An-Najah National University

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Designing a Device for Industrial Boilers Efficiency Monitoring and Analysis

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Dedication

"I dedicate my achievement to my family, my lovely wife Ro'a and all my friends. A special feeling of gratitude Dr. Mohammad who stands to me from begin to the end.

الإقرار

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Designing a Device for Industrial Boilers Efficiency Monitoring and Analysis

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The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degrees or certifications.

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Date: 9/12/2021 **التاريخ:**

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List of Abbreviations

Abbreviation	Meanig
A/F	Air to Fuel Ratio
AFBC	Atmospheric Fluidized Bed Combustion Boiler
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASME	The American Society of Mechanical Engineers
CFBC	Circulating Fluidized Bed Combustion Boiler
cp	The specific heat of water = 4186 (J/kg.℃)
DPP	Discounted Payback Period
ET	Evacuated Tube
f	The monthly heating load solar energy fraction
F	Annual solar fraction
FD	Forced Draft
FP	Flat Plate
GCV	Gross Caloric Value
HHV	Higher Heating Value
HL1	Heat loss due to dry flue gas (%)
HL2	Heat loss due to evaporation of water formed due to hydrogen in the fuel (%)
HL3	Heat loss due to moisture content in the fuel (%)
HL4	Heat loss due to moisture content in the air (%)
HL5	Heat loss due to the formation of carbon monoxide (%)
HL6	Heat loss due to surface radiation, convection, and other unaccounted losses (%)
HL7	Heat loss due to unburnt carbon (%)
ID	Induced Draft
IRR	Internal Rate of Return
kWh	kilowatt Hour
LHV	Lower Heating Value
LPG	Liquefied Petroleum Gas
m	The mass of heated water ($\frac{\text{kg}}{\text{day}}$)
MJ	Megajoule
MW	Megawatt
NIS	New Israeli Shekel
O/F	Oxygen to Fuel Ratio
PLC	Programmable Logic Controller
PW	Present Worth
Qu	The amount of heat (joule)
SIR	Saving to Investment Ratio

SPP	Payback Period
SWH	Solar Water Heating
TJ	Terajoule
Ti	The inlet water temperature (℃)
USD	United States Dollar

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Abstract

This study aims at calculating the gross and net efficiency of the boiler, monitoring the pressure and temperature of water entering and leaving the boiler and monitoring the amounts of water, gas and electricity consumed from the boiler.

In order to achieve these goals, water temperature and pressure transmitters were installed on the inlet and outlet of the boiler. In addition, flow meters were installed to read the amount of water and gas, and electricity meter to read electric power consumed by the boiler. These transmitters, meters and smart recorder are manufactured by Schneider Company specializing in the production of various electrical products, especially in the fields of automation and industrial control.

The transmitters were selected based on their design to withstand the high temperature and pressure of the vapor outgoing from the boiler. The meters for electricity, water and gas were selected based on the factory consumption. To achieve the main objective of the study, which is to calculate the efficiency of the boiler and monitor these parameters continuously, either directly or remotely through a mobile application, these transmitters and meters were connected with a smart recorder.

It is found that the gross and net efficiency vary from day to day for several different reasons , including the duration of the boiler operation, the temperature of the inlet water, the amount of feed production (the required amount of steam) and the heat exchange inside the boiler room. Furthermore, the gross efficiency of the boiler ranges from 54.85% to 86.91%, while the net efficiency ranges from 54.18% to 82.74%. A technical and economic study was carried out to install a solar water heating system to heat the water entering the boiler by the sun leading to save the amount of gas discharged and raise the efficiency of the boiler. The cost of this project is estimated at 10,675 $ with an estimated life of 20 years, saving 2195 $ per year from the cost of gas and a recovery period of 4.9 year.

By designing the program, the owner of the factory can take instantaneous readings of temperature and pressure for the incoming water and steam leaving the boiler, and take daily readings of the consumption of water, electricity and gas, thus it is possible to know the consumption of water, gas and electricity to produce one ton of animal feed , and this enables him to improve the thermal system to reduce cost.

It also helps the owner of the facility in how to set the price one ton of animal feed, and calculate the profits for it, so that all the factory operational costs are known.

Chapter One
Introduction

1.1 Energy Crises

Fossil fuels are main sources of energy around the world from the industrial revolution until now. Also, they are not renewable energy, their quantity is decreasing every day, since the consumption of global energy is increasing by 2% every year, and it is expected that fossil fuel depletion will be more critical by 2042 and coal by 2112 [1].

Energy is the stability of the economy in the developed countries, so it is normal for countries to compete to seize control of these resources. To achieve this goal, the sales of arms and armament increased in these countries to control the oil resources, especially in the Middle East leading to several global and local political conflicts between several countries such as the Cold War between the Soviet Union and the United States of America, the war between Israel and the Arab states in 1967 and 1973, the war between Iraq and Iran in 1980 and the Gulf War in 1990 [2].

Global consumption continues to grow with population growth and continuous development in various areas of life despite improved energy efficiency. The sources from which energy is obtained differ, but the most dominant sources in the world can be summarized as in figure 1.1.

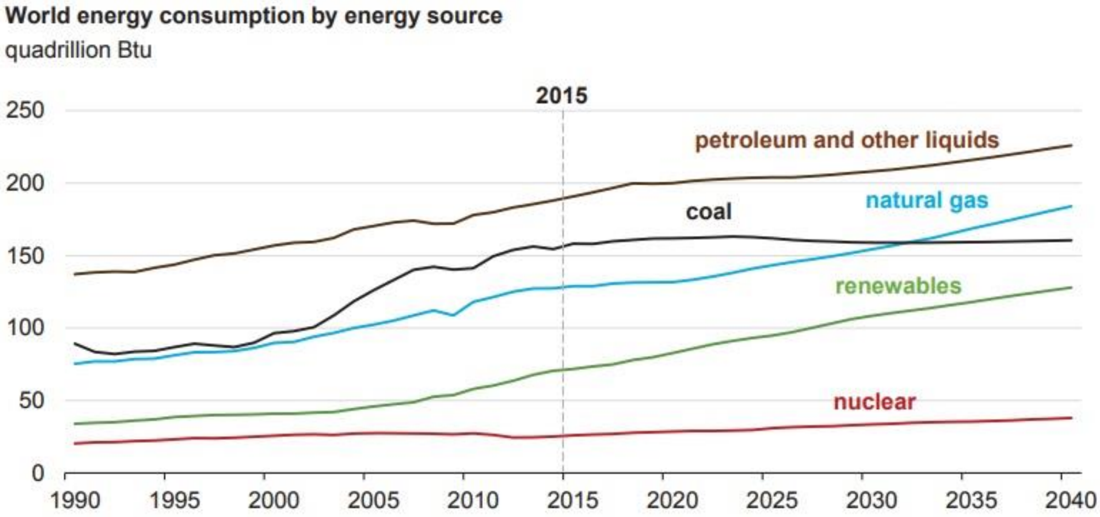

Figure (1.1): World energy consumption for different energy types [3].

Figure 1.1 shows global consumption of each source with future projections based on "U.S. Energy Information Administration" statistics and analysis. However, it is obvious that fossil fuel is still the main source of energy in the world, and will be the only one in the near future. Energy consumption continues to grow year after year due to population growth, the development of industries and increased transportation. Figure 1.2 shows how energy demand has increased in the past and future in the most energy-consuming sectors: industrial, transportation and buildings [3].

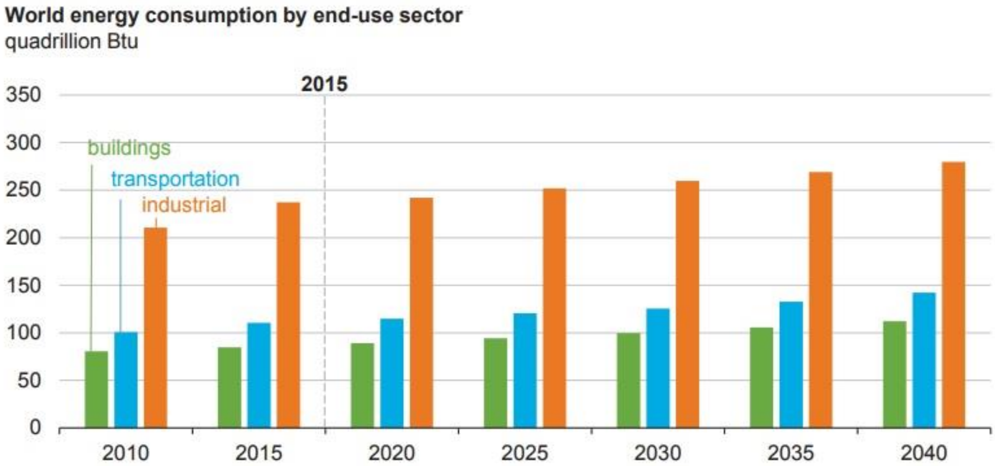

Figure (1.2): World energy consumption by end-use sector [3].

The increase in energy consumption is related to modern societies which have become remarkably dependent on energy in several fields, notably industrial and transportation. This development has led to higher consumption of energy per capita in modern societies than other societies [4].

1.2 Environmental Problems

In recent decades, the problem of global warming has emerged, which has led to a rise in global temperatures and this will change the different aspects of life especially climate change. Greenhouse gases (carbon dioxide, methane and others) resulting from the use of fossil fuel to produce energy in their various forms are the main cause of global warming. To mitigate this impact on the world, fossil fuel consumption and non-renewable sources should be reduced in energy production as much as possible. Instead it is imperative to increase the use of clean energy sources in energy production. Another problem related to greenhouse gases is the ozone hole, which reached 38% in the winter of 2010-2011 and then began to shrink to 27% in the winter of 2015-2016, so the ozone layer is expected to return to normal in the mid-2030. Delaying its return to normal is due to greenhouse gases, so reducing greenhouse gases will help the ozone layer back to normal faster [5,6].

Another environmental problem is acid rain, which occurs when Sulfate and Nitrate are produced due to fuel and coal burning. Sulfate and Nitrate precipitate and descend with rain, affecting plants and buildings. Sulfur dioxide and Nitrogen Dioxide are produced from energy production, transportation and industrialization [7].

1.3 Industrial Heating Loads in Palestine

The use of energy in the industrial sector is diverse and depends mainly on the requirements of the plants (raw materials, the method of production, storage and distribution of the product). The use of thermal energy is an essential part of most factories; it is used to convert water into hot water or steam, as well as their uses in heating the facility in general.

The consumption of Palestine in the industrial sector is 3985.2 Tera joule (TJ) of the total 70563.1 TJ, which is the total consumption of energy in Palestine, equivalent to 5.6%. The industrial sector in Palestine relies mainly on electricity at an annual consumption of 2468.2 TJ and secondary on LPG with an annual consumption of 547.4 TJ. Table 1.1 shows Palestine's consumption of energy by different sectors.

Table 1.1: Energy Performance Indicators in Palestine, 2014-2019 [8].

Indicator	**Year**					
	2014	**2015**	**2016**	**2017**	**2018**	**2019**
Renewable energy share in the total final energy consumption (%).	13.8	13.8	13.6	10.3	10.7	11.7
Energy Dependency Rate (%).	80.3	84.8	84.7	87.3	86.9	86.4
The Energy Consumption of the Transport Sector to the total energy Consumption (%).	48.7	43.6	45.6	46.6	45.4	43.2
The Energy Consumption of the Household Sector to the total energy Consumption (%).	38.4	41.4	39.7	38.4	38.0	38.8
The Energy Consumption of the Service Sector to the	7.6	8.5	8.8	8.8	9.8	11.3

total energy Consumption (%).						
The Energy Consumption of the Industry Sector to the total energy Consumption (%).	4.2	5.2	4.8	5.4	6.1	5.6
Annual Electricity Consumption Per Capita (kWh/Capita).	1048	1151 .4	1141.9	1138.3	1148.7	1280

Table 1.1 shows also the increase in energy consumption during the successive years (2014-2019), especially in the industrial sector, but in contrast, the contribution of renewable energy to the total energy consumed in Palestine decreases with successive years. On the environmental level in Palestine, the industrial sector contributes to the emission of carbon dioxide, methane and nitrous oxide. The CO_2 emission (ton) is 243.8 tons per year, or 5.4% of total emissions from all sectors [8].

The feed industry for livestock and poultry is part of the industrial sector in Palestine. The number of factories is 44, more than half of which are grain milling factories and packaging. Between 30-40% of the Palestinian market needs 284,000 tons of feed, and these factories rely on 100% raw materials imported from Israel [9].

Most of these factories rely on steam to produce feed, heat the water and convert it to steam boilers are used mostly fuel oil or liquefied petroleum gas, so the efficiency of these boilers must be increased for economic and environmental benefits.

This research developed an efficiency-monitoring device and installed it on the boiler of the local feed factory, by monitoring and analyzing the pressure and temperature of the water entering the boiler, and the steam coming out from it. In addition to measure the quantities of water, electricity consumed and fuel (LPG) in order to calculate the overall and net efficiency of the boiler based on these inputs.

This device enables the user to display these results to the user on the same device through a display screen, or through a computer device or through an application specific to the device that can be downloaded on the mobile phone. The device, computer and mobile phone can be connected through the internet or local network and get the results directly.

The device allows to set the period between each of two readings based on what the user wants and in this research this period was set to 30 seconds and the data was recorded for a whole month.

The device allows downloading these results and the data collected on a computer for use in the analysis for other statistical, financial, technical and other purposes. This assists the factory management in drawing up its policy and building plans to determine the main directions of the factory.

1.4 Case Study

Al-Manar Animal Feed Factory is located in the town of Arraba - Jenin - the West Bank, and it was established in 1994.The factory uses grains as raw materials for the manufacture of fodder, where the grains are crushed and mixed together, and then packed and distributed directly or cooked using water vapor and pressed, and then packed and distributed.

The number of factory employees is six, 1 manger and 5 workers, the average monthly expenses is 50,000 NIS distributed over bills, salaries, materials, maintenance, transportation and insurances.

The factory consumes electricity with a monthly bill of 7,000 NIS, the average consumption of LPG is 1975 litter per month, which is equal 5000 NIS, the monthly average consumption of water is 100 cubic meter, which is equal 700 NIS, and the average monthly production of fodder is 400 tons.

1.5 Problem Definition

Most of the measurements to determine the efficiency of the boiler in Palestine are done by the combustion analyzer, so they read the combustion efficiency at the time of the reading (instantaneous). Due to the facts that the load is often unstable (variable), the required steam pressure and temperature are also variable, and the fuel quality is different from one source to another. The measured efficiency is not representative, moreover, it is misleading most of the time, especially when the boiler operating conditions are variable.

On the other hand, boilers owners and/or operators do not have any real time monitoring tool to keep their boilers efficiency under periodic checks. Thus, a suitable device for monitoring boilers efficiency and providing periodic notifications and predefined thresholds exceeding alarms is crucial.

1.6 Project Objectives

The objectives to be achieved from the project include the following:

1. Measuring boiler efficiency and monitoring water pressure and temperature, monitoring the amount of water, LPG and electricity quantities entering the boiler during any period desired by the user, knowing the real efficiency of the boiler and the possibility of improving it by knowing the places of loss.

2. Knowing the amount of water, electricity and LPG during any day of the project period, and calculating the cost of these quantities on the factory.

3. Calculating the cost of producing one ton of animal feed from knowing the cost of water, electricity and LPG.

Chapter Two
Theoretical Background

2.1 Industrial Boilers

It is a device used to heat the water or convert it to steam. The spark of the idea of the boiler was a pot containing water and heated from the bottom. Furthermore, it is evolved due to the need to hot water and steam in industrial processes, and water or steam quantity of specific temperature and pressure demand. The evolution of boilers' industry is due to interests in its development and the increase in the surface area of the heating leading to increase the thermal transfer by making the tubes inside the boiler in a winding way [10].

2.1.1 Boilers Types

Boilers can be classified into two main types:

1. Fire Tube Boiler

In this type of boilers, there is a tube of flame and around it water is heated or converted to steam. Also, there is an outlet for gases resulting from the combustion process and the outlet of hot water or steam. As shown in the figure 2.1:

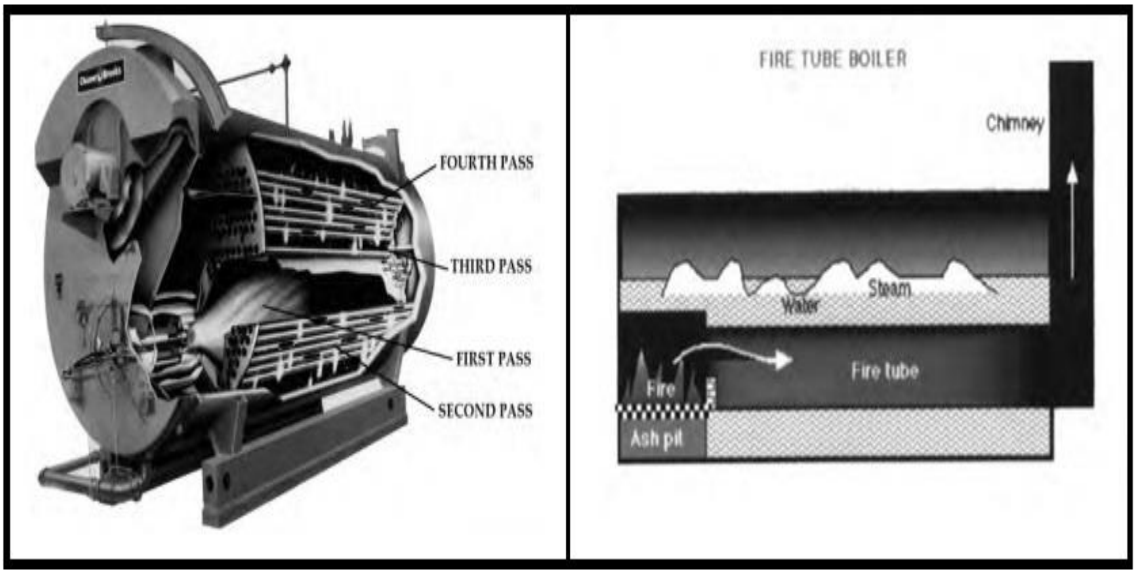

Figure (2.1): Fire Tube Boiler [11].

This type of boilers is used in applications requiring low steam flow rates and with specific specifications in quantity, temperature and pressure [11].

2. Water Tube Boiler

In this type of boilers, water inside the tube surrounded by fire, and water is converted to vapor by heat transfer of flame through the conduction and radiation unlike the fire tube. As shown in the figure 2.2:

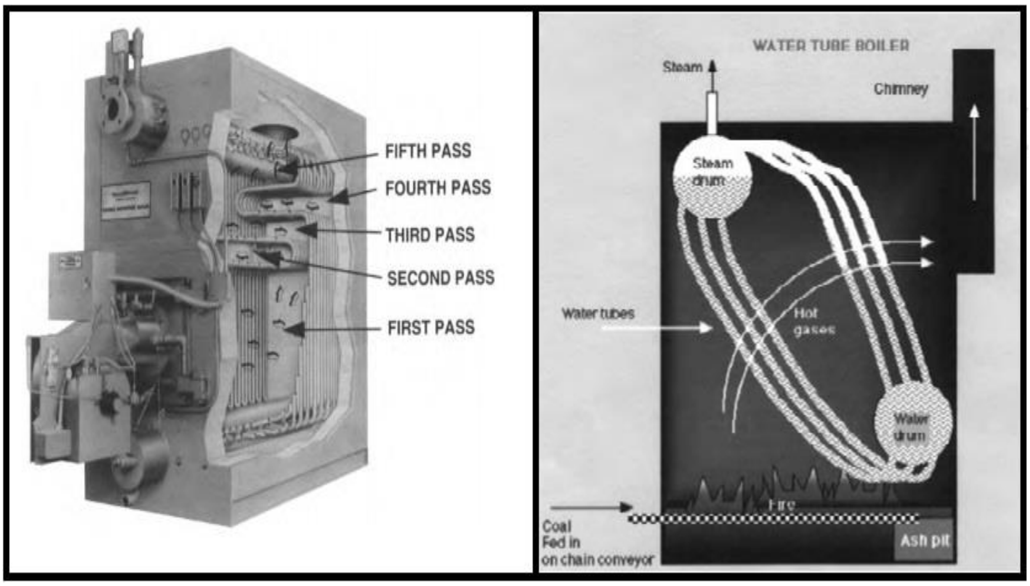

Figure (2.2): Water tube boiler [11].

Most uses of Water tube boilers are in large industries that require high pressure and temperature [11].

For more comparison between two types, the table 2.1 shows the most important differences between fire tube boilers and water tube boilers.

Table 2.1: Important differences between fire tube boilers and water tube boilers [12].

Comparison item	Fire tube boilers	Water tube boilers
Position of water and hot gases	Hot gases inside the tubes and water outside the tubes	water inside the tubes and hot gases outside the tubes
Mode of firing	Generally internally fired	Externally fired
Operation pressure	Operating pressure limited to 16 bar	Can work under as high pressure as 100 bar
Rate of steam production	Lower	Higher
Suitability	Not suitable for large power plants	suitable for large power plants
Risk on bursting	Involves lesser risk on explosion due to lower pressure	Involves more risk on bursting due to high pressure
Floor area	For a given power it occupies more floor area	For a given power it occupies less floor area

2.1.2 Boiler Fuels

Typically, the boiler is designed to operate on a particular type of fuel based on several factors in the plant namely: the thermal content of the fuel, its availability in various conditions, the storage of fuel and the environmental emissions resulting from combustion. Coal, fuel oil and liquefied petroleum gas (LPG) are among the most common fuels for boilers worldwide. There are also some new types of boilers that use unconventional sources as fuel, such as boilers that burn municipal waste.

Characteristics of fuel oil that its density is 0.978 kg / liter, the higher heating value is 43.5 MJ/kg, the flash point is 120.6 ° C and the molecular weight is as following (Carbon: 82.25 %, Hydrogen: 11.8 %, Oxygen: 0.0 %, Nitrogen: 2% and Sulfur: 2.75%) [13].

For LPG, the lower heating value is 46.6 MJ/kg, the higher heating value is 50.15 MJ/kg, and the stoichiometric air/fuel ratio is 15.5 and the autoignition temperature Is 724 ° K [14].

With regard to coal, it has many sources and varies according to its main components, as there is no specific value for the gross calorific value of coal. In this reference, the researcher calculated the gross calorific value of five samples and the results ranged from 9.5 MJ/kg to 27 MJ/kg [15].

