ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
Department of Electrical and Computer Engineering

Energy Distribution and Utilization Assessment in Industries (Case Study at Mughar cement factory)

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Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been acknowledged.

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This thesis has been submitted for examination with my approval as a university advisor.

Dr. Getachew Bekele ___________________________

Advisor's Name Signature

Acronyms

MCF	Mughar cement factory
CFL	Compact florescent lamp
EU	Energy used
ER	Energy required
ALR	Actual lamp required
ED	Energy difference
AS	Actual saving
IL	Lamp illumination
OH	Operating hour
KWh	Kilo watt hour
KJ	Kilo joule
Kg	Kilogram
KW	Kilo watt
IMSSA	International Motor Selection and Analysis
PF	Power factor
PDS	Power demand saving
ES	Energy saving
BS	Birr saving

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Abstract

Energy conservation and efficient usage are vital to the country's development. Demand for energy is ever increasing worldwide due to the depletion of fossil fuel sources and other related issues. Focusing on energy utilization assessment and consumption reduction efforts through improvement, better production management and also introduction of new technologies significant results can be achieved; saving money on energy bills, improving energy efficiency and maintaining sustainable environment.

The cost of energy as part of the total production cost is significant in the mughar cement industry in Ethiopia. They spend millions of dollars annually on electric power and fuel oil for their energy requirement. Hence, considerable work of efficiency improvement on energy utilization efficiency at the selected cement factory is important.

The aim of this thesis is to assess the energy sources and utilization in the selected factory. And also, it is to study and identify energy utilization efficiencies of the different utilities of the factory. Finally, to suggest alternatives based on measurements collected data and benchmarked cement factories experiences.

In this thesis work energy losses at the selected factory have been assessed. Based on the losses, energy efficiency performance assessments on the major energy intensive equipments like electric motors and drives, lightings and the kiln have been done. At last energy efficiency improvement opportunities both for electrical energy as well as fuel energy are recommended.

***Key words**: Energy efficiency, energy intensity Mughar cement factory, electric motors, industrial energy.*

CHAPTER ONE

1. Introduction

1.1 Background

Energy is an integral part of a modern economy. It is an essential ingredient in nearly all goods and services, but its use exacts heavy financial, environmental, and security costs. The key method of reducing energy costs while retaining its benefits is to use it more efficiently [1]. The industrial sector accounts around 40% of the commercial energy. It uses both the electrical and thermal energy in various equipments like motors, pumps, boilers, compressors, furnaces, diesel generating engines, refrigerators, etc. But there are many problems in the industry sectors to efficiently use their energy. They are not well informed on the concept of energy conservation. Due to this they lose lots of money on energy bills, causes problems on the environment, industries will not be competitive, etc. [3]

Many manufacturing companies are currently seeking new ways to reduce costs and optimize the operation of their facilities. In this regard energy management has been given low priority.

Energy efficiency does not mean rationing or having to do without energy rather, energy efficiency means identifying wasteful energy use and taking actions to reduce or illuminate that waste. Production levels should not be affected, only the amount of energy and the expense incurred in generating that production. The objective is to reduce energy costs and consequently increase profitability. [4]

In some industries energy costs may make a relatively small contribution to over all operating costs; but there could be a significant part of controllable costs. Reducing energy costs, without any reduction in productivity, results in a direct increase in profit. If the annual energy bill is proportional to the annual profit, then reducing energy costs by an achievable 10%, would contribute a 10% increase in profit. Increasing profit by 10% could also be achieved by increasing sales, but this has its own costs, financial and otherwise. Presumably these costs are prohibitive, or the effort would already have been made. Some reduction in energy costs, by contrast, could cost little or nothing[11].

Improving energy efficiency at the plant could be approached from several directions. Firstly, plants use energy for equipment such as motors, lightings, pumps compressors, boilers, etc. These important utilities require regular maintenances, good operation and replacement when necessary. Thus, a critical element of the plants energy management involves the efficient control of crosscutting equipments or utilities that powers the production process of the plant. A second important area is the proper and sufficient operation of the process. Process optimization and ensuring the most efficient technology is in place a key energy savings in plant's operations. [3- 6]

Energy efficiency is important both for companies and for the nation. For companies, increased efficiency generally means improved profitability. Assuming that companies are profit maximizing there can be no more compelling motive. Additionally, as firms expand beyond their border to compete in world markets, factors such as production costs, product quality and price become increasingly important. Under these conditions of increased competition, efficiency improvements are an important key to long – term competitiveness.

For nations, energy efficiency offers a number of benefits; including improved use of national resources, reduced energy imports, improved balance of trade, conservation of foreign exchange, reduced capital requirements for new energy production facilities, and reduced environmental pollution from energy use and production. Improper energy investment may even slow the rate of national economic growth. [14]

There could be secondary benefits as well. Energy–aware companies tolerate less idle running of equipment, and hence enjoy less tear and wear, less frequent breakdowns, less noise, and often improved thermal comfort for the workforce.

There are different energy consumers such as cement industries, sugar industries, textile industries, etc. Cement industries are one of the most energy intensive plants that use mostly electrical and fuel energies. The energy distribution and utilization assessment that has done on several industries mostly occur on the thermal energy efficiencies but the electrical energy has also major impact on the industries. [2]

Industrial power systems are often characterized as large consumers of reactive powers and also significant generators of harmonics because most of the loads are generally composed of induction motors and static power converters. Reactive power compensation and harmonic control have a vital role to improve the electrical energy efficiencies in industries. It is also possible to improve the efficiency of energy utilization at industries by improving the performance of thermal energy efficiency. [12]

1.2 Objectives

1.2.1 General objective

The general objectives of this study include the assessment of the energy utilization efficiency of cement industries with special attention on Mughar cement factory (MCF) and comment on current energy utilization and also suggest better ways of conserving energy.

