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Energy efficiency improvement procedures and audit results of electrical, thermal and solar applications in Palestine

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Abstract

Energy conservation in utilities has played a vital role in improving energy efficiency in the industrial, commercial and residential sectors. The electrical energy consumption in Palestine has increased sharply in the past few years and achieved by the end of 2001 to 10% per year. It is expected that this percentage will increase to about 12% if the current political situation will end hopefully with peace. Modern energy efficient technologies are needed for the national energy policy. Such technologies are investigated in this paper. Implementing of a national 3 years project aiming at energy efficiency improvement in residential and industrial sectors as well as in public utilities, which include wide range of diversified audits and power measurements, had led to creating this paper. Measurement and audit results had shown that the total conservation potential in these sectors is around 15% of the total energy consumption. The associated costs of the investment in this field are relatively low and correspond to a pay back period varying in the range from 6 to 36 months. Consequently, the energy conservation policy will be seriously improved in the forthcoming years. It is estimated that 10% of the new energy purchasing capacity will be reduced accordingly.

Keywords: Electrical energy conservation; Energy efficiency; Energy efficient technologies; Power measurements

1. Introduction

The energy consumption per capita of the majority of the population has been considerably increased especially in the developing countries. Energy growth in developing countries has been realized recently due to major developments in several sectors such as residential, industrial and commercial.

The primary sources, such as heavy oil, natural gas and other conventional are limited resources formed by geological processes through solar energy accumulation into the earth over millions of years. Because of their fluctuations in reserves and prices and due to the increased costs of power stations, it is very important to consider new measures for energy conservation in both developed and developing countries. Energy conservation could be defined as an applied technique in energy utilization without affecting the standard of living in the society. Energy conservation will definitely save investments of constructing and generating capacities of electrical energy and consequently will enhance the current economy of the nations (Imad and Mahmoud, 2002; Saadat, 1999).

In Palestine, the electrical energy consumption in the residential sector is at the highest levels compared to the industrial and commercial sectors. The percentage of energy consumption in various sectors is 50% for residential, 15% for industrial, 10% for commercial and governmental, and 15% for pumping stations (Imad and Mahmoud, 2002; Mahmoud and Ibrik, 2002).

In this paper, the energy conservation by utilizing solar water heaters (SWH) and the available technologies for energy efficiency and energy conservation methods and tools are discussed. For example, it is estimated that the percentage range of energy saving is 25–70% for lighting, 10–20% for motors, and 10–30% for electrical losses in the distribution networks. In Palestine, other supporting tools for energy conservation are also studied, such as energy and public awareness, energy regulations, energy information and programming. Finally, concluding remarks and recommendation are summarized for promoting better energy conservation policy.

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Table 1
Peak load and energy consumption in the main districts of Palestine

Area/district	Peak load (MW)	Energy purchased (kW h/year)
Jenin	10	39,947,520
Tulkarem	12	51,237,520
Nablus	40	156,818,065
Qalqiliah	7	31,946,083
Jerusalem	135	768,345,285
Gaza	120	668,107,000
Hebron	40	158,674,520

2. The electrical networks in Palestine

There is limited electrical power generation capacity in Palestine as most of the required electrical power is supplied by the Israel Electric Corporation (IEC). The electrical networks in Palestine are all considered as distribution networks. The voltages of these networks are 400 V, 6.6, 11, 22, and 33 kV. IEC supplies electricity to the electrified communities by 33 or 22 kV overhead lines. Electricity is purchased from IEC and then distributed to the consumers.

The largest company in West Bank is Jerusalem Electricity Company (JEC), it supplies electricity to around 120,000 consumers that serves 500,000 inhabitants. The municipality of Nablus, Hebron, Jenin, Tulkarem and Qalqiliah are supplying electricity to around 92,000 consumers that serves about 435,000 inhabitants. The peak load and energy consumption in the main districts of Palestine has been estimated as shown in Table 1 (Palestinian Energy Authority, 2001).

Recent statistical studies on electricity growth and energy demand in Palestine illustrate a sharp increase in electrical energy consumption with an annual average growth of 10%. It is also expected that power capacities will be increased in the next 5 years due to the national development in all sectors. However, such increment will be accompanied with restricted regulations on energy consumption under the energy conservation measures.