The table 2.2 is a summary of the boiler efficiency, fuel price and the calorific value based on the type of fuel used for the boilers in average operating condition in Canterbury city, UK [16].

Table 2.2: Comparison of Boilers by Type of Fuel Used.

Type of Fuel	Cost of Fuel	Boiler Efficiency (%)	Calorific Value
Coal	0.167 $/kg	75	21 MJ/kg
Light Fuel Oil	0.84 $/kg	78	42 MJ/kg
LPG	2.8 $/kg	84	49.51 MJ/kg

2.2 Liquefied Petroleum Gas (LPG)

In the efficiency calculation of the case studied boiler, the fuel used was LPG. LPG is a mixture of propane and butane and some other compounds. There are two main sources of liquefied petroleum gas, namely: oil fields and refining barrels of oil several times to get it [17].

2.2.1 Specifications of LPG

As stated, propane and butane are the two main components of liquefied petroleum gas (LPG), which are in different percentages depending on the source and use of the gas. LPG used in the boiler was 70% butane and 30% propane. The value of the LPG density in the liquid state is 0.559 kg/liter, and the gross calorific value is 49.51 MJ/kg [18].

2.3 Combustion Process

Fuel combustion is like any combustion, it as a chemical reaction between oxygen, carbon and hydrogen to produce heat, water and carbon dioxide. Fuel burns in two types of combustion, which are in the presence of oxygen only and the other is at presence of air.

2.3.1 Combustion of fuel in oxygen

The combustion equation is as follows:

$$C_xH_y + (x + \frac{y}{4})O_2 \rightarrow (x)CO_2 + (\frac{y}{2})H_2\text{O} + \text{heat} \tag{2.1}$$

Where; x and y are integer numbers to balance the equation chemically [19].

Since the atoms do not perish and are not created, the fuel interacts with oxygen and the combustion process produces water, carbon dioxide and heat with the same number of atoms entering the reaction. The combustion equation must be balanced as any other chemical equation, meaning that the number of moles of the materials entering the interaction with the materials leaving it must be equal. In addition to the law of conservation of mass, it must be equal before and after the reaction process, according to the following [20]:

1. For butane (C_4H_{10}):

$$C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O + \text{heat} \quad (2.2)$$

Through the above equation, we notice that the number of moles is equal on both sides of the combustion equation, as the number of moles of carbon is 4, hydrogen 10 and oxygen 13.In addition, the atomic mass must be preserved on both sides of the equation, and since the atomic mass of carbon is 12, hydrogen is 1 and oxygen is 16, so the atomic mass of the reaction is 266, according to the equation (2.2):

$$C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O + \text{heat} \quad (2.2)$$

$$[4(12) + 10(1)] + [13(16)] \rightarrow 4[12 + 2(16)] + 5[2(1) +16] = 266.$$

2. For propane (C_3H_8):

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O + \text{heat} \quad (2.3)$$

The above equation represents the complete combustion of propane with the presence of oxygen, and it is weighed in terms of moles, with respect to the atomic mass, it is equal to 204 on both sides of the equation.

2.3.2 Combustion of fuel in air

If air is the source of oxygen in the combustion process, nitrogen is added to the equation and the combustion equation is as follows:

$$C_xH_y + (x+\frac{y}{4})O_2 + 3.76\ (x+\frac{y}{4})N_2 \longrightarrow (x)CO_2 + (\frac{y}{2})H_2O + 3.76\ (x+\frac{y}{4})N_2 + \text{heat}$$ [19] (2.4)

Where; x and y are integer numbers to balance the equation chemically.

The combustion process with the presence of air does not differ much from the presence of oxygen alone, but by adding nitrogen with oxygen (the main components of air) in the combustion process, as every 1 mole of oxygen corresponds to 3.76 moles of nitrogen.

Since LPG consists mainly of propane and butane, the combustion in air as the following [20]:

1. For butane (C_4H_{10}):

The process of combustion of butane in the presence of air is as follows:

$$C_4H_{10} + 6.5O_2 + 24.44N_2 \rightarrow 4CO_2 + 5H_2O + 24.44N_2 + \text{heat} \quad (2.5)$$

Through the combustion equation, the equation is balanced, meaning that the number of moles of the elements on both sides of the equation is equal, and the atomic mass of the equation is also equal on both sides of the equation and is equal to 950.32.

2. For propane (C_3H_8):

The process of combustion of propane in the presence of air is as follows:

$$C_3H_8 + 5O_2 + 18.8N_2 \rightarrow 3CO_2 + 4H_2O + 18.8N_2 + \text{heat} \quad (2.6)$$

As for the propane combustion equation, the equation is balanced and the atomic mass is equal on both sides of the equation, which is 730.4.

2.4 Heating Value

By comparing burning the same amount of fuel with the presence of oxygen on the one hand and with the presence of air on the other hand, the combustion of the fuel produces the same amount of heat, as some Nonreactive nitrogen molecules absorb a lot of the energy released from burning the fuel, and thus the energy produced preventing the combustion process with the presence of air is shared with more combustion products.

It must also refer to two important terms, the first is the higher heating value (HHV) and the second is the lower heating value (LHV), where the first term refers to the heating value so that the produced water vapor is allowed to condense, and the resulting heat is calculated as part of the heating value. Whereas in the second term, the water remains steam and does not produce heat of evaporation. The incomplete combustion process is a result of the lack of oxygen or air in sufficient quantities in the combustion process, which leads to incomplete combustion of the fuel used in the combustion process, and the products of the combustion process appear such as carbon, carbon monoxide or hydrogen [20].

2.5 Air-Fuel Ratio

It is the ratio of air or oxygen that must be supplied to the fuel to ensure a complete combustion process, as the air-fuel ratio (A/F ratio) is called if the air was used in the combustion process, or the oxygen-fuel ratio (O/F ratio) is called if the oxygen is used in the combustion process.

The air-fuel ratio can be calculated by dividing the atomic mass of air by the atomic mass of the fuel in the weighted equation, as well as by calculating the oxygen-fuel ratio. The A/F for butane is 15.38 and for propane is 15.6. If the amount of air or oxygen exceeds this amount (theoretical quantity), becomes combustion under excess air or oxygen conditions, and since air is free, easy to obtain and fuel is expensive, so it is important to burn the entire fuel using a larger amount of air (theoretical quantity), and here appears the term excess air that most burners operate on it. The excess air for natural gas and for LPG is (5 to 10) % [20].

There are several factors that affect combustion efficiency such as:

1. Flow gas temperature, the higher the temperature the lower the efficiency.

2. Fuel specification, what's the components of fuel and the source of it.

3. Ambient air temperature, higher the temperature the lower the efficiency.

4. Radiation, convection and conduction losses from boiler.

2.6 Boiler Efficiency

Most boilers are 65% to 85% combustion efficient. As energy is conserved, most of the heat is transferred to the water to heat it (65% to 85%), while the other part is different losses so that there is no practical benefit from it [21].

The determination of the efficiency of the boiler can be done in one of two ways according to The American Society of Mechanical Engineers (ASME) Power Test Code 4.1 (PTC-4.1-1964).There are the Input-Output Method and The Heat-Loss Method [22].

2.6.1 Input-Output Method

Input-Output Method also called direct method, efficiency is calculated as illustrated in equation (2.7) and (2.8) below:

$$\text{Boiler efficiency (\%)} = \frac{\text{Heat output}}{\text{Heat input}} \times 100\% \qquad (2.7)$$

$$= \frac{\text{Steam flow rate x (steam enthalpy} - \text{feed water enthalpy)}}{\text{Fuel firing rate x Gross Calorific Value of fuel}} \times 100\% \qquad (2.8)$$

This is the simplest method for determining the efficiency of the boiler, as the fuel is burned and the heat produced is calculated, and how much of this heat the water gained is calculated during a certain period, as in Figure 2.3 [23].

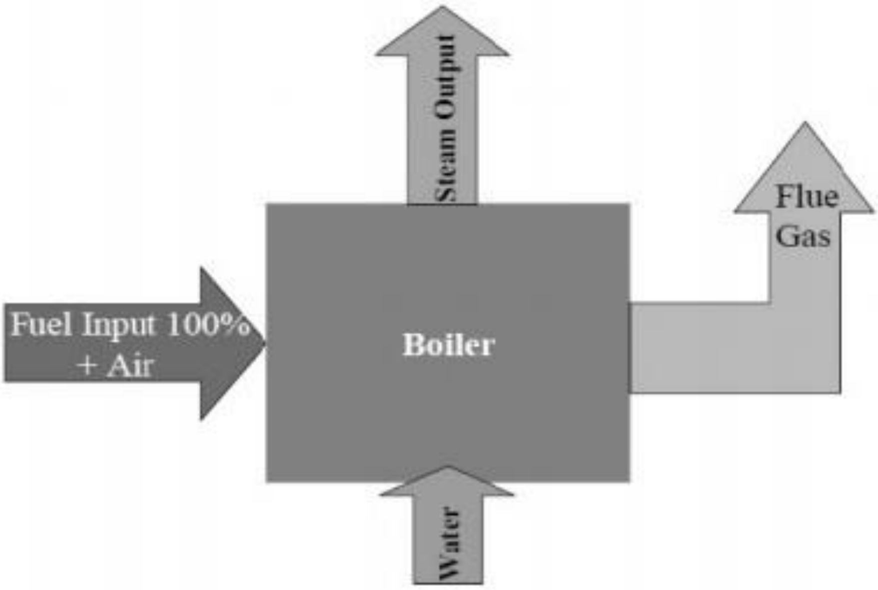

Figure (2.3): Input-Output (Direct) Method.

The definition of enthalpy expressed generally as the sum of internal energy per unit mass and the product of pressure and specific volume [24].

The advantages of this method are that plant workers can quickly assess boiler efficiency, require fewer parameters for calculation, and require fewer tools to monitor.but the disadvantage of this method that does not give why the efficiency is lower or where the losses are.

2.6.2 Heat-Loss Method

Heat-Loss Method also called indirect method; efficiency is calculated as shown in equations (2.9) and (2.10).

Boiler efficiency=100% - heat losses (2.9)

Boiler efficiency =100% – (HL1 + HL2 + HL3 + HL4 + HL5 + HL6 + HL7). (2.10)

Where;

HL1: Heat loss due to dry flue gas (%).

HL2: Heat loss due to evaporation of water formed due to hydrogen in the fuel (%).

HL3: Heat loss due to moisture content in the fuel (%).

HL4: Heat loss due to moisture content in the air (%).

HL5: Heat loss due to the formation of carbon monoxide (%).

HL6: Heat loss due to surface radiation, convection, and other unaccounted losses (%).

HL7: Heat loss due to unburnt carbon (%).

Figure 2.4 shows losses in the boiler [23].

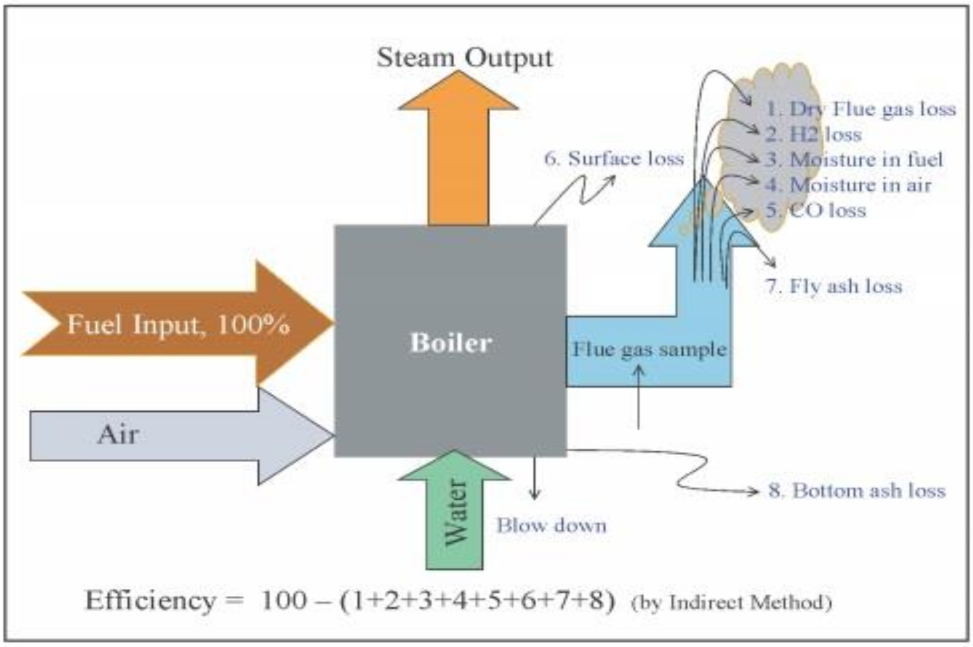

Figure (2.4): Heat-loss (Indirect) Method.

One of the advantages of this method is that it accurately determines where the losses are and how much they are worth, and then work to reduce these losses by appropriate methods, but its disadvantage is that it takes time and needs to analyze the fuel components and needs sensors to know the temperature and the percentage of oxygen or carbon dioxide.

In the case study presented in this project, the direct method will be used to calculate the boiler efficiency.

Efficiency through previous methods is called gross efficiency, but if the energy input of auxiliary devices such as pumps, fans and controlled are introduced, it is called net efficiency [25].

As the formula for gross efficiency, using the direct method is as follows:

$$\text{Gross.efficiency} = \left(\frac{\left(\text{water consumption(kg)x}\left(\text{steam enthalpy}\left(\frac{\text{kJ}}{\text{kg}}\right) - \text{feed water enthalpy}\left(\frac{\text{kJ}}{\text{kg}}\right)\right)\right)}{\left(\text{gas consumption(L) x gas density}\left(\frac{\text{kg}}{\text{L}}\right)\text{ x Gross Calorific Value of gas}\left(\frac{\text{kJ}}{\text{kg}}\right)\right)} \right) \text{x 100 \%} \qquad (2.11)$$

In contrast, the net efficiency equation using the direct method is as follows:

$$\text{Net efficiency} = \left(\frac{\left(\text{water consumption(kg)x}\left(\text{steam enthalpy}\left(\frac{\text{kJ}}{\text{kg}}\right) - \text{feed water enthalpy}\left(\frac{\text{kJ}}{\text{kg}}\right)\right)\right)}{\left(\left(\text{gas consumption(L) x gas density}\left(\frac{\text{kg}}{\text{L}}\right)\text{ x Gross Calorific Value of gas}\left(\frac{\text{kJ}}{\text{kg}}\right)\right) + \text{electric energy consumed (kJ)}\right)} \right) \text{X100\%.} \qquad (2.12)$$

We note that the electrical energy consumed in operating the fans, burners, pumps and monitoring devices has been entered, and thus the net efficiency value will be lower than the gross efficiency.

Another very well-known way to calculate the efficiency of the boiler is the combustion efficiency, from the equation of combustion of any fuel with air. The combustion efficiency is comparable to the indirect method, but only the indirect method due to the exhaust gases are considered and it is defined as the ratio of the fuel energy input minus the flue gas losses (dry flue gas, incomplete combustion and moisture formed by combustion of hydrogen) to the fuel energy input. It can determine the combustion efficiency by knowing the measuring the carbon dioxide or oxygen in the exhaust gas inasmuch as the excess air determined [25].

Combustion efficiency can be calculated using figure 2.5, this figure is specific to the type of fuel, natural gas, and different other figures can be used depending on the type of fuel. To calculate the efficiency, the operator must know the present flue gas oxygen or the present flue gas carbon dioxide in addition to calculating the current stack temperature rise which can be calculated by measure the exhaust stack temperature and combustion air temperature (ambient temperature) [25].

Current stack temperature rise = exhaust stack temperature - combustion air temperature. (2.13)

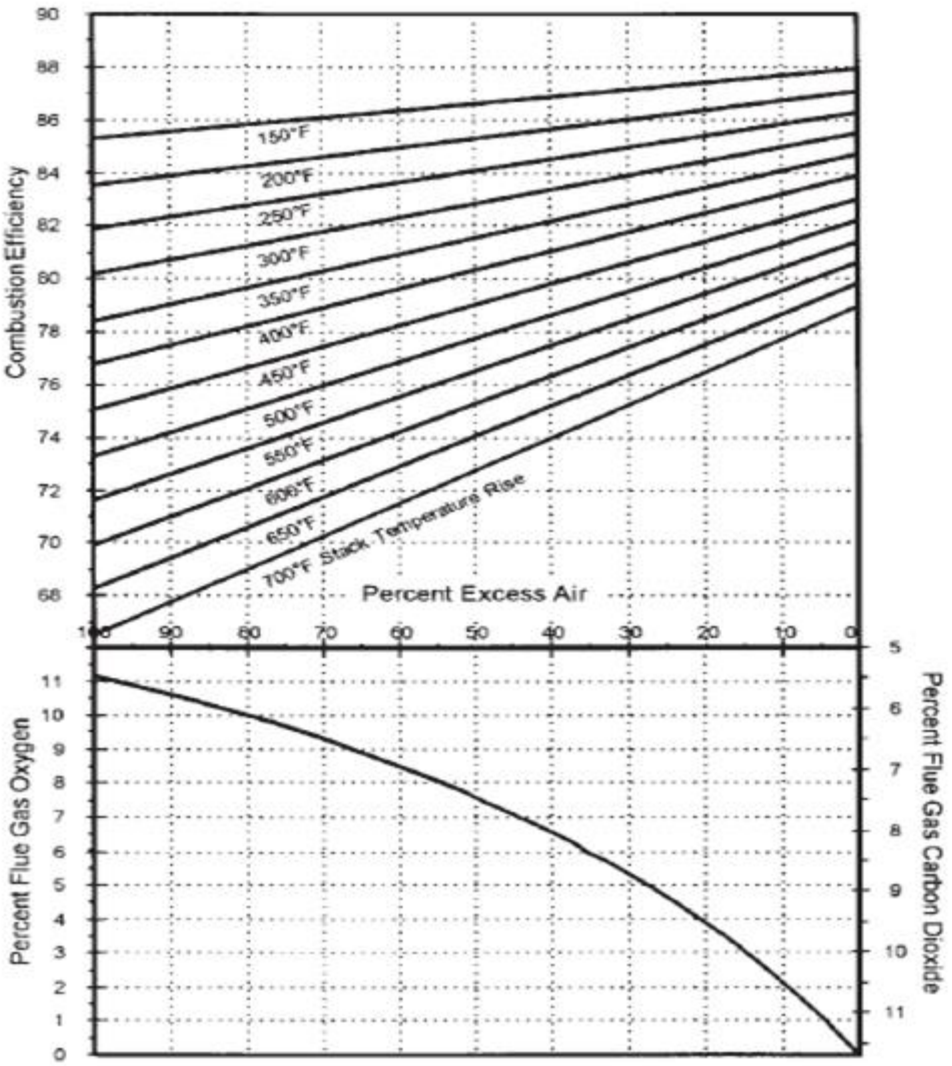

Figure (2.5): Combustion efficiency chart for natural gas [25].

To calculate the combustion efficiency through Figure 2.5, we follow the following steps:

1. Determine the present flow gas oxygen or present flow gas carbon dioxide using specific analyzers.

2. Enter the level of present flow gas oxygen or present flow gas carbon dioxide and following a line to the curve, then red the present excess air.

3. Complete the line to the stack temperature rise and read the current combustion efficiency.

2.7 Standards for Measuring Temperature and Pressure

From engineering professionalism point of view, energy efficiency measurement must be standardized, in this context, the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) has developed the following related standards:

- Standard 41.1 - Standard Method for Temperature Measurement: this standard focuses on type, accuracy, scale, calibration and practice [26].
- Standard 41.3 - Standard Methods for Pressure Measurement: this standard focuses on type, accuracy and scale [27].

2.8 Boiler Components

Boilers consist mainly of pipes, a closed vessel containing pipes inside it, incinerator and exhaust gas chimney. While there are additional parts that are in most boilers are water treatment, economizer cylinders and some environmental protection devices [11].

Figure 2.6 shows the basic components of industrial boiler [27].

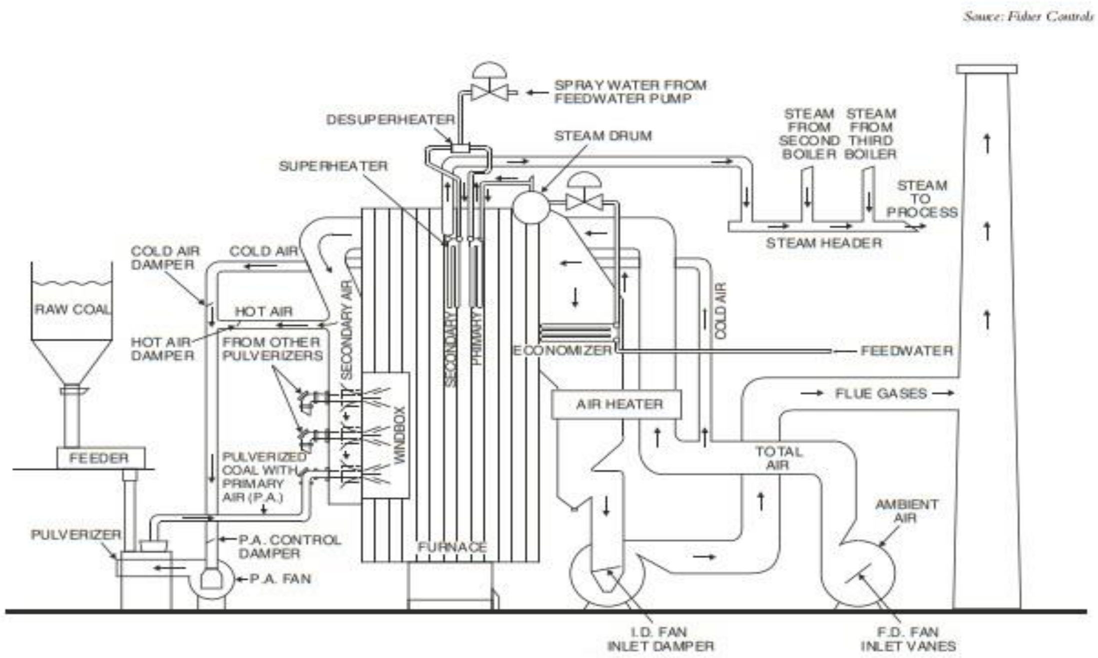

Figure (2.6): Boiler components.

The main boiler components and their functions can be summarized in table 2.3 [28].

Table 2.3: Basic Component of Industrial Boiler.