1.2.2 Specific objective

The specific objectives are to:

- Survey the working condition of the selected industry and to take relevant data for the thesis
- To assess the energy losses at MCF.
- To analyze the major causes of energy losses at MCF.
- To recommend possible energy saving solutions such as:
    1) Opportunities to improve motors performance
    2) Opportunities to improve lighting systems
    3) Opportunities to improve fuel oil consumptions reduction

1.3 Problem Description

Industries use both the electrical and thermal energy in various equipments like motors, pumps, boilers, compressors, furnaces, diesel generating engines, refrigerators, etc. But there are many problems in the industry sectors to efficiently use their energy. Due to this they lose lots of money on energy bills, cause problems on the environment, industries will not be competitive, etc. [3]

A lot of attention is being paid to generate enough electricity by government and individuals to serve its consumer but little is being done to check that the amount of energy presently being generated is efficiently used. Industries have been able to maintain better efficiency in their usage of electricity due to the improved monitoring of these places by specialized organizations like Ethiopian electric and power corporation (EEPCO). But this approach has yet to be used. Even organized environments such as industries, colleges and schools still find it difficult to make sure there is an efficient use of electrical energy in its domain. [1]- [2]

Some of the problems of inefficient use of energy are:

- The cost of energy like petroleum is increasing from time to time as a result high energy costs will occur at the factories.
- Causes environmental pollutions.
- The factories will not be competitive with the world market.
- The factories will produce poor qualities of products with incomparable costs.

This work addresses problems encountered by the cement factories with respect to energy starting from the resources and through energy users equipments like electric motors and drives, the kiln, boilers, pumps, air compressors, etc. and also suggest better solutions to improve the efficiencies of these energy usages.

1.4 Methodology

The methods employed to achieve the objectives of the research are:

1.4.1 Literature Review

A review of literature is conducted on the area of industrial energy use and efficiency in related to cement factory. Available books, journals, case studies, previous research works, policies & guidelines are surveyed in order to have a clear understanding of the subject matter

1.4.2 Data collection

The necessary data for the thesis are collected from different sources. The necessary data are:

- The energy consumptions of the factory for the last four years.
- The current energy requirement to produce a unit product (specific electrical and fuel consumptions).
- Specification, working conditions and maintenance procedures of the equipments in utility plants.
- The current production cost of the factory, energy bill, lighting data.
- Measurements like 3-phase voltage, 3-phase current, power factor, active power, reactive power, etc.

And also the performance of the major energy intensive equipments like motors, kiln, lightings, are assessed. Then the data are analyzed quantitatively and qualitatively. Depending on the assessed data opportunities to reduce even illuminate energy loses are done. From the analyzed data, conclusion and recommendation are forwarded.

CHAPTER TWO

2. Overview of the Cement Manufacturing Processes and Energy Efficiency Improvements

2.1 Overview of the cement manufacturing processes

The Cement sector is one of the major energy intensive industries while playing an important role in the economy of a country. Presently there are 4 operating cement plants with a total installed capacity of about 1,366,000 million tons of ordinary Portland cement per annum in Ethiopia. Table1.2 presents the installed capacities and locations of the cement plants of Ethiopia. The cement industry is energy-based which constitutes 45 % of the cost of production. The total average annual consumption of furnace oil by these factories based on their installed clinker capacity and average oil consumption is estimated to reach 120 million liter or around 30 million dollar in value. [21]

Table 2.1 Ethiopian cement plants [25]

Regional state	Name of the cement plant	Operating unit	Year established (E.C.)	Installed cement capacity (tone/year)
Dire Dawa City Council	Dire Dawa cement Plant	1	1936	36,000
Addis Ababa	Addis Ababa	1	1964	70,000
Oromia	Mugher Cement Enterprise	line 1 line 2	1977 1982	350,000 350,000
Tigray	Messobo Cement Factory	1	1992	600,000

2.1.1 Unit operations in the cement production

The cement industry is essentially a chemical process industry entailing various engineering unit operations. Cement is manufactured by intimately mixing together calcareous and argillaceous and/ or silica, alumina or iron oxide bearing materials, burning them at clinkering temperature and grinding the resultant clinker so as to produce cement. Thus grinding, mixing, burning and grinding are the main operations entailed in the manufacture of cement.

There are different types of equipment available for transportation of materials, crushing and grinding of materials, mixing of materials and there are three different processes of burning the cement raw mix, each having two or three modifications. The unit operations entailed and the equipment available are explained below.[20]