3. Energy conservation by utilizing solar energy

Palestine is considered as a country of high solar energy potential since the daily average of solar radiation intensity in it amounts to 5.4 kW h/m^2-day. Furthermore, the annual average of total sunshine duration amount to 2850 h. In addition, it should be emphasized that the daily average of solar radiation intensity during the period from beginning of April to end of September varies in the range from 6 to 7.8 kW h/m^2-day and vary in the range from 2.8 to 5 kW h/m^2-day during the remaining period. These figures are very encouraging to exploit this energy as far as possible. However, the security of economic feasibility depends mainly on selecting the appropriate application and on design of the solar system.

Exploiting of solar energy occurs through converting it into thermal energy which used in water heating, space heating and drying of vegetables and fruits. Solar energy can be also converted into electric energy by photovoltaic cells.

3.1. Solar water heating

Utilizing of SWH had begun actually in Palestine since 1970 and SWH occupy now high percentage of roofs in many countries to provide the daily requirements of households with hot water. The thermosyphone open loop system of SWH is the mostly used type for domestic use all over the world and especially in the Middle East area. Such a system consists of flat plate collectors connected to each other and to an isolated storage tank by means of galvanized steel pipes (1 inch diameter) sizing the appropriate area of the flat plate collectors A_{SWH} is calculated as follows (Kreider and Kreith, 1977):

$$Q = mC_{\mathrm{w}}\Delta T, \tag{1}$$

$$\Delta T = T_2 - T_1, \tag{2}$$

$$A_{\mathrm{SWH}} = \frac{Q}{\eta_{\mathrm{SWH}} E_{\mathrm{sd}}} S_{\mathrm{f}}, \tag{3}$$

where Q is the thermal energy (in W s) required to heat a water amount of m (kg) from an initial temperature T_1 (C°) to T_2 (C°), and C_{w} is the specific heat value of water 4186 W s/kg − C°, η_{SWH} is the efficiency of a solar collector (about 40% in average), E_{sd} is the daily average of solar radiation intensity (5.4 kW h/m^2-day in Palestine) and S_{f} is a safety factor whose value is site specific (1.15–1.3 for Palestine) . This thermosyphone SWH type is widely spreaded in Palestine and it consists mostly of three parallel connected collectors each of 1.7 m^2 area and a hot water storage tank of 200 litre capacity. It is manufactured and installed by local workshops using absolutely construction materials available in the Palestine market. Although its efficiency curve varies from 25% to 65%, but its very low price (200$ including installation), justifies its utilization. SWH types with higher efficiency are available rarely in the local market and must be imported at much higher price from abroad.

Such a system, is enough to cover the total daily hot water requirements of a family existing of 6–10 persons for a period of 9 months per year. It means during this period the mentioned family can dispense with other water boilers operating with diesel, gas or electricity which are accompanied with frequent high fuel cost and maintenance. For comparison purposes, the solar water

Table 2
Running cost and efficiency of the different boiler types

Boiler type	Annual production (litres of water)	Water temperature (°C)	Efficiency (%)	Annual running cost (NIS)
Electric	54,750	65	92	2022
Diesel	54,750	65	75	963
Gas	54,750	65	82	897
Solar water heater	54,750	65	34	—

Table 3
Technical specification of major lighting devices

Type	Lumens (W)	Life time (h)	Response time (min)
Incandescent	15–25	1000	0
Mercury	35–65	16,000	3.5
Fluorescent, conventional	25–65	18,000	0
Compact fluorescent lamp (CFL)	40–81	18,000	0
Metal halide	80–100	7500	10–15
High pressure sodium	80–140	20,000	<1

Table 4
Comparison between incandescent lamp and CFL using the cost annuity method (based on the capital recovery factor and the operation cost) by a discount rate of 6%

Feature	Incandescent lamp	CFL
Power (W)	75	15
Price (NIS) (1 US$ = 4.8 NIS)	1.5	30
Life cycle (h)	1000 = 0.4 year	10,000 = 4 years
Electricity consumed in 10,000 h (4 years)	$(75/1000) \times 10{,}000 = 750$ kW h	$(15/1000) \times 10{,}000 = 150$ kW h
Annual electricity cost	131.64 NIS	33.033 NIS

Annual saving through using CFL = 131.64−33.03 = 98.61 NIS.
Total saving over CFL life cycle = $4 \times 98.61 = 394.44$ NIS.

heater saves for a family house an amount of 75 NIS ($\approx$16 US$) per month which means it has a simple pay back period not higher than 1 year.

