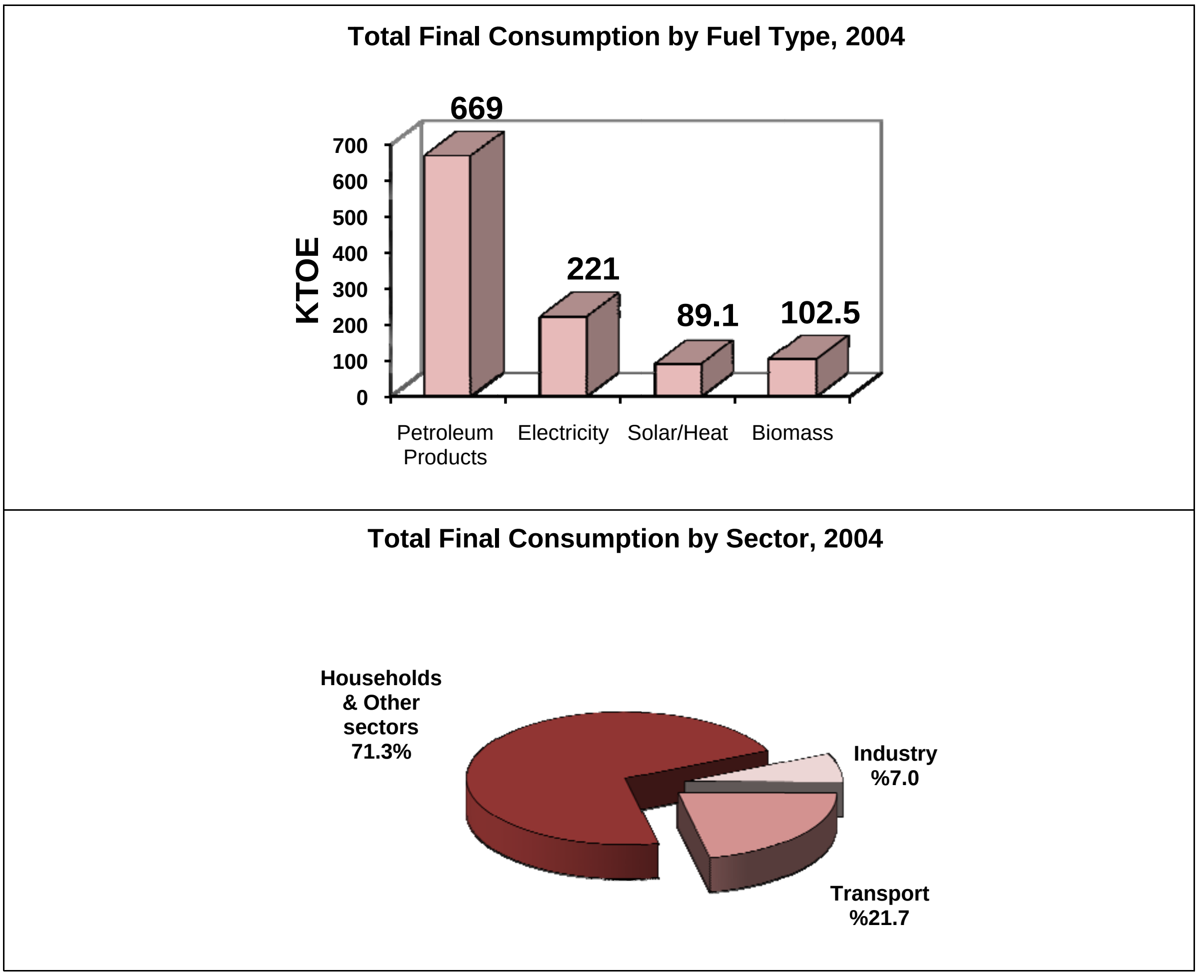


Fig.2: Total Final Energy Consumption by Fuel Type and Sector for the year 2004