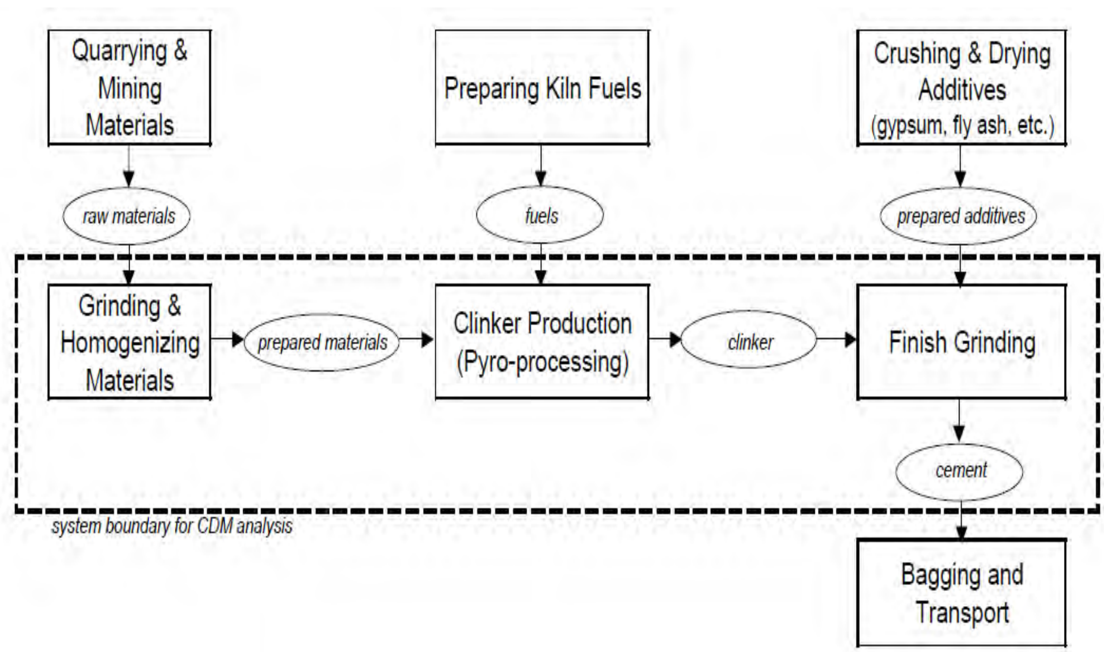


Fig. 2.1 Cement production process [8]

a) **Transportation of lime-stone from the quarries to the crusher:** mostly quarries diesel or electric loaders of capacity 1.5 meter cube, 2.5 meter cube or even 3.5 meter cube of capacities are used for loading blasted limestone to the transporting equipment which may be diesel dumpers rail cars ropeway or rubber belt conveyor according to the distance from the quarries to the crushing plant.

b) **Transport of clay and other corrective materials:** as the quantity of clay, shale or other corrective materials is very small, smaller dumpers or tracks are used. Generally, these deposits are very near to the factory.

c) **Pumping and storage of water required for the process:** a good source of water must be located and adequate pumping arrangements made. It may be advisable to have one high level storage tank and one ground level storage tank at the factory site.

d) **Crushing:** stones of large dimensions are sent to the crushers hence the crushing has to be done in two or three stages. Various types of crushers primary, secondary and tertiary are available. For primary crushing jaw crushers, impact crushers or gyrator crushers are available which can deal with pieces as large as one meter cube. For the secondary crushers jaw crushers, hammer crushers, cone crushers , hammer mills, etc. are available.

e) **Transport and storage of crushed materials:** limestone, clay or shale, gypsum are crushed to a maximum size of 25mm before being fed to succeeding grinding units. For the storage of crushed raw materials it is more economical and convenient to have a separate open or covered storage with an overhead feed belt and underground reclaiming belt for each raw materials.

f) **Grinding of the raw mix:** grinding of the raw mix is carried out in a high capacity compartment mills. Some times, hot air is used in close circuit dry raw mills to dry and grind the raw mix simultaneously. At some factories grinding is carried out in two stages, primary grinding in short ball mill and final grinding in a long tube mill. This increases the number of units, but is more economical in power consumption.

g) **Transportation of the ground raw mix:** if the ground raw mix is dry the following equipment is available. I) bucket elevator plus screw conveyor II) fuller-kiinion pump III) air lift transporter

h) **Storage and correction of the ground raw mix:** tall concrete silos are the most economical and convenient mode of storage of the ground raw mix waits or dry. During and after the grinding operation the composition of the raw mix has to be corrected to the exact content desired. For this job means has to be available for transporting the ground raw mix from one silo to another.

i) **Burning:** burning of the raw mix is the most important operation in the manufacturing of cement. There are three main processes for burning I) dry II) wet III) semi dry. For all processes equipment for feeding measured doses of raw mix, wet or dry to the burning equipment (kiln) has to be used. Various types of Ferries Wheel type wet slurry feeders are available for the wet process and various types of weigh feeders are available for the dry process. In the case of the semidry powder has to be nodulized either in a drum noduliser or a pan noduliser.

At the back of the kiln ,arrangements has to be made to suck the flue gases from the kiln system through a series of dust collectors and in some cases through electrostatic dust precipitator with the help of suction fan.

j) **Transport of clinker:** the **transport of** clinker poses some problems which are not encountered in the transportation of crushed limestone. Clinker is more abrasive than limestone and the temperature is generally 80 degree to 100 degree and sometimes more. The equipment used must be abrasion resistant and temperature resistant. The equipments available are a) shaking conveyors b) drag chains c) bucket conveyors d) screw conveyors e) belt conveyors.

k) **Grinding of cement:** of all the unit operations entailed in the manufacture of cement, grinding of clinker to cement is the most electrical power consuming. Hence proper design and operation of the grinding equipment would go a long way towards increased power efficiency. The most common equipment available is tube mills with two compartments, open circuit and closed circuit.

l) **Transport and storage of cement:** cement being in powder form the means of transport available is; a) a system of screw conveyors and bucket elevator b) a system of belt conveyors c) a system of pneumatic conveyors d) air slides. For the storage of cement, the modern trend is high capacity tall concrete silos. The present day demand for various types of cement would indicate installation of four or more storage silos instead of two large silos, one for filling and the other for emptying.

m) **Packing of cement**: the old practice was to pack cement in bags, wooden casks barrels or steel drums manually. Then slow speed automatic packing machines were developed. Now high speed high capacity automatic packing machines for packing cement in gunny bags or paper bags are available in various patented models**.**

n) **Transport of packed cement:** packed bags of cement are transported to a point as near the trucks or rail way wagons as possible with help of a system of belt conveyors and then loaded and sacked into them manually.

