

Effect of Wide Spread Implementation of Solar Water Heaters on the Electricity Peak Load in Libya

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Abstract

Electricity plays an important role in the contemporary life, and it has become indispensable nowadays. Reducing the peak electricity load and increasing the load factor have been considered as one of the main tasks that have to be accomplished by both electricity generation-side and demand-side managements. The residential sector of Libya consumes over 31% of the total sold electricity, and 29.8% of that is delivered to the electric water heating load. This is inefficient way of electricity utilization. Usually, the electricity supplier in Libya increases the local generation capacity or import electricity from neighboring countries. Both solutions do not resolve the problem. This work attempts to investigate the effect of replacing electric water heaters in the residential sector of Libya by solar water heaters on reducing the electricity peak load and increasing the load factor. Our results show that on average 3% of the peak load demand can be saved. This is equivalent to 149.5 MW of reduced power. The study also revealed that an annual energy savings up to 2.55 TWh, and the load factor is improved by 2% (i.e. from 65% to 67%). This saved energy is equivalent to a power plant with a nominal capacity of 448 MW considering load factor of 0.65.

Keywords: *solar water heaters, electricity peak load, hot water load pattern, Energy saving.*

1. Introduction

Libya witnessed a rapid and significant development in various sectors and economic activities during the last quarter of the previous century. This development led to the growth in electricity demand. It is reported that the energy consumption per dwelling in Libya is over five times the consumption in Morocco. This could be attributed to the fact that electricity prices in Morocco is six times electricity prices in Libya (Missaoui, 2012). The consumption per capita of energy has been multiplied more than 13 times from 1970 to 2010, where consumption per capita increased from 338 kWh in 1970 to 4651 kWh in 2010. Therefore, meeting this demand has become a significant problem of concern, and it will impact the economy of the country. Thus, it is clear that Libya will face serious challenges as it attempts to meet the apparent rising demand of energy. At the same time, it seeks to decrease the dependence on the short-lived and potentially volatile oil and natural gas to reduce the negative environmental impacts.

Although Libya possesses high installed capacity per capita compared to other developing countries, Libya has suffered severe electricity shortages. The shortages have become worse in the past few years due to the loose of a part of the generated capacity as a consequence of the turbulence in the country and the continued increased electricity demand. In the past, this shortage was reduced by importing electricity from neighboring countries. However, this is no longer the case due to the experienced shortage of the electricity in these countries as well. Many solutions have been suggested and implemented to resolve this problem. Quick solutions such as installing new gas turbine power plants and renting diesel generators did not solve the problem.

From the aforementioned high electricity consumption per capita, it is obvious that it is not an electricity generation problem, but it is a demand side management problem. It is believed that implementing energy efficiency and energy saving strategies will alleviate this issue to high extent. In Libya, almost 100% of the domestic water heaters are electric, and they consume approximately 9.3% (3028 GWh) of the total electricity generated in the country in the year 2010 (Report 2010).

This is equivalent to a power plant with a capacity of 532 MW considering load factor of 65%. There are many studies that deal with the demand side management including domestic water heating in the literature. Moreau (2010) conducted a study to see the effect of domestic water heaters during peak periods and its impact on the demand for electricity. He suggested a shifted load control strategy to minimize such effect. The study is conducted on the province of Quebec, Canada that has a high penetration rate of water heaters, approximately 1.7GW. It is based on an experimentally validated simulation model of water heaters, and the population diversity of hot water load profile. Three scenarios of controlling the number of deactivated water heaters during the peak demand are considered. In scenario 2 the results show that the peak reduction potential is approximately 595 MW at which the pick-up is controlled according to a prioritized random function spread over a range of two hours of the peak period. However, in scenario 0, controlled reactivation case, the peak demand is 225MW.

To alleviate the effect of the domestic water heating on peak demand and energy consumption, this article attempts to investigate the influence of replacing all expected electric water heaters with solar water heaters on the Libyan grid. The investigation includes an analysis of peak load in the Libyan electricity supply, hot water load pattern of the residential sector, complete replacement scenario of electrical water heaters with solar ones, and, eventually, perform estimation of the amount of saved energy, reduced peak power, and load factor improvement.

2. Electricity Sector in Libya

Libya is a country with a large area and relatively small population spread all over the place. The state owned General Electric Company of Libya (GECOL) is solely responsible for the generation and distribution of electricity for the whole country. By law, it has the responsibility of providing electricity to every household in the nation. Libya is a rapidly developing country, and the electrical demand is expected to grow at an annual rate of 6-8 % for the next 10 years due to the economic development and increase in people level of standard (Report, 2008). Currently, approximately 37 % of the generated electricity is using natural gas, 18% heavy oil, 34% light oil, and the rest 11% is obtained from cogeneration (Report, 2010). Apparently, all used energy resources are from fossil fuels, and there is no contribution to new and renewable energy sources.