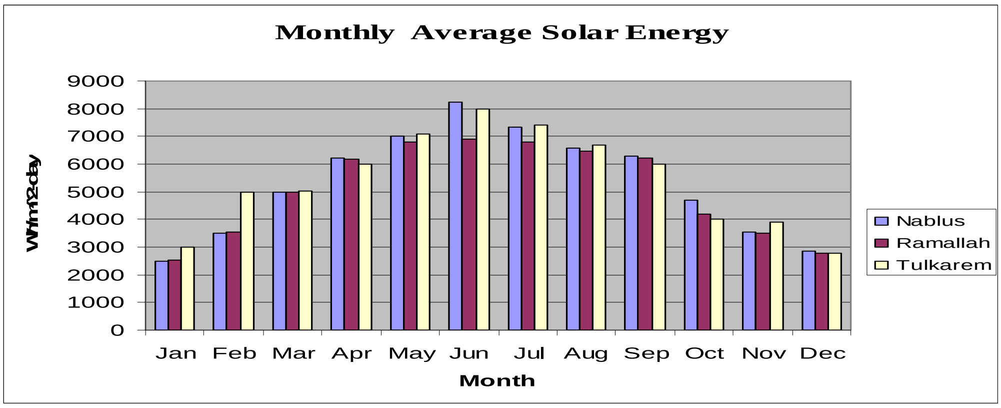
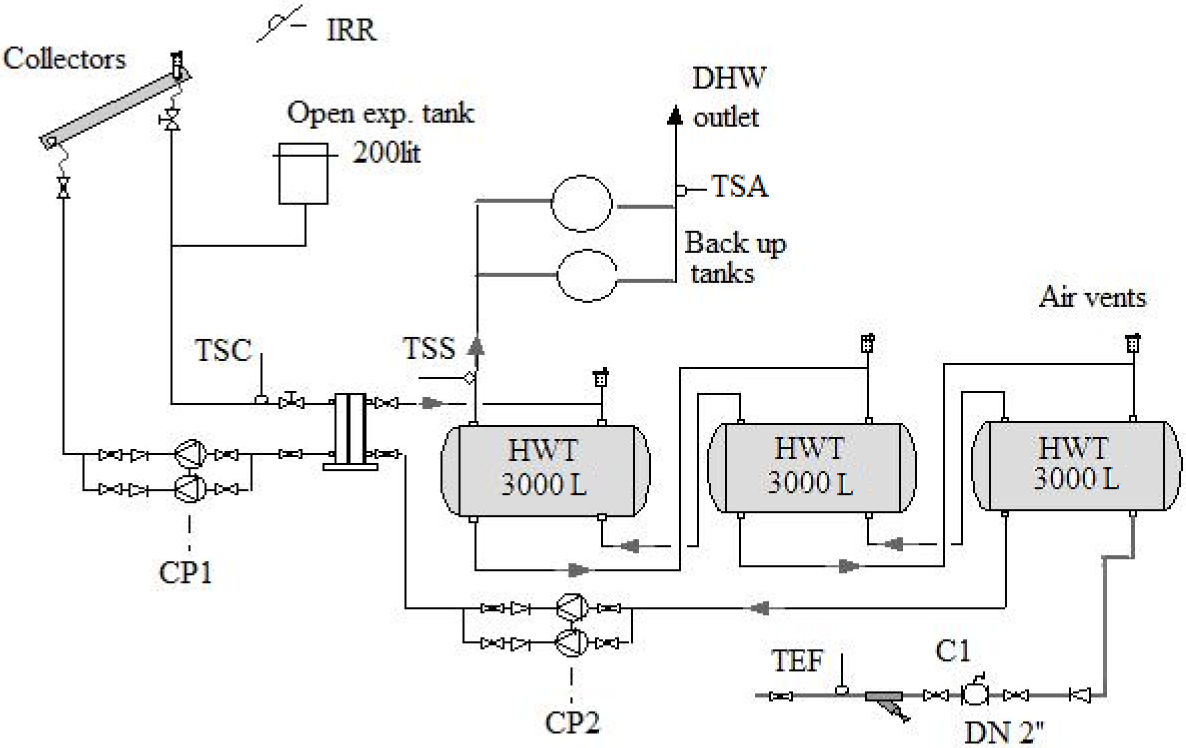


Fig.3: Monthly average solar energy of three location in Palestine.