2.1.2 Energy requirement in cement production

Fuel oil and electricity are the main sources of energy in the cement production. For example, electricity is consumed to crash and grind the raw materials and in finish grinding mills, to operate fans and blowers in preheating or precalcining facilities and to cool the clinker. A small amount of electricity is also used to rotate the kiln itself. In addition to electricity however, the core function of turning the raw materials into clinker is accomplished through the consumption of large amounts of fuel.

Dry and wet kilns have different heating and cooling temperatures and thus different electric and fuel needs. In simple terms, wet kilns takes less electricity to run since all the drying functions occur within the kiln itself, but do require significantly more fuel to burn. The reverse is true for dry kilns.

Theoretically only 430Kcal/ Kg clinker of heat is required for burning one Kg of clinker, but in practice twice or more times this is necessary.

For each of the process steps within the boundary, we focus on the major energy use at that step; for example, in clinker production we just include the combustion of fuel to generate the heat required, not the electricity used to rotate the kiln. Thereby, I have left with three categories:

- Electricity use for raw material preparation,
- Fossil fuel use for clinker production, and
- Electricity use for cement grinding (or finish grinding).

2.2 Background about MCF

2.2.1 The mughar cement enterprise

Mughar cement enterprise (MCE) is a government owned enterprise established with a purpose of producing and supplying cement and carrying out such activities that are deemed important for the attainment objectives. The enterprise, established with an authorized capital of birr 334,716,000 of which birr 257,516,000 is paid in cash and in kind, is formed in 1999 through amalgamation of two formerly independent factories: Mughar cement factory and Addis Ababa cement factory. [20]

2.2.2 Mughar cement factory (MCF)

Mughar cement factory lies 105km west of the capital, Addis Ababa, on an elevation of about 2450 meters above the sea level and towering over its raw materials descending down the hill as low as 500 meters to the foot of the valley. The mugher cement factory: the mother plant of the enterprise is a factory with two production lines. The first line started operation in 1984 G.C and the second one commenced production in 1990. Each line has a production capacity of 1000 tons of clinker per day. The total production capacity of the factory is 600,000tons of clinker per year. The attained production capacity has now reached 777,766 tons of Portland pozzolana cement (PPC) per year. [20]

Fig. 2.2 Mughar cement plant [20]

2.2.3 The Addis Ababa cement plant (AACP)

The Addis Ababa cement plant formerly known as Addis Ababa cement factory was built in 1964.e.c. Initially it had a production capacity of 70,000 tons of cement per annum. However, following the obsolescence of the machineries and increase in the emission level, which brought about pollution in the surroundings, the plant has been forced to stop production of clinker in 1996. It, however, is reconditioned into a grinding plant and now transports about 100,000 tons of clinker per year from MCF and produces ordinary Portland cement as a major product. Portland pozzolana cement is also produced by the plant when the need arises. AACP has two cement mills each with 12.5 tones/hr capacity.

2.2.4 Paper sacks and shopping bag making plant

This plant was established in year 2000 with the objective of producing and supplying paper sacks which are to be used for packing cement, lime, fillers and other products. The plant also has a production line for producing paper made bags for the market. The production capacity of the plant is 60 million pieces of shopping bags per annum.

2.2.5 Products and kiln technology at MCF

The type of cement technology used by Mughar cement factory is a dry process five stage preheater kiln with rotary cooler. The cement production is continuously monitored. This activity is mainly carried out at the central control room. On line monitoring is conducted at each step so as to ensure smooth flow of production.

Products of the factory include:

- Ordinary Portland Cement(OPC)
- Portland Pozzolana Cement(PPC)
- Quick and hydrated lime
- Paper sacks and shopping bags

2.3 Introduction to industrial energy efficiency

Energy efficiency is a means of using energy more efficiently, either through change of behavior, improved management or the introduction of new technology. By increasing efficiency, energy demand can be reduced without reducing structural changes or adversely affecting economic growth. [15].

Replacing failed electric motors with energy efficient or premium efficient electric motors; Scheduled and proper greasing of electric motor bearings, reducing electric motor system friction losses, properly sizing electric motors to the load; testing questionable equipment before and after repair, improving the fuel consumption efficiency, improving lighting systems; and other measures that can be immediately implemented or implementation plan after energy losses assessment. These examples and other related activities can improve the factories over all energy efficiency.

There are many reasons why we should use energy efficiently some of these are:

- Most energy sources are depeletable, so increased energy conservation will extend the availability of energy sources.
- Investments in energy conservation will provide a better return than investments in energy supply. Increased energy conservation will therefore improve the general efficiency of the economy.
- Energy conservation will reduced the negative environmental consequences of energy production and use.
- Cost effective energy conservation techniques can save industries from 10 to 30 percent of industrial energy consumption.

Depending on the industry, energy expenditures can reach 70 percent of the total production costs. The higher the share of energy costs as a proportion of total costs, the more important that energy management become. [16]

The table below shows the share of energy costs in the total production costs of some of the industrial sectors.

Table.2.2 Energy costs relative to total production of different industrial sectors.[16]

Industrial sectors	Share of energy costs
Ice	70%
Cement	55%
Ammonia	50%
Aluminum	30%
Steel	30%
Glass	30%
Fertilizer	25%
Paper	25%
Ceramics	20%
Metallurgical	15%
Textile finishing	12.5%
Food products	10%
Oil refining	7.5%

2.3.1 Industrial energy systems

Every industrial process is unique, and has its own specific areas where energy efficiency can be improved. There are a few common to many industries, which have opportunities for energy efficiency improvement. All plants are designed with at least one form of energy conversion systems. It is very important that the systems are efficient and reliable and that the environmental impacts are considered. Some of the utility systems in industrial set up are[15]:

- Electrical power systems
- Lighting systems
- Heat energy systems
- Compressed air systems
- Refrigeration and air conditioning systems

2.3.1.1 Electric power systems

Electric motors and drive systems are common to most industrial processes. Motors are prime movers of such equipments as pumps, conveyors, compressors and various industrial production equipments. In fact, electric motors account for approximately 70 percent of industrial energy use. Motors can consume up to 20 times their purchase value in electricity each year. Properly sized, energy efficient motors with electronic variable speed controls, and improved gears, belts, bearings and lubricants, use only 40 percent as much energy as standard systems while their prices are 15-20 % more than standard motors.[15]

There are several occasions in industries that motor systems are over sized due to consideration of successive safety factors in the design of the systems. Motors that are oversized present high losses, lower efficiency and also low power factor. In such a situation oversized motors have to be changed by the correct sized motors.