In Libya, the generated electric energy in 2010 is 32,558 GWh, and the total installed power capacity was 8,347 MW with an available power of 6,357 MW (Report, 2010). The calculated load factor of this year is 65%. Figure 1 illustrates the average hourly power for the four seasons of the year 2010.

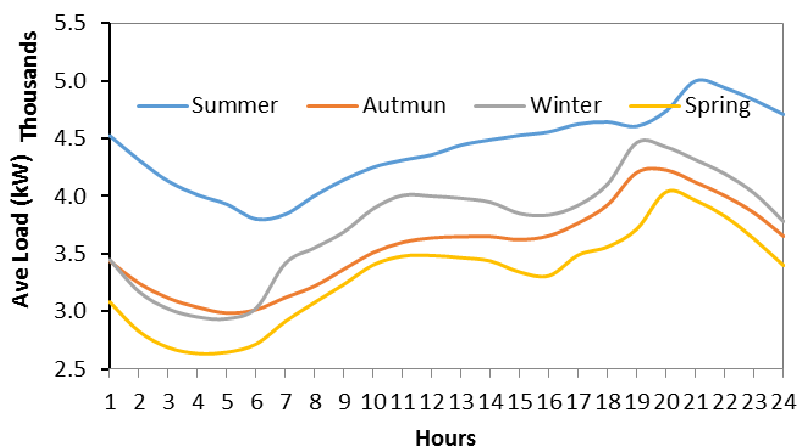


Figure 1. The average load of electricity during the four seasons of the year 2010.

It is clear that the peak power is almost after the sun set time, and, therefore, using solar energy without storage will not alleviate the peak power demand issue. However, solar water heating technology can store energy for later use, and, therefore, it can be a solution to this dilemma. Figure 2 shows the hourly maximum electricity peak during the year 2010, and it reveals that the global maximum is 5,759 MW in August month.

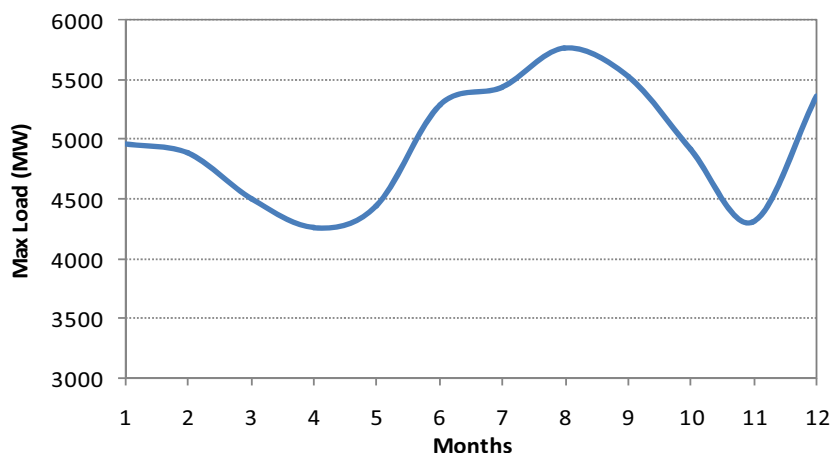


Figure 2. Monthly maximum electricity load for the year 2010

The reported incremental annual average change of the electricity peak load during the past few years is over 8% as shown in Figure 3. The year 2011 is the year of the revolution in Libya, and the supply of electricity was highly intermittent. Therefore, the years 2011 and beyond are not considered in this study.

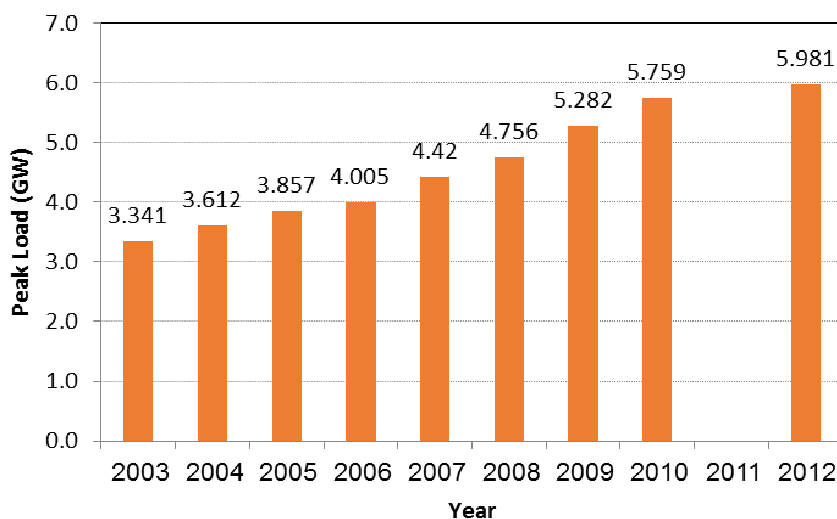


Figure 3: development of electricity load peak of Libya

Figure 4 shows the daily maximum electricity load for the year 2010. It is clear that the global peak is in the summer season with 5759 MW, and the average maximum power during the same season is 5060 MW. The second maximum occurs in the winter season with 5360 MW with the daily average maximum power of 4545 MW. The lowest maximum season power is the spring season with 4505 MW and the daily average maximum load of 4111 MW. In the autumn season, the maximum peak power is 5523 MW and the daily average maximum peak power during this season is 4333 MW. The drop in power between the summer and spring season is over 1000 MW in the maximum peak and in the daily average maximum peak. This huge difference could be attributed to the increased demand in buildings to meet the cooling load in the summer season.

