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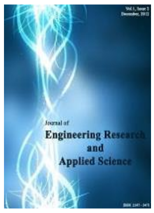

Investigation of energy saving potentials of a food factory by energy audit

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Abstract
There is no doubt that energy efficiency is the best solution for the challenges of modern society such as global warming, environmental impact assessment, industrial ecology, improved energy management and new energy sources. Within this scope, energy efficiency policy has been developed by the many countries to minimize the energy consumption of unit products and to recover the industrial waste heat. This paper presents a case study for determining whole energy saving potentials arising from the main selected equipments in a biscuit factory. For this purpose, several instruments were used to measure heat losses, surface temperatures, properties of stack gas, flow rate of stack gas and luminous intensity, etc. From the analysis results, it reveals that total energy saving amount based on natural gas and electricity is 50.96 TOE/year after various remedies, which corresponds to 8% total energy consumption of the investigated equipment in the factory. Thus, energy efficiency applications result in a profit of about 24766 $/year and a reduction of 89.91 tons CO2 emission per year. This study has shown that with the simple applications in food factories, efficient use of energy can be increased and therefore energy intensity can be improved. We hope that this study will be a reference for energy managers in food factories to provide more energy savings.

Keywords: Energy efficiency; energy audit; CO_2 emission reduction.

1. Introduction

Energy is indispensable power for both industry and human life but it should be efficiently used due to the limited fuel – based sources and its high cost. Besides, major air pollutants from energy are liable for global climate change, acid rain and many respiration diseases [1]. Therefore, energy issues, especially in the industry, have become more important due to increasing of energy cost and environmental awareness such as reducing emission of greenhouse gases [2]. The industrial sector is composed of a different set of industries such as mining, metal, chemical, paper, food etc., which are responsible for 37% of worldwide energy consumption and 36% of CO_2 emissions [3]. One of the major industries is food industry. In Europe, the food industry represents a universe of 286,000 industries with 4.2 million direct jobs and had a turnover of 1,048 billion Euros in 2014 [4-6]. In Turkey, the food industry follows the European trend with one of the largest group of manufacturing industries in the country (% 16.5), and they reached a business turnover of 21.5 billion Euros in 2014 [7]. Since more than 50 % of Turkey's biscuit production is fulfilled at nearly 40 large and small biscuit factories in the Karaman Industry, it has very significant position in biscuit production in Turkey.

The protection of the environment and maximum utilization of energy used during the process are important issues for all industries. In developed countries, most of the plants have focused to energy efficiency applications due to the limited energy sources, environmental effects of fossil-based fuels and sustainable development [8,9]. By this way, they can reduce the energy consumption per product. By detecting the unnecessary usage of energy and minimizing the energy losses, producers can increase their competitive capacity in national or global market by producing the same goods with less energy [7]. Over the last decades, several researchers have mainly focused on a component of the system such as boiler, furnace, steam systems, electrical motors, lighting fixtures, etc. [10-15] in order to obtain energy savings by applying some precautions; using high efficiency engines, high lighting armatures, variable speed driver, heat recovery systems, preheat combustion air with waste heat, insulation of hot or cold surfaces, reducing pressure drop and leak prevention [16]. In addition, some researchers have preferred to energy auditing the whole of the processes for different industrial sectors such as rubber, iron and steel, sugar, etc. [17-22]. Major

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part of these studies has studied on total first law efficiency, total exergy efficiency or relative primary energy savings.

However, according to the best of our knowledge, there is no any report for energy saving potentials in a biscuit factory. Therefore, this work describes an overview of energy saving measures, complete with an analysis on potential savings of energy and cost including simple payback periods in a selected biscuit factory in Karaman, Turkey. This energy analysis also involves precious information such as energy consumption patterns of the factory and the specification of high energy intensive equipments, feasible energy saving measurements and cost benefit analysis. By this way, it is expected that the results of the present study create awareness on the energy saving potentials for the similar industrial energy users not only in Karaman region but also in all over the world..

2. Energy audit

2.1. Energy auditing procedure

An energy audit is a supervision, search and analysis of energy consumptions for conservation of energy to lower the amount of energy influx into the process without negatively affecting the output [3]. Basic factory tools with regards to energy consumption in a biscuit factory are cooking furnaces, steam boilers, hot water boilers, electric motors, compressed air system, lighting fixtures, air conditioning, and heat transfer pipes with valves. Among them, the major potential areas for energy saving in the selected factory were determined as in a cooking furnace, a steam boiler, a group of valve connections, a hot water boiler, an electric motor and lightening system. The cost of the investment and pay-back period was analyzed for all these applications. In addition, based on the measurements for predetermined factory equipment, all possible energy saving potential was calculated and presented at the end of this study. Furthermore, apart from these applications, several remedies were offered at the end of this study. The energy auditing instruments with descriptions used in the present work are given in Table 1.

Table 1. The energy auditing instruments and descriptions.