Table 2 illustrates the running cost (only) for the different boiler types producing daily 150 litres of hot water at 65°C, where the annual saving through using SWH is clear. SWH does not need any worth mentioning maintenance as the other boiler types.

Moreover, the SWH offers a considerable advantage represented in the independency on the supply of electricity, gas or diesel from Israeli companies.

4. Electrical energy efficient equipment

Considerable energy saving can be achieved by selecting high efficient electric equipment, improving the power factor (PF) (Imad and Mahmoud, 2002) and by changing the style of power consumption. Major fields of applications are discussed hereafter.

4.1. Lighting

The percentage of electrical energy used for lighting in industrial sector in Palestine represents 10–20% of its total energy consumption while it amounts to about 40–45% in residential sector (Mahmoud and Ibrik, 2002). Energy saving can be achieved by different advanced lighting devices and control methods. Table 3 enables the comparison between various lighting devices.

There are voluminous chances for energy conservation in the field of lighting as Table 4 illustrates the comparison in power consumption and energy cost between incandescent (tungsten) and CFL lamps. Similar positive results are also achievable when replacing mercury lamps with high-pressure sodium or at least with metal halide lamps.

However, we propose the following measures for power conservation in this area:

- Luminance should be designed according to standards related to the nature and requirements of the space or area.
- Use compact fluorescent lamps, instead of incandescent lamps.
- Fluorescent lamps must be fitted with capacitors to raise its PF.
- Use small diameter fluorescent lamps (26 mm instead of 38 mm) because they have higher luminance efficiency.

- Use occupancy control sensors in side private and public offices.
- Separate light controlling circuits from other circuits.
- Make use of natural daylight as far as possible in side buildings.
- Install voltage control devices to control lamp luminous flux based on outside lights.
- Use photocells and other control devices to light out side places.

The municipalities of the Palestinian cities, which are responsible for all electricity services and distribution networks have to carry out more intensive activities to invoke the awareness towards energy conservation in general and the possible achievable cost savings and environmental profits by using CFL instead of incandescent lamps. The publicity activities of the municipalities can be popularized by all information media (radio, TV, newspaper, brochures, etc.) and the consumer advisory centres. In addition, financing schemes and soft credits managed by environmental projects and associations as well as national banks could be an effective tool for convincing the consumers to use CFL lamps.

4.2. Refrigerator

A refrigerator forms mostly the largest load in the residential sector since it's consumption represents 30–40% of the electricity bill of a household. High percentage of the Palestinian households uses inefficient second hand refrigerators (10–15 years old) due to their low initial cost. Audit results had shown that the consumption of these old refrigerators amounts to about 1.5–3 times higher than the same new types.

Creating and enforcing of an energy label for refrigerators as legislated in the European Community Countries is an effective tool for energy saving. The label appears on the refrigerator package and identifies the energy consumption of the individual models (A, B, C, D, E, F, G (less efficient)), that helps the consumer to select the energy saving model. The following major points are recommended to achieve higher energy saving:

- Purchase only a new refrigerator/ with an energy label and of a capacity appropriate to the household size.
- Place the refrigerator with a distance of about 30 cm from the wall and far enough from the oven or any other heat sources and not under solar radiation.
- Adjust the thermostat properly for winter and summer (cooler setting means higher energy consumption).
- Do not keep the refrigerator doors open for a prolonged time, hot and humid air will penetrate into the cabinet and will cause moisture accumulation.

4.3. PF improvement

PF is the ratio of real power (useful power in kW) P, to total apparent power (S) in kVA (Saadat, 1999):

$$PF = \cos\phi = P/S, \tag{4}$$

$$P = VI\cos\phi, \tag{5}$$

where ϕ is the electric phase angle between voltage (V) and load current (I).

The magnitude of S is equal to the root of the squared sum of P and the reactive power Q in kVAr:

$$S = \sqrt{P^2 + Q^2} \tag{6}$$

Although reactive power performs no actual work, an electric utility must maintain an electrical distribution system, (i.e. power transformers, transmission lines, etc.) to accommodate this additional electric energy. To recoup this cost burden, utilities may pass this cost on to industrial customers in the form of a PF penalty for PF below a certain value. PFs in industrial plants are usually low due to the inductive or reactive nature of induction motors, transformers, lighting, etc. Low PF is costly and requires the electric utility to transmit more kVA than would be required with an improved PF. Low PF also reduces the amount of real power that an electric distribution system can handle, and increased line currents will increase losses in the distribution system. An inexpensive method to improve PF is to connect properly sized capacitors parallel to the inductive loads. The reactive power of capacitor (Q_c) is calculated as (Saadat, 1999):

$$Q_c = P(\tan\phi_1 - \tan\phi_2), \tag{7}$$

where ϕ_1 and ϕ_2 are the angles between voltage and current before and after improving the PF, respectively.