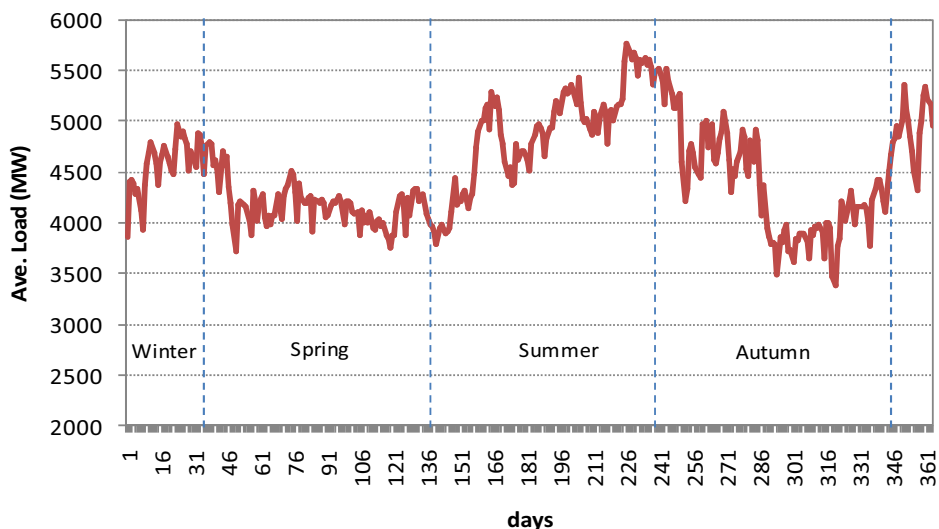


Figure 4. Daily maximum load for the year 2010

Studies made by CADMUS group (Khawaja, 2010a,b) show that the biggest demand at peak hours in the winter season is acquired by the residential sector with 34%. In the summer season the same sector demands 20% of the consumed peak energy, which comes the second after the public lighting demand as shown in Figures 5 and 6.

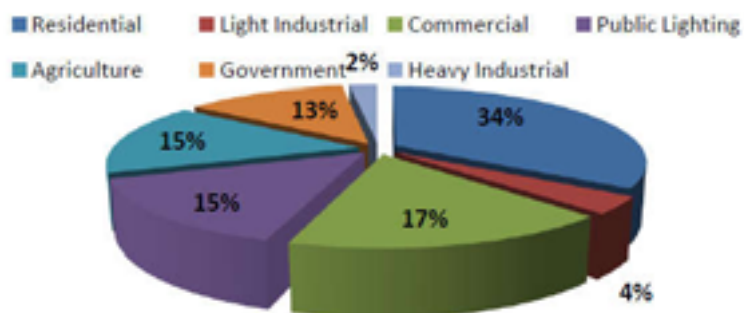


Figure 5: Winter demand at peak hours by sectors

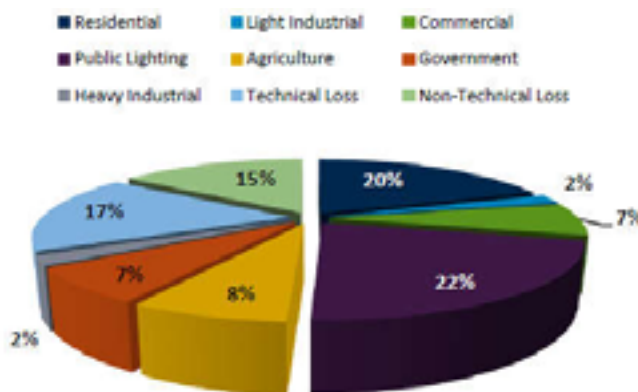


Figure 6: Summer demand at peak hours by sectors

Therefore, implementing energy conservation measures in the residential sector will highly alleviate the peak demand issue in the electricity system of Libya. Also the commercial sector composes a great share of power demand (17%) than energy consumption (13.06%). This is expected because these sectors have demand associated more with evening than daytime hours.