IRR: the solar radiation sensor
TSC: the contact sensor on the heat exchanger inlet (collector outlet temperature)
TSS: the contact temperature sensor on the solar storage tank outlet.
TSA: the contact sensor on the auxiliary tank outlet.
TEF: the contact sensor on the feed water inlet.
C1: flow meter with pulse emitter (water consumption) .
CP1 and CP2: These sensors follow the pump operation.

Fig.4: Collective SWH system layout with the required measuring sensors

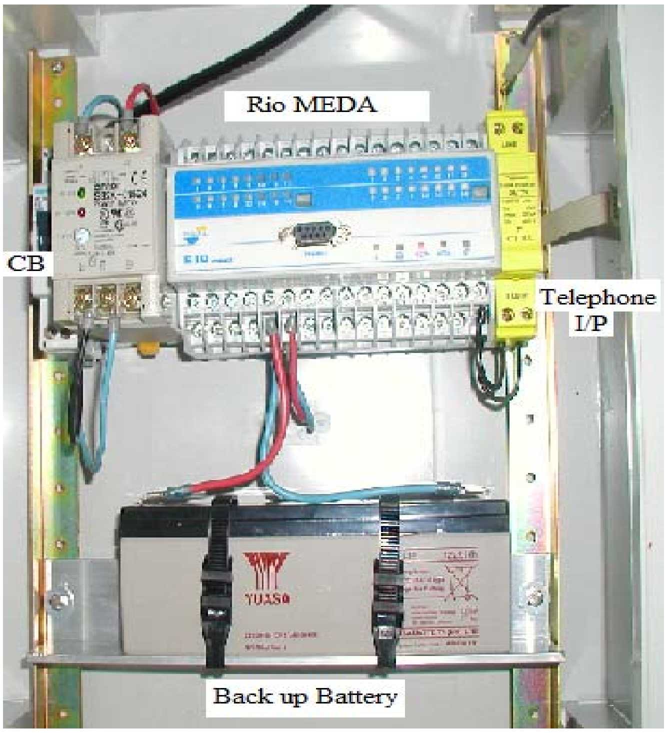


Fig. 5: Data logger Components

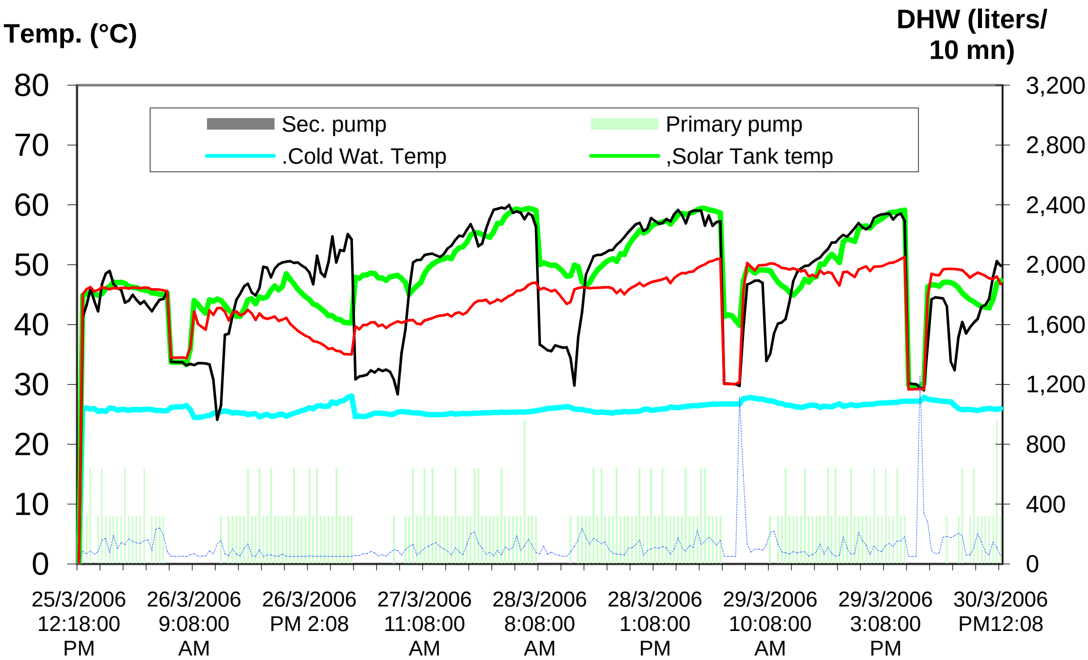


Fig.6-a: Temperature distribution in the SWH, solar radiation, and water flow consumption and primary pump work time from 25-30 March 2006.

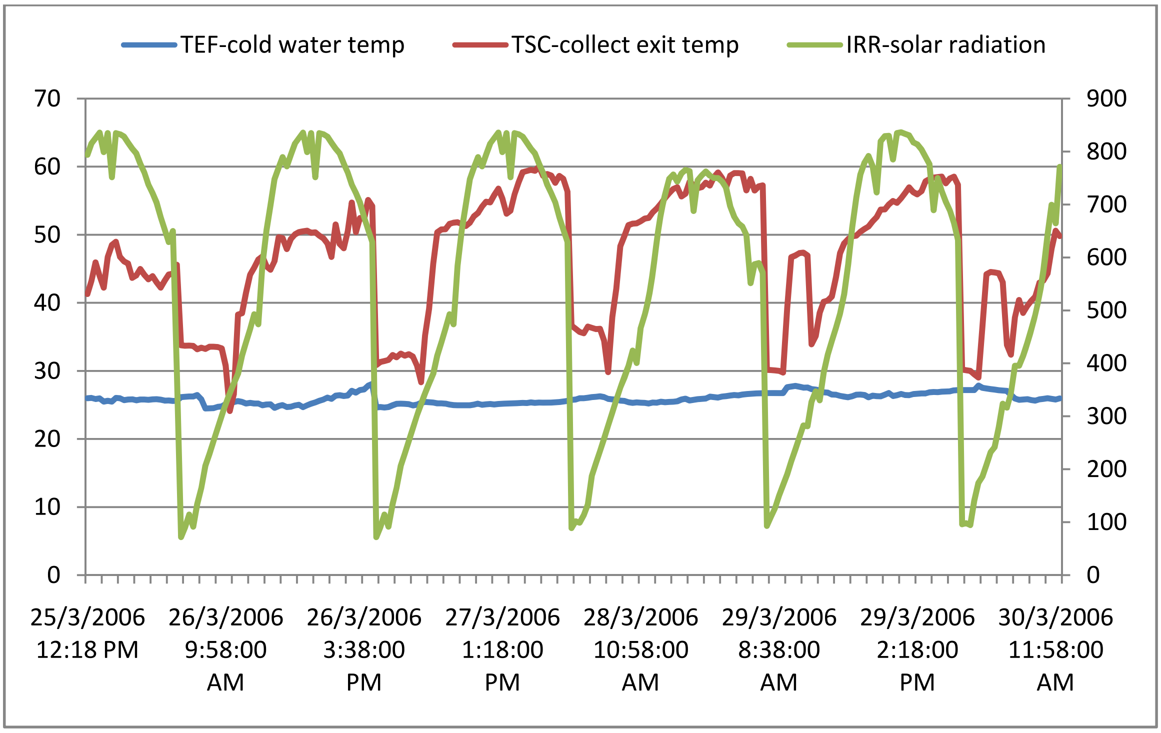


Fig.6-b: Solar tank and collector exit temperatures in the SWH and solar radiation from 25-30 March 2006.