Based on Eq. (5), improving the PF (at constant power and voltage) leads to decreasing the load current (I) which consequently results in decreasing the power losses (P_l) defined as (Saadat, 1999):

$$P_l = R_l I^2, \tag{8}$$

$$P_l = R_l P^2 / V^2 \cos\phi, \tag{9}$$

where R_l is the ohmic resistance of the network.

According to Eq. (9), $P_l \sim 1/\cos^2\phi$ which means for instance that improving the PF from 0.75 to 0.95 would cause a power loss reduction of 37.7%.

Therefore improving the PF increases the energy efficiency of the supply system through decreasing the losses, raising the voltage level, increasing the potential capability of the supply system and release the customer from the penalty.

4.4. Electrical motors

Electrical motors represent the highest percentage of loads in all technical systems worldwide. This issue is due to the fact that motors are the backbone of industry in addition to their use in running air conditions, fans, refrigerators, washing machines, dish washers and unlimited number of house hold appliances. In the rest of the world, the motor consumption may be anticipated to about 50% of the total electrical energy.

Due to this fact the competition is very high among manufacturers to improve motor efficiency and performance. To ensure optimum operation and achieve conservation below are some instructions and guidelines for the selection of electrical motors:

- Nominal capacity of electric motor must be suitable to the mechanical power of the load.
- Use high efficient motors with an efficiency over 90%.

Therefore a motor must be replaced if its repair cost is greater than 60% of the cost of a new energy efficient motor. In average efficient motors, are 4% more efficient than standard motors. Proper preventive maintenance will result longer life time, less energy consumption and high reliability service (Bose, 1992).

It is very useful to record information and measurements of the motor for performance evaluation to help in making decisions at the proper time for preventive maintenance. The use of DC motors, whenever it is possible, will provide up to 40% reduction in energy consumption as compared to conventional AC motors of similar rating capacity (Bose, 1992). The efficiency of old and new types of electrical motors is shown in Fig. 1 while the effect of speed variation on the energy consumption of the motor is illustrated in Fig. 2.

4.5. HVAC and heat pump

Much equipment is used for heating, ventilation and air conditioning (HVAC) in various types of buildings.

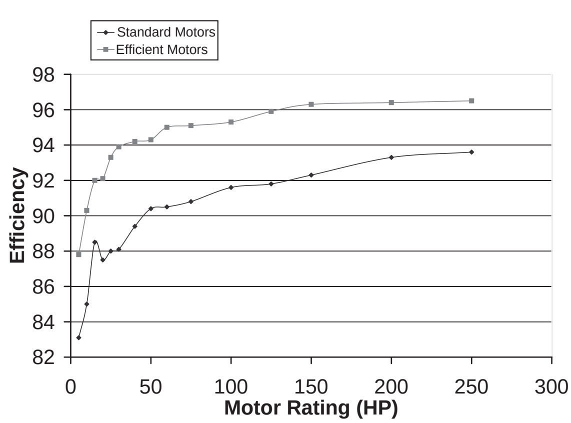

Fig. 1. Comparison between standards and high efficient motors.

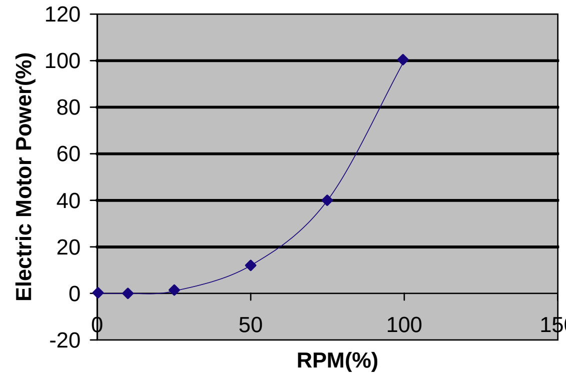

Fig. 2. Relation between power and speed for electric motors (air handling units).