3. Residential Sector

According to the annual report of GECOL of the year 2010, domestic sector consumes 31.18% of the total electricity sold to different sectors of Libya as shown in Figure 7. In the meantime, a study conducted by (Ekhlal et al. 2009) shows that water heating in the domestic sector is the biggest consumer and represents about 30% as shown in Figure 8. Thus, around 9.3% of the national electricity consumption in the country is consumed by water heating for domestic purposes. In the year 2010 the total production of electric energy was about 32,558 GWh, and the amount of electricity sold was about 20,602 GWh. Therefore, the annual electricity used for domestic hot water based on generated electricity is around 3028 GWh.

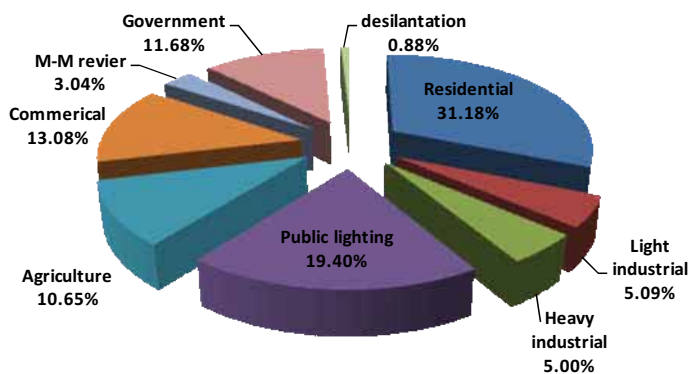


Figure 7. Sectorial distribution of electricity in Libya, 2010

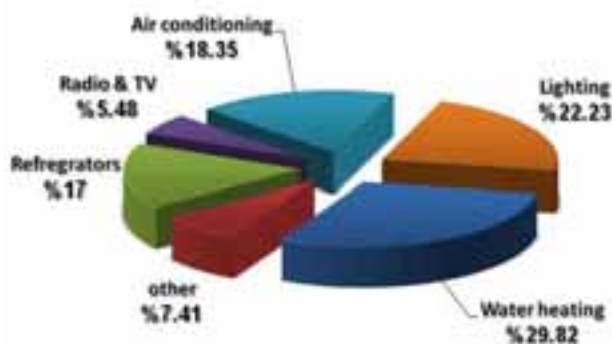


Figure 8. Electricity distribution in the Libyan houses

4. Hot water load in the Residential sector

More than a year of in-situ measurements of five solar water heaters installed in residential buildings are used to predict the average hot-water-load (HWL) pattern and quantity. The measurements were taken every 10 seconds and recorded every 30 minutes for more than a year. In this study, longer periods of measured data are used compared to the previously published data (Abdunnabi, 2005, Abdunnabi, 2012). The summary of the main results is presented in Table 1. The collected data is analyzed, and the hot water patterns for each season are obtained for the average Libyan family of 6 people. Figure 9 shows the typical seasonal hot water load pattern for the average Libyan family.

The methodology used to calculate the HWL pattern and quantity from the measured data is by unifying the different water quantities from five systems as energy, and the quantity of water is calculated at withdrawal temperature of 45°C. The results of all five systems were included in calculations as shown in Table 1. However, the summer results of the 240 liters system is excluded because the owner of this system declares that he purposely discharging large quantity of hot water daily during the summer season to protect the system from high temperature.

The study reveals that the daily quantity of hot water withdrawn at 45°C per person is about 60 liters. The estimated annual amount of energy consumed for water heating per person is about 510 kWh. For an average

Libyan family of six people, the annual amount of energy consumed per family is about 3060 kWh, which is slightly different from the previously obtained results of 2731 kWh/year/family (Abdunnabi, 2005). The study shows also that the average annual solar fraction is 70%.

Table 1: solar water heaters field study average data

Tank volume (L)	Collector area m ²	Persons/family	Ave consump. (Lit)	Ave. inlet Temp (°C)	Ave. outlet Temp (°C)	Annual energy kWh	Solar Fraction (%)
240	3.54	6	353	26.3	49.6	3450	75.2
280	4.4	4	274	24.36	47.3	2037	83.6
210	3.4	5	158	20.55	46.4	1698	57.7
240	3.54	4	319	21.82	44.44	2925	66.1
170	3	3	131	21.91	44.2	1190	58.7