Instrument	Description
TESTO 870X2i	thermal camera
TESTO 435	multifunctional measuring instrument, (pitot-tube, luxmeter, thermometer)
TESTO 350	stack gas analyzer
METREL 2883	electric analyzer

2.2. Energy view of the selected factory

The selected factory for this study is composed of 4 different production areas (Biscuit, Chocolate, Cake and Wafer) and supported by a single energy center. Within the scope of this study, only biscuit production lines (areas) with energy center of the factory are examined. The total energy consumption of the selected factory is determined as 5794 TOE/year, 942 TOE of which is used for electricity and 4852 TOE for natural gas. Approximately 15% of the total energy goes to biscuit production. In this factory, the cogeneration system with 1 MWh capacity is used to generate the electricity by burning the natural gas. Since the cogeneration system is activated in daytime and peak hours, but stopped at nights, so the electricity is purchased from the main energy distribution frame during the nights. The natural gas is used in the boilers and the furnaces as well as the cogeneration system.

3. Energy saving applications

Food industry is considered as energy-intensive sector [23]; especially, fuel is used for thermal processing and electricity is used for pump motors. The energy saving potential and applications for the selected biscuit factory is summarized as below.

3.1. Energy saving on furnaces

In a biscuit factory, the energy consumption especially is very high in the cooking furnaces due to the extensive use of thermal energy for baking process. In general, these furnaces have a potential energy in their exhaust gases. The waste heat in the exhaust gas is recoverable by many techniques: preheating the boiler’s feed water with an economizer, preheating the combustion air with the recuperator and preheating the bunker oil etc.

In this section of the study, a recuperator (gas-to-gas heat exchanger) is devised to achieve high heat recovery from the exhaust gas of the furnace in the predefined biscuit factory.

There are 3 flush-seamed biscuit production lines at the manufacturing area, each of them have a typical tunnel furnace with 45 m long and 1.1 m wideness furnace, in the examined factory. Each furnace output capacity is 26.4 tons/day of biscuit with the consumption of 32.73 Nm3 natural gas/ton biscuit. Physical properties and ultimate analysis of natural gas used in the furnace are given in Table 2.

Table 2. Physical properties and ultimate analysis of natural gas (All the data is provided by fuel supplier).

C1 (Methane) (%)	**91.22**	**N_2 (Nitrogen) (%)**	**3.16**
C2 (Ethane) (%)	3.39	CO_2 (Carbondioxide) (%)	0.45
C3 (Propane) (%)	1.17	HHV (Kcal/Sm^3)	9233.97
I-C4 (I-Butane) (%)	0.18	LHV (Kcal/Sm^3)	8364.26
N-C4 (N-Butane) (%)	0.24	Specific weight	0.61
I-C5 (I-Penthane) (%)	0.07	Density (kg/Sm^3)	0.75
N-C5 (N-Penthane) (%)	0.05	Atmospheric Pressure (bar)	0.90
C6+ (Hexane) (%)	0.06	Cost of Fuel ($/Sm^3)	0.35

Energy balances were performed around the control volume, determined by the outer surface of the furnace, and expressed on a basis of one ton biscuit. The energy balances were obtained by combining both average measurement values and calculations based on the following assumptions:

- The furnace works at steady state conditions.
- The composition of the natural gas and the average inlet of natural gas at ambient temperature do not change over time.
- Surface temperature changes along the furnace, which is divided into sections according to these temperatures. The average surface temperatures of these sections do not change in time.
- The average ambient temperature (T_0) 21.8°C is constant throughout the study.
- All gas streams are assumed to be ideal gases. The average specific heat capacities at constant pressure and fractions of the gas species that compose the exhaust gas, as well as its temperature and enthalpy are shown in Table 3.

Table 3. Energy balance data of the furnace

Fuel Consumption	**36 m^3/hour**	**Furnace Efficiency**	**0.57**
Exhaust Gas Flow	345 m^3/hour	h, $_{200,1\,°C}$	475.32 kJ/kg
T_{EG}	200.1 °C	h, $_{111\,°C}$	384.81 kJ/kg
T_0	21.8 °C	h, $_{21,8\,°C}$	294.97 kJ/kg
T_M	111 °C	Density	0.96 kg/m^3
LHV	35012.79 kJ/ m^3	Efficiency	0.5

Energy demands before and after recuperator implementation was calculated by following formulas by using data which procured from the measurements:

$$Q_1 = M_{EG} \text{ x } \rho \text{ x } \left(h_{200,1\,°C} - h_{21,8\,°C}\right) \quad (1)$$

$$Q_2 = M_{EG} \text{ x } \rho \text{ x } \left(h_{200,1\,°C} - h_{111\,°C}\right) \quad (2)$$

Where Q_1 and Q_2 are energy requirement for the furnace without and with recuperator, respectively, M_{EG} is flow rate of the exhaust gas and ρ is density of the exhaust gas.

$$Q_{income} = Q_1 - Q_2 \quad (3)$$

$$\text{Gas savings} = Q_{income} / (\text{LHV x Furnace Eff}) \quad (4)$$

Investing in an energy efficiency improvement is needed to perform an economic analysis. Therefore, in this study, the economic analysis of investment to save energy was evaluated by the payback period analysis method.