An air conditioning unit consists mainly of a compressor, evaporator and condenser. Recent energy efficient designs of the main components of air conditioning systems have contributed in reducing their energy consumption. For instance, the use of a variable speed motor will reduce the energy consumed in an air conditioning unit. Other methods for efficient energy use include proper sizing, selection of optimum hardware, i.e. type of motor, valves, shape of fan, and adequate maintenance, i.e. filters, motors and, thermostat settings (Kreider and Kreith, 1977). The recent centrifugal chiller has lower electrical consumption (0.5–0.65 kW/ton refrigeration), as compared to the old values of 1.2–1.5 kW/ton refrigeration, which represents an energy saving of 40–50% (Kreider and Kreith, 1977) (1 ton refrigeration = 12,000 Btu/h or = 3.525 kW). Also, the frequent operation of a limited number of chillers at full rated load is more efficient because a chiller operating at partial load will consume higher energy. The design specification of the air conditioning system must be based on the real conditions of the plant. Therefore any over sizing may be cancelled. Many available industrial air conditioning units have a built in heat pump. Heat pumps are manufactured with various capacities suitable for various applications, both for heating and cooling purposes. However, we propose the following measures for power conservation in HVAC equipment:

- Shading the heat exchanger for all types of air conditioning units (central, split units, window types, etc.), because this saves about 10% of the power consumption.
- Shade all pipes conveying cold air and electricity cables.
- Regular periodic cleaning for the filters and air vents (3–4 times monthly).
- Regulation of electrical equipment use reduces the emitted heat, which helps in conserving the air conditioning devices.

- Use air screen to separate high temperature areas and rooms from air-conditioned areas.

The integration of a heat pump with the space conditioning system will reduce the energy consumed. Also, heat pumps are used with domestic hot water systems (Kreider and Kreith, 1977).

4.6. Other electrical appliances

The use of energy efficient technology is already applied for much electrical equipment, i.e. audio and video equipment, personal computers, washing machines, elevators, freezers, etc. Power converters can be used to convert alternating current to direct current or vice versa, under high efficiency. The use of power converters with reliable controllers reduces energy consumption also.

The industries must try to improve the existing systems with their equipment and units and increase efficiency which can be done through energy audits.

5. Supportive tools of energy conservation and management

The supportive tools and current methods are another way for successful energy technology and conservation policy. There are three classical approaches known as Energy and Public Awareness, Energy Regulation, and Energy Information and Programming.

5.1. Energy and public awareness

Public awareness could implement policies and programs on creating mass awareness and extending simplified information and knowledge about energy conservation topics. In order to achieve this purpose, it is possible to use available methods and techniques, like video films, radio and TV, local press, posters, communication and networking. Exhibitions are a very important medium for direct publicity to a vast number of people within a short period of time. The exhibitions could present samples for new energy efficient devices and renewable energy equipments. Publicity handouts and brochures in local language should also be distributed. Organizing conferences, seminars, meetings and workshops could bring about mutual interaction, exchange of latest information in specialized fields of knowledge and create awareness among the people.

5.2. Energy regulations

Energy regulations are essential for any successful energy policy. Energy management includes a number of regulations for energy consumption and direct/indirect electrical loads. It includes the variable tariffs of electrical energy (kW h) for base and peak loads. Energy decision makers could initiate rules and laws for reducing energy losses in various sectors by incorporating energy conservation technologies (Mahmoud and Ibrik, 2002; Palestinian Energy Authority, 2001).

Energy education is another way to establish a proper energy education scheme in the field of energy conservation by means of introducing new courses for both conventional and renewable energy sources. Such education schemes may include energy basic principles, consumption loads and the relevant environmental effects. It is also important to pursue academic research work and postgraduate studies in conjunction with industry in order to solve problems related directly to energy conservation and management (Mahmoud and Ibrik, 2002). Standards must be issued and applied on energy efficient equipment to achieve energy conservation. It is possible to list special regulations on energy conservation in buildings, insulation materials, energy efficient wall paints, SWH, photovoltaic lighting systems, photovoltaic electric grid connection, etc. (Imad and Mahmoud, 2002; Kreider and Kreith, 1977).

5.3. Energy information and programming

Energy information may include the latest scientific technological progresses published in useful books, reports and journals. Maintaining a specialized library and documentation could help to provide such requested information by individuals, organizations and institutions. Information packages on energy conservation should be provided to decision makers, planners, research scholars and the public computer software for energy projects should be designed and accumulated for solving problems related to energy conservation and management.