Component	Function
Furnace	The combustion furnace releases heat, and then it becomes a heat transfer system. There are three important factors required for combustion, which are temperature, time and turbulence. The control of the combustion furnace is important to make the inlet pressure negative to ensure that the flame does not go out.
Fans	There are two main types of fans in boilers, which are induced draft (ID) fan and forced draft (FD) fan. The induced draft fan function is pulls air through the boiler to produce a negative pressure in the furnace, while the forced draft fan function pushes air for combustion through the boiler.
Windbox	The windbox disseminates secondary air to the burners.
Combustion air preheater	It is a type of heat exchanger, when the flue gas leaves the boiler, it passes through the combustion air preheater, and the ignition air goes through the air preheater heat exchanger prior to being blended in with the fuel.

Economizer	The economizer heats the boiler feed water through the heat exchange between the high temperature flue gas and the lower temperature water, thus cooling the flue gas and increasing the water temperature and thus increasing the boiler efficiency.
Superheater	It is a kind of heat exchanger, used to convert wet steam into dry steam.
Steam drum	It is a tank at the upper end of the water tubes; it collects the steam produced in the tubes and acts as a separator for the water and steam mixture. The hot water collects inside the tank after the steam is separated from it and the water returns to the cold-water tank.

2.9 Boiler control

To reach the required steam at a specific temperature and pressure according to what the user requires (load), there are several standards for controlling the boiler as in table 2.4 [29].

Table 2.4: Standards for Controlling the Boiler.

Standard	**Function**
Steam pressure control with load index	If the load increases with the same percentage in burning the amount of fuel, the pressure will decrease and vice versa, so it is important to send a feed signal to the controller to maintain the steam while controlling the combustion and the amount of fuel.
Air flow control	It is important to control the amount of air required for combustion, taking into account the air-fuel ratio, as required by the system, to maintain the steam pressure at the required value.
Fuel flow control	Controlling the amount of fuel is an important matter from a technical and economic point of view. When obtaining a demand signal in the load, it generates a demand for fuel, and therefore the amount of fuel entering the combustion is controlled with the provision of an adequate amount of air to achieve complete combustion.
Furnace draft control	A negative pressure must be maintained inside the combustion furnace, as the main goal of this control is to achieve the required pressure by absorbing the appropriate amount of flue gas and gases not participating in the combustion process by opening and closing the control accessories.

Drum level and feed water control	To force the feed water into the drum, there are several fixed speed pumps or variable speed pumps. When the feed water level in the drum becomes high, water particles can move into the main steam, which leads to problems in the final use of the steam, and if the level of the feed water in the drum becomes low, the drum itself becomes very hot, which poses a danger. It is controlled by measuring the actual drum level and its set point, and controlling the increase or decrease accordingly.
Superheater temperature control	The importance is to eliminate the problem of wet steam so that it makes the steam completely dry, as well as prevents the transfer of water in the saturated steam, which leads to allowing higher speeds of steam in the pipes, and therefore the pipes can be designed to be of a lower diameter.

2.10 Solar Water Heating System

Water temperature is raised by the use of fuel or by the use of renewable energy such as the sun, and the most important ways to raise the temperature of water is the solar water heater, where the solar radiation is exploited to raise the temperature of water. The solar water heater consists of a glass plate containing tubes passing through the water to heat it. In order to provide hot water, there is an isolated tank with different capacities. This is the simplest form of solar water heater, which is divided into two types of solar water heaters, namely: the passive solar water heating system and the active solar water heating system.

2.10.1 Passive Solar Water Heating System

In this system, water is heated by the natural cycle of the water without any external forces. Its main features are cheap, easy and cheap maintenance, a long default age (30 years) and easy design. Still, its disadvantage is that its efficiency is rather small. There are two main types of passive system; batch solar water heaters and Thermosyphon systems [30].

2.10.1.1 Batch Solar Water Heaters

Batch solar water heaters also called integrated collector storage systems; has a simple design, simple components and little maintenance. It was first marketed commercially in the 1980s, and its components are a metal plate to absorb heat over the storage tank as shown in figure 2.7, in this system also does not need any pumps to work [30].

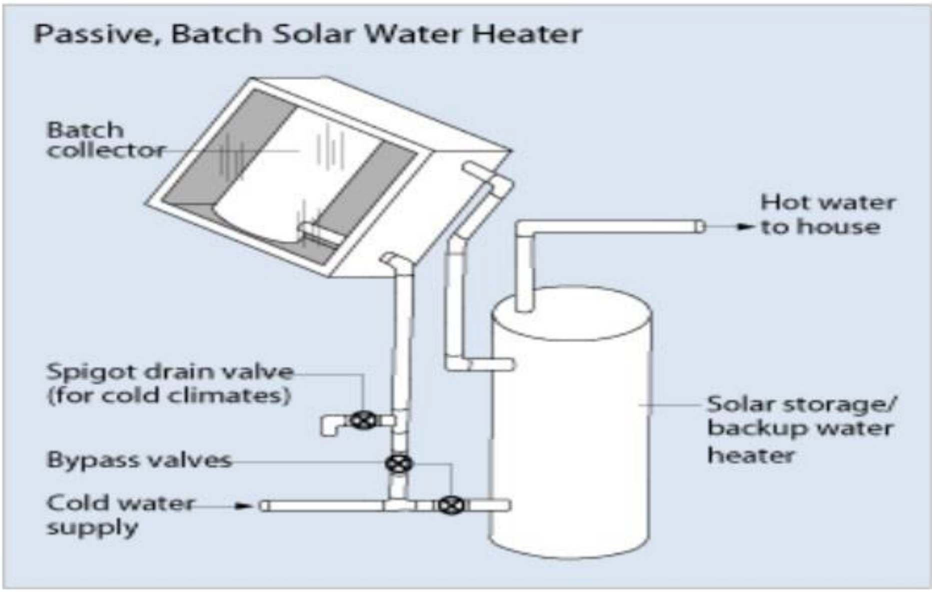

Figure (2.7): Batch solar Water Heater system [30].

2.10.1.2 Thermosyphon Systems

This type consists of an absorber plate with pipes inside, and at the top a transparent layer to prevent the loss of heat to the surrounding air, there is also an insulator underneath. The system conveys heat through the principle of natural convection without using any pumps as shown in

Figure 2.8. This system is prevalent mainly in homes, where it raises the temperature to 45-50 degrees Celsius [30].

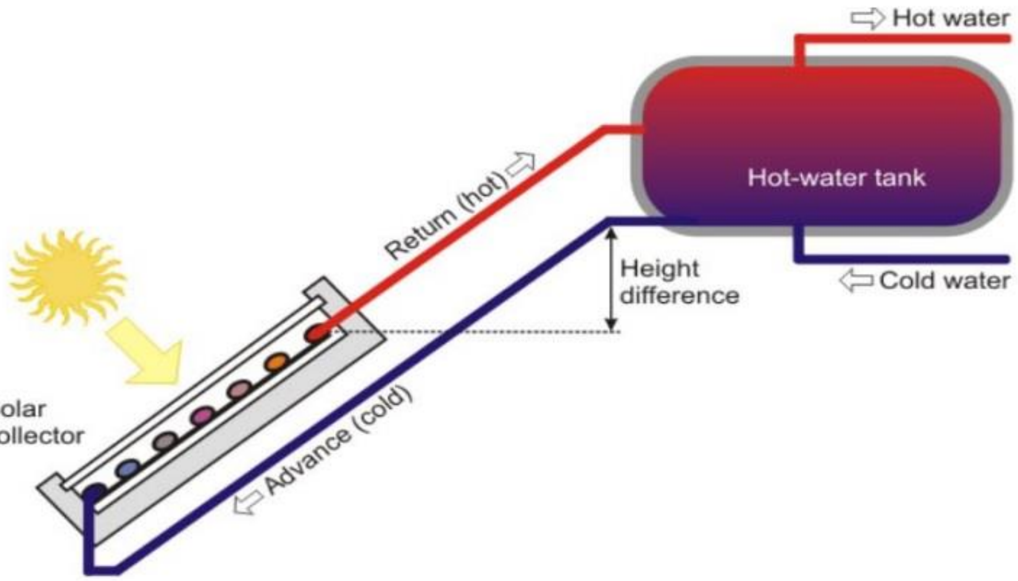

Figure (2.8): Thermosyphon solar water heater system [30].

2.10.2 Active Solar Water Heating System

This type of system uses a pump, controllers, storage tank for hot water and valves to circulate the water inside the solar collectors, and this type is suitable for very cold areas. There are two types of active solar water system; the first type is open loop (direct) active solar water system; the second type is close loop (indirect) active solar water system [30].

2.10.2.1 Open Loop (Direct) Active Solar Water System

In this type of system, a pump is used to circulate the water in the collectors and operate at a certain pressure in the line, which is more prevalent in areas where there is no freezing for long periods as long freezing leads to the destruction of internal pipes. It is also easier to expand the system in the future if more hot water is needed, this system is cheaper, easier to design and operate than the other type [31].

2.10.2.2 Close loop (indirect) active solar water system

This type of system uses heat transfer fluids inside the collectors, where the temperature of these fluids is raised by sunlight and then transfers this heat to the water to be heated by a heat exchanger. The spread of this type of system in cold areas because of its ability to protect against freezing, and this type is more complex than the other type, because it is designed to work at high temperatures.

The design of the system and its parts are shown in Figure 2.9. There are two loops; the first is closed to the liquid inside the collector, and the second is an open for tank of hot water where the cold water enters and the hot water comes out, so that the tank inside contains a heat exchanger [31].

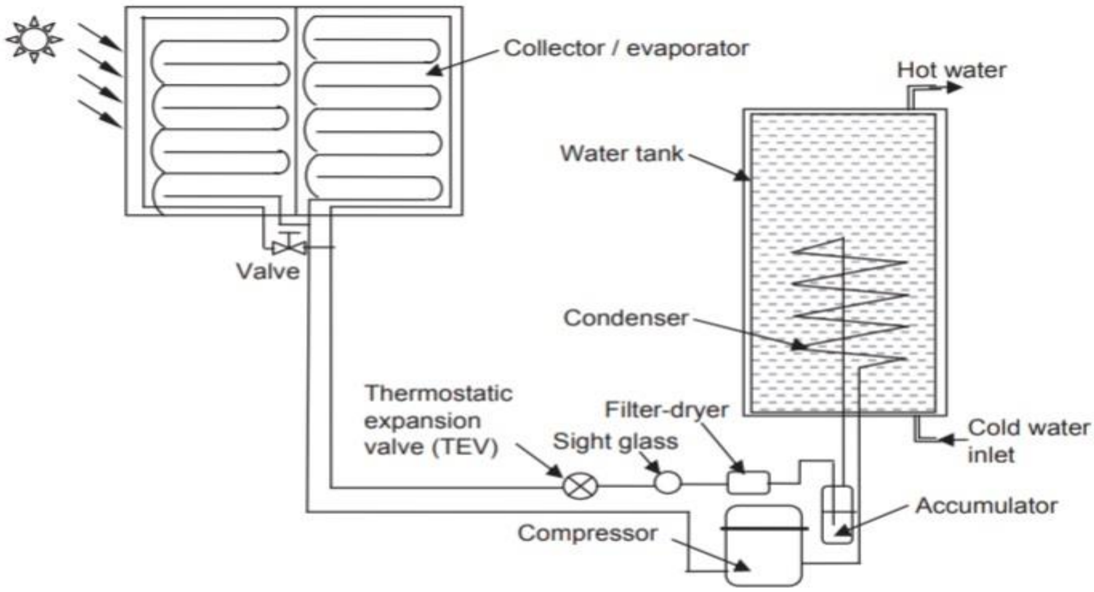

Figure (2.9): Close loop (indirect) active solar water system [31].

2.10.3 f-chart method

The f-chart is used to estimate the annual thermal performance of the solar water heating system (SWH). There are two types of SWH: flat plate (FP) and evacuated tube (ET), where the results of simulating the thermal performance of the solar water heating system are used, by estimating the solar energy for the monthly thermal loads (f) [32].

$$f = \frac{TLi - TLaux}{TLi} = \frac{\text{QSWH}}{TLi} \tag{2.13}$$

where;

TLi: the total required thermal load in month i.

TLaux: the purchased energy to operate an auxiliary system when SWH system is not enough.

QSWH: the provided energy by the SWH system.

To calculate the value (f), two factors X and Y are used, where X and Y representing collector loss and gain, respectively.

$$X = (F_R\, U_L)\left(\frac{\acute{F}_R}{F_R}\right)\left(T_{ref} - T_a\right)(\Delta t)\left(\frac{A_c}{L}\right) \tag{2.14}$$

$$Y = \left((F_R)\, (\tau\alpha)_n \left(\frac{\acute{F}_R}{F_R}\right) \left(\frac{(\tau\alpha)}{(\tau\alpha)_n}\right) (H_T)\, (N)\, \left(\frac{A_c}{L}\right) \right. \tag{2.15}$$

where F_R is the collector heat exchanger efficiency factor, U_L is the collector overall loss coefficient (W/m^2.°C), Δt is the total number of seconds in the month, T_a is the monthly average ambient temperature (°C), T_{ref} is an empirically derived reference temperature (100 °C), is the collector heat exchanger correction factor (0.97), A_c is collector area (m^2) and L is monthly total heating load for space heating and/or hot water (J). $(\tau\alpha)_n$ is monthly average transmittance absorptance product, ($\frac{(\tau\alpha)}{(\tau\alpha)_n}$) is the ratio of the monthly average to normal incidence transmittance absorptance product (0.96), N is number of days in the month, and H_T is the monthly average daily radiation incident on the collector surface per unit area (J/m^2).

To acquire the f esteem, reenactment conditions are differed over explicit scopes of boundaries of functional framework plans as displayed in table 2.5 [32].

Table 2.5: Design parameters ranges for developing f-chart.

Parameter	Range
$(\tau\alpha)_n$	0.6-0.9
$\acute{F}_R A_c$	5-120 m^2
U_L	2.1-8.3 W/m^2.°C
$(UA)_h$	83.3 – 666.6 W/°C

After X and Y are calculated, the solar energy for the monthly thermal loads (f) can calculated as

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3 \quad (2.16)$$

The annual heating load supplied by solar energy (F) is calculated as following:

$$F = \frac{\sum_{i=1}^{12}(f_i L_i)}{\sum_{i=1}^{12}(L_i)} \quad (2.17)$$

If F value is less than 0, a value 0 is used, if the value is greater than 1, a value 1 is used.

2.10.4 Economic Performance Analysis for SWH System.

To approve the project, it must be examined from an economic point of view, and analyzed using several indicators, in order to find out whether the project is feasible from an economic point of view or not.The most prominent economic criteria adopted are Payback Period (SPP), Discounted Payback Period (DPP),Present Worth (PW), Internal Rate of Return (IRR), and Saving to Investment Ratio (SIR). To calculate these indicators, equations (2.18-2.23) are used as following [32]:

$$\text{SPP} = \frac{Investment}{Savings} \tag{2.18}$$

$$\text{r = d + inf + (d) (inf)} \tag{2.19}$$

$$\text{DPP} = \sum_{n=1}^{SC} \frac{F_n}{(1+r)^n} \tag{2.20}$$

$$\text{PW} = \text{Investment} + \sum_{n=1}^{Yr} \frac{F_n}{(1+r)^n} \tag{2.21}$$

$$PW_{IRR} = \text{Investment} + \sum_{n=1}^{Yr} \frac{CF_n}{(1+IRR)^n} = 0 \tag{2.22}$$

$$\text{SIR} = \frac{\sum_{n=1}^{Yr} \frac{Saving\ n}{(1+r)^n}}{\text{Investment} + \sum_{n=1}^{Yr} \frac{Cost_n}{(1+r)^n}} \tag{2.23}$$

Where investment represents system initial cost in ($), savings represent achieved annual savings due to system installation in ($/year), r is the market combined annual interest rate in (%), d is the market annual discount rate in (%), inf is the average annual inflation rate in (%), n represents the year number in the project considered life span in years, SC means that summation will continue until DPP sign change from negative value (cost) to positive value (revenue) will be achieved, CF_n represents the net cash flow at year n in ($), Yr is the project total life time in years, $Cost_n$ is the system annual operation and running cost in ($/year). Cost sign convention must be assumed minus, while savings are positive. And for the SIR, system is considered feasible if its value is greater than 1.

Chapter Three
Literature Review

Since the invention of the boiler and to this day, studies and research are still ongoing on the boiler, in order to develop its work in a way that ensures that the consumer gets the best efficiency of the boiler, and these studies include:

1. The researcher made a study on a local hospital boiler as a case study, where the annual fuel consumption cost is 37,753 dollars, and the required water temperature is 60 degrees Celsius, the installation of a solar water heating system was analyzed from a technical and economic point of view, using f-chart for the technical study and economic transactions Simple Payback Period (SPP), Present Worth (PW), Internal Rate of Return (IRR), and Saving to Investment Ratio (SIR) for the economic analysis [32].

2. The aim of this study was to measure the efficiency of a 200 megawatt boiler, where the two researchers measured the boiler efficiency through the direct method by measuring the heat produced by burning the fuel and the heat absorbed by the water during a certain period of time, in order to know the operating status of the boiler and the surrounding conditions. The efficiency of this boiler was 80.77% [33].

3. In this study, the researchers focused on calculating the thermal efficiency of coal-fired boilers, for economic calculations and their use for control considerations and overall utilization of the boiler. The

researchers used the indirect method to calculate the efficiency of the boiler with a capacity of 300 MW, by measuring the real efficiency of the boiler, and a serious method was developed to calculate the LHV for coal, and then calculate the boiler efficiency based on LHV. The percentage of error compared to the actual value ranged between (2.844 to -2.455) %. The boiler efficiency ranged between (88.3 to 89.3) % [34].

4. In this study, the efficiency of a natural gas boiler was calculated and how to improve the efficiency and the estimated cost in addition to the payback period. Where the efficiency using the indirect method is 88.28% and the most prominent reason for the decrease in efficiency is the leakage of air into the internal air heaters, which does not allow water to enter the normal capacity of the boiler. The efficiency can be increased by approximately 2%, the cost of reducing air leakage is 600,000 $ to 700,000 $, and the payback period is 15 months [35].

5. In this study, the researchers calculated the efficiency by indirect method for atmospheric fluidized bed combustion boiler (AFBC) and circulating fluidized bed combustion boiler (CFBC). As in the direct method, the heat entering into the outlet of the boiler is calculated, while the indirect method depends on calculating losses during the heating process in the boiler. Efficiency was calculated by direct and indirect methods at the same conditions (amount of steam produced, number of operating hours, steam temperature, steam pressure, ambient temperature and humidity). By using coal with an enthalpy of between

3000 kcal/kg and 5800 kcal/kg, the efficiency results for AFBC boiler type using the direct method were between 74.61% and 83.69%, and the indirect method was between 73.47% and 82.34% by increasing the gross caloric value (GCV) of the coal. The efficiency was calculated by the direct method for AFBC and CFBC boilers at the same operating conditions and by using coal with a gross caloric value of 4000 kcal/kg, where the efficiency results were as follows: 77.8% for AFBC and 81.35% for CFBC. The efficiency of the CFBC boiler is greater than the efficiency of the AFBC boiler at the same operating conditions and the same type of coal by (2-3) %, because the CFBC boiler returns unburned fuel particles to the combustion furnace while the AFBC boiler does not have it, even though they both have the same principle at work [36].

6. The researchers studied the heating efficiency of a single boiler, two boilers connected in series or three boilers connected in succession, through the direct method. To calculate the efficiency, meters and sensors were used to measure temperature and pressure. All meters and sensors connected to a programmable logic controller (PLC) that was programed and monitored through a laptop, so that the laptop and the PLC were connected to a wireless Ethernet network. The direct efficiency was measured six times for each type of installation (one boiler, two boilers or 3 boilers), where the average efficiency for a single boiler was 60.81%, for two boilers it was 75.84% and for three boilers it was 79.15%. In the analysis of the results, it was found that

three boilers are the most efficient system, so it is useful for use in large enterprises with high consumption, but in general and in fact, the use of two boilers is better in terms of cost comparison with efficiency for medium and small enterprises [37].

7. In this research, the researchers studied how to raise the efficiency of a fire tube boiler (9 tons / hour) running on solid fuel (rigid), using three methods, controlling the amount of air for combustion, heat recovery from flu gas for fuel drying and recovering the heat to heat the air before entering the combustion chamber, where each method was studied separately. Before starting to study these methods, the efficiency of the boiler was 76.48%, and by studying the first method to improve the efficiency, which is to control the amount of air for combustion, the efficiency of the boiler can be raised to 80.82%, which saves 195.88 tons of fuel annually. As for the second method, which is drying fuel, it can raise the efficiency to 76.89% and save 18.5 tons per year of fuel. Through the third method, which is air preheating before it enters the combustion chamber, the efficiency can be raised to 77.2%, which saves 32.5 tons of fuel annually. The three methods can be used together to improve efficiency to reach 81.63%, saving 246.88 tons of fuel annually [38].

Chapter Four
Problem Statement

4.1 Scope of Project

The proposed solution is to design and install a device to read the actual boiler efficiency (net and gross) over various periods of times. The device will read pressure, temperature, current, and mass flow at various points. It will be equipped with a data logger to store the data, analyze it, and provide user friendly reports. Moreover, it will be connected with a mobile application to enable owners/operators to monitor their boilers from remote places.

In addition, the design calculates periodic and non-periodic efficiency, it also monitors the pressure and temperature of the water entering the boiler, monitoring the pressure and temperature of hot water or steam coming out of the boiler, as well as monitoring the amount of water and fuel. To do this, two temperature transmitters, two pressure transmitters, flow meter for water, flow meter for fuel and electrical energy meter are used. All these transmitters and flow meters connected to the data analyzer for this purpose as shown in figure 4.1.

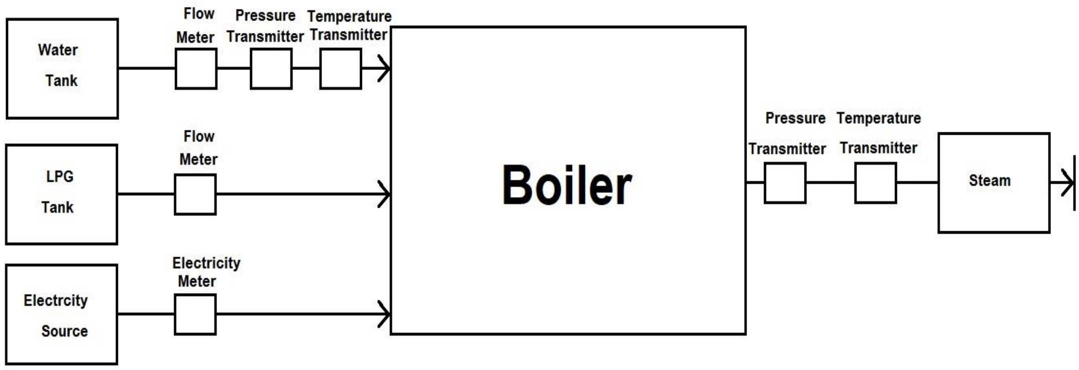

Figure (4.1): Schematic diagram for the proposed device.