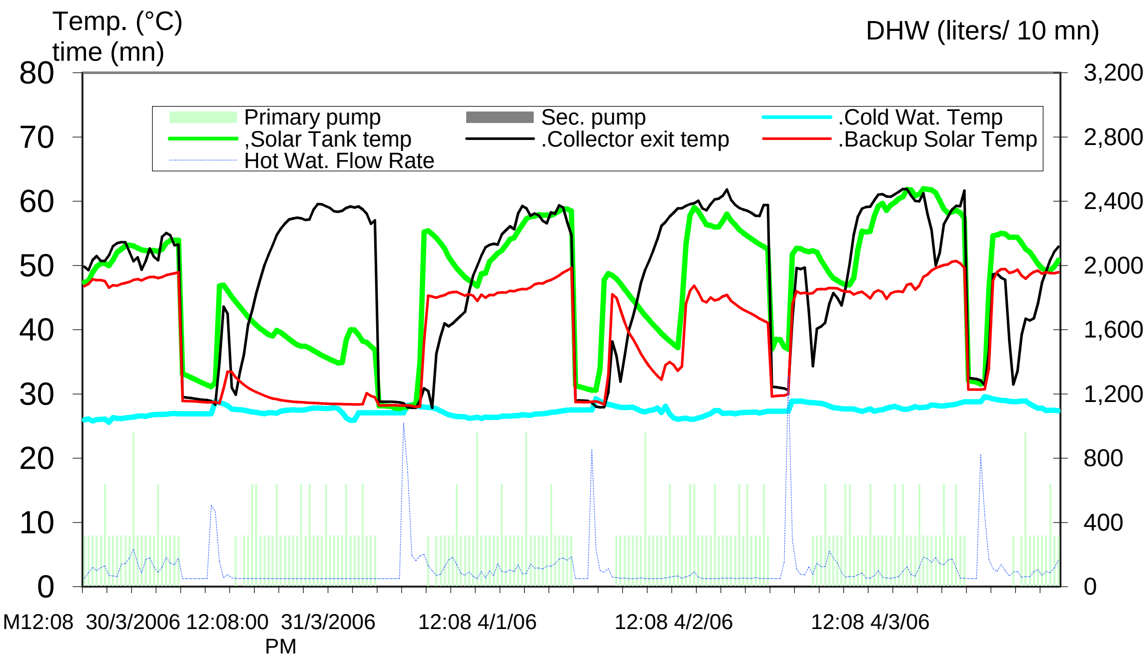


Fig.7-a: Temperature distribution in the SWH, solar radiation, and water flow consumption and primary pump work time from 30March to 3 April 2006.