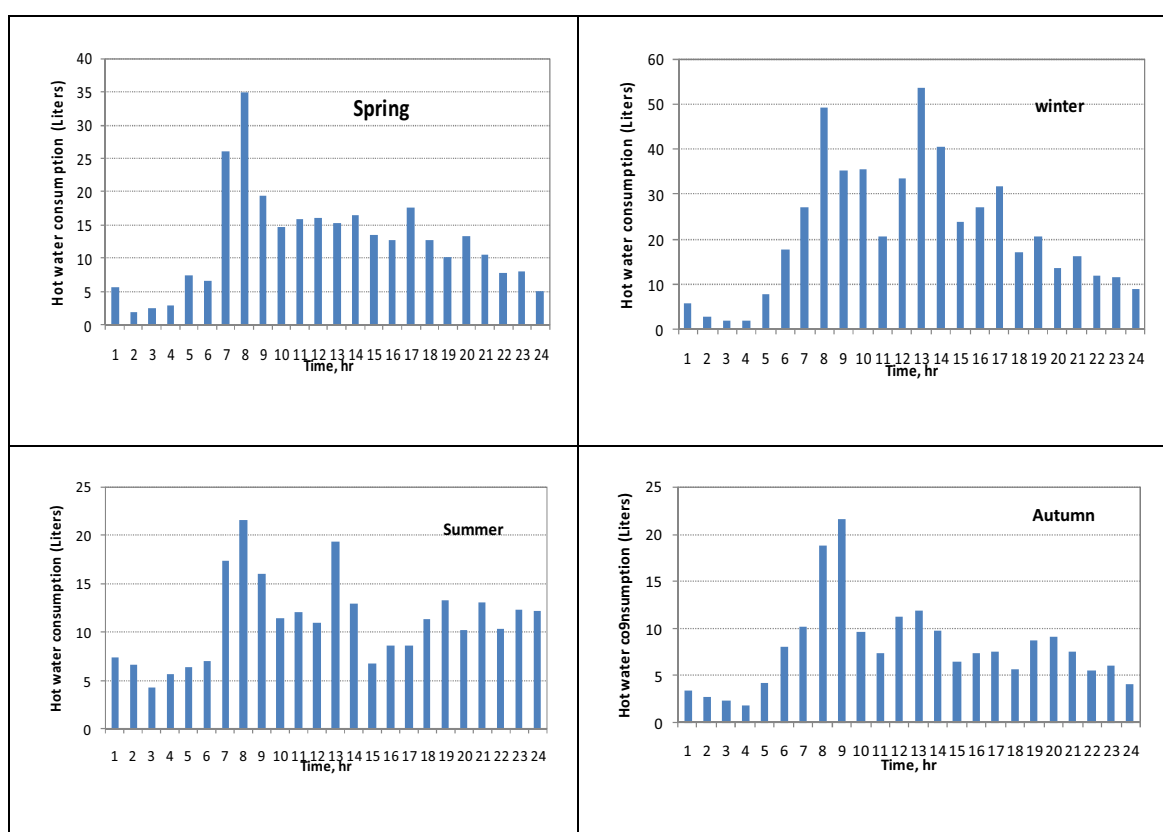


Figure 9: Typical seasonal hot water load pattern of Libyan families

To estimate the energy used for water heating in residential sector, two approaches are used: The first approach is based on the data obtained from GECOL (Report, 2010) and General Authority for information (GAI) (Report, 2007). The second approach is based on data collected from SWH field tests. The following sections will go through these two approaches in details.

First Approach

This approach will give the possible energy consumed for domestic water heating per family according to data obtained from GECOL and GAI. These data are listed in Table 2.

Table 2: Various data from GECOL and GAI

No	Category	Value	Remarks
1-	Electric Energy Sold	20,602GWh	GECOL (2010)
2-	Electric Energy Generated	32,558 GWh	GECOL (2010)
3-	Percentage of water heating in the residential sector	29.82%	Khlat, 2009
4-	Electricity consumption in the residential sector	31.18%	GECOL (Report,2010)
5-	Percentage of electricity used for water heating in domestic sector	9.3%	31.18% × 29.82%
6-	Number of Clients	889,447	GECOL (Report, 2010)
7-	Number of Houses, 2010	921,642	GAI, (Report, 2007)

From Table 2 we can calculate the maximum possible hot water energy consumption (HWEC) per family based on the generated electricity:

$$\begin{aligned}
 HWEC_{max} &= \frac{\text{Electric Energy Generated} \times \% \text{ of water heating}}{\text{Number of Clients}} & \text{(eq. 1)} \\
 &= \frac{32,558,000,000 \times 0.093}{889,447} = 3403 \text{ kWh}
 \end{aligned}$$

The minimum possible HWEC per family based on electricity sold can be obtained using the same formula:

$$HWEC_{min} = 2153 \text{ kWh} \quad \text{(eq. 2)}$$

Second approach

This approach is based on the SWH field test data of HWEC and the data from GAI as given in section 4.

$$HWEC_{measured} = 3060 \text{ kWh} \quad \text{(eq. 3)}$$

Fortunately, this measured value lies between the minimum and maximum values obtained using the first approach, which makes this quantity acceptable although the number of measured samples is very small. Therefore, it is chosen to represent the typical value of HWEC for domestic sector of an average Libyan family of six people. This value is representing the useful energy of the hot water and does not represent the energy provided by the electric element in the water tank. The heat loss to the environment is not included, and it will be calculated in next section.

5. TRNSYS Simulation of EWH Performance

Commonly used electric water heaters are simulated using TRNSYS simulation program to calculate the heat loss to the environment. It is also used to assess the electric energy required to compensate the energy due to heat loss and useful energy consumed (i.e. for typical Libyan house consumption of 3060 kWh/year). Figure 10 shows the implementation of eclectic water heater in TRNSYS using a simplified electric heater model (Type 60).