4.2 Methodology

To achieve the intended objectives, the researcher implemented the following methodology:

The boiler, which was used to conduct the study, works on liquefied petroleum gas fuel and its specifications are density of 0.559 kg/L and the gross caloric value is 49.51 MJ/kg.

The boiler efficiency can be calculated through two methods, the direct and indirect method. The direct method was used to calculate the efficiency of the boiler used in the study, according to equation (2.8).

In order to calculate the boiler efficiency, before choosing the transmitters and meters, a simulation model was created for what it would be, what the expected readings were and how to obtain them, and analyzed them together to calculate the efficiency.

Before starting the construction of the device, data were collected about the boiler in terms of pressure and temperature of the water entering the boiler and the steam coming out of it, in addition to the average consumption of electricity, water and fuel, in order to choose the appropriate transmitters and meters for the boiler, so that they are suitable for temperature and pressure. In order to calculate efficiency, pressure, temperature, water quantity and fuel quantity must be monitored. Schneider's monitoring and analysis equipment were used; the detailed specifications of these devices are attached in appendix 1 to 5.

The following table 4.1 shows the prices of the devices and transmitters used (form Al-Takamul Engineering Company (Qashoo')) [39]:

Table 4.1: Price of Transmitters, Meters and the Recorder.

Type	**Amount**	**Price for each (USD $)**	**Uses**
Temperature Transmitter	2	28$	To measure the temperature of the water entering the boiler, and the temperature of the steam coming out of it.
Pressure Transmitter	2	155$	To measure the pressure of the water entering the boiler, and the pressure of the steam coming out of it.
Electric Flow Meter	2	450 $	To measure boiler water consumption and boiler fuel consumption.
Power Supply (24 Volt DC)	1	20$	To convert electricity from 230 Volt AC to 24 Volt DC needed to operate the smart recorder.
3 Phase Electrical Energy Meter	1	230$	To measure the electricity consumption of the boiler and its accessories.
Smart Recorder	1	1500$	To take readings from meters and transmitters and save data inside it, in addition to displaying direct readings of transmitters on a screen.
Total price: 3016$			

After selecting the appropriate transmitters and meters for the boiler, and choosing the appropriate smart recorder to display and save the readings, the transmitters were connected to it as the pressure transmitters operate on the 4-20 mA system, and the temperature transmitters operate on the 0-10 volt system, where the smart recorder analyzes these readings and display them on its screen in instantaneous time and save the readings every 30 seconds for later analysis. After programming the smart recorder and preparing it to take the readings from the transmitters, display the instantaneous values, and store all the values in a memory for reference and analyze them to calculate the efficiency during any period the user wants, so that the user can know the efficiency on a daily basis. Figure 4.1 shows the transmitters and meters that are installed on the boiler, where the transmitters readings were taken every 30 seconds over a period of 30 days, and the meters readings were taken once a day.

After taking the readings from the smart recorder and storing them in the form of an excel file, the transmitters were read over the course of a whole month, so that the readings were taken when the boiler was turned on and off, and thus for taking the readings correctly, the periods of inactivity of the boiler were excluded, and it was also made sure that the correct readings were identical when boiler was working in terms of temperature and pressure at its inlet and outlet.

After collecting the correct readings, the data analysis was started to calculate the gross and net efficiency of the boiler by the direct method, on a daily basis, then taking the whole period (one month) by taking the average readings of the transmitters, total electricity consumption, total water and fuel consumption and calculating the gross and net efficiency of the boiler throughout the study period. Then take conclusions from analyzing the data and the results obtained, recommending ways to raise the efficiency of the boiler, and then start writing the final report for the study. This device is programmed to give results and reports at any time, and create a database for reference at any time.

Chapter Five
Results and Discussion

All of temperature and pressure transmitters are connected to the smart recorder, and since the smart recorder works at 24 volts (direct voltage), the rectifier was connected to convert the voltage from 220 volts (Alternating voltage) to 24 volts (direct voltage), and the laptop was connected through the smart recorder network to become the program is ready for programming.

5.1 Programming the System

The logger device (smart recorder) has been installed with pressure and temperature transmitters, water meter, electric energy meter and gas meter with each other as in figure 5.1.

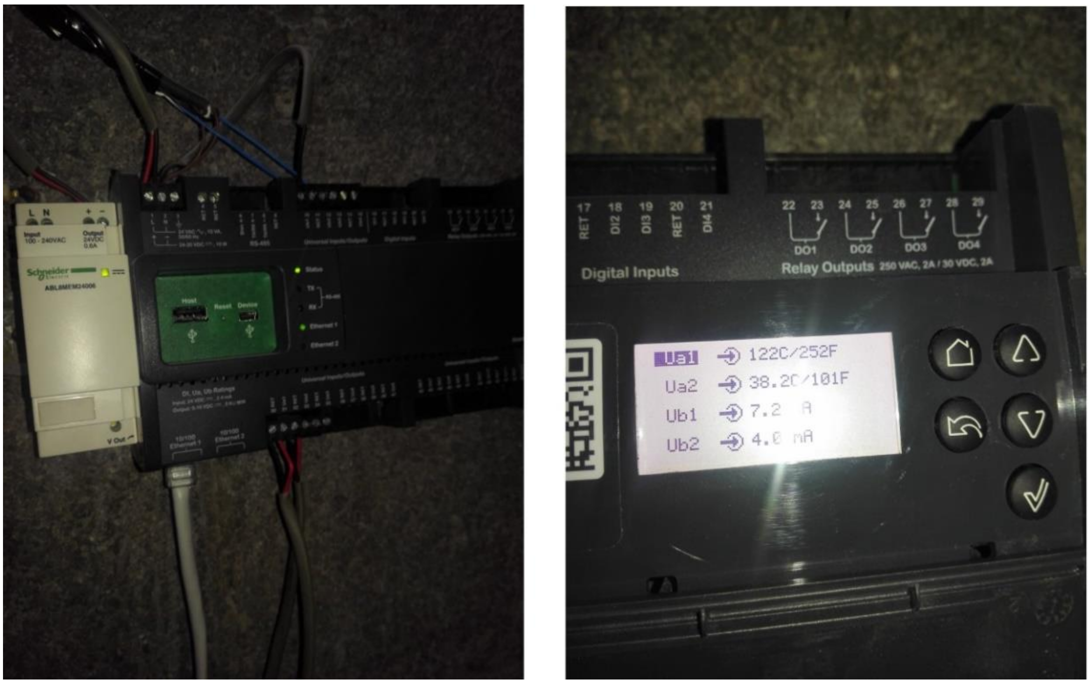

Figure (5.1): Wire connections and the home screen of the device.

In order to get the readings in real time, and store them inside the memory of the smart recorder, smart recorder connected via laptop using Ethernet cable, and then open the program "Building operation WorkStation by Schneider electric company", (the software provided by the manufacturer of smart recorder). Then begin programming the device as shown in figure 5.2 using username and password given with the smart recorder.

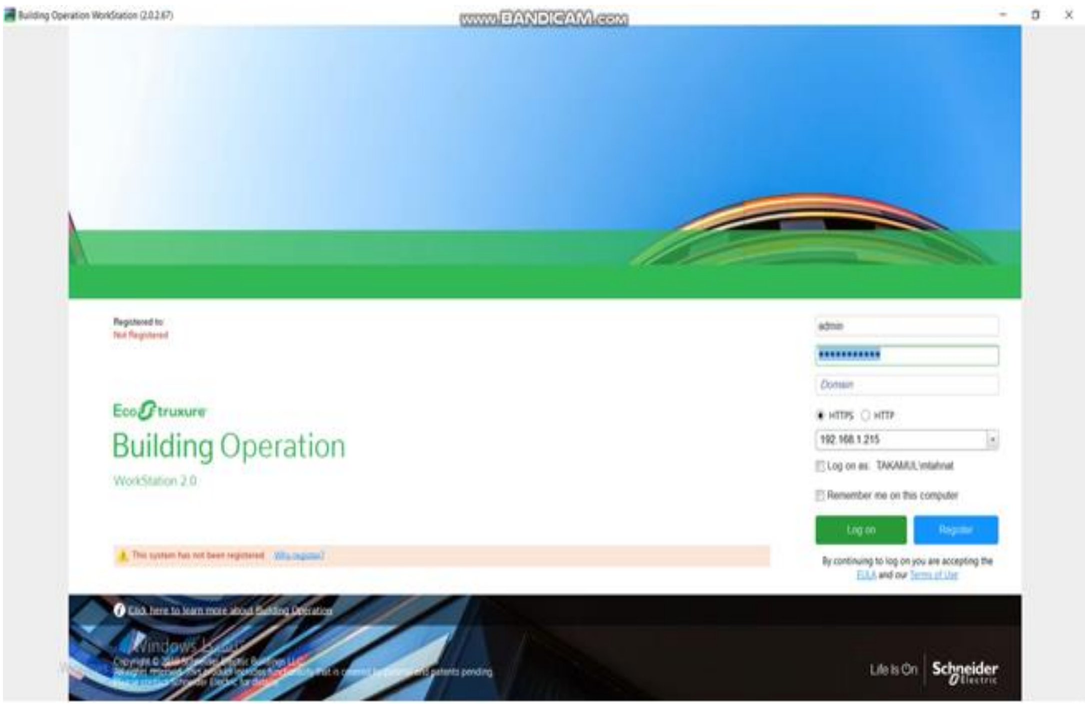

Figure (5.2): Main page of Building operation WorkStation program.

Using the program, design the transmitters and meters connected to the boiler in the form of icons within the program as shown in the figure 5.3.

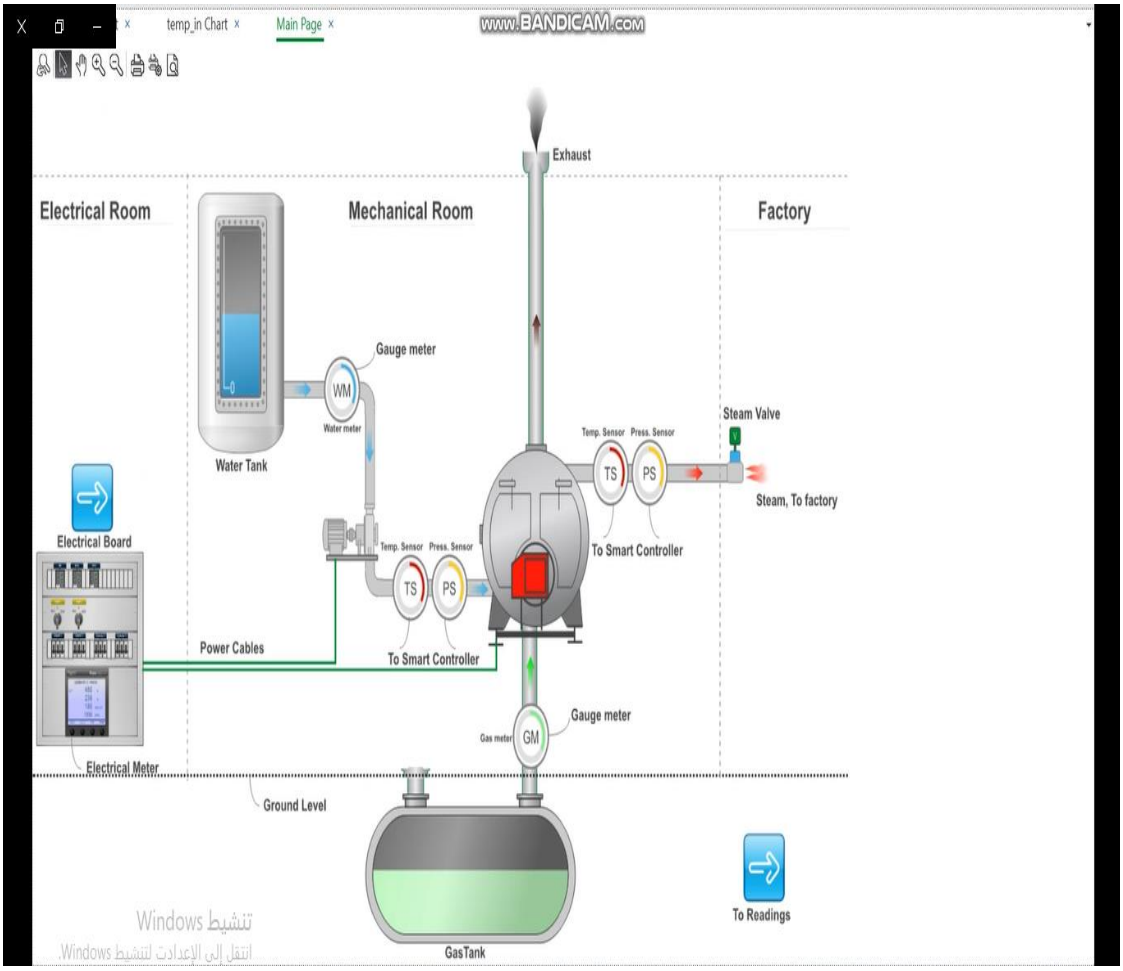

Figure (5.3): Boiler and installation places for meters and transmitters.

Selecting the input transmitters linked to the smart control, and taking readings from them using the "Building operation WorkStation" program, in order to display and store these instantaneous values, as shown in figure 5.4.

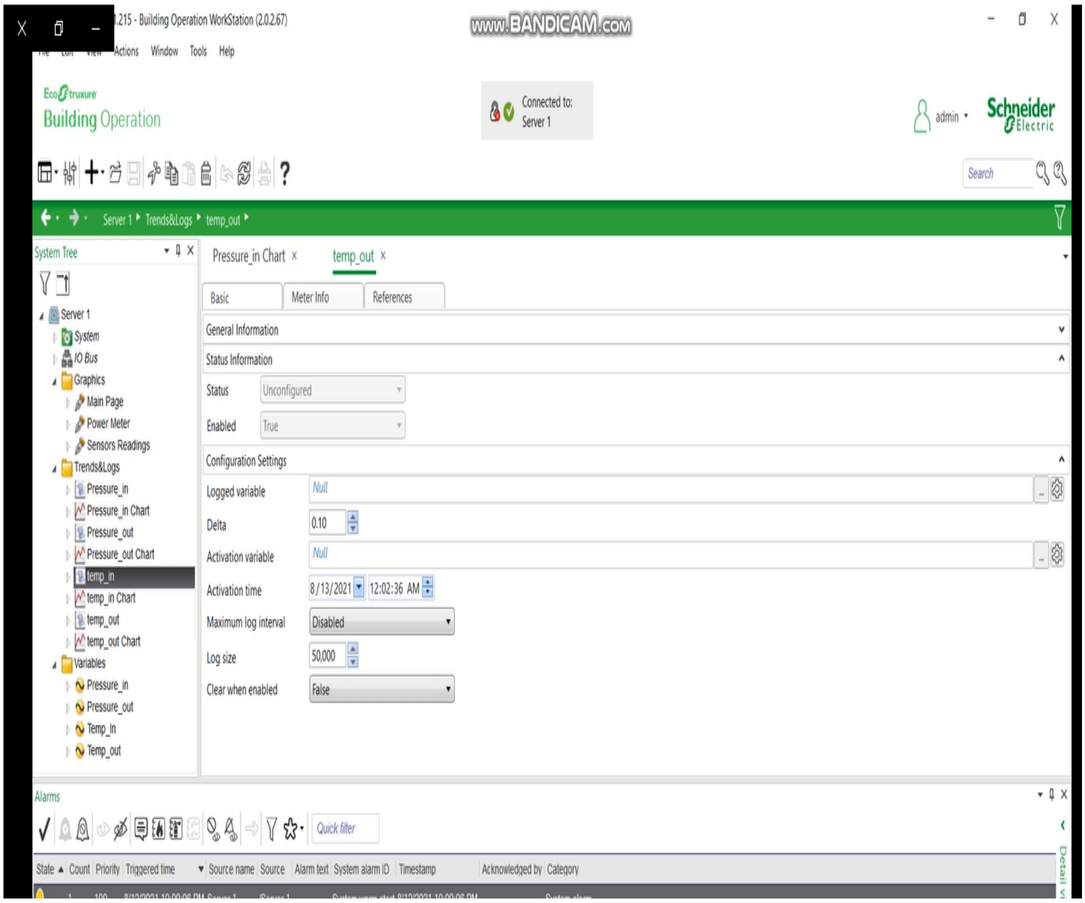

Figure (5.4): Configuration of Inputs Parameters.

The data logger is used to store the values in the tables every 30 seconds according to what is set for it for a month as shown in figure 5.5. The data can also be displayed through a table or graph. In addition to store the data, it is possible to read the instantaneous values through the screen on the data recorder or through the application or the site using a local network as shown in figure 5.6.

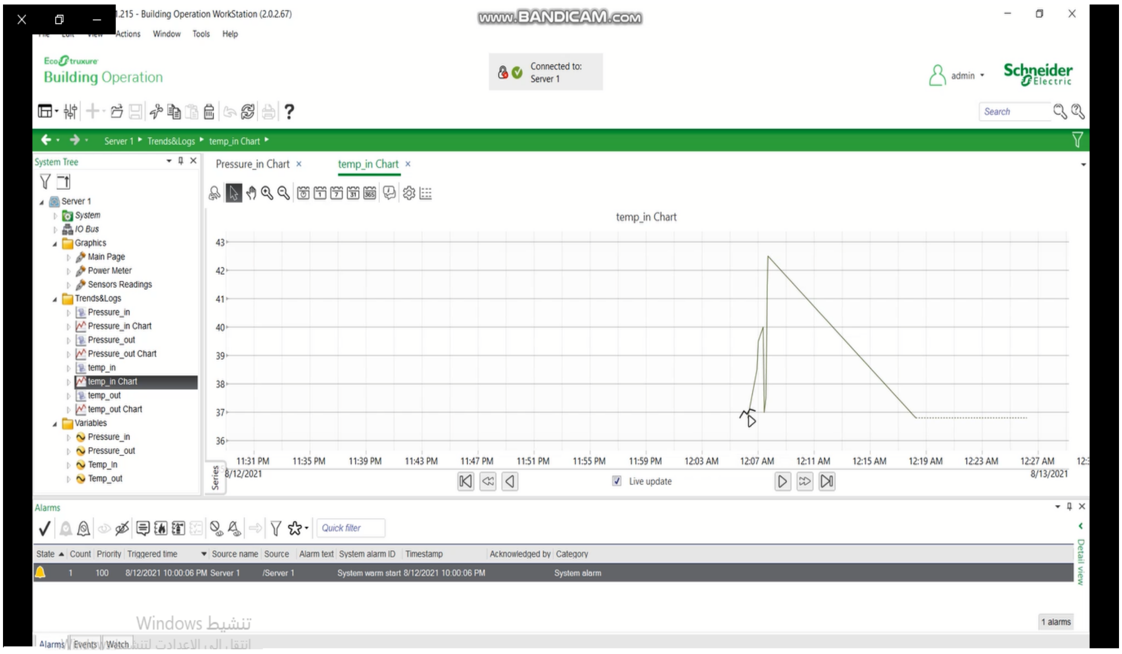

Figure (5.5): Online reading as chart for the data from the program interface.

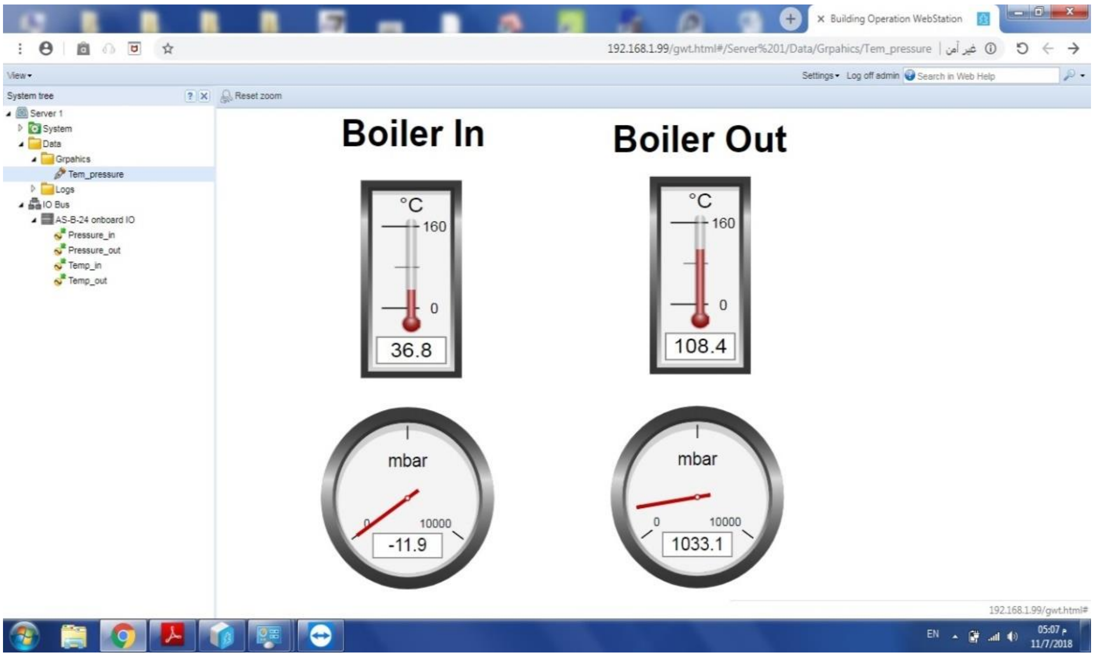

Figure (5.6): Instantaneous values of readings on a laptop screen.

Through the data stored in Excel tables, the owner of factory can calculate the efficiency for any period, and to create a database of his own to monitor and review the data available for any time he wants.

The user can access the current readings using three methods: through the same program as shown in figure 5.5, through a link via the local network browser to access the display page, which can be accessed from a laptop or a smart mobile device as shown in figure 5.6, and through a display screen on the same smart recorder as shown in figure 5.1.