Assuming that the biscuit factory is working 24 hours in day and 365 days in a year, savings cost and payback period were calculated by the Eq.5-6;

$$\text{Savings cost} = \frac{\text{Gas savings}}{\text{year x unit fuel cost}} \quad (5)$$

$$Payback\ period = \frac{\text{Investments cost}}{\text{Saving cost}} \qquad (6)$$

Following outcomes could be obtained from this section:

1. These savings are derived from two factors: (i) recirculating the hot exhaust gases back into the furnace, and (ii) a reducement in the mass of flue gases due to the use of oxygen.
2. From the calculations it has been found that 23131 kJ/hour of energy and 10074 m^3/year fuel can be saved by using a recuperator in the furnace, which corresponds to 11081 $/year.
3. The payback period for heat recovery system in the furnace found to be 2.15 year is economically very viable [23].

3.2. Energy saving on steam boiler

Large quantity of hot flue gases is commonly generated from boilers, kilns, ovens and furnaces. Much of the heat could be recovered and the loss could be minimized by realizing required applications [24]. According to the researchers, for every 60 ^{0}C rise in feed water temperature through an economizer or 200 ^{0}C rise in combustion air temperature through an air pre-heater, 1% saving of fuel occurs in the boiler [25].Therefore, in this study, a condensing economizer is offered to obtain high heat recovery from the exhaust gas of the steam boiler in the biscuit factory. By this way, the reuptake of sensible heat and condensation of the exhaust flue gas will be beneficial for both the environment and economy. In the selected factory, there are two steam boilers; each of them made by stainless steel has 5.5 m length and 2.7 m diameter. The natural gas is used as a fuel (Table 2) in the steam boilers. Ambient temperature (T_o: 20^{o}C) of the steam boiler room was determined and surface temperature of the steam boiler (Ts) was measured by the multifunctional measuring instrument and the thermal camera, respectively. Besides, the components (temperature, CO, O_2, CO_2 etc.) of the exhaust flue gas were identified by the flue gas analyzer.

An important amount of the energy is lost through exhaust flue gases as all the heat generated by the burning fuel cannot be transferred to steam in the boiler. As the temperature of the exhaust flue gas removing the steam boiler typically ranges from 150 to 250 °C, about 10–30% of the heat energy is lost through it. Since most of the heat losses from the steam boiler transpire as heat in the flue gas, the recovery of this heat can result in substantial energy savings. This demonstrates that there are huge savings potentials of the steam boiler energy savings by minimizing its losses. The calculated heat balance in the steam boiler is shown in Figure 1.

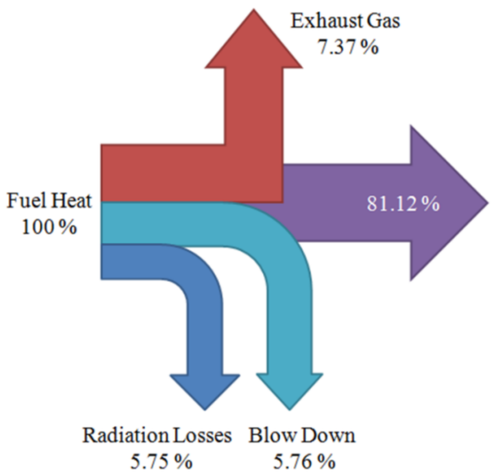

Figure 1. Heat balance of the steam boiler

Boilers bedecked with condensing economizers can have an overall efficiency that surpasses 90%. A condensing economizer can enhance total heat recovery and steam system efficiency by up to 10% by decreasing the exhaust flue gas temperature below its dew point, resulting in improved effectiveness of the waste heat recovery. The temperature of the exhaust flue gas of the steam boiler determined as 214.4 °C from the measurements. Since dew point temperature in Karaman is between 50-60 °C depending on the weather conditions, final temperature of the flue gas can be reduced as 70 °C by installing a condensing economizer. Therefore, the reduced temperature by the condensing economizer of the exhaust gas was determined as 70 °C.

Energy balances are fulfilled around the control volume, determined by the external surface of the steam boiler. The energy balances are acquired by combination of both average measurement values and calculations based on the same assumptions with the furnace. The average specific heat capacities at constant pressure and fractions of the gas species that compose the exhaust gas, as well as its temperature and enthalpy are shown in Table 4.

Table 4. Energy balance data of the steam boiler

Fuel Consumption	**44.86 kg/hour**	T_M	**118.2 °C**
Exhaust Gas (EG) Flow	423.22 m^3/hour	LHV	57381.088 kJ/ kg
n_{EG}	15.27 kmol/hour	C_{pM}	31.93 kJ/kmol K
T_{EG}	214.4 °C	h_{fg}	2015 kJ/kg

Energy losses before and after installing the condensing economizer was calculated by following heat transfer formulas by using data which obtained from the measurements:
Energy of the fuel was;

$$E_{fuel} = m_{fuel} x\, LHV \quad (7)$$

Where E_{fuel} is energy obtained from combustion of the fuel (kJ/s), m_{fuel} is consumption of the fuel (kg/s) and LHV is low heat value of the fuel (kJ/ kg).
Sensible heat (E_{SH}) and latent heat (E_{LH}) of the exhaust flue gas were;

$$E_{SH} = n_{EG} x C_{PM} x\,(T_{EG} - T_O) \quad (8)$$

$$E_{LH} = (n_{EG} x x_{H2O}) x h_{fg} x Ma_{H2O} \quad (9)$$

$$E_{TOTAL} = E_{SH} + E_{LH} \quad (10)$$

Heat loss from the exhaust flue gas was;

$$\%\ \text{Heat losses from EG} = \frac{E_{TOTAL}}{E_{fuel}} x\, 100 \quad (11)$$