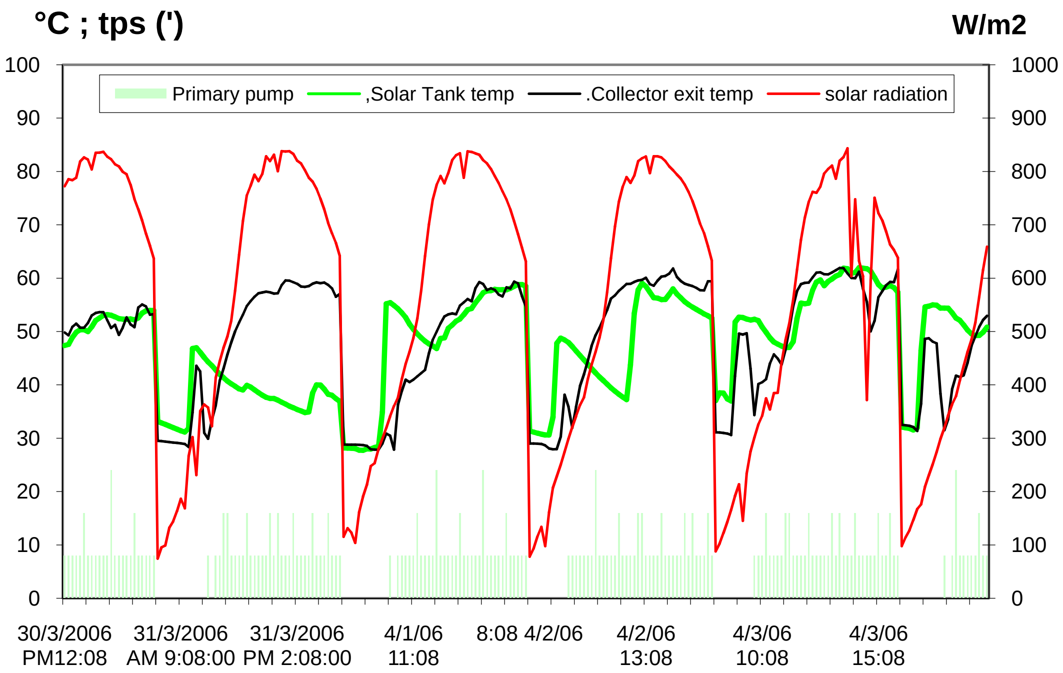


Fig.7-b: Solar tank and collector exit temperatures in the SWH and solar radiation from 30March -3 April 2006.

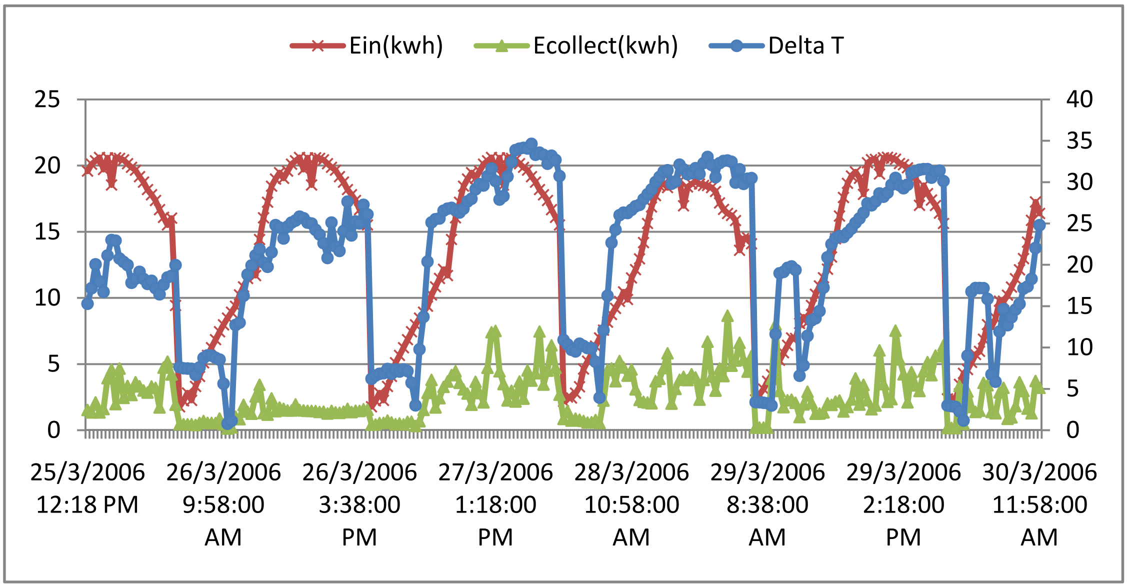


Fig.8-a: Input solar energy and collector output energy with the coressponding temperature difference. (25-30) May/2006