5.2 Values for 24 Hour Sample

As for the readings and their analysis, they were close in behavior for pressure and temperature, while the consumption of gas, electricity and water depended on several variables, including the quantity of feed produced and the duration of operation. Data were collected for the entire period and data analysis was carried out for each day. For example, we will take the analysis on 10/12/2018, which reflects on the rest of the other days as well, since all the data obtained and then analyzed are completely applicable to this sample.

5.2.1 Inlet Water Temperature

Based on the relationship between the temperature of water entering the boiler over time, it is observed that the temperature is at a fairly constant level (the temperature of the tank feeding the boiler), and then the temperature begins to rise gradually to reach the highest value and then begins to go down again as shown in figure 5.7.

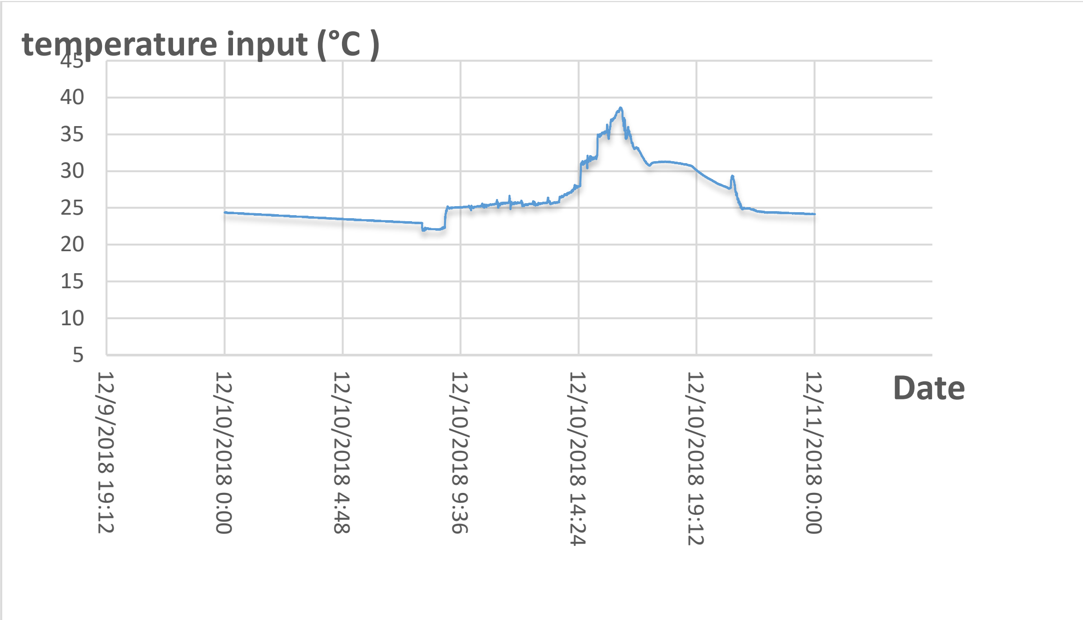

Figure (5.7): Inlet water temperature.

To illustrate why the relationship is so, the water that enters the boiler was monitored. The following can be observed:

1. In the first period from 12 am to the moment of operation of the boiler, the water temperature is fairly constant with a slight gradual decrease because the tank is not completely insulated, so there will be heat exchange between the tank and the surroundings around it, especially that the readings recorded during the winter where external temperatures are very low (usually less than 10 °C at night).

2. During the period between the start and shutdown of the boiler, the temperature of the water inside the boiler gradually increases until it reaches its highest value. This increase is due to two reasons: mainly: there is a feedback of the water collected in the pipes containing the water vapor used in the feed industry after steam condensation Inside

these tubes, where they are in the form of small drops coming back into the tank.

3. Secondly, the existence of the tank inside the boiler room and therefore there is a heat by convection and radiation between the boiler and the tank during the operating period of the boiler, and between the reservoir and part of the pipes that contain water vapor at a very high temperature within the same room, as these pipes are not isolated enough and There are large leaks in the water vapor.

4. During the last period, which extends from the shutdown of the boiler until the end of the day, the temperature of the water begins to decrease gradually due to heat exchange between the tank and the outside surroundings.

For the rest of the day, the figure 5.8 shows the relationship between the average temperatures of the water entering the boiler with the days of operation of the boiler.

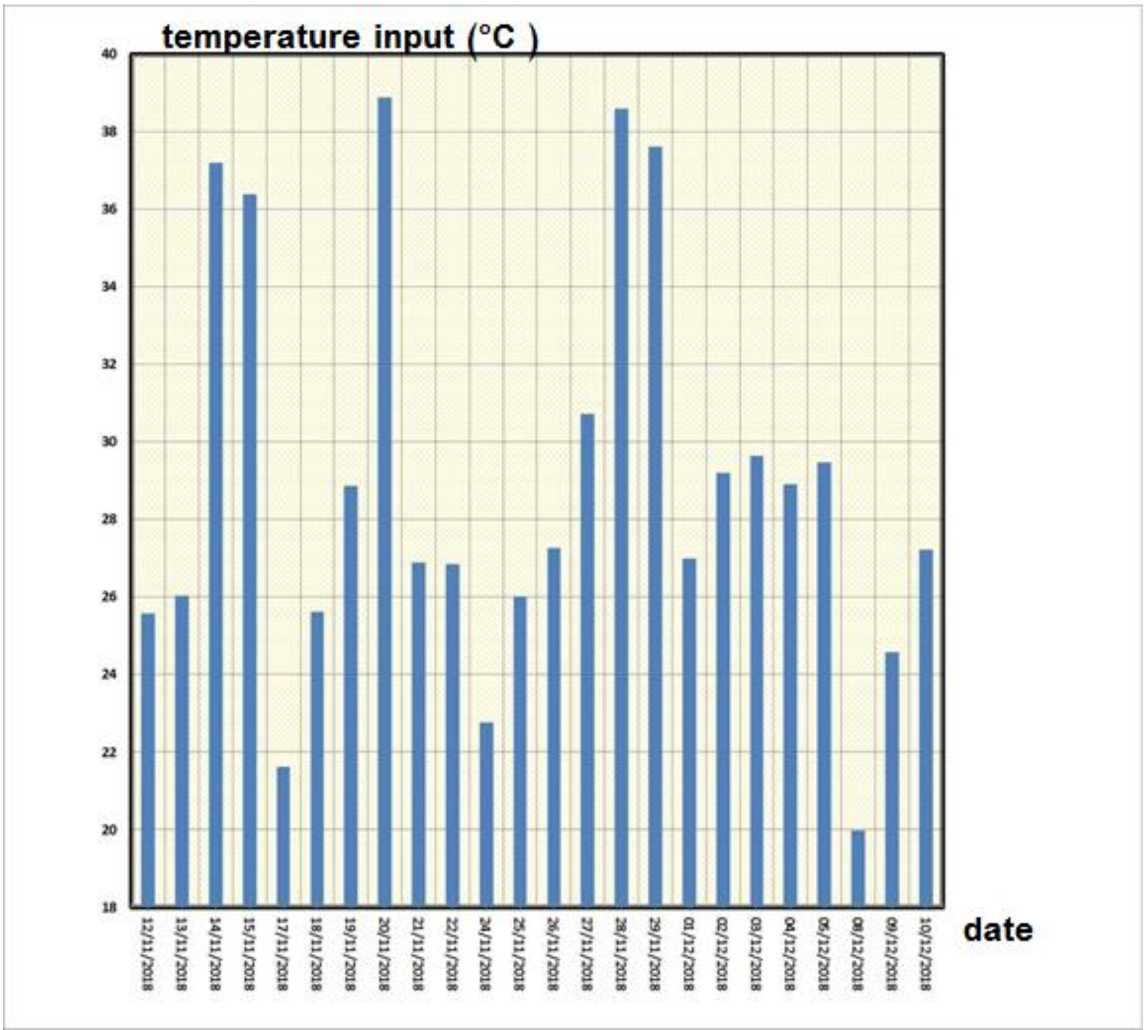

Figure (5.8): Average inlet water temperature for each day of the study period.

Figure 5.8 above shows that there are clear differences in the average temperature of the water entering the boiler from day to day, as the lowest average temperature is 20 degrees Celsius and the highest temperature average is 39 degrees Celsius.

This difference between temperatures is due to several reasons, which are:

1. Ambient air temperature, as the tank that feeds the water to the boiler is located inside the boiler room itself, and therefore there is heat exchange between the air surrounding the tank and the surface of the tank itself.

2. The water entering the tank comes from the municipal water network, and since the tank have a capacity of 3000 liters and the maximum amount of steam required is less than this amount, the water supply to the tank is not instantaneous, but takes place every two or three days, depending on the required quantity, so the average temperature of water entering the tank is much lower than the average temperature of the water inside the tank previously, knowing that the study period taken in the winter season, as the temperature is low.

3. Condensed water from steam is not disposed of, but returns to the feeder tank of the boiler at a high temperature, so the temperature of the water inside the tank is raised, and this depends on the amount of condensed water returned to the tank.

4. The number of operating hours, as the time of starting of the boiler and its stopping is not fixed, but rather variable, depending on the demand for steam in certain hours, as the boiler operated on one day for a period of 98 minutes and on other days for a period of 600 minutes.

5.2.2 Outlet water/steam temperature

The figure 5.9 indicates the relationship between the temperature of the vapor or the hot water outside of the boiler over time during the same day.

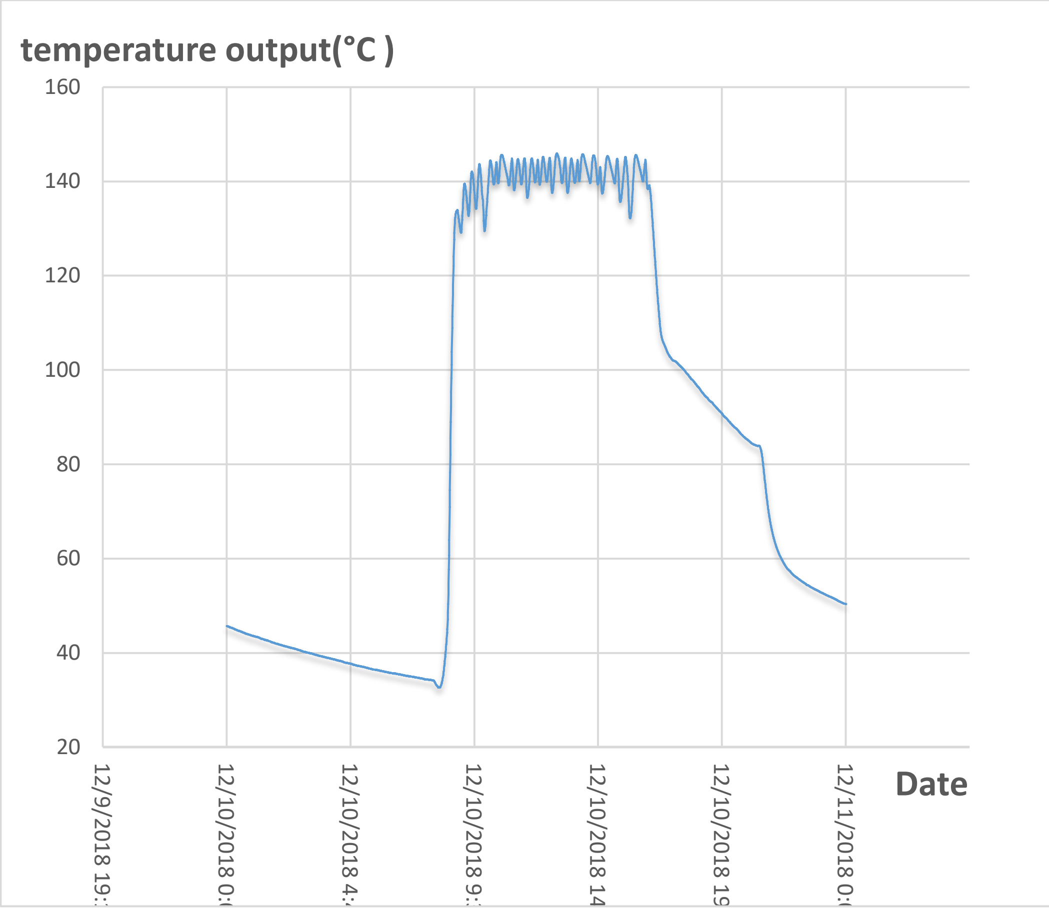

Figure (5.9): Outlet water/steam temperature.

The following can be observed through checking the figure 5.9:

1. The beginning of the day until the starting of the boiler, the temperature is fairly constant with a slight decrease, but initially the temperature is somewhat high, because the water is inside the boiler pipes, which are isolated and retain their temperature through the process of water heating for the previous day. However, with time and the low temperature of the room inside which the boiler is large because of the winter as we explained earlier, the temperature of water drops to the lowest value.

2. In the operation of the boiler and when burning gas to heat the water and turn it into vapor, the temperature of water coming out of the boiler directly rises to a value higher than the boiling temperature, and as the pump enters the amount of water and then burner burns an appropriate amount of gas to convert the water entering the vapor then stops the burner from burning the gas, and repeats the process. It is therefore observed through the figure how the temperature decreases slightly and then rises over several periods depending on the consumption of steam in the feed industry.

3. After the working day in the feed industry, the owner of the plant stops the operation of the boiler from work, and therefore it does not burn any additional quantities of gas, which leads to a drop in the temperature of steam and turn it into hot water as seen from the figure above, Steam and its transformation into hot water is such a rapid difference between the temperature of the steam temperature and the surroundings of the boiler, leading to a large heating exchange between them. This decline continues to the end of the day so that as the time progresses, the decline will be less severe.

For the rest of the day, the figure 5.10 shows the relationship between the average temperature of the water coming out of the boiler and the days of operation of the boiler.

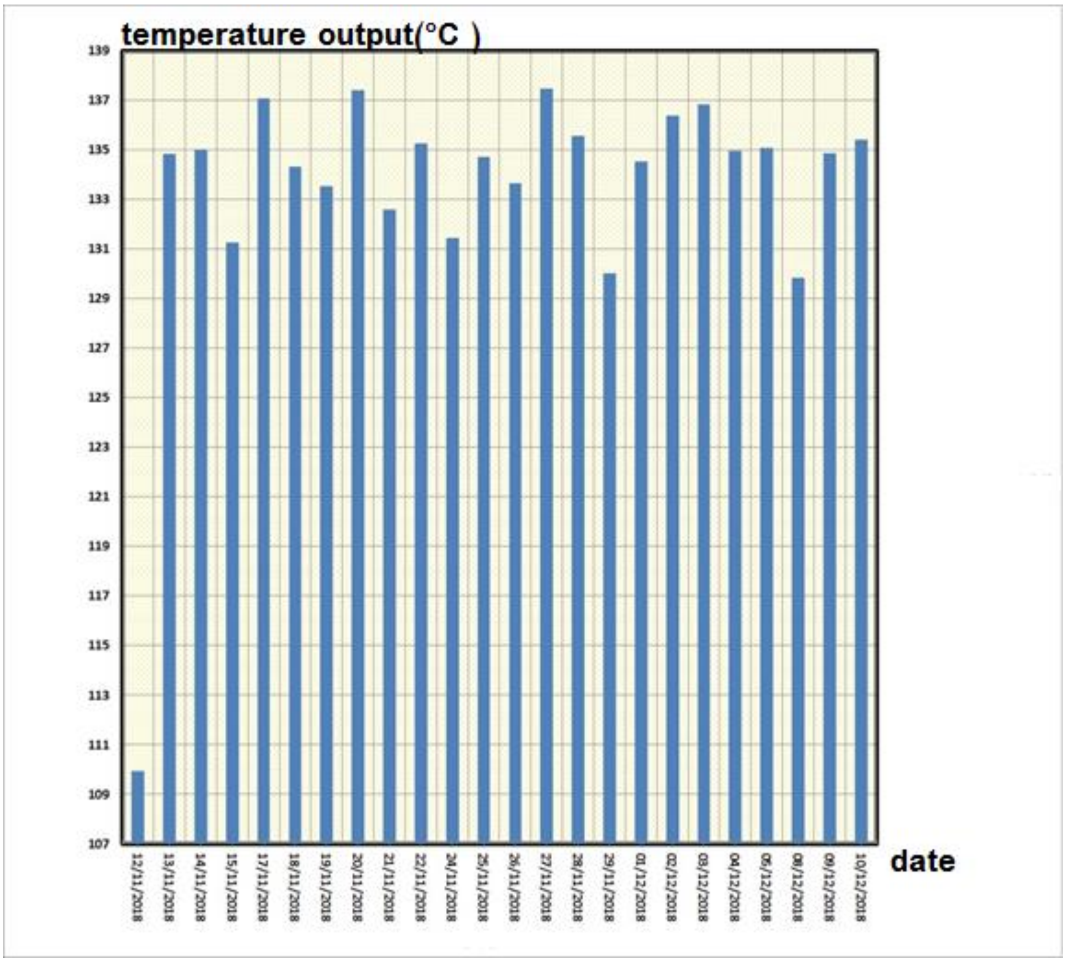

Figure (5.10): Average outlet water/steam temperature for each day of the study period.

Through the data on the average temperature of the steam leaving the boiler, a very important note appears, that the quality of the steam is low, since at these temperatures and under the operating pressure there is still a small part of the water.

It is also clear that there is a difference in the average temperature of the steam leaving from day to day by 7 degrees Celsius (except for the day when the average steam temperature was 110 degrees Celsius), and this affects the production process, as it needs special specifications for steam in the production process.

5.2.3 Inlet Water Pressure

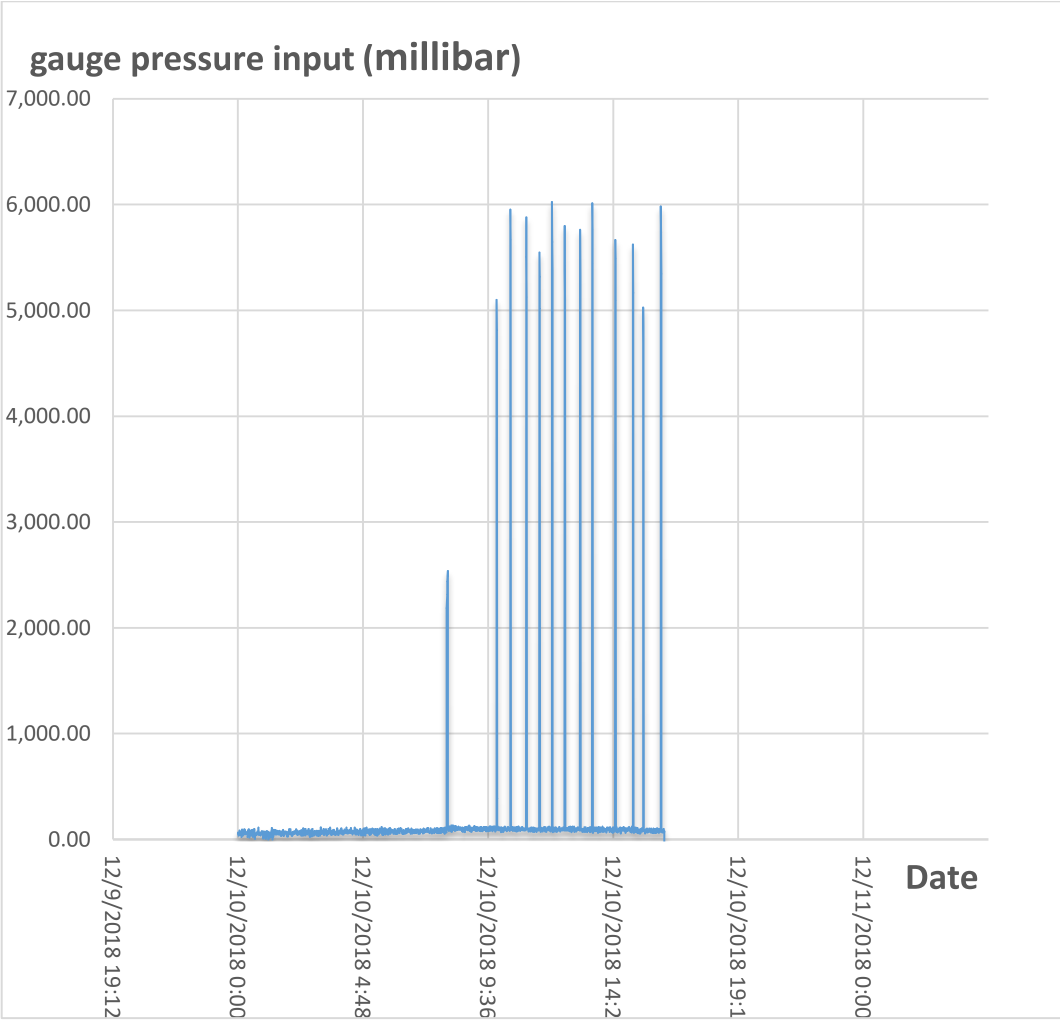

Figure (5.11): Inlet Water Pressure.

The relationship between the pressures of water entering the boiler with time is as follows:

The figure 5.11 can be divided into three periods, the first period from the beginning of the day to the moment of operation of the boiler, the second period during the period of operation of the boiler, and the third period from the moment of stopping the boiler to the end of the day.

During the first and third periods, when the boiler is not in operation, there is no pumping of water to the boiler and therefore the pressure is zero because the system is closed and not opened to atmospheric pressure. During the second period it appears that the pump pumps water in the form of pulses, depending on the steam consumption. The pressure of the water entering the boiler during this period was calculated and the average of the pump operating period was taken only (as shown in Figure 5.11 that the pump worked 13 times), the average pressure for water entering the boiler was 4.964 bars for the presented sample.