As mentioned before, the reduced temperature by the condensing economizer of the exhaust gas was determined as 70 °C. At this temperature, recovered energy (E_{RE}) was;

$$E_{RE} = n_{EG} x C_{PM} x (T_{EG} - T) \quad (12)$$

It can be drawn from this section that the method of heat recovery by installing a condensing economizer from flue gas is one of the effective ways to save energy in a steam boiler. According to the results, it has been determined that 70405.27 kJ/hour of energy can be saved by using a condensing economizer in the steam boiler. From the calculations by Eq. 4, it is found that 21724.8 m^3 fuel /year can be saved for a maximum 3.3 % energy savings. The payback period for heat recovery system in the steam boiler calculated by Eq. 6 as 1.13 year is economically very viable.

3.3. Energy saving on hot water boiler-valves

Generally, steam or hot water used in manufacturing processes are provided by boilers and transferred by pipelines and valves. Hot water boiler is the main equipment for all food factories. According to the Indian Bureau of Energy Efficiency [26], there are various opportunities about the energy recovery from boilers:

- Preheat combustion air with waste heat,
- Add an economizer to preheat boiler feed-water using exhaust heat,
- Use variable speed drivers on large boiler combustion air fans with variable flows.
- Automate/optimize boiler blow-down,
- Recycle steam condensate,
- Insulate the heat surfaces.

Among them thermal insulation is an easy and low cost way which can be performed by users on industrial processing equipment such as pipeline, furnace, heat exchanger and valves to reduce the energy usage and the CO_2 emission [27]. Removable insulation jackets are generally used for insulation of valves, flanges, regenerators, pumps and other irregular surfaces in industrial plants. Once fastened tightly with rope, they are durable and stand up against effects of water and oil even at high temperatures.

Therefore, the purpose of this section is to determine the heat losses from a boiler and a group of valves where hot water produced and transferred for different processes in the food factory. In addition, energy saving amount was calculated in case of insulation of the boiler and valves with different diameters. Furthermore, the cost of the investment and pay-back period was analyzed.

Although there are several hot water boiler with different sizes in the selected factory, the biggest boiler was selected to investigate in terms of heat losses, which is made by stainless steel has 4.5 m length and 1.2 m diameter. Similarly, though there are more than 300 valves with different sizes and temperatures in the factory, 22 of them in the boiler room of the factory were selected and examined. Number of the selected valves and their diameters with temperatures are given in Table 5.

Table 5. Number of valves and diameter

Valve Dia. (mm)		Outside Dia. (mm)	Number of Valves	Wall Thick. (mm)	Inner Dia. (mm)	Temperature (°C)
1’’	DN 25	33.7	6	3.4	26.9	160
1’’	DN 25	33.7	4	3.4	26.9	91
2’’	DN 50	60.3	2	3.9	52.5	160
2’’	DN 50	60.3	3	3.9	52.5	91
$2^{1/2}$’’	DN 65	73.0	1	5.2	62.6	160
3’’	DN 80	88.9	1	5.5	77.9	160
4’’	DN 100	114.3	2	6.0	102.3	160
5’’	DN 125	141.0	3	6.6	127.8	160

Rockwool was chosen as an insulation material due to the superior properties such as corrosion, moisture and fire resistant. All calculations were made for application of 50 mm thick rockwool on the boiler and the valves. Energy losses before and after the insulation were calculated by following heat transfer formulas (Eq.13-16) by using data which obtained from the measurements.

$$\boldsymbol{Q_1 = (U_c + U_r)\ x\ A\ x\ (T_s - T_a)} \quad (13)$$

$$\boldsymbol{U_r = \left[\frac{Ex5.67}{(T_s - T_a)}\right] x\ [(\frac{T_s}{100})^4 - (\frac{T_a}{100})^4]} \quad (14)$$

$$\boldsymbol{U_c = B\ x\ (T_s - T_a)^{0.25}}$$

(15)

where $\boldsymbol{Q_1}$ is heat losses before insulation, $\boldsymbol{U_r}$ and $\boldsymbol{U_c}$ are heat transfer coefficients by radiation and convection, respectively.

$$\boldsymbol{Q_2 = A\ x\ (T_s - T_a)/[(L/\lambda) + (1/\alpha_d)]}$$

(16)

where $\boldsymbol{Q_2}$ is heat losses after insulation, T_s and T_a are the surface and ambient temperatures, respectively, A is surface area of the boiler, B is the multiplying factor which equals to 1.2 when the boiler is located to parallel to ground, E is the emissivity coefficient of surface material of the boiler (0.77), L is the insulation thickness, λ is the thermal conductivity coefficient of the insulation material (0.068 W/m.K) and α_d is the thermal conductivity coefficient by heat convection (20 W/m^2.K).