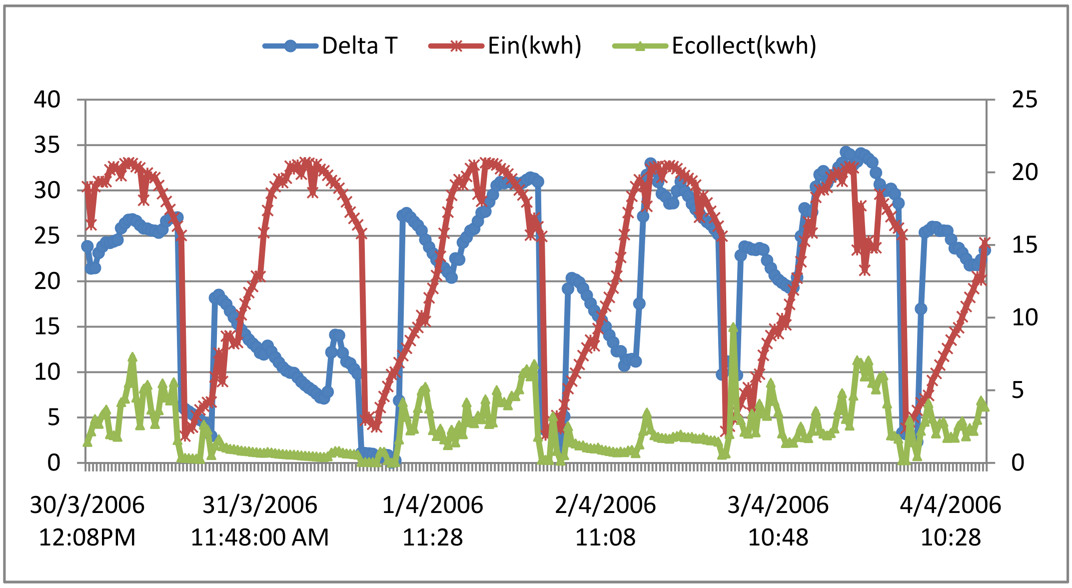


Fig.8b: Input solar energy and collector output energy with the coressponding temperature difference.

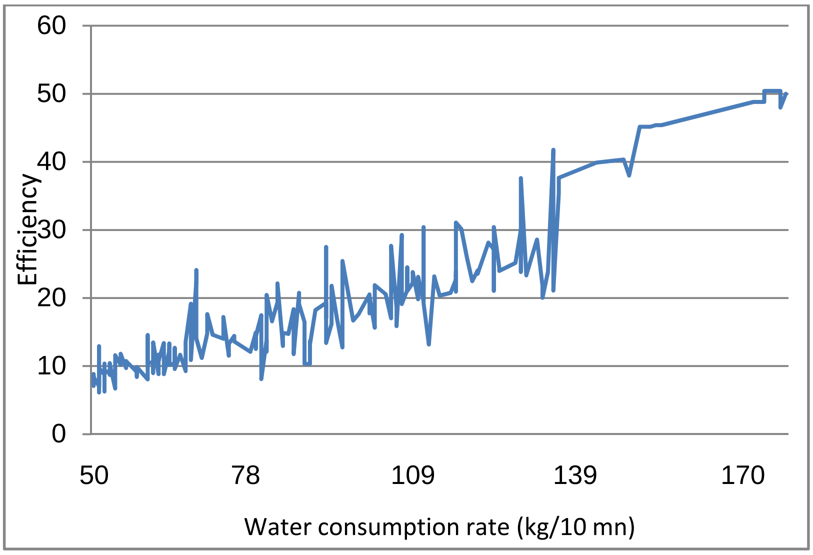


Fig.9: Collective SWH system effectiveness versus water consumption rate

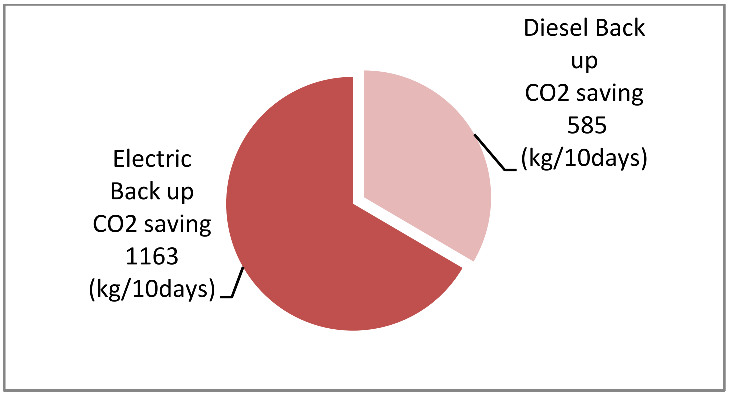


Fig.10: CO_2 saved emissions by utilizing collective SWH of 'Birzeit university'