5.2.4 Water/Steam Pressure Output

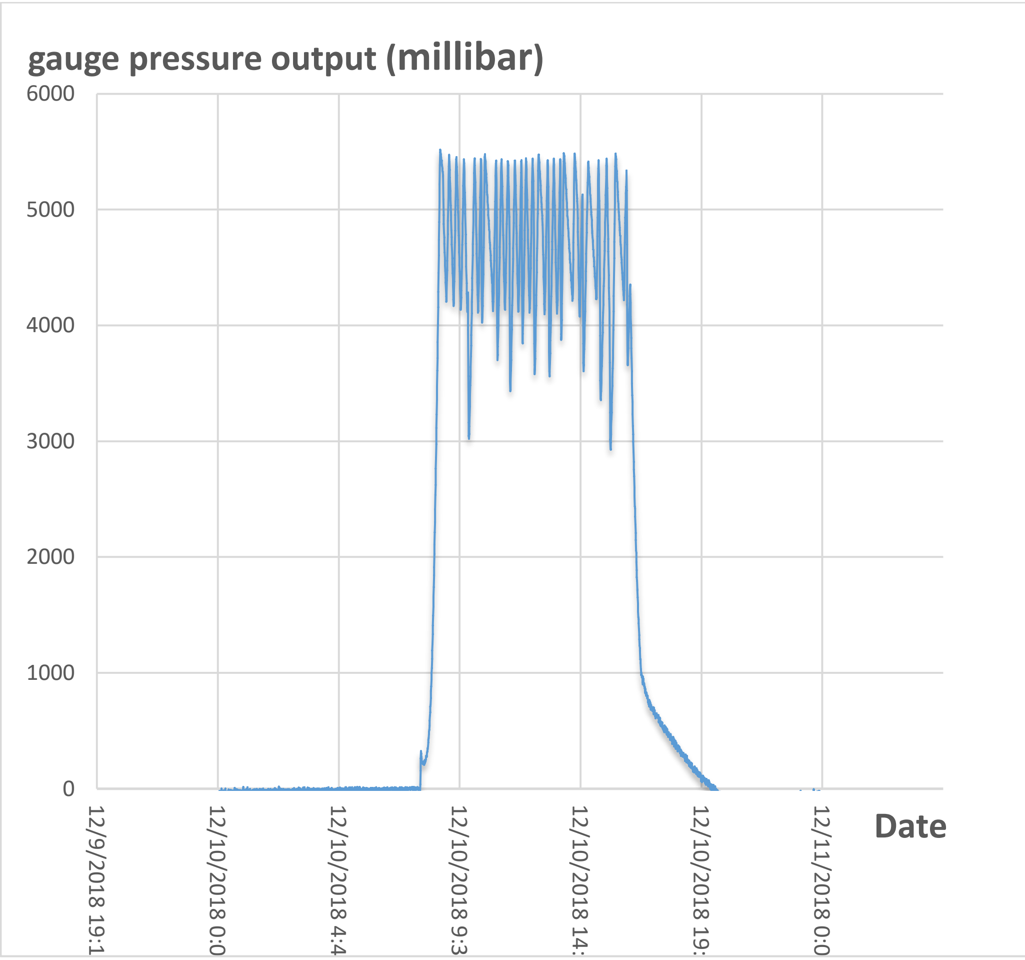

Figure (5.12): Outlet Water Pressure.

From figure 5.12, it is noted that the relation of vapor pressure outside of the boiler with time can be divided into 3 periods: pre-boiler operation period, boiler operation period, post-shutdown period of the boiler. The boiler usually starts operating in the morning, and when it turns on, pressure starts to rise gradually until it reaches its highest value. Then, it begins to increase and decrease gradually depending on the load profile of steam, and when the boiler stops; steam pressure starts to decrease until it reaches zero (gauge) because it is not open to Atmospheric pressure. The average steam pressure during the operation period of the boiler is 4.502 bars for the presented sample.

Similarly, the average pressure of water in and out of the boiler was calculated, and the average pressures were as shown in figure 5.13.

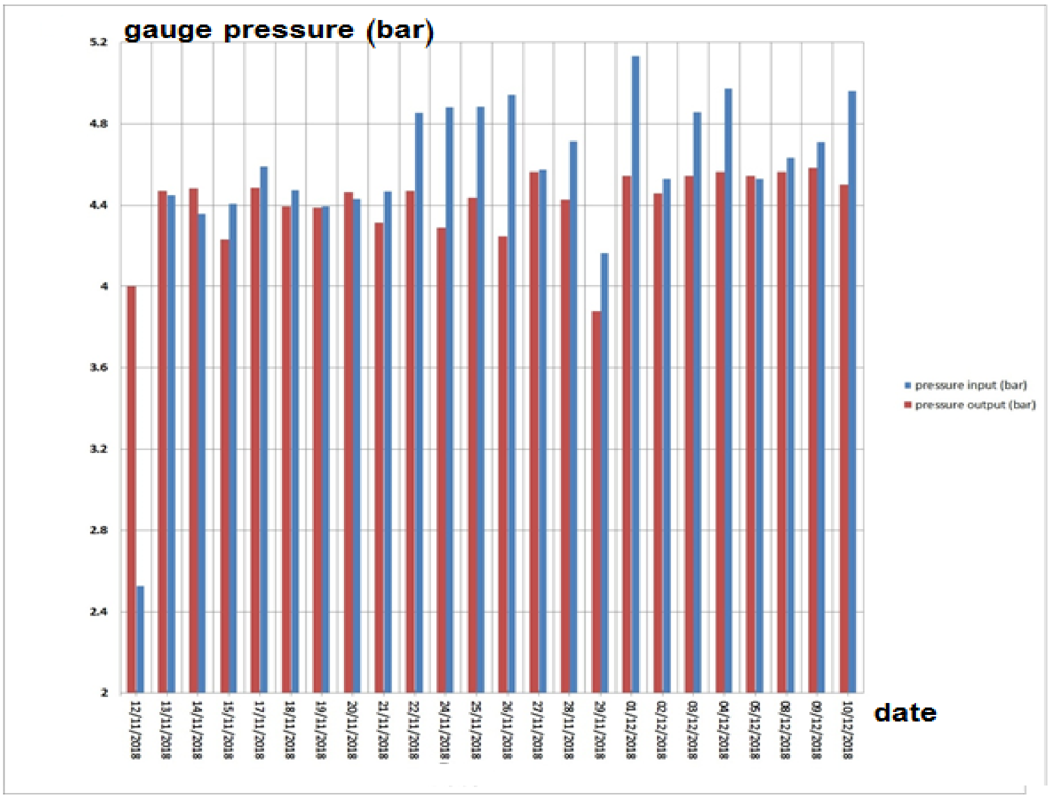

Figure (5.13): Average Inlet and Outlet Water for each Day of the Study Period.

5.2.5 The Amount of Water Consumed

The source of used water is from the municipality. Since there is a water crisis in all the Palestinian cities and towns, water is not available at all times, but it is supplied to the consumers at certain hours and days. The factory collects the water inside a tank of 3000 liters ensuring constant water supply for the boiler (this is to ensure that the water is not interrupted, as the water supply is the municipal water network). Water consumption varies from day to day depending on several factors, including the amount of feed produced, and how to use the steam in the right way for the production process. Water consumption per day (for presented sample) was 600 liters.

The water consumption in the days of operation of the boiler are shown in the following figure 5.14:

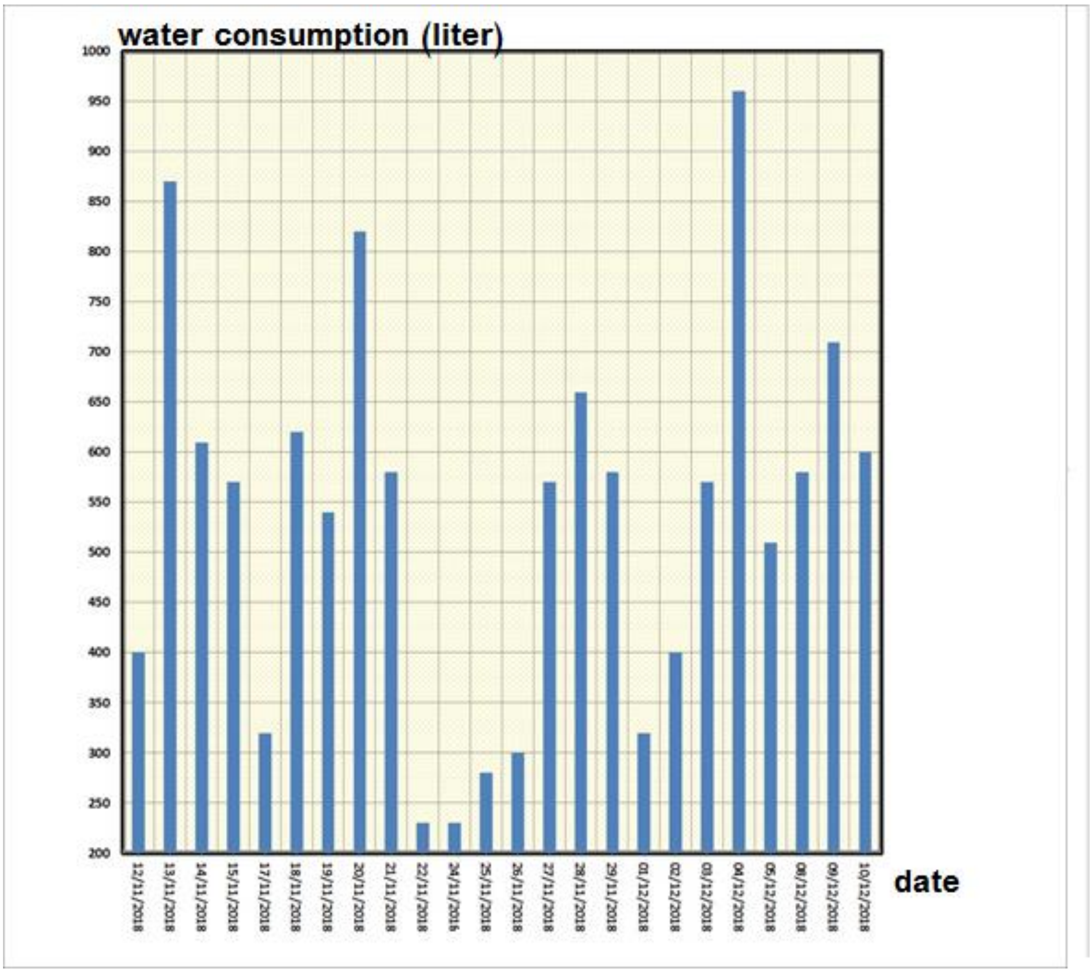

Figure (5.14): Water Consumption for Each Day of the Study Period.

5.2.6 The Amount of Gas Consumed

The fuel used in a 3000-liter underground tank is kept under pressure to turn into a liquid state, and then passes through the pipes to a vaporizer. Its function is to turn the gas back into the gaseous state in order to burn it into the burner.

The amount of gas consumed during the day varies significantly from day to day due to several reasons, notably: the amount of water that is heated to turn into steam, the temperature of the water entering the boiler, as well as the running time of the boiler. During presented sample (1 day), the gas liquid consumption was 80 liters, which is equivalent to 2,214 MJ.

Gas consumption in the rest of the boiler operation was as shown in figure 5.15:

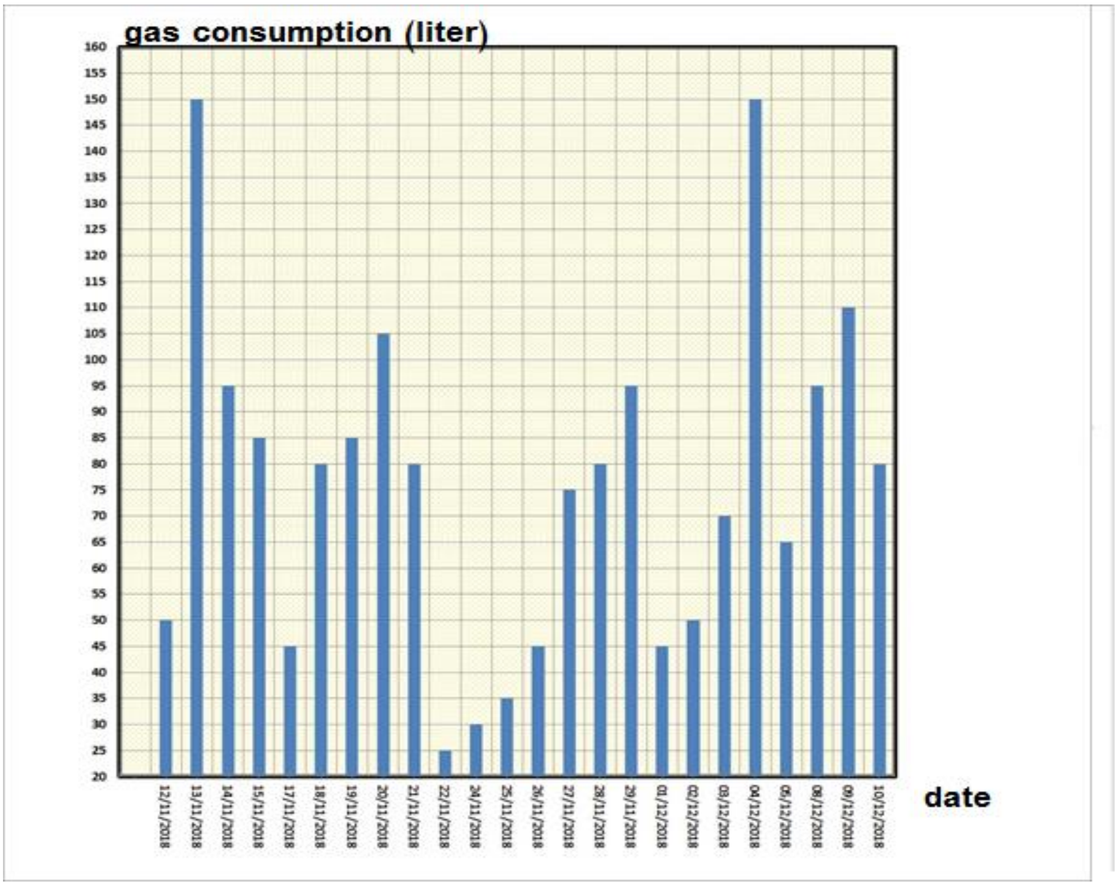

Figure (5.15): Gas Consumption for Each Day of the Study Period.

5.2.7 Electric Energy Consumption

There is also consumed electrical energy in the pumps, control panel and evaporator. To calculate this energy, a 3-phase electric energy meter was placed on the main panel of the boiler room. The electrical energy consumed was different from day to day and depended on this auxiliary equipment for the boiler.

Power consumption for presented sample (10/12/2018) was 15.5 kWh which equal 55,800 kJ. The figure 5.16 shows the electrical energy consumption for each day of operation that was observed.

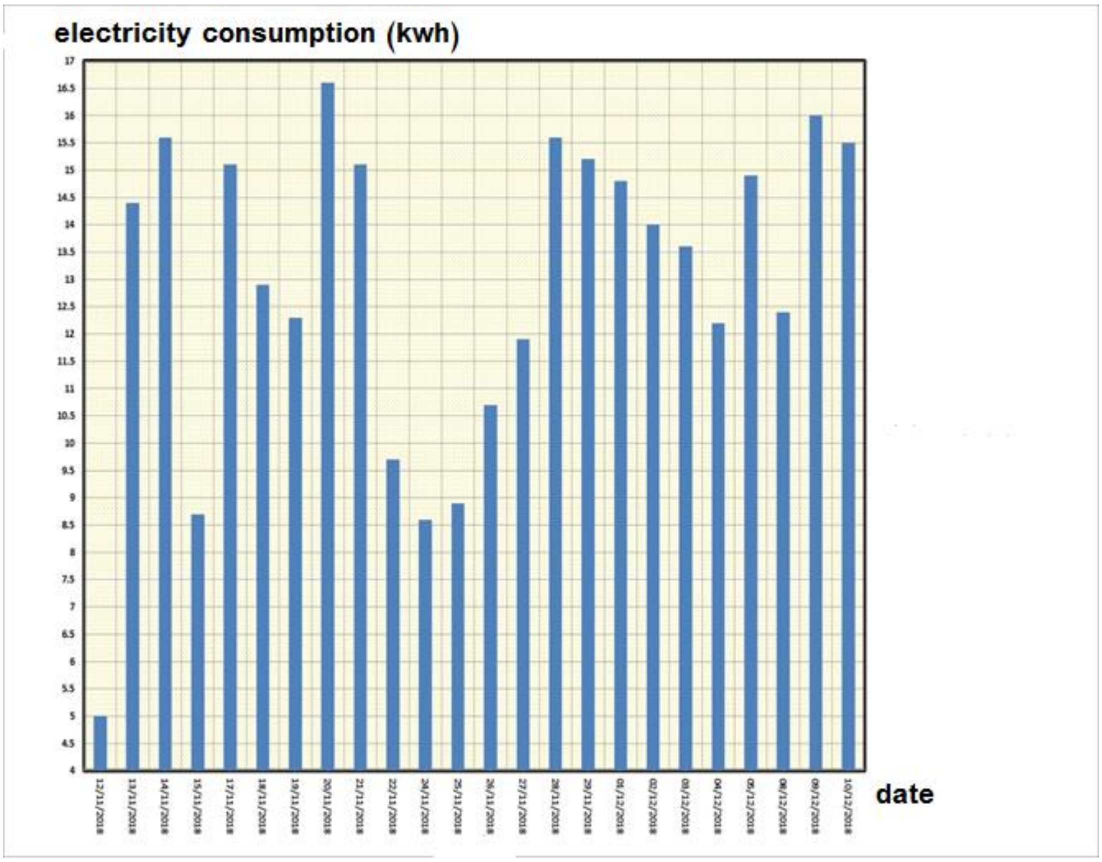

Figure (5.16): Electric Energy Consumption for Each Day of the Study Period.

5.3 Gross Efficiency Calculation

Based on the above data, consumption can be monitored and the boiler behave view can be observed, but in order to calculate the efficiency of the boiler, these data must be entered with each other and the enthalpy of the water at certain temperature and pressure for the sample day 10-12-2018.

To calculate the gross efficiency according to the equation 2.11:

$$=\left(\frac{\left(\text{water consumption(kg)x}\left(\text{steam enthalpy}\left(\frac{\text{kJ}}{\text{kg}}\right)-\text{feed water enthalpy}\left(\frac{\text{kJ}}{\text{kg}}\right)\right)\right)}{\left(\text{gas consumption(L) x gas density}\left(\frac{\text{kg}}{\text{L}}\right)\text{ x Gross Calorific Value of gas}\left(\frac{\text{kJ}}{\text{kg}}\right)\right)}\right)\text{ x 100\%}$$

$$=\left(\frac{\left(600\text{(kg)x}\left(2727.4\left(\frac{\text{kJ}}{\text{kg}}\right)-114.2\left(\frac{\text{kJ}}{\text{kg}}\right)\right)\right)}{\left(80\text{ (L) x }0.559\left(\frac{\text{kg}}{\text{L}}\right)\text{ x }49510\left(\frac{\text{kJ}}{\text{kg}}\right)\right)}\right)\text{ x 100\% = 70.815 \%.}$$

5.4 Net Efficiency Calculation

To calculate the net efficiency for the sampled day 10-12-2018, the electric energy consumed in the pumps and control panel of the boiler is added as follows:

$$\text{net efficiency} = \left(\frac{\left(\text{water consumption(kg)x}\left(\text{steam enthalpy}\left(\frac{\text{kJ}}{\text{kg}}\right)-\text{feed water enthalpy}\left(\frac{\text{kJ}}{\text{kg}}\right)\right)\right)}{\left(\left(\text{gas consumption(L) x gas density}\left(\frac{\text{kg}}{\text{L}}\right)\text{ x Gross Calorific Value of gas}\left(\frac{\text{kJ}}{\text{kg}}\right)\right)+\text{electric energy consumed (kJ)}\right)}\right)\text{ X 100\%.} \quad (2.12)$$

$$=\left(\frac{\left(600\text{(kg)x}\left(2727.4\left(\frac{\text{kJ}}{\text{kg}}\right)-114.2\left(\frac{\text{kJ}}{\text{kg}}\right)\right)\right)}{\left(\left(80\text{(L) x }0.559\left(\frac{\text{kg}}{\text{L}}\right)\text{ x }49510\left(\frac{\text{kJ}}{\text{kg}}\right)\right)+55800\text{ (kJ)}\right)}\right)\text{ x 100\% = 69.075\%.}$$

The boiler gross and net efficiency values can be summarized in figure 5.17:

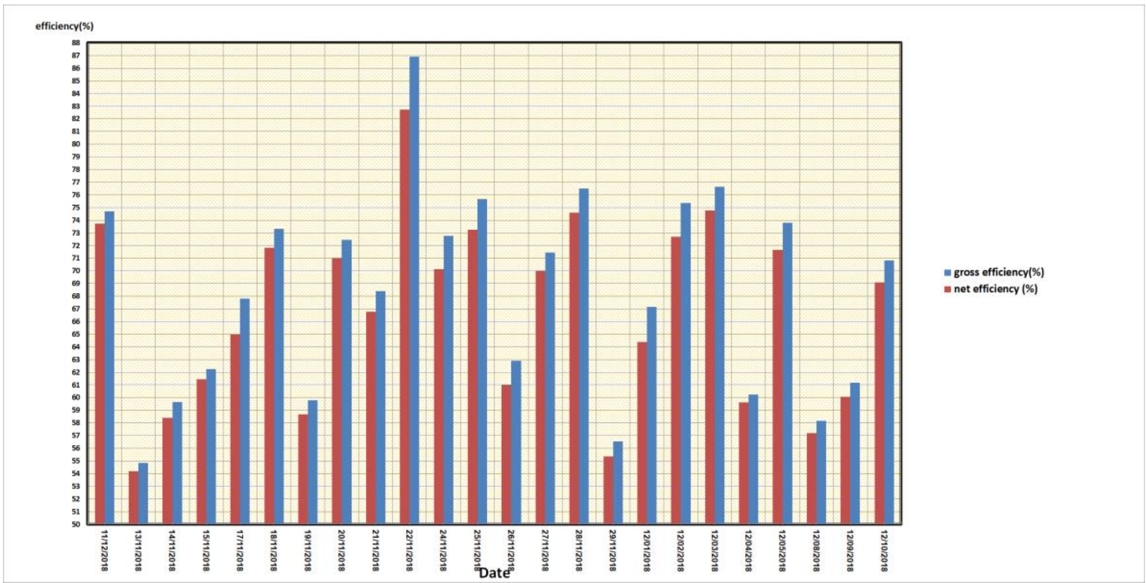

Figure (5.17): Gross and Net Efficiency for Each day of the Study Period.