The heat saving amount obtained by after the insulation was calculated by using following assumptions:

- Boiler and valves work at full capacity during all year,
- Ambient temperature where the boiler and valves operate is 15 °C and it remains constant at this temperature.
- Insulation for boiler and valves was designed by using rockwool with 50 mm.
- The lower heating value and unit cost of fuel was taken from fuel provider as 8364.6 kcal/Sm^3 and 0.35 \$/Sm^3, respectively.
- According to the supplier, the investment cost of the insulation of boiler and valves are 933$ and 1927$, respectively.

Surface temperatures of the boiler and valves were detected by the infrared imaging camera and calculated the computer software (Testo IR software). Figure 2 shows the thermal camera images of the boiler, and Figures 3a and 3b show the thermal images of the valves located just outside of the boiler and the valve placed outside of the economizer, respectively.

According to the results, there is a homogeneous temperature distribution on the boiler surface. The average surface temperatures of front and lateral surfaces of the boiler were 74.9°C and 70.4 °C, respectively. The heat is lost from the boiler surface to the surrounding due to the differences between its surface temperatures and ambient temperature (15°C).

As seen from Figure 3, the highest temperature was founded in the center of the each valve whereas its edges have lower temperatures. Also, it can be noted that the valves close to boiler have hotter maximum and average temperatures (Ts= 160 ºC) than those (Ts= 91ºC) of the other valves.

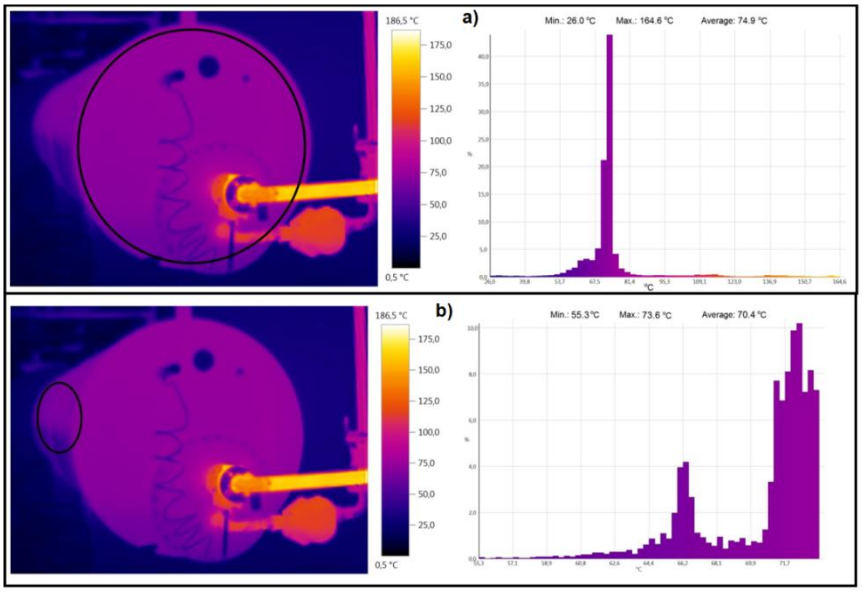

Figure 2. a) Thermal and real images of front surface of the boiler with profile line and b) Thermal and real images of lateral surface of the boiler with measuring points

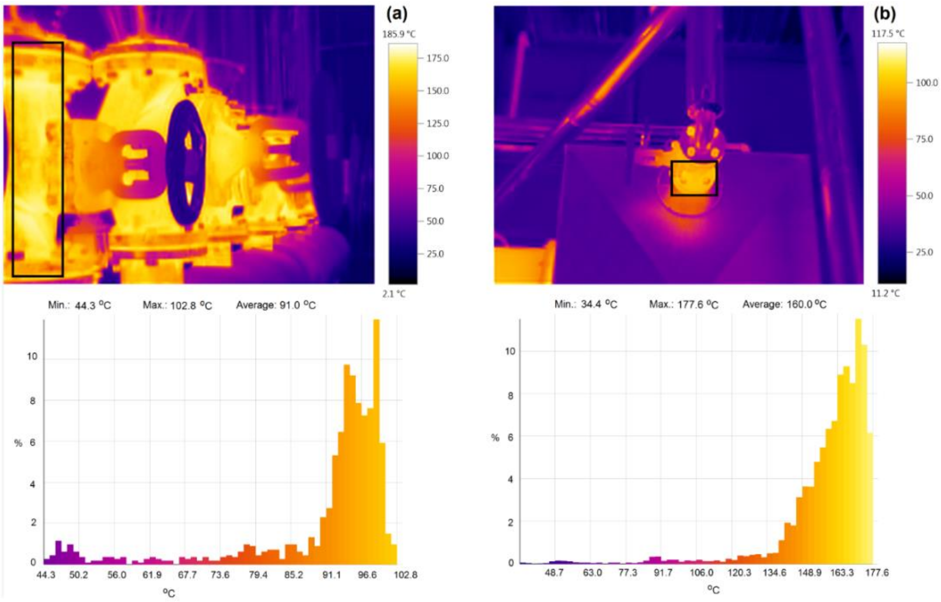

Figure 3. Thermal images and profile lines of (a) steam boiler valve groups and of (b) pipeline valves.