The results of a single year simulation of a typical hot water load pattern of a typical Libyan house show that the consumed electric energy is increased by 8% due to the consideration of energy loss to the environment as shown in Figure 11. The calculations are made at a set point temperature of 45°C. The figure also shows the effect of increasing the set point temperature of the electric heater assuming a consumption of the same amount of useful energy (Q_{useful}). It is clear from the figure that increasing set point temperature from 45°C to 60°C is accompanied with an increase in the energy supplied by 4% to reach to 12%. Whereas, the heat loss to the environment is increased above 50%. In all calculations of different set point temperatures, the user temperature is maintained at 45°C.

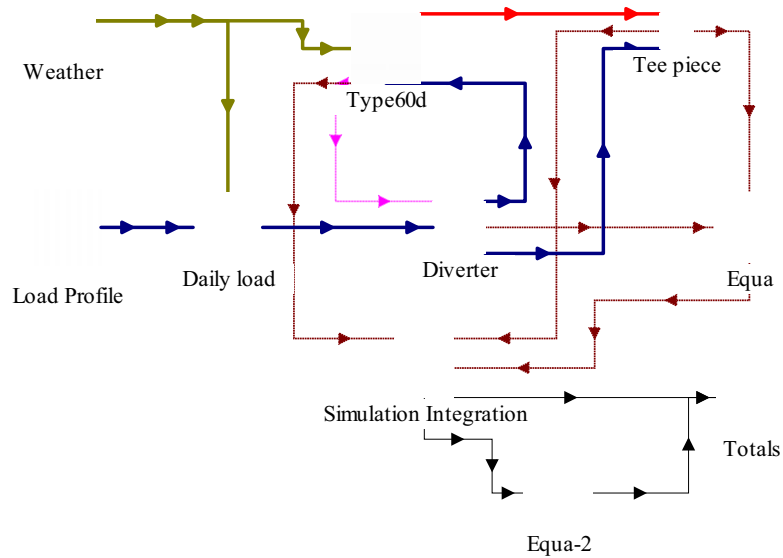


Figure 10: simulation of EWH in TRNSYS program

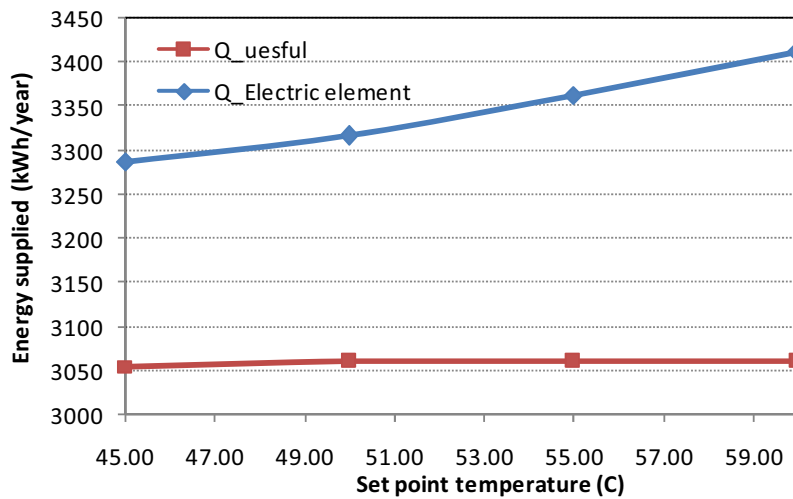


Figure 11: Effect of set point temperature on the energy supply and consumption

In This study, it is considered that the common set point temperature is 55 °C. The accompanied heat loss is about 10%. Therefore, the annual energy supplied by the electric heater per family is increased from 3060 kWh to 3364 kWh.

6. The Replacement scenario

The primarily results show that the effect of the electricity load of water heating in the residential sector on the electricity peak demand is very small. Therefore, in this study, we will investigate the maximum possible impact of a replacement scenario on the electricity peak demand without going in details of a gradual replacement. The replacement scenario is to replace the electric water heaters of the whole residential buildings by solar water heaters with an average annual solar fraction of 70%. This means that still there is 30% of the load energy demand that has to be covered by electricity.

7. Results and Discussion

The implementation of the results obtained on the residential water heating energy consumption on the electricity load for the four seasons are shown in Figures 11 to 14.