5.5 Data Collection for Case Study

For the rest of the study period days, the same method was applied by utilizing the data from the data logger for temperature readings, pressure, electric power consumption and quantities of gas and water consumed. As in the following table 5.1:

Table 5.1: All Data and Information for the Measurement Period.

net efficiency (%)	gross efficiency(%)	specific enthalpy output (kJ/kg)	specific enthalpy input (kJ/kg)	temperature output (◦C)	temperature input (◦C)	pressure output (bar)	pressure input (bar)	day	date
69.07479808	70.81563906	2727.4	114.2	135.42	27.23	4.502	4.964	MO	12/10/2018
60.05074388	61.18691424	2726.7	103.1	134.86	24.58	4.581	4.715	SU	12/09/2018
57.1807466	58.15158214	2719.9	83.8	129.85	19.98	4.562	4.637	SA	12/08/2018
71.66922926	73.80622379	2727	123.6	135.08	29.48	4.543	4.532	WE	12/05/2018
59.62281664	60.25359796	2726.8	121.2	134.97	28.92	4.563	4.979	TU	12/04/2018
74.7550844	76.64429064	2729.3	124.3	136.84	29.65	4.546	4.862	MO	12/03/2018
72.68977332	75.33723152	2728.7	122.4	136.38	29.2	4.457	4.533	SU	12/02/2018
64.3841836	67.13857822	2726.2	113.2	134.53	27	4.545	5.138	SA	12/01/2018
55.37550263	56.52798803	2720.1	157.6	130.01	37.61	3.877	4.166	TH	29/11/2018
74.5951366	76.4872314	2727.6	161.7	135.57	38.6	4.426	4.719	WE	28/11/2018
69.98859006	71.43306732	2730.1	128.8	137.47	30.72	4.564	4.576	TU	27/11/2018
61.00265818	62.88942308	2725.1	114.3	133.65	27.26	4.248	4.947	MO	26/11/2018
73.23570431	75.6580861	2726.5	109.1	134.72	26.01	4.435	4.886	SU	25/11/2018
70.14491966	72.7605188	2722.1	95.5	131.46	22.76	4.288	4.885	SA	24/11/2018
82.73797342	86.91372228	2727.2	112.6	135.25	26.86	4.47	4.86	TH	22/11/2018
66.75844163	68.39748678	2723.7	112.7	132.61	26.89	4.313	4.472	WE	21/11/2018
70.98050714	72.4401804	2730.1	162.9	137.41	38.88	4.463	4.432	TU	20/11/2018
58.66725268	59.77153395	2724.9	121	133.55	28.87	4.387	4.4	MO	19/11/2018
71.81820241	73.32457367	2726	107.5	134.33	25.63	4.394	4.476	SU	18/11/2018
64.9683307	67.80405437	2729.6	90.7	137.09	21.63	4.485	4.592	SA	17/11/2018
61.43588335	62.253821	2721.8	152.5	131.25	36.39	4.232	4.412	TH	15/11/2018
58.40387604	59.65137569	2726.9	155.8	135.01	37.2	4.483	4.361	WE	14/11/2018
54.17974433	54.85630376	2726.7	109.1	134.84	26.03	4.469	4.453	TU	13/11/2018
73.72497377	74.68396005	2691	107.3	109.93	25.58	4.001	2.53	MO	11/12/2018
64.71	66.14	2,724.70	121	133.42	28.87333333	4.40975	4.563625		total

Based on the above table, the average gross and average net efficiency of the boiler during the total operating period was 68.3% and 66.56% respectively.

If we take the averages for temperature of input water, temperature of output water, pressure of input water , pressure of output water and the total consumption of water, gas and electricity. Through equation 2.11, the gross efficiency is 66.14%.Through equation 2.12, net efficiency was 64.71%.

5.6 Cost of Feed Production

After knowing the consumption of water, gas and electricity during the study period, it became possible for the director to know the costs of water, electricity and gas separately. The table 5.2 shows the consumption of water, gas and electricity for each day during the study period.

Table 5.2: Water, gas and electricity consumption during study period.

electricity consumption (kwh)	water consumption (liter)	gas consumption (liter)	duration (minutes)	production (ton)	day	date
15.5	600	80	476	25	MO	12/10/2018
16	710	110	414	20	SU	12/09/2018
12.4	580	95	348	11.5	SA	12/08/2018
14.9	510	65	427	21	WE	12/05/2018
12.2	960	150	379	22	TU	12/04/2018
13.6	570	70	436	19	MO	12/03/2018
14	400	50	448	18.5	SU	12/02/2018
14.8	320	45	548	30	SA	12/01/2018
15.2	580	95	421	17	TH	29/11/2018
15.6	660	80	407	17.5	WE	28/11/2018
11.9	570	75	441	18.5	TU	27/11/2018
10.7	300	45	479	24.5	MO	26/11/2018
8.9	280	35	495	27	SU	25/11/2018
8.6	230	30	444	19	SA	24/11/2018
9.7	230	25	421	20.5	TH	22/11/2018
15.1	580	80	434	17	WE	21/11/2018
16.6	820	105	600	29	TU	20/11/2018
12.3	540	85	360	14	MO	19/11/2018
12.9	620	80	365	17	SU	18/11/2018
15.1	320	45	387	16	SA	17/11/2018
8.7	570	85	330	14	TH	15/11/2018
15.6	610	95	376	17	WE	14/11/2018
14.4	870	150	435	22	TU	13/11/2018
5	400	50	98	8	MO	11/12/2018
309.7	12830	1825	9969	465		total

After knowing the consumption of gas, water and electricity for each day during the study period, it became possible to calculate their cost for each day separately, and by knowing the amount of production for each day of feed, the cost of one ton of feed was calculated. Since the cost of a liter of gas is 5.152 NIS, and the cost of a cubic meter of water is 5 NIS, the cost of a kilowatt-hour of electricity is 0.68 NIS.

The results show that the average cost of producing one ton of animal feed during the study period is 22.42 NIS, as shown in table 5.3.

Table 5.3: Cost of electricity, gas, water during study period.

cost for production of 1 ton feed (NIS)	cost of feed prodction (NIS)	production/electricity (NIS)	production/water (NIS)	production/gas (NIS)	day	date
17.028	425.7	10.54	3	412.16	MO	12/10/2018
29.0575	581.15	10.88	3.55	566.72	SU	12/09/2018
43.5453913	500.772	8.432	2.9	489.44	SA	12/08/2018
16.55057143	347.562	10.132	2.55	334.88	WE	12/05/2018
35.72254545	785.896	8.296	4.8	772.8	TU	12/04/2018
19.61778947	372.738	9.248	2.85	360.64	MO	12/03/2018
14.54702703	269.12	9.52	2	257.6	SU	12/02/2018
8.1168	243.504	10.064	1.6	231.84	SA	12/01/2018
29.56917647	502.676	10.336	2.9	489.44	TH	29/11/2018
24.34674286	426.068	10.608	3.3	412.16	WE	28/11/2018
21.47794595	397.342	8.092	2.85	386.4	TU	27/11/2018
9.821061224	240.616	7.276	1.5	231.84	MO	26/11/2018
6.954518519	187.772	6.052	1.4	180.32	SU	25/11/2018
8.503052632	161.558	5.848	1.15	154.56	SA	24/11/2018
6.660780488	136.546	6.596	1.15	128.8	TH	22/11/2018
25.01929412	425.328	10.268	2.9	412.16	WE	21/11/2018
19.18441379	556.348	11.288	4.1	540.96	TU	20/11/2018
32.07028571	448.984	8.364	2.7	437.92	MO	19/11/2018
24.94305882	424.032	8.772	3.1	412.16	SU	18/11/2018
15.23175	243.708	10.268	1.6	231.84	SA	17/11/2018
31.90614286	446.686	5.916	2.85	437.92	TH	15/11/2018
29.594	503.098	10.608	3.05	489.44	WE	14/11/2018
35.77009091	786.942	9.792	4.35	772.8	TU	13/11/2018
32.875	263	3.4	2	257.6	MO	11/12/2018
22.42137246	9677.146	210.596	64.15	9,402.40		total

Chapter Six
Technical and Economic Study for the Installation of Solar Water Heating System

6.1 Technical Study for Solar Water Heating System

To calculate the size of the solar water heating system for the animal feed factory (collective system), we will take the highest water consumption during the boiler monitoring period, which was 960 liters. We want to raise the temperature to at least 55 ℃ before entering the boiler, as also the average temperature in the year is 21.5 ℃ in Jenin as shown in table 6.1 [8].

Table 6.1: Al-Manar animal feed factory information.

Parameter	**Description**
Name	Al-Manar Animal Feed Factory.
Address	Arrabah-Jenin-Westbank.
Longitude	35.20168 degree
Latitude	32.408268 degree
Average daily water consumption	534.6 (Litter).
Highest daily water consumption	960 (Litter).
Annual average ambient temperature	21.5 (C°).
average daily solar radiation	5.4 ($\frac{kWh}{m^2 .day}$).
Surface area of the factory	720 (m^2).
Required temperature from the SWH system	55 (C°).
gross boiler efficiency	68.3%.
Net boiler efficiency	66.56%.

$$Qu = m * cp * (To - Ti) \tag{6.1}$$

Where;

Qu: The amount of heat required to raise the temperature from Ti to To (joule).

m: The mass of heated water ($\frac{kg}{day}$)

cp: Is the specific heat of water = 4186 (J/kg.°C).

Ti: The inlet water temperature (°C).

To: The outlet water temperature (°C).

We want to heat at least 960 kg of water to at least 55 °C. Using equation 6.1

$Qu = m * cp * (To - Ti)$ = 960 ($\frac{\text{kg}}{\text{day}}$)* 4186 ($\frac{\text{J}}{\text{kg.°C}}$)* (55-21.5)°C. = 134621760$\frac{\text{J}}{\text{day}}$.

6.2 Technical and Economic Parameters for SWH Systems

To begin the analysis of the SWH, technical and economic parameters must be defined. Table 6.2 shows the inputs for the mathematical model analysis [32].

Table 6.2: Technical and Tconomic Parameters of flat plat (FP) system and evacuated tube (ET) system.

Parameter	**FP (glazed)**	**ET**
Manufacturer	Jiangsu sunrain solar energy	Beijing Tsinghua solar systems
Model	SR210	SLU-1500/12 III
Gross area per collector	2.14 m^2	1.28 m^2
Aperture area per collector	1.86 m^2	1.08 m^2
F_R $(\tau\alpha)$	0.669	0.512
F_R U_L	4.62(W/m^2)/°C	1.43(W/m^2)/°C
Temperature coefficient for F_R U_L	0.0(W/m^2)/°C	0.0(W/m^2)/°C
Cost per collector (NIS)	615	462
Cost per tank V is tank volume in m^3	1487.2 V^3 -3333.3 V + 8000	
Temperature required from the SWH(°C)	55	
Hot water storage tank (Liter/m^2)	75	

LPG energy content (MJ/kg)	49.51
LPG $/L	1.6
gross studied boiler efficiency	68.3%
life time in years	20
D	10%
Inf	2.5%
Combined interest rate r	12.8%

6.3 Technical Performance for FP and ET Systems

After collecting all data to calculate the solar fraction value, equations (2.13 – 2.17) are used to calculate it. The results are shown if figure 6.1

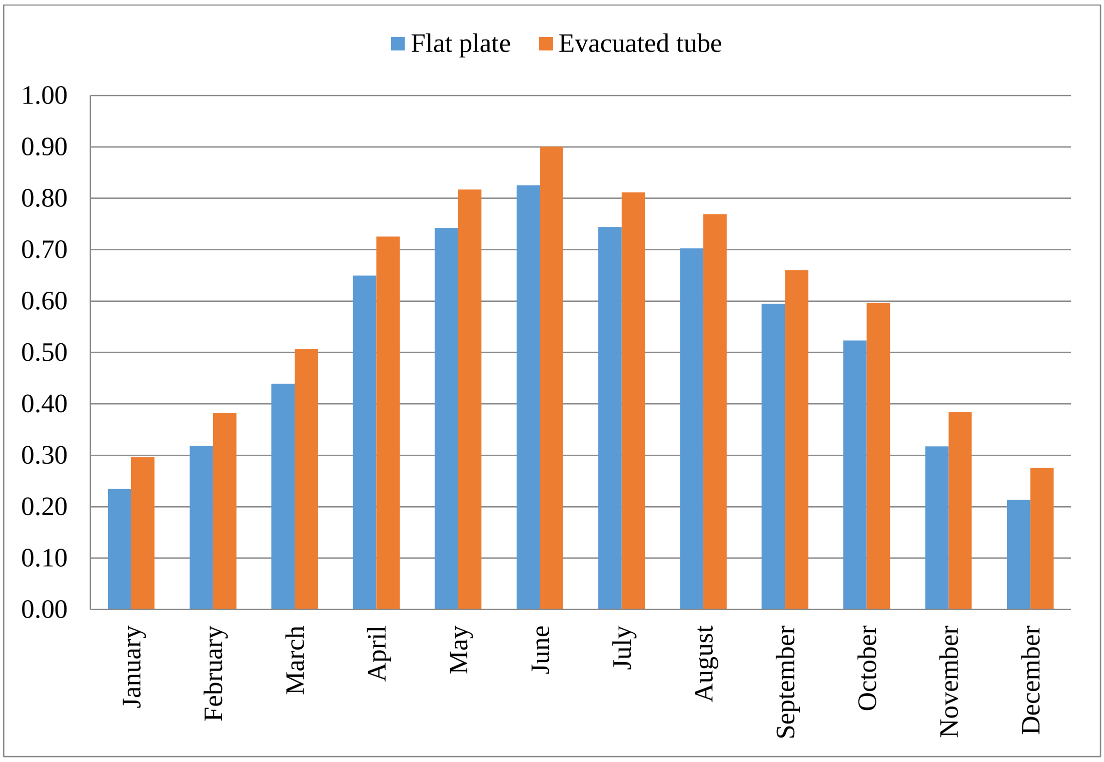

Figure (6.1): Monthly solar fraction f for FP and ET SWH systems.

From the figure 6.1, the lowest and highest values of f for ET system are 28% and 90% respectively. The lowest and highest value of f for FP system are 21% and 82% respectively. From the results, ET system gives higher f than FP system, which it means ET will cover higher proportion of the hot water demand.

The annual solar fraction F for ET system equals to 58.15% and for FP system equals to 51.34%.So, from the technical analysis the ET system is much better from FP system.

6.4 Economic Performance for FP system and ET system

For economic analysis, initial investment and annual saving must be calculated. Figure 6.2 shows the cash flow for ET system and FP system.

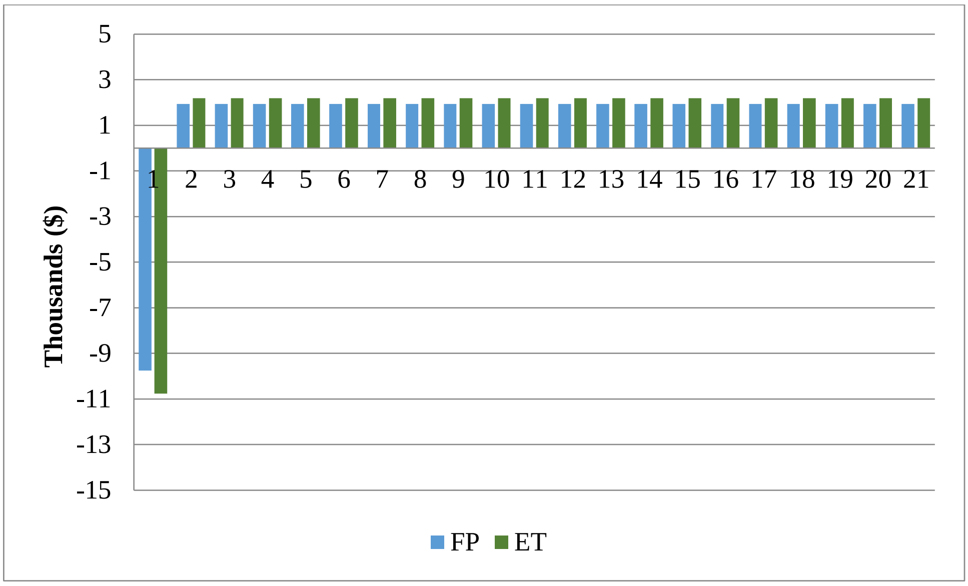

Figure (6.2): Estimated cash flow of the ET and FP systems.

From the figure 6.2, the initial investment for ET system is higher in comparison with FP system by 1,019 $, but it will save 257 $ yearly more.

Equations (2.18 – 2.23) are used to analyze the systems from economic performance. Results show that the SPP for ET system equals to 4.9 year, and for FP system equals to 5.03 year. The PW indicator for ET and FP systems are higher than zero, which means that both systems recover the initial investment and exceed the conditioned combined interest rate r (12.5%).

The IRR for ET system equals to 20%, and for FP system equals to 19%. The SIR indicator must be higher than 1 to indicate that the system is feasible. The value of SIR for ET system is 1.45, which means that for every dollar invested, a 1.45 dollars will be saved from the annual LPG equivalent savings. The SIR for FP system equals to 1.42. The results summarized in table 6.3.

Table 6.3: Economic analysis comparative.

indicator	**FP**	**ET**
annual F	0.5134	0.5815
baseline L LPG/Y	2360	
baseline $/Y	$3,775	
saving L LPG/Y	1211	1372
saving $/Y	$1,938	$2,195
investment $	$9,746	$10,765
SPP	5.03	4.90
PW	$3,615	$4,339
AW	$507	$608
IRR	19%	20%
SIR	1.42	1.45

The table 6.3 shows that the both systems are feasible for technical and economic analysis, but ET system gives higher F value, and better economic performance.

According to the above calculations, installing a solar heating system is a good investment, as it saves 2195 $ annually with a payback period of 4.9 years.

Chapter Seven
Conclusions and Recommendations

7.1 Conclusions

In Palestine, boilers are spread in most factories, hospitals, commercial centers, ministries and others. The main purpose is to heat water or turn it into steam and use it in different applications. The majority of these boilers are powered by gas or diesel, so that they consume large amounts of fuel.

The fluctuation of the boiler efficiency from day to day during the study period is due to several reasons, most notably: the instability of the heat load (the amount of animal feed production), the difference in the operating time of the boiler, the difference in the temperature of the boiler's surroundings (boiler room) and the difference in the temperature of the water entering the boiler from day to day (water tank temperature).

Furthermore, it is necessary to know the efficiency of these boilers and know the characteristics of water entering the boiler and out of it. After installing the device and its accessories, the gross and net efficiency of the boiler was 68.3% and 66.56% respectively. Also, it is vital to monitor the pressure and temperature of water entering and leaving the boiler every 30 seconds 24 hours a day through the device itself or via the Internet using a device a computer or mobile phone, and store this data in memory within the device to be accessible at any time for different analysis.

The quantities of water, gas and electricity consumed by the boiler were also monitored and recorded. These values were stored for monitoring, analysis and future use in various studies.

A technical and economic studies of the solar water heating project have been prepared to raise the temperature of the water entering the boiler to a temperature of at least 55 degrees Celsius. Different economic methods are used to see if the project is economically feasible, different methods have shown that the project is economically feasible.

7.2 Recommendations

After concluding the previous results, the researcher recommends the following:

1. After taking the measurements, analyzing them and calculating the efficiency, it was found that they are different from day to day, and the current study can be completed in order to improve the efficiency of the boiler to its best value after analyzing and treating the causes.

2. Transferring the boiler to a place close to the final use of steam, where the boiler is currently 20 meters away from the final place for the use of steam. Also, the owner of the plant uses steam at 90 ℃. Whereas steam comes out at a temperature of 130℃ from the boiler.

3. If the manufacturer puts the boiler closer to the final place to use steam, it should calibrate the burner, the air-to-fuel ratio and the controls inside the boiler to suit the new situation.

4. Pipes should be well insulated better than the current situation. In the current situation there is a large leak of steam through the pipes, especially in the bends in the pipes, and this is an economic loss for the manufacturer.

5. The manufacturer is currently recovering thermal water, but more heat can be gained through the use of better equipment and tools, and it is possible to heat the air entering the burner in order to increase the efficiency of combustion, as the manufacturer is heating the gas before entering the burner.

6. One of the best steps to maintain the boiler in the best condition is to perform periodic maintenance of it, as the owner of the factory did not do the maintenance of the boiler only once within 20 years.

7. The manufacturer provides the boiler directly with water without any treatment processes. This method of supplying the boiler directly with water without filtration or removal of salts increases the calcification inside the pipes in the boiler.

8. In order to calculate the efficiency of the boiler, many transmitters and meters were assembled with the recorder so that each piece separately functions. Then connected together to form the desired device, which in turn led to the price of the required device to a high price, so a device can be designed commercially only to calculate Efficiency, monitoring the pressure and temperature of water entering and leaving the boiler

and knowing the quantities of gas, water and electricity consumed from the boiler at a much lower price.

9. During the installation of the device, several parameters and variables associated with the boiler are not shown through the eye, or through the combustion analyzer device.

10. This study should be pursued more broadly in the future, by starting to control the boiler and its various characteristics in order to achieve the greatest efficiency.

11. It is feasible to install a solar heating system in order to raise the temperature of the water entering the boiler, thus reducing gas consumption, which leads to reducing carbon dioxide emissions.

12. The combustion analyzer must be used to calculate the combustion efficiency of the boiler, in order to determine the ratio of fuel to air in order to calibrate the boiler to the best efficiency, and a heat exchanger can be used in the exhaust stack to achieve an increase in boiler efficiency.