By using Eq. 13 and 16, the heat losses before and after insulation of the boiler was calculated as 34524 kJ/h and 4143 kJ/h, respectively. The difference between these two values equals to energy saving amount as 30381 kJ/h, and energy recovery rate was detected as 88 %. It is found that 7621.2 m3/year fuel can be saved with 2667.42 $/year saving amounts. According to the pay-back analysis method, energy saving amount calculated for the investment cost of the isolation is corresponds to about 0.35 years.

On the other hand, energy saving amount from the 22 valves was calculated as 80360 kJ/h. Also, it is found that 2.3 m^3/hour and 20148 m^3/year fuel can be saved with 7051.8 $/year saving amounts. Insulation of the valves working at high temperature disburdened the energy cost of the industrial plants with very low payback period (0.27 year) [28]. Taking into account more than 300 valves with different sizes and temperatures, considerable amount of energy saving can be obtained by insulation of them with proper material.

3.4. Energy saving on electric motors

Electric motors systems consume approximately 60% of industrial electricity consumption and about 15% of total energy use in industry over the world [29]. It is predicted that all applications of efficiency improvement options could reduce worldwide electricity demand by a half [30]. So the use of highly efficient electric motors is important for both an industrial energy saving and CO_2 emission [31].

Motor efficiency is essentially the ratio between the mechanical output power and the electrical input power. The efficiency of electric motor is a factor of a variety of mechanical and electrical imperfections within the motor. The Figure 4 shows that there are several types of energy losses in an electric motor.

There are three steps of the efficient growth projects in electric motor systems. First step is the take inventory of the all motors in the process. The input power, output shaft power, efficiency, operating period, the efficient class (label value) and the loading rate are the main parameters for detecting the efficiency of the motor by using Energy (Power) Analyzer and Thermal Camera. Then, in the efficiency analysis, the energy consumption and payback periods are calculated based on the measurements. Lastly, in the decision step, there are several precautions for the reducing the electric energy consumption as the using frequency inverter and replacement the low efficient motor to high efficient one.

In the selected the biscuit unit contains the same 14 motors which active power is 37 kW with 14 years old. Looking at label values and the measurement results of the one of these mixer motors, its active power is 37 kW. The demand load is constant, but not a full load, %60 of motor power (approximately 22 kW). The annual working period is 4368 hours. According to the declaration by European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP 28 July 1999), the selected mixer motor is EFF3 type with reference to classification for 37 kW electric motors [32]. Therefore, in this study, the investment of the high efficiency motor could be thought to obtain energy saving by renovated old one.

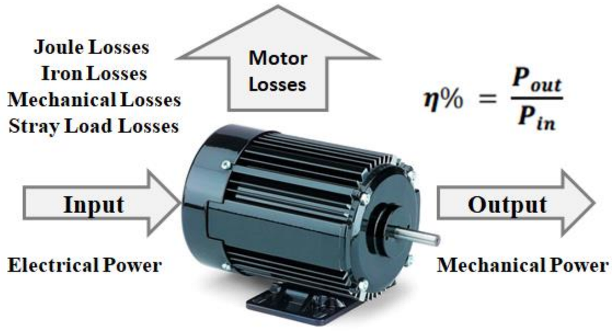

figure 4. Energy losses in electric motor.

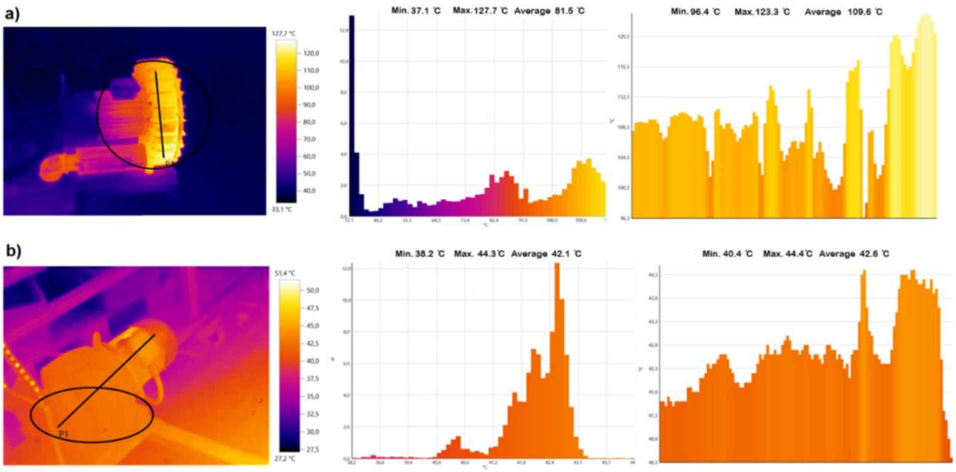

Figure 5. Thermal image, histogram and profile line a) for the one of the low efficiency electric motors, b) for one of the efficient electric motors.