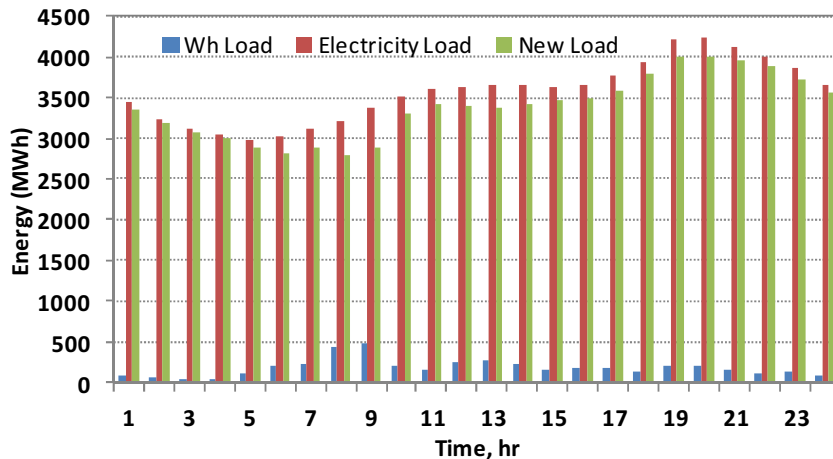


Figure 11: Energy load for autumn season

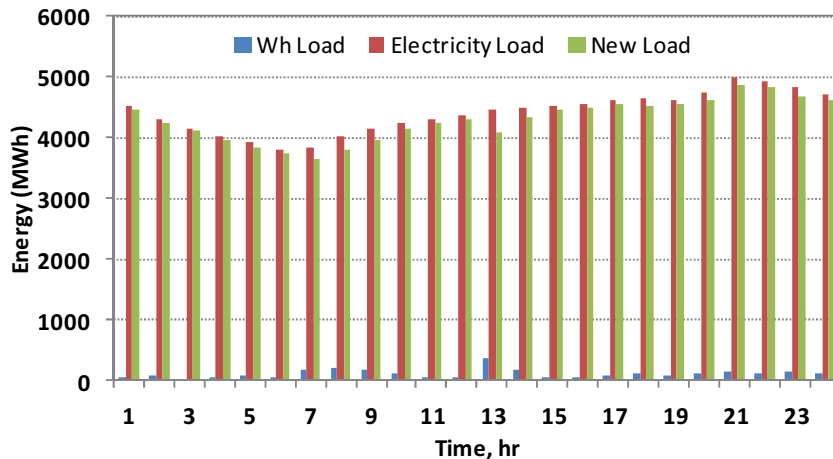


Figure 12: Energy load for summer season

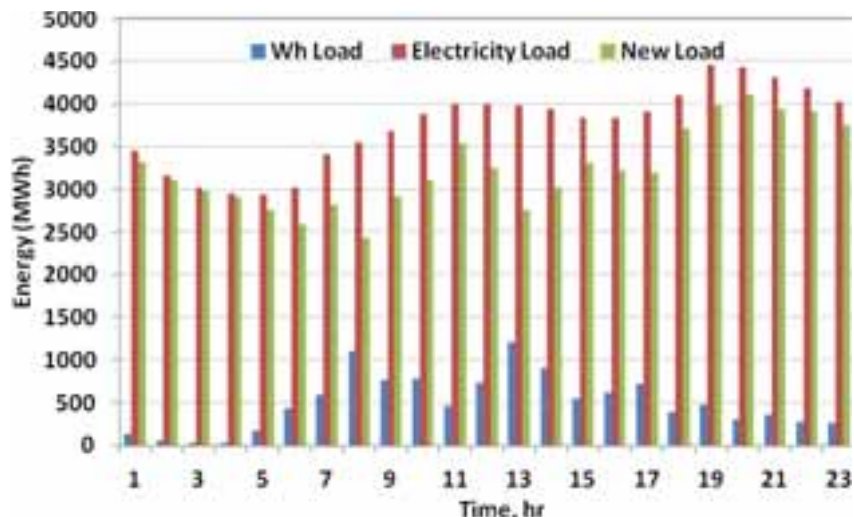


Figure 13: Energy load for winter season

In general, the obvious effect of the replacement scenario is in the winter season, so the peak load drops from 4465 MW to about 4085 MW with maximum saving in the peak load about 381 MW. Thus, the peak load is shifted one hour from 7:00 pm to 8:00 pm. Unfortunately, the maximum power capacity is needed in the

summer season where the lowest savings due to the replacement is achieved. The maximum peak load is nearly 5 GW at 9:00 pm, and the new peak load is 4.85 GW with maximum peak load savings of 149.5 MW.

In other mild seasons, autumn and spring, the maximum peak load savings are 237 and 329 MW, respectively. The peak times are at 8:00 pm for both seasons, and the new peak is shifted in spring to 9:00 pm, and in autumn it remains at the same time 8:00 pm.

The maximum peak load savings during summer, winter, autumn, and spring are 3%, 8.5%, 5.6%, and 8.1%, respectively. The average daily energy savings due to the replacement scenario in the summer, winter, autumn, and spring are 2.96 GWh, 12.8 GWh, 4.88 GWh, and 7.22 GWh, respectively. This is a considerable amount of energy that can be saved due to the suggested replacement scenario. When it comes to the reduction in the maximum capacity power installed due to the replacement scenario, it is only 149.5 MW that can be reduced. The maximum peak load of 5760 MW occurs in the summer (August) at night nearly 9:00 pm. Figure 15 shows the electricity load at the day of maximum peak load. The total energy consumption during this day is 122.45 GWh.