Distribution cables are used to supply currents to motors and these cables produce I*I*R losses. Correct sizing of the cables will allow cost effective minimization of those losses and it will also reduce voltage drops in the distribution cables.

2.3.1.2 Lighting systems

Lighting accounts for up to seven percent of industrial energy costs. The installation of energy – efficient lighting systems can cut lighting bills by as much as 40 %. With lighting, it’s a question of choosing long life and low maintenance technology to suit the requirements of the industry. For instance, in a warehouse, significant savings can be achieved by the installation of translucent roof panels or skylights, which reduces the need to operate artificial lighting during the day. Light colored ceilings and flooring reflect light and reduce the number of lights needed.

2.3.1.3 Compressed air system

Compressed air, widely used throughout industries, is the most expensive industrial utility. About 10 percent of all electrical energy used by industry is employed in compressed air.

Only 5% of input electrical energy is converted into useful energy and the rest is wasted as heat. This is an area which offers large potential for energy savings through simple measures.

Regular maintenance program for the compressed air system can reduce electricity consumption by identifying air leaks, reduce intake air temperature, optimize system pressure, manage compressor operation and eliminate inappropriate uses of compressed air.

It's likely that a typical plant will have a leak rate of at least 20 percent. As well as wasting energy, leaks cause a drop in system pressure, which can cause equipment to operate less efficiently. Repairing air leaks can save between 25 and 40 percent of energy costs.

2.3.1.4 Heat energy

This is the primary path of energy conversion i.e. from the chemical energy of fossil fuel to the thermal energy of the steam. Steam is produced by boilers, usually located far way from steam using equipment. The steam must be distributed by piping arrangements and valves. The use of large pipe means unnecessary heat loss and higher cost of piping and installation and if the pipe is too small there will be excessive noise in the pipe line due to excessive velocity as well as loss of pressure and capacity.

The main types of fuels used in the boilers include coal, oil and gas. A decision on which fuel to use in a particular case must be made in the context of the complete plant and with the knowledge of the current market prices of fuels and the likely trend in prices within the lifetime of the plant.

CHAPER THREE

3. Data Collections and Energy Loss Assessments

3.1 Data Collections

For undergoing the research work on industrial energy utilization efficiency assessment at Mughar cement factory, data has been collected from many sources; documents, interviews, direct observation and questionnaires. Generally two types of data have been collected: primary data and secondary data. Primary data is obtained from the researchers and it is the result of the researcher's studies of the problem. It includes the collection of information through direct observation, personal interviews, and conducting conversation. The secondary data, on the other hand, is the result of other people's research in the same problem area, or from other related problem areas. It includes the study of documents, web-sites and other historical and documentary records relevant for the study.

The following tables provides the factory four years of cement production and energy consumption data and also shows the specific energy consumption, costs of energy per year, energy costs of MCF as well as the standard plants taken as a benchmark. And there are electric motors data and lighting data obtained from the selected factory.

Table 3. 1. Review of cement production and energy consumption at MCF [10]

No.	Items	unit.	years (e.c.)			
			1999	2000	2001	2002
1.	Cement production	ton	712,372	662,278	654,250	727,000
2.	Clinker production	ton	603,458	610,000	590,745	600,000
3.	Electric consumption	kwh	84,452,500	77,918,048	65,609,144	76,297,000
4.	Fuel cnsumption	lit.	63,061,361	62,464,000	59,842,467	64,164,000
5.	Specific ele. consum.	kwh/ton cement	118.5	117.6	100.3	104.9
6.	Specific fuel consum.	lit./ton clinker	104.5	102.4	101.3	106.9
7.	Energy intensity (ele)	KJ/Kg cement	426.6	423.36	361.08	377.64
8.	Energy intensity (fuel)	KJ/Kg clinker	4,193.6	4,109.3	4,065.2	4,289.9

Table 3.2. Energy Costs at MCF for both electrical and furnace oil [10]

Items	Unit.	years (e.c.)			
		1999	2000	2001	2002
Furnace oil	Birr	260,308,208	257,074,033	294,261,968	382,957,949
Electric energy	Birr	34,431,781	29,270,155	42,899,377	31,750,770
Total	Birr	294,739,989	286,344,188	337,161,345	414,708,719

Table 3.3.Cement production and energy consumption of different plants in china [7]

plants	Spec. electric consumption KWh/ton cement	spec. fuel consumption Lit. /ton clinker	Energy intensity (elec) KJ/Kg cement	Energy intensity (fuel) KJ/Kg clinker
1.	82.75	78.25	297.90	3140.00
2.	87.79	58.81	316.04	2360.00
3.	101.83	91.95	366.59	3690.00
4.	88.65	90.75	319.14	3641.80
5.	78.99	65.54	284.36	2630.00
6.	87.20	54.07	313.92	2170.00
7.	94.60	71.27	340.56	2860.00
8.	78.56	56.07	282.82	2250.00
9.	82.42	55.57	296.71	2230.00
10.	86.69	59.06	312.08	2370.00