The Figure 5 shows that the difference between the thermal analysis of the efficient and non-efficient motors. These thermal images have taken in the same place where the temperature is variable between 28.3℃ and 32.1℃. As can be seen from the profile line and histogram of the low efficiency electric motor thermal image, there are large temperature differences over the stator shaft. In Figure 5, thermal images clearly illustrate that, the difference between the average temperatures of high efficient and low efficient motors is about 40℃, which resulted in considerable amount of the heat energy losses. The total energy saving is given by calculation (Eq. 20);

$$\text{Energy save} = \text{Total power} * \text{WH} * \text{LR} * \left({}^{1}/_{\eta_{\text{std.}}} - {}^{1}/_{\eta_{\text{high eff.}}} \right) \tag{20}$$

Where the yield of standard motor ($\eta_{std.}$) with a 37 kW power for 4 pole and 1500 rpm, is % 91, the yield of high efficiency motor ($\eta_{high\ eff.}$) with the same features is % 93.7, WH is an annual working period, and LR is loading rate.

From the calculation by using Eq. 20, annual energy saving amount for only the selected mixer motor was detected as 3070.56 kWh/year, which corresponds to 414.3 $/year. Considering there are 14 non-efficient motors, the total energy saving is 42987.84 kWh/year and total money saving is 5800.2 $/year. According to the pay-back analysis method, energy saving amount calculated for the investment cost is corresponds to about 4.57 years.

3.5. Energy saving on lighting

Lighting is a significant issue to minimize whole energy consumption especially in the industrialized countries due to the fact that it corresponds to about 15% of the total electric energy consumption [33]. The energy consumed by of a lighting fitting mainly depends on the kinds of lighting fixtures and lighting parameters such as daylight, presence detection, dimming, etc. [34,35].

The selected areas of the factory to investigate in terms of lighting are nearly 5.000 m^2 indoor areas which correspond to 1/10 of the total indoor areas of the factory, including production lines, laboratories, stock areas, technical-administrative staff offices, etc. There are lots of staff offices in the administrative building with 30*36W florescent lambs, and also 3 flush-seamed biscuit production lines at the manufacturing area with 288*36W florescent lambs. During the measurements of the current lighting fixtures, we have focused on the application of the enough intensity illumination with the lower power consumption, improving comfort conditions and reducing lighting costs with offering proper lighting solutions instead of systems already used.

According to the EN 12464-1-2011 standard, the minimum luminance values should be 300 lux for the staff offices and 200 lux for the production lines; however, illumination levels were measured in the staff offices as 100 lux and hallways at the biscuit production lines as 80 lux. As the result of the luminous intensity measurements, it has been determined that the current illumination fixtures are insufficient for working conditions and even so they consume over power. Therefore, the usage of LED panel fixtures instead of florescent ones was investigated in detail, and it was recommended to replace low efficient lamps (florescent lambs) with high efficient ones (LED fixtures) for saving energy and getting sufficient illumination.

Table 6 presents the sizes of each office and each production line, as well as data needed for lighting calculations. 46 W total values of 3789 lumens LED fixtures were found appropriate for offices and production lines.
The results of analysis for the factory are given below:
The annual energy consumption of the existing lighting systems can be calculated as follow (Eq. 21);

$$Energy\ Cons.(y) = 154\ x\ 72(W)\ x\ 365\ x\ 24 = 97130\ kWh/y \qquad (21)$$

Electric unit price is 0.096 $/kWh, so; annual lighting consumption price is 9324 $. The annual energy consumption values of the proposed lighting systems (LED) are calculated by Eq. 22;

$$Energy\ Cons.(h) = 98\ x\ 46(W)\ x\ 365\ x\ 24 = 39490\ kWh/y \qquad (22)$$

Since electric unit price is 0.096 $/kWh, annual lighting consumption price for proposed LED is 3791 $. Therefore, by replacement of the existing lambs with proposed LED fixture, annual profit is totally 5530 $. Taking into account that investment cost of the each LED fixture with 46 W and 3789 lm is 71$, the payback period for the recommended lighting system can be calculated by Eq. 6 as 1.25 year, which is economically very viable.

To reveal the difference in illumination distribution between the existing fluorescent fixtures and proposed LED fixtures, the light levels of the both systems were compared by using LUX-2000 software program. The light level of the available fluorescent system and the proposed LED system for hallways at the biscuit production line and for each office are seen in Figure 6 a, b, c and d, respectively.

Table 6. Data needed for LED fixture calculations

	Office	**Production Line**
Width (m)	4.5	16.6
Length (m)	6.0	82.0
Height (m)	3.15	5.9
Fixture Height (m)	3.0	4.5
Min. Illumination intensity (lux)	300	200
Fouling factor	1.25	1.25
Index of the area $(\frac{axb}{hx(a+b)})$	0.86	3.07
Efficiency	0.31	0.47
Power of new fixture (W)	46	46
Light flux of new fixture (lm)	3789	3789
Number of LED fixtures $(\frac{Exaxbx1.25}{Qxh})$	1	44

As mentioned before, while light level of the available fluorescent systems is quite inadequate, the light level with the proposed LED system is more evenly distributed and its average lux value has increased.

It can be summarized from the results of the lighting part that total necessity of LED fixtures for offices and production lines can be decreased, therefore, notable energy saving can be provided (29960 kWh/year) by using the LED fixtures (46 W and 3789 lm). This work also shows that changing the current fluorescent lamps with the LED fixtures could reduce energy cost of the company burden with very short payback period (1.25 years).