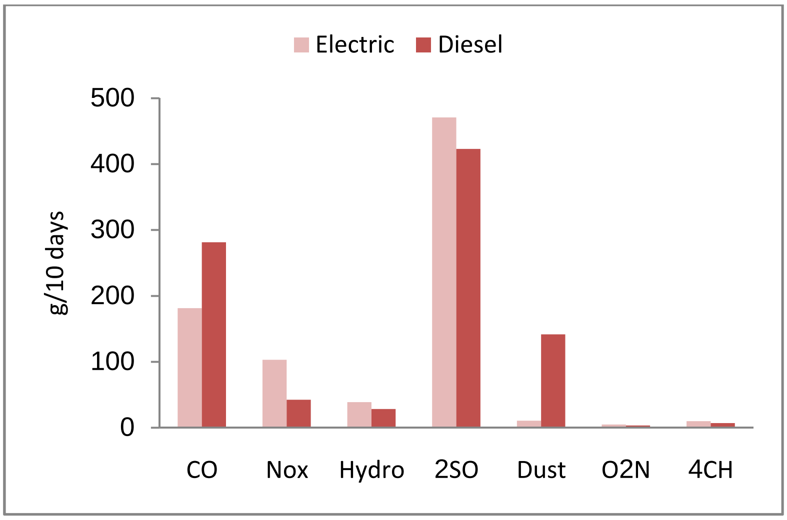


Fig.11: Different saved gas emissions by utilizing collective SWH of Birzeit university

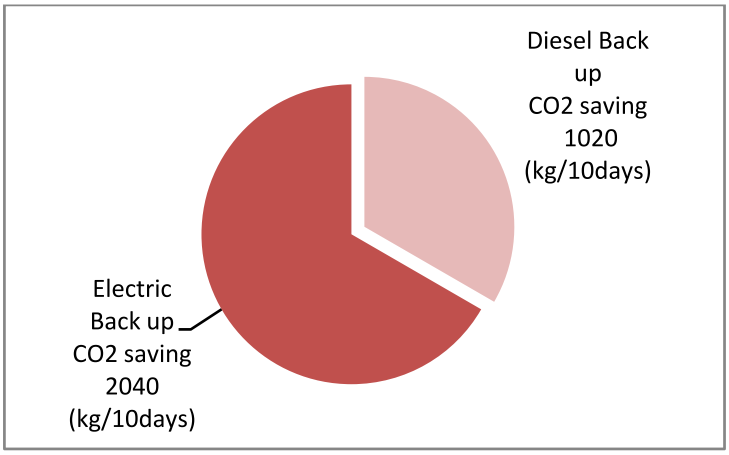


Fig.12: CO_2 saved emissions by utilizing collective SWH Crown Plaza Hotel, Amman

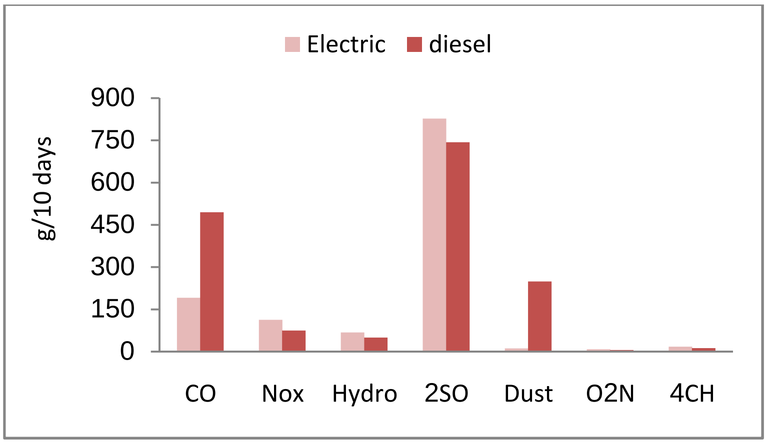


Fig.13: Different saved gas emissions by utilizing collective SWH Crown Plaza Hotel, Amman