Table 3. 4. Lighting data

No.	Department	LN	TP	TL	RA	IL	OH
1.	Guard	6	240	20400	34	600	24
2.	Time Keeper	3	120	10200	17.5	582.86	24
3.	Eng. Dep.	46	1840	156400	290	539.3	24
4.	Adm. Bdg	115	4600	391000	717	545.32	8
5.	Finance bdg	112	4480	380800	616	618.18	8
6.	Substation	10	400	34000	45.5	747.25	16
7.	Workshops	34	1360	115600	70	880.00	8
8.	Latrines	30	1200	102000	120	833.33	24
9.	Production control rooms	18	720	61200	72	850.00	24
10.	Water Pump	4	160	13600	28	485.71	24
11.	Maintenances.	20	800	68000	60	1133.33	16
12.	Kiln control rooms	33	1320	112200	155	723.87	24
13.	Clinker prep.	19	760	64600	93.5	690.9	24
14.	Raw materials stores	26	1040	88400	138.5	638.27	24
15.	Finishing control rooms	36	1440	122400	266.5	459.28	24
16.	General Service	15	600	51000	158.5	321.18	8
17.	Garage	13	520	44200	60.5	730.58	8
18.	Kibebs	24	960	81600	216	377.78	8
19.	Packing & transport	42	1680	142800	385	370.55	16
20.	Crushing	12	480	40800	108	377.77	24
21.	Oil Pump Room	5	200	17000	33	515.15	16
22.	Cement Stores	25	1000	85000	102	833.33	24
23.	Library	6	240	20400	50	408	8
24.	Clinic	6	240	20400	58	351.72	8
25.	Raw mills control rooms	36	1440	122400	266	460.15	24
	Total	696					

Table 3.5 Electric motor data summary

No.	Motor Description	Input power (kW)	Nameplate power (kW)	Nameplate speed (RPM)	Output power (kW)	Loading (%)	Efficiency (%)	Current draw (A)	voltage measured (V)	power factor (pf)	Department
1	Mill main drive no.1	1113	1600	1000	912.66	69.6	82	95	6.09k	0.92	Raw mill
2	Mill main drive no. 2	1113	1600	1000	879.27	69.6	79	95	6.08k	0.9	Raw mill
3	Impact drier no. 1	118	225	1000	95.58	52.4	81	10	6k	0.91	Rotary kiln
4	Impact drier no. 2	65	225	1000	55.25	28.9	85	6.78	5.9k	0.88	Rotary kiln
5	Circulating gas fan no. 1	162	250	1000	121.5	64.8	75	13	6.02k	0.94	Raw mill
6	Circulating gas fan no.2	164	250	1000	123	65.6	75	13	6.04k	0.93	Raw mill
7	Hot gas fan no. 1	582	710	992	471.42	82	81	50	6.1k	0.9	Raw mill
8	Hot gas fan no. 2	582	710	1000	477.24	82	82	50	6.1k	0.89	Raw mill
9	Waste gas fan no. 1	117	250	600	99.45	68	85	11	5.88k	0.88	Rotary kiln
10	Waste gas fan no. 2	154	250	600	120.12	61.6	78	154	5.9k	0.9	Rotary kiln
11	cement mill main drive no. 1	1727	2500	750	1450.7	69.1	84	175	6.12k	0.89	Finish grinding
12	cement mill main drive no. 2	1925	2500	750	1655.5	77	86	175	6k	0.91	Finish grinding
13	Mill waste- gas blower no. 1	90	160	750	74.7	56.3	83	122	388	0.91	Raw mill
14	Mill waste- gas blower no. 2	113	150	750	81.36	75.3	72	134	380	0.93	Raw mill
15	Piston ring blower no.1	70	132	600	56	53	80	73	390	0.88	Raw mill

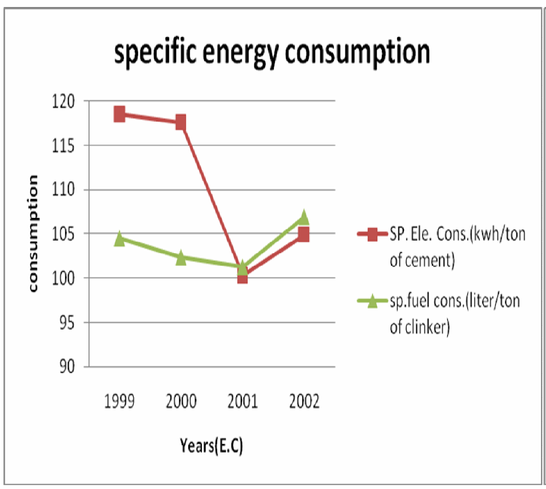
16	Piston ring blower no. 2	70	125	600	51.8	56	74	87	386	0.89	Raw mill
17	Piston ring blower no.3	71	132	600	55.38	53.8	78	96	380	0.88	Raw mill
18	Piston ring blower no.4	71	125	600	53.96	56.8	76	93	391	0.86	Raw mill
19	rotary kiln main drive no. 1	128	180	180	107.52	71.1	84	183	394	0.86	Rotary kiln
20	rotary kiln main drive no.2	89	180	180	71.2	49.4	80	121	390	87	Rotary kiln
21	rotary cooler main drive no.1	82	180	180	63.14	45.6	77	103	380	0.94	Rotary kiln
22	rotary cooler main drive no.2	123	180	180	97.17	68.3	79	153	395	0.93	Rotary kiln
23	Bridge scraper	69.69	140	750	57.843	49.8	83	94	389	0.92	Finish grinding
24	Stack depositing device	23.86	40	750	18.134	59.6	76	32	380	0.87	Finish grinding
25	Belt conveyer drive no.1	22.932	30	1000	19.492	76.4	85	33	380	0.9	Finish grinding
26	Belt conveyer drive no.2	4.2	7.5	1000	3.234	56	77	6	379	0.89	Finish grinding
27	Belt conveyer drive no.3	4.527	7.5	1000	3.6669	60.4	81	6	400	0.9	Finish grinding
28	Belt conveyer drive no.4	4.977	7.5	1000	4.0811	66.4	82	7	383	0.91	Finish grinding
29	Belt conveyer drive no.5	5.27475	7.5	1000	4.1143	70.3	78	7	351	0.84	Finish grinding
30	Belt conveyer drive no.6	1.5788	4	1000	1.3736	39.5	87	2	360	0.88	Finish grinding
31	Belt conveyer drive no.7	1.6852	4	1000	1.4156	42.1	84	3	390	0.94	Finish grinding
32	Reversible belt conveyer no.1	4.61325	7.5	1000	3.6906	61.5	80	7	388	0.92	Raw mill
33	Reversible belt conveyer no.2	3.921	7.5	1000	3.1368	52.3	80	6	380	0.9	Raw mill
34	Movable belt conveyer	3.465	5.5	1000	2.8067	63	81	6	377	0.86	Raw mill