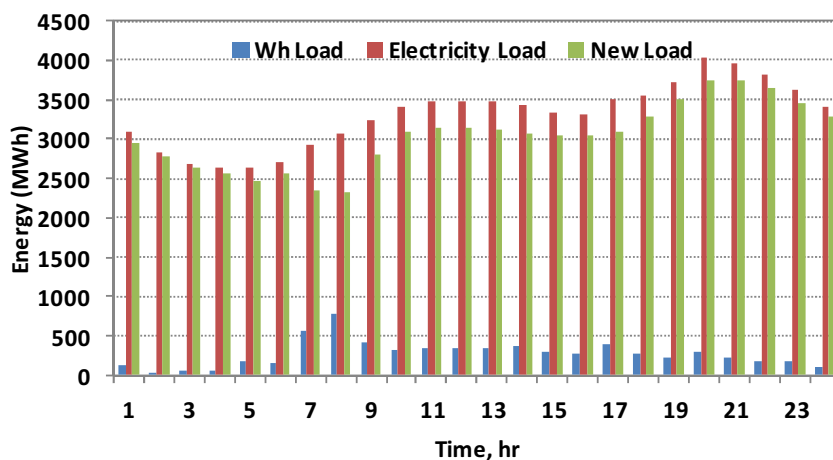


Figure 14: Energy load for spring season

The total annual saved energy using the replacement scenario of EWH with SWH is 2.55 TWh, and the load factor is improved from 65% to 67%. This saved energy is equivalent to a power plant with a capacity of 291 MW considering a load factor of 0.65. The nominal capacity will be 448 MW. This will be added to the fuel savings and huge environmental benefits due to avoiding burning fossil fuel that release harmful gaseous.

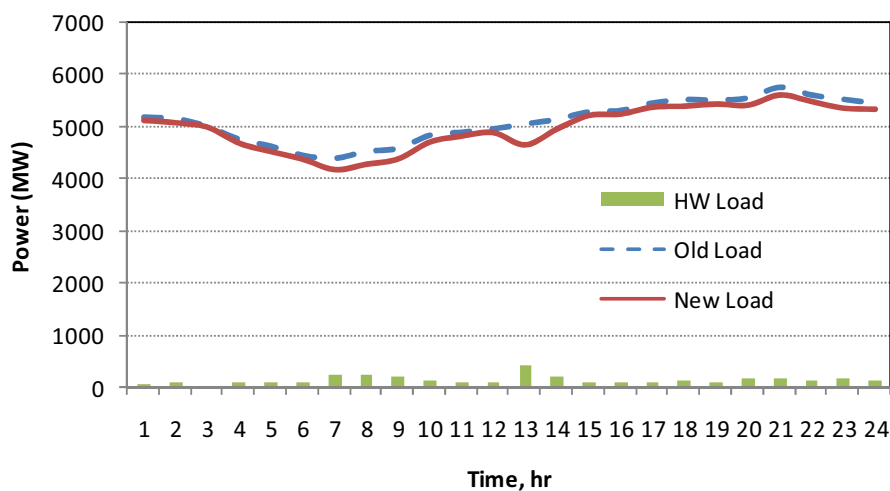


Figure 15: Effect of water heating load on summer peak load (15 August)

8. Conclusion

The Libyan electricity sector suffers from long terms intermittent for many years due to many reasons among of which bad of billing system and the high technical and non-technical losses. The total installed capacity is over 8 GW and the available operating capacity in 2010 is about 6.36 GW. The variation of the peak load among the four seasons of the year is over 1.5GW between summer and spring; this variation could be attributed to the energy consumption in buildings. On a daily basis, the maximum variation in the maximum peak load along the year is over 2.3 GW which is a very huge difference and has to be studied. Space heating/cooling, domestic water heating, and lighting are among the highest energy consumers in buildings.

Water heating for domestic purposes constitutes over 9.3% of the national electricity consumption in the country, which is equivalent to 3028GWh in 2010. The commonly utilized technology for water heating in the residential sector is the electric water heaters. This means that the most expensive along the expected life-long and the most pollutant technology used for domestic water heaters. Field study information about the hot water usage (profile and quantity) is used, and the annual hot water consumption for typical Libyan house is found 3060 kWh. The typical seasonal hot water load patterns are also obtained.

The study concluded that complete replacing of electric water heaters with solar water heaters in the residential sector will alleviate the electricity peak by 3% (149.5 MW) and improve the load factor by 2% (i.e. from 65% to 67%). However, the annual energy savings reach to 2.55TWh, and this is equivalent to a power plant with nominal capacity of 448 MW considering a load factor of 0.65. This will be added to the fuel savings and huge environmental benefits due to avoiding burning fossil fuel that release harmful gaseous.

9. References

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