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Appendix

Appendix 1

Data sheet for temperature sensor

Product datasheet
Characteristics

STX120-400
STX120 - under floor sensor temperature - 4 m

Main

Range of product	STX120
Product or component type	Under floor sensor temperature
Number of cables	1 <4 m

Complementary

Former part number	5123304000
Material	PVC (polyvinyl chloride): cable Stainless steel: sensor
Temperature probe type	NTC 1800 Ohm at 25 °C
Measurement accuracy	+/- 0.3 °C 25 °C +/- 0.5 °C 0 °C +/- 0.6 °C 50 °C +/- 0.7 °C -25 °C +/- 0.9 °C 75 °C +/- 1.3 °C 100 °C
Net weight	0.15 kg
Time constant	6 s

Environment

IP degree of protection	IP65
Ambient air temperature for operation	-40…120 °C
Relative humidity	0…90 %

Offer Sustainability

REACh Regulation	REACh Declaration
EU RoHS Directive	Pro-active compliance (Product out of EU RoHS legal scope) EU RoHS Declaration
China RoHS Regulation	Download RoHS China Declaration
Environmental Disclosure	Product Environmental Profile

Contractual warranty

Warranty	18 months

Appendix 2

Data sheet for pressure sensor

Product data sheet
Characteristics

XMLG010D21
pressure sensor XMLG - 0..10 bar - G 1/4A (male) - 24 V - 4..20 mA

Main

Range of product	OsiSense XM
Product or component type	Electronic pressure sensors
Pressure sensor type	Pressure transmitter
Pressure sensor name	XMLG
Pressure sensor size	10 bar
Fluid connection type	G 1/4A (male) conforming to DIN 3852-E
Controlled fluid	Fresh water (0...125 °C) Air (-15...125 °C) Corrosive fluid (-15...125 °C) Hydraulic oil (-15...125 °C)
Type of output signal	Analogue
Analogue output function	4...20 mA, 2 wires
Electrical connection	3 pins 1 male connector M12
[Us] rated supply voltage	12 V DC, voltage limits: 8...33 V 24 V DC, voltage limits: 8...33 V
Quantity per set	Set of 1
Type of packing	Individual
Diameter	22.8 mm

Complementary

Pressure setting range	0...10 bar
Maximum permissible accidental pressure	22 bar
Destruction pressure	25 bar
Local display	Without
Electrical circuit type	Control circuit
Current consumption	< 20 mA
Materials in contact with fluid	Ceramic Stainless steel type AISI 303 FPM (Viton)
Operating position	Any position
Protection type	Load short-circuit Reverse polarity
Surge withstand	1 kV (42 Ohm) conforming to EN/IEC 61000-4-5

	500 kV (12 Ohm) conforming to EN/IEC 61000-4-5
[Uimp] rated impulse withstand voltage	0.5 kV
Response time on output	< 2 ms
Drift of the sensitivity	+/- 0.015 % of measuring range/°C
Drift of the zero point	+/- 0.015 % of measuring range/°C
Measurement accuracy	+/- 0.3 % of the measuring range
Repeat accuracy	+/- 0.1 % of the measuring range
Mechanical durability	>= 10000000 cycles
Product weight	0.095 kg
Height	58.1 mm
Length	48.5 mm
Scale type	Fixed differential

Environment

Standards	CE EN/IEC 61326-2-3
Product certifications	CSA C22.2 No 14 EAC UL 508
Protective treatment	TC
Ambient air temperature for operation	-15...85 °C
Ambient air temperature for storage	-40...85 °C
Vibration resistance	20 gn (f = 9...2000 Hz) conforming to EN/IEC 60028-2-6
Shock resistance	25 gn for 11 ms conforming to EN/IEC 60068-2-27
Resistance to electrostatic discharge	15 kV (in air) conforming to EN/IEC 61000-4-2 8 kV (on contact) conforming to EN/IEC 61000-4-2
Resistance to electromagnetic fields	200 V/m (80...1000 Hz) conforming to EN/IEC 61000-4-3
Resistance to fast transients	4 kV conforming to EN/IEC 61000-4-4
Resistance to conducted disturbances	30 V (0.15...80 Hz) conforming to EN/IEC 61000-4-6
Resistance to magnetic fields	30 A/m conforming to EN/IEC 61000-4-8
IP degree of protection	IP66 conforming to EN/IEC 60529 IP67 conforming to EN/IEC 60529
NEMA degree of protection	NEMA 4

Offer Sustainability

RoHS (date code: YYWW)	Compliant - since 0627 - Schneider Electric declaration of conformity Schneider Electric declaration of conformity
REACh	Reference not containing SVHC above the threshold Reference not containing SVHC above the threshold

Contractual warranty

Warranty period	18 months

Appendix 3
Data sheet for power supply

Product data sheet
Characteristics

ABL8MEM24006
regulated SMPS - 1 or 2-phase - 100..240 V AC - 24 V - 0.6 A

Main

Range of product	Phaseo
Product or component type	Power supply
Power supply type	Regulated switch mode
Input voltage	100...240 V AC phase to phase, terminal(s): L1-L2 100...240 V AC single phase, terminal(s): N-L1 120...250 V DC
Output voltage	24 V DC
Rated power in W	15 W
Input protection type	Integrated fuse (not interchangeable)
Power supply output current	0.6 A
Output protection type	Against short-circuits Thermal
Ambient air temperature for operation	-25...55 °C without 55...70 °C with

Complementary

Input voltage limits	85...264 V
Network frequency	47...63 Hz
Inrush current	20 A
Cos phi	0.5
Efficiency	80 %
Output voltage limits	22.2...28.8 V adjustable
Power dissipation in W	3.8 W
Current consumption	0.25 A at 240 V 0.4 A at 100 V
Line and load regulation	+/- 3 %
Residual ripple	250 mV
Holding time	>= 10 ms at 100 V >= 150 ms at 230 V
Connections - terminals	Screw type terminals for input connection, connection capacity: 2 x 0.14...2 x 2.5 mm² AWG 26...AWG 14 Screw type terminals for output connection, connection capacity: 2 x 0.14...2 x 2.5 mm² AWG 26...AWG 14
Marking	CE

Mounting support	35 x 15 mm symmetrical DIN rail 35 x 7.5 mm symmetrical DIN rail Panel 2 screws, diameter : 4 mm
Operating position	Vertical
Operating altitude	2000 m
Output coupling	Series Parallel
Name of test	Harmonic current emission conforming to EN/IEC 61000-3-2 Conducted emissions on the power line conforming to EN 55022 Class B Electrostatic discharges conforming to EN/IEC 61000-4-2 Emission conforming to EN 50081-1 Induced electromagnetic field conforming to EN/IEC 61000-4-6 Primary outage conforming to IEC 61000-4-11 Radiated electromagnetic field conforming to EN/IEC 61000-4-3 Radiated emissions conforming to EN 55022 Class B Rapid transient conforming to IEC 61000-4-4 Surge conforming to EN/IEC 61000-4-5
Status LED	1 LED green for output voltage
Depth	59 mm
Height	100 mm
Width	36 mm
Product weight	0.1 kg

Environment

Product certifications	TUV 60950-1 EAC KC CCSAus RCM CSA 22-2 No 950 CULus 508
Standards	CSA C22.2 No 60950-1 UL 508
Environmental characteristic	EMC conforming to EN 55022 Class B EMC conforming to EN 61000-6-3 EMC conforming to EN/IEC 61000-6-2 EMC conforming to EN/IEC 61204-3 Safety conforming to EN/IEC 60950-1 Safety conforming to SELV
IP degree of protection	IP20 conforming to EN/IEC 60529
Ambient air temperature for storage	-40...70 °C
Relative humidity	0...90 % during operation 0...95 % in storage
Overvoltage category	Class II conforming to VDE 0106-1
Dielectric strength	Between input and output
MTBF reliability	561085 H with MIL-HDBK-217F calculation method

Contractual warranty

Warranty period	18 months

Appendix 4
Manual for 3-phase electric meter

SGE-353-M100

STATIC THREE PHASE MODULAR WATT-HOUR METER INSTRUCTION

Ⅰ. Summary

Three-phase four-wire electronic watt-hour meter is adopted special large scale integrated circuit and international advanced technology, designed particularly, made with fine crafts. Its general goal is the high reliability, it is carried out in every step of designing, producing, testing, aging and exam. Compared with traditional watt-hour meter, it is higher accuracy, higher reliability, light and compact. It's easy to realize the expanding the modern managing function, It has the indication of short phase, and puts out the impulse.

Ⅱ. Principle

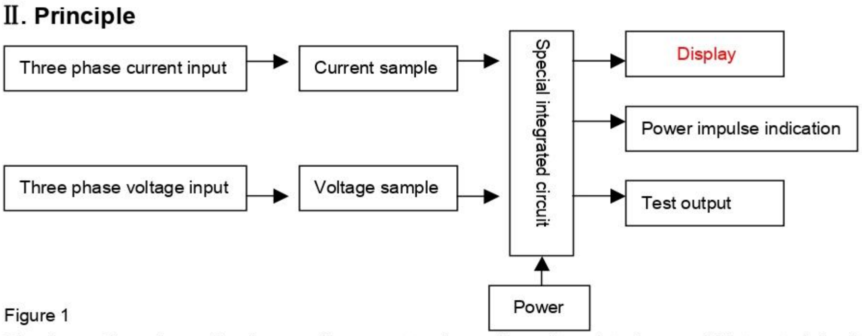


Figure 1

Showing as figure 1, sending the sampling current and sampling voltage into the special integrated circuit, through the inner cushion amplifier, next to multiplying unit, multiply the voltage and current signals. Then through A/D conversion, convert the logic signal to the digital signal, next to frequency circuit and drive circuit, then put out the drive impulse and show the watt-hour indication.

Ⅲ. Technology specification

1.Specification

Class index	Voltage (V)	Current (A)
1.0	3x220/380	10(100)A

2.Start

The instrument can be started and recorded continuously at the reference current (see the table)

Meter	Meter grade			Power factor
	1	2	3	
Directly pass	0.004Ib	0.05Ib	0.01Ib	1.0
Via mutual inductance	0.002Ib	0.003Ib	0.005Ib	1.0

3. Creep

Its output is not more than one impulse when the voltage is 115% voltage rating, the circuit doesn't has any current.

4. Electric parameter

Reference Voltage	: 0.9—1.1 voltage rating
Ultra Voltage	: 0.8—1.15 voltage rating
Display Mode	: LCD 6+1 = 999999.9kWh
	: Counter 6+1 = 999999.9kWh
Impulse Constant	: 800imp/kWh
Power	: ≤2W, 10VA

5. Climate condition

5.1 Temperature

Normal temperature	: -10~45℃
Ultra temperature	: -20~55℃
Temperature for storage and transportation	: -25~70℃

5.2 Humidity

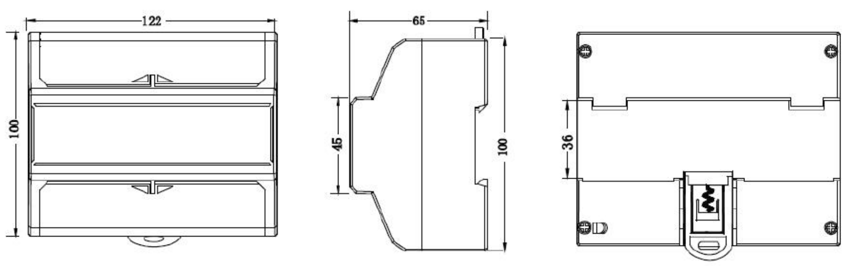
Annual average humidity : ≤75%

30 days in a year (as natural diffusion) may reach 95%,and other time may reach 85%, sometimes.

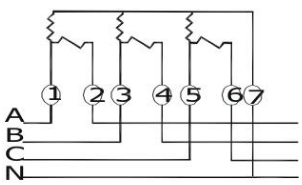
6. Outer size : 122mmx100mmx65mm

Ⅳ. Installation and connection of the meter

1. The installation size (figure 2)



2. The figure of connection



Direction mode

Ⅴ. Transportation and storage

It must be packed when transporting, it cannot be vibrated and struck tempestuously. Its pack should be accordance with IEC1036<The universal technical condition for instruments and meters pack>. When storage it should not pile up more than 5 layers, and the storehouse must be clean ,the temperature should be between -20℃--+70℃, the humidity is not over 85%, any cautery gas and mildew cannot be in the air.

Ⅵ. Assurance term

The manufactory will repair or exchange the products while the lead seal is still exited, within 18 months, when discovering the products not accordance with the technical specification.

SAFETY

This instrument has been constructed and tested in accordance with IEC 61036 / EN61036 class 1 standards and left the production factory in perfect condition of technical safety. In order to maintain these conditions and to ensure safe operation, the user must comply with the instructions. During opening of covers or the removal of parts, expect carried out by hand, live components may be stripped. The connection points may also be live. Before carrying out any compensation, servicing, repair or replacement of parts requiring the instrument to be opened, it must be disconnected from all power sources. The capacitors inside the instrument may be charged even after it has been disconnected from all power sources.

If the safe use of the instrument is no longer possible, it must be taken out of service and precautions taken against accidental use.

Safe operation is not possible in the following cases:

when the instrument shows clearly visible damage.

when the instrument no longer works.

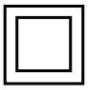
after lengthy storage in unfavorable conditions.

after serious damage incurred during transport.

Operator safety

Read this pages carefully before installing and using the instrument.

The instrument described in this manual is intended for use by suitably trained staff only. Maintenance and / or repair operations must be carried out – exclusively – by qualified, authorized staff. For proper, safe use of the instrument and / or repair it is essential that the person instructed to carry out the procedures follow normal safely precautions.

Symbols  Read the instructions  Double insulation  4 wires network/3 drives system

Precautions in case of break-downs

In case of suspect that the instrument is no longer safe, for example because of damage incurred during transport or use, it must be taken out of service and precautions taken to prevent accidental use. Contact authorized technicians for control and any repairs.

Installation instructions

Preliminary inspections:

When the instrument is received, check that it is complete and has not been damaged during transport. For any problem contact the after-sales services for repairs or replacements.

Safety instructions

Measurement and power supply voltage:

The instrument is able to take a three-phase voltage of:

3×127V phase-neutral; 220V phase-phase (-20%)1VA;

to 3×230V phase-neutral; 400V phase-phase (+15%)1VA;

Frequency ranges from 50 to 60Hz.

While the meter is connected, the furnished covers must be in place.

Appendix 5
Data sheet for smart Recorder

Product datasheet
Characteristics

SXWASB24H10001
SmartX Controller - AS-B-24H, 24, I/O, manual override, BACnet MS/TP, Modbus

Main

Range	EcoStruxure Building Operation
Device short name	AS-B-24-H
Product brand	Schneider Electric
Product or component type	Controller system
[Us] rated supply voltage	19...29 V AC 21...33 V DC
Discrete input number	4
Discrete output number	4 relay

Complementary

Network frequency	50 Hz 60 Hz
Maximum power consumption in W	10 W
Maximum power consumption in VA	15 VA
Input type	Digital
Product compatibility	Satchwell I/NET Balco Continuum Johnson Control Honeywell Xenta
Analogue input type	Configurable voltage, current or probe 0...20 mA Configurable voltage, current or probe 0...10 V input voltage Configurable voltage, current or probe 20 kOhm connection of probes Configurable voltage, current or probe 10 kOhm connection of probes Configurable voltage, current or probe 2.2 kOhm connection of probes Configurable voltage, current or probe 1.8 kOhm connection of probes Configurable voltage, current or probe 1 kOhm connection of probes Configurable voltage, current or probe 10 kOhm with shunt
Analogue input number	12 configurable voltage or probe 4 configurable voltage, current or probe

Temperature probe type	LG-Ni 1000 - 50...150 °C Ni 1000 - 50...150 °C Pt 1000 - 50...150 °C
Switching frequency	25 Hz
Processor name	Spear 320s
Memory description	Internal RAM 256 MB Flash 4 GB
Realtime clock	With
Clock drift	+/- 52 s/month
Integrated connection type	USB 2.0 type A USB type mini B Ethernet with RJ45 connector Serial link with RS485 connector
Supply	Power supply: 24 V, <0.5 A
Communication port protocol	BACnet Modbus TCP master - RS485 - 2-wire Modbus TCP slave - RS485 - 2-wire HTTPS 10/100BASE-T - RJ45 HTTP 10/100BASE-T - RJ45
Port Ethernet	10/100BASE-TX 2 port
Web services	Programmable scripts : alarm summaries, report management HTTP server TLS 1.0
Communication service	SNMP network management SMTP e-mail notification SMTPS e-mail notification Modbus TCP server Modbus TCP client
Display type	FSTN transflective LCD
Display colour	Monochrome
Display resolution	128 x 64 pixels
Display size	36 x 17 mm
Electrical connection	plug-in sub-base terminal with a manual overide switch
Material	ABS/PC
Mounting support	DIN rail
Height	114 mm
Depth	64 mm
Width	198 mm
Net weight	5.04 kg

Environment

Standards	UL 916 FCC CFR 47 part 15
Product certifications	ICES-003 BTL FCC part 15 class B CULus CE WEEE RCM
Ambient air temperature for operation	0…50 °C
Ambient air temperature for storage	-20…70 °C
Relative humidity	0…95 %, non-condensing
IP degree of protection	IP20
Flame retardance	UL94V0-5VB

Offer Sustainability

Sustainable offer status	Green Premium product

REACh Regulation	REACh Declaration
EU RoHS Directive	Compliant EU RoHS Declaration
Mercury free	Yes
RoHS exemption information	Yes
China RoHS Regulation	Download RoHS China Declaration
Environmental Disclosure	Product Environmental Profile
Circularity Profile	End of Life Information
WEEE	The product must be disposed on European Union markets following specific waste collection and never end up in rubbish bins

Appendix 6

10%			Compound Interest Factors						10%
	Single Payment		Uniform Payment Series				Arithmetic Gradient		
	Compound Amount Factor Find F Given P	Present Worth Factor Find P Given F	Sinking Fund Factor Find A Given F	Capital Recovery Factor Find A Given P	Compound Amount Factor Find F Given A	Present Worth Factor Find P Given A	Gradient Uniform Series Find A Given G	Gradient Present Worth Find P Given G	
n	F/P	P/F	A/F	A/P	F/A	P/A	A/G	P/G	n
1	1.100	.9091	1.0000	1.1000	1.000	0.909	0	0	1
2	1.210	.8264	.4762	.5762	2.100	1.736	0.476	0.826	2
3	1.331	.7513	.3021	.4021	3.310	2.487	0.937	2.329	3
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378	4
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862	5
6	1.772	.5645	.1296	.2296	7.716	4.355	2.224	9.684	6
7	1.949	.5132	.1054	.2054	9.487	4.868	2.622	12.763	7
8	2.144	.4665	.0874	.1874	11.436	5.335	3.004	16.029	8
9	2.358	.4241	.0736	.1736	13.579	5.759	3.372	19.421	9
10	2.594	.3855	.0627	.1627	15.937	6.145	3.725	22.891	10
11	2.853	.3505	.0540	.1540	18.531	6.495	4.064	26.396	11
12	3.138	.3186	.0468	.1468	21.384	6.814	4.388	29.901	12
13	3.452	.2897	.0408	.1408	24.523	7.103	4.699	33.377	13
14	3.797	.2633	.0357	.1357	27.975	7.367	4.996	36.801	14
15	4.177	.2394	.0315	.1315	31.772	7.606	5.279	40.152	15
16	4.595	.2176	.0278	.1278	35.950	7.824	5.549	43.416	16
17	5.054	.1978	.0247	.1247	40.545	8.022	5.807	46.582	17
18	5.560	.1799	.0219	.1219	45.599	8.201	6.053	49.640	18
19	6.116	.1635	.0195	.1195	51.159	8.365	6.286	52.583	19
20	6.728	.1486	.0175	.1175	57.275	8.514	6.508	55.407	20
21	7.400	.1351	.0156	.1156	64.003	8.649	6.719	58.110	21
22	8.140	.1228	.0140	.1140	71.403	8.772	6.919	60.689	22
23	8.954	.1117	.0126	.1126	79.543	8.883	7.108	63.146	23
24	9.850	.1015	.0113	.1113	88.497	8.985	7.288	65.481	24
25	10.835	.0923	.0102	.1102	98.347	9.077	7.458	67.696	25
26	11.918	.0839	.00916	.1092	109.182	9.161	7.619	69.794	26
27	13.110	.0763	.00826	.1083	121.100	9.237	7.770	71.777	27
28	14.421	.0693	.00745	.1075	134.210	9.307	7.914	73.650	28
29	15.863	.0630	.00673	.1067	148.631	9.370	8.049	75.415	29
30	17.449	.0573	.00608	.1061	164.494	9.427	8.176	77.077	30

جامعة النجاح الوطنية

كلية الدراسات العليا

تصميم جهاز لمراقبة وتحليل كفاءة المراجل الصناعية

إعداد

عبدالله أحمد خليل طحنات

إشراف

د. محمد السيد

قدمت هذه الرسالة استكمالاً لمتطلبات الحصول على درجة الماجستير في برنامج هندسة الطاقة النظيفة وترشيد الاستهلاك، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2021

تصميم جهاز لمراقبة وتحليل كفاءة المراجل الصناعية

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عبدالله أحمد خليل طحنات

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الملخص

هذه الدراسة قامت على أساس قياس كفاءة المراجل الصناعية لفترات يحددها المستخدم، بالإضافة للمراقبة المستمرة وعلى مدار الساعة لضغط ودرجة حرارة الماء والبخار في المرجل، ومعرفة كميات الغاز، والماء والطاقة الكهربائية المستهلكة في عمل المرجل، ولتحقيق هذه الأهداف تم أخذ مرجل صناعي يستخدم في مصنع المنار لصناعة الأعلاف في بلدة عرابة – جنين كحالة دراسية.

لم يتواجد الجهاز وملحقاته كجهاز واحد في السوق الداخلي أو الخارجي بصورة مباشرة، بحيث يتم تركيبه على المرجل فحسب، لذلك تم تجميع الجهاز من خلال عدة مرْسلات وعدادات للطاقة الكهربائية، الماء والغاز، وربطها مع متحكم ذكي لتحقيق الهدف المرجو من الدراسة.

الدراسة بينت الكفاءة الكلية والصافية للمرجل، ومراقبة جميع مدخلات المرجل بشكل لحظي، وتخزينها كل 30 ثانية على مدار فترة تركيب الجهاز، أظهرت المعلومات بعد تحليل البيانات التي جمعت من خلال الجهاز الأرقام الحقيقية للمرجل، حيث كانت الكفاءة الكلية 68.3% بينما الكفاءة الصافية 66.56%. هذه المعلومات والبيانات التي تم تحليلها تفيد بكيفية تحسين كفاءة المرجل، ومعرفة السلبيات في المرجل نفسه، أو خط الانابيب المتصل به لمعالجتها والحصول على أفضل أداء للمرجل مستقبلاً.

بعد الحصول على النتائج وتحليلها، تبين وجود إمكانية لإنشاء نظام تسخين شمسي خصوصاً بوجود المساحة الكافية، لذلك تم في نهاية الدراسة إجراء تقييم فني واقتصادي لمشروع نظام تسخين يقوم باستغلال الطاقة الشمسية لتسخين المياه ورفع درجة حرارتها، وبالتالي التوفير في الغاز المحروق لتسخين المياه إلى درجة الحرارة التي يتم تسخينها عن طريق الشمس، فمن خلال الدراسة

الفنية فإن تكلفة رأس المال لإنشاء النظام هي10765 دولار، ويقوم بتوفير مبلغ 2195 دولار سنوياً في سعر الغاز، وبفترة استرداد 4.9 سنة علماً بأن العمر الافتراضي للمشروع هو 20 سنة. أما في الجانب البيئي فإن التوفير في حرق الغاز يقلل من انبعاث الغازات الملوثة للبيئة وأبرزها ثاني أكسيد الكربون، حيث أن أنظمة تسخين المياه الشمسية هي أنظمة صديقة للبيئة.