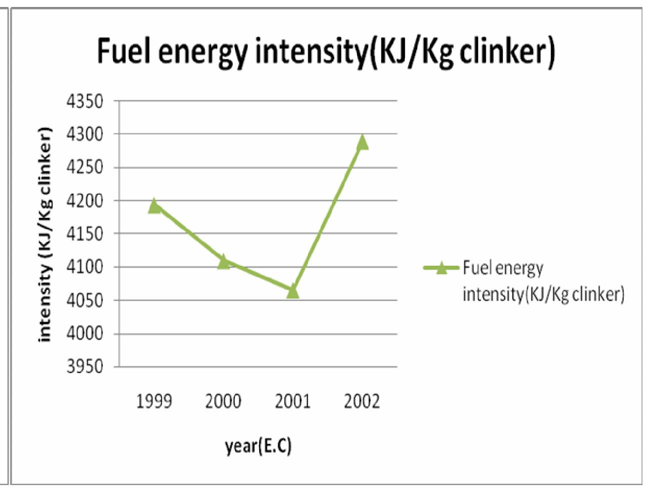
3.2 Energy losses Assessment at MCF

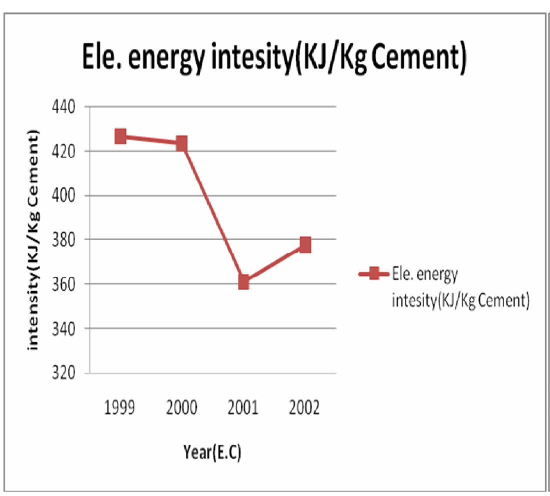
3.2.1 Computation of energy intensity of the plant

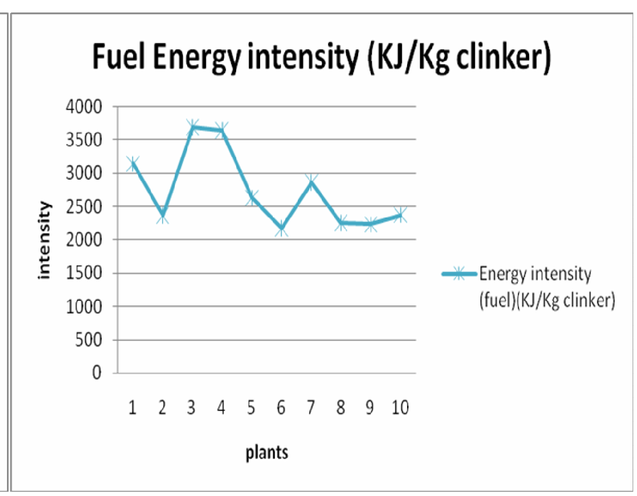
Energy intensity is the amount of energy consumed to produce a unit amount of product and is a measure of the energy efficiency of the plant. The following graphs show the plot of the energy intensity of the mughar cement factory from year 1999- 2002 e.c. and the energy intensity of the selected cement plants taken as a benchmark. The graph also compares the specific energy of the MCF and the selected benchmark cement plants.

The selected benchmarks have used fuel oil for their clinker production which is the same as mughar cement factory and also they have same kiln technology as MCF. These cement plants are higher energy efficiency performance as compared to other cement factories.