6. Energy audits with considerable saving opportunities

Considerable opportunities for energy efficiency improvements were identified through the energy audits conducted by the authors of this paper through the Energy Research Centre (ERC) at An-Najah National University. The audited sites included a wide spectrum of institutions ranging from factories in the different industrial sub sectors, to hospitals, hotels and public buildings. The expected savings to be achieved upon the implementation of the audit recommendations range from 10% to 15% of the total energy consumption. The amount of investment required to achieve those savings were rather small with a simple payback period not

Table 5
Energy measurements and audit results

Facility	Annual energy consumption	Energy efficiency measures recommended	Annual energy saving	Annual cost saving (NIS)
Hospital-1	72,000 kW h/year, 12,900 litres of diesel	• Lamps removal • Lamps replacement • Solar heater installation	kW h/year 32,640, 5000 litres of diesel	35,216
Mattresses Factory	500,000 kW h/year	• PF correction • Compressed air system • Electrical boiler replacement	45,800 kW h/year	29,770
Industrial Company	2,000,000 kW h/year	• PF correction • High efficiency motors (HEM)	20,150 kW h/year	13,097
Food Company-1	700,000 kW h/year, 40,000 litres of diesel	• PF correction • HEM • Improving boilers combustion efficiency	24,623 kW h/year, 2273 litres of diesel	22,369
Food Company-2	1,200,000 kW h/year	• PF correction • HEM • Improving boilers combustion efficiency	23,480 kW h/year	15,262
Food Company-3	500,000 kW h/year	• Replacing big PAN electrical heater with a LPG fired burner	153,900 kW h/year	100,035
Metallic Furniture Factory	1. 600,000 kW h/year (electricity) 2. 145 tons of LPG/year.	• HEM • Improving LPG Ovens combustion efficiency • PF correction for old factory lighting system	94,605 kW h/year, 1368 kg of LPG	64,673
Lubrication Oil Company	150,000 kW h/year	• PF correction • Boiler combustion efficiency	7300 kW h/year, 5640 litres of diesel	20,537
Paper Industries	160,000 kW h/year	• Lighting system	15,000 kW h/year	9750
Shoes Company	500,000 kW h/year	• PF correction • Replacing conventional motors with high efficiency motors • Lighting system	18,900 kW h/year	12,285
Hospital-2	1,000,000 kWh/year, diesel = 22,000 litres/year	• Lighting • Improving boiler combustion efficiency • Solar heaters	28,852 kW h/year, 8325 litres of diesel	42,064
Shoes Company	500,000 kW h/year	• PF correction • Lighting	28,784 kW h/year	18,709
Stone Company	600,000 kW h/year	• Save energy consumption at trailers • HEM • PF correction	55,960 kW h/year	36,374

exceeding 3 years on average. Table 5 summarizes the energy saving opportunities at some of the audited sites. Common fields for potential energy saving include improving boiler combustion efficiency, replacing conventional motors with high efficiency motors, replacements of conventional lighting devices with energy efficient lighting and installing PF correction panels. Each of the recommended measures was analyzed in detail from the technical and financial point of view. Several no/or low cost measures for energy saving were recommended to almost all of the audited sites as: removal of extra lamps, adjusting the cooling and heating temperatures, insulating all steam and hot water pipes to limit heat losses and periodic cleaning of lighting devices and other machines and appliances.

The audit team of the Energy Research Centre stressed specially the importance of improving commitment to control the use of lighting, refrigerators, electric boilers and other electrical devices by enhancing the awareness of energy saving measures. The management of different businesses and institutions were advised to adopt training plans for the operational and maintenance staff in order to upgrade their performance and skills in the fields of energy efficiency. This target group was informed of the importance of training in minimizing human errors and improving product quality on the operational side, in addition to the benefits of adopting periodic preventive maintenance schedules, which will keep machines in good condition and reduce breakdown and repair time.

7. Conclusion

After implementing a 3 years project on energy efficiency improvement, which included numerous diversified power measurements and audits in residential sector, hospitals, hotels and industrial sector we can conclude that applying the mentioned energy efficiency measures would save surely considerable amounts in the electric energy bill and fuel. Using efficient lighting devices, new refrigerators (with energy label), SWH instead of diesel, gas or electric boilers, high efficiency motors beside improving the PF in industrial plants and adjusting properly the HVAC systems and the steam boilers can save in average about 15% of the energy consumption. To achieve this goal, the simple pay back period of the corresponding investment cost range mostly between 6 and 36 months.

In addition, energy efficiency improvement would effectively contribute in protecting the global environment.

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