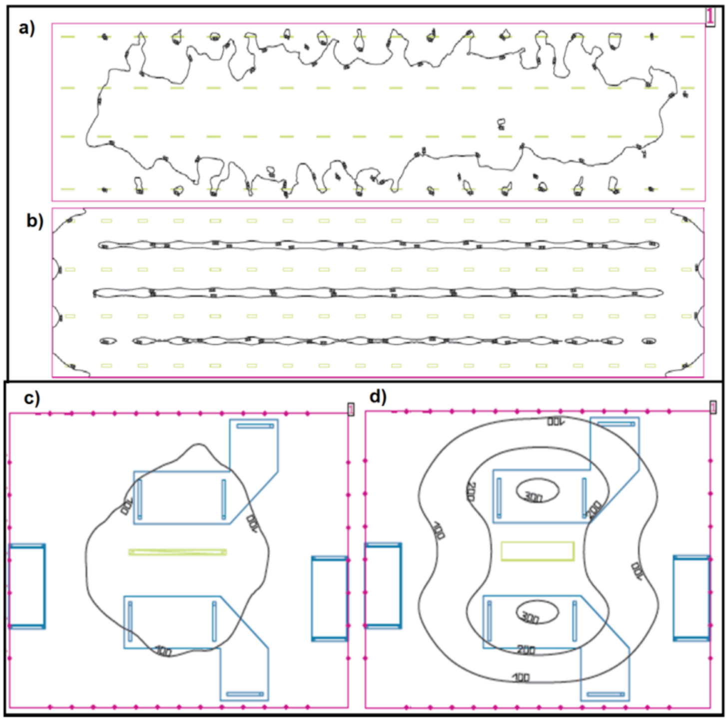

Figure 6. The light level in hallways at the biscuit production line a) for the available fluorescent system, b) for the proposed LED system, c) the light level in each office for the available fluorescent system, d) the light level in each office for the proposed system.

3.6. Energy saving remedies on other equipment

In addition to the above energy saving applications for the industrial plant, following remedies can be offered to save energy in the factory [8,36];

- Compressor air inlet temperature reduction by changing their location,
- Reduction of air pressure in compressors according to process requirements,
- Operation of smaller compressors at full capacity,
- Correction of voltage imbalance and improvement of the power factor,
- Overvoltage reductions in plant distribution system,
- Adaptation of the lighting level to working condition,
- Optimization of parallel pumps and selection of optimum pipes in pump systems,
- Setting the condensate water temperature in the cooling group,
- Recalibration of the chilled water pumping pressure,
- Closing unused equipment and monitoring of electricity demand.

With the implementation of these remedies, the energy saving potential of the selected factory will increase steadily, which results in more profit and less CO_2 emissions per year.

4. Conclusions

The results disclose that the biscuit factory has considerable saving potentials on energy in areas of boilers, furnaces, valve connections, electric motors and lighting. The total energy saving is recorded as 50.96 TOE/year after applications of investigated parameters on representative tools in the selected factory. Considering the total energy consumption of the investigated equipment in the biscuit factory, approximately 8% energy saving could be achieved through by performing the energy audit. This ratio can be enlarged by applying additional remedies offered at the last part of the study. Following results can be summarized after the investigated remedies with energy analysis and different simple pay back periods;

- 23131 kJ/h of energy and 10074 m^3/year fuel can be saved by using a recuperator in the furnace, which corresponds to 11081 $/year. The payback period for heat recovery system in the furnace is found to be 2.15 years.
- According to results, it is found that 70405 kJ/h of energy and 21725 m^3/year fuel can be saved

after application of a condensing economizer in the steam boiler. By this way, a maximum 3.3 % energy savings can be obtained, which corresponds to 1.13 years payback period.
- After insulation of the boiler and the valves, total energy saving amount can be found as 110741 kJ/h, 27769 m^3/year fuel, and 9719.22 $/year. The pay-back analysis method for the insulation is found about 0.30 years.
- From the calculation, annual energy saving amount for only selected mixer motor was found as 3070.56 kWh/year, which corresponds to 414.3 $/year and 4.57 years payback period.
- As a result of the measurements, it can be revealed that there are inadequate light intensity and irregular light distribution level in the selected region of the factory due to the usage of low efficient fixtures. 29960 kWh/year energy saving can be provided by using the LED fixtures instead of florescent lambs. Annual profit and the payback period for the recommended lighting system are calculated as 5530 $ and 1.25 years, respectively.
- Many advantages could be succeeded through the energy audit in the selected biscuit factory such as decreasing environmental pollution (90 tons of CO_2) and minimization in specific energy consumption (totally 59568 m^3/year fuel and 33030 kWh/year).

During the present study, authors have described the motivation of the employees is the key topic to save the energy without a sizable investment. The probable benefits to employees from a prospering energy management project should mention to improve the ecological and human risk assessment, the work safety, developed working conditions, industrial ecology, and environmental impact assessment, encouragement payments, auditing efficiency and environmental standards and criteria. It is significant to have a well-structured personnel information program regarding energy savings and its returns.

The application of above energy saving measurements is just dependent upon the judgment of the factory management. Various energy conservation methods that are cost effective are not usually applied due to the lack of internal funding. But it is the energy auditor responsibility to persist the factory management to detail the advantages that can be succeeded through successful application

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