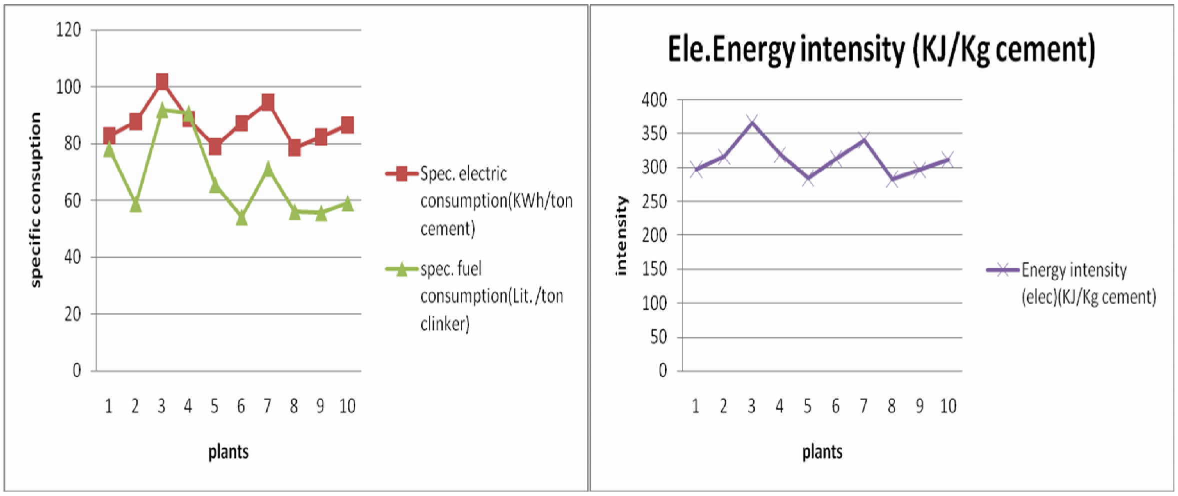


Fig. 3.1 Comparison of energy consumption between MCF and the selected benchmarks.[22]

The annual fuel energy intensity of MCF in the years 1992- 1998 e. c. ranges from 4065.2-4289.9 KJ/kg of clinker with average intensity of 4164.5 KJ/Kg of clinker. The energy intensity of various cement plants taken as bench mark shown in Fig. 3.1 gives an average energy intensity of 2934.1 KJ/Kg of clinker. Hence a difference of 1214.5 KJ/Kg intensity exists between the average practice and what exists at MCF.

With regards to electricity energy intensity of MCF in the year 1999 - 2002 e.c. it ranges between 100.3 -118.5 kWh/ton of cement with average intensity of 110.33 kWh/per ton of cement. The energy intensity of various cement plants taken as bench marks shown in Fig. 3.1 give average energy intensity of 86.95 kWh/per ton of cement. Hence a difference of 23.38 kWh/per ton of cement exists between the average practice and what exists at MCF.

3.2.2 Explanation of the results

From the analysis of the energy intensity of MCF, it can be seen that there is a significant difference between the energy intensity of the plant as compared to the selected benchmarks cement plant experience. This shows that there is actually a room for improving the energy efficiency of the plant. The following calculation shows clearly how much the company is actually spending for energy which actually was not necessary.

- Production = 700, 000 ton of cement per year and 600,000 ton of clinker/year. (average)
- Cost of fuel oil = 4.1 birr/per lit. (2001 e.c.)
- Cost of electricity = 0.50birr per/kWh.
- Specific heat of fuel oil = 40,128KJ/lit.
- Difference in fuel oil energy intensity

  = 1214.5KJ/per Kg of clinker.

  Difference in electricity energy intensity

  = 23.38KJ/per ton of cement

- Annual cost due to inefficient use of fuel oil energy intensity

  = fuel in lit * cost of fuel

$$= \frac{energy\,\text{int}(\frac{KJ}{Kg}) * production(ton)}{specific \quad heat \quad of \quad fuel(KJ/lit)} * fuel\cos t(birr/lit) \qquad (3.1)$$

  = 72,453,000birr/per year.

- Annual cost due to inefficient use of electricity energy intensity

  = electricity consumption in kWh * cost of electricity.

$$= energy\,\text{int}(kWh/ton) * production(ton) * \cos t \quad of \quad electricity(birr/kWh) \qquad (3.2)$$

  = 8,183,700 birr/per year

- Total annual cost due to inefficient use of energy intensity

= cost of fuel + cost of electricity

= 72,453,000birr/per year + 8,183,700 birr/per year

= 80, 636,700 birr/year.

As we have seen there is a huge energy loss at the mughar cement factory. This inefficient use of energy in the MCF also caused many problems. Such as:

- High energy cost.
- Causes environmental pollution.
- MCF is not competitive with the world market.
- Also produce products with incomparable cost.

CHAPTER FOUR

4. Causes of Major Energy Losses and their Opportunities to Improve Energy Efficiency

Energy efficiency measures on cement plant should be taken on equipments like motors, lighting, kiln, heat ditribution, etc. and also on preparation, melting, electric furnace, etc. There are diffrent opportunities to improve energy efficiency at Mughar cement factory while maintaining or enhancing productivity. Improving energy efficiency at cement plant should be approached from several directions. First, a cement plant uses energy for equipment such as motors, kiln, pumps, mills, etc. These important components require regular maintenance, good operation, and replacement, when necessary. Thus, a critical element of plant energy management involves the efficient control of cross-cutting equipment that powers the production processes of a plant. A second and equally important area is the proper and efficient operation of the processes. Process optimization and ensuring that the most productive technologies are in place are key to realizing energy savings in a plant's operation.[12]

In general, throughout a cement plant, there are many processes in operation at the same time. Coordinating their efficiency and operation is necessary to ensure energy savings are realized. If a corporation operates more than one plant, energy management can be more complex than just considering the needs of a single plant. Whether for a single plant or for an entire corporation, establishing a strong organizational energy management framework is important to ensure that energy efficiency measures are implemented effectively.[18]

4.1 Lighting systems

4.1.1. Lighting Data collection

Energy use in lighting is very small in the cement industry. Still, energy efficiency improvement opportunities may be found that can reduce the energy use cost effectively. Lighting is used either to provide overall ambient throughout the manufacturing, storage, and office space or to provide lighting to a specific areas. High intensity discharge (HID) sources are used for the former, high pressure sodium and mercury vapor lamps, florescent, compact florescent (CFL) and incandescent lights are typically used for task lighting in offices.

Lighting is significant because it enters in every phase of operation. The lighting point's data in each section of the factory has been collected and presented in table 3.4.

We must know the efficiencies and performance of the different types of lighting systems in the market in order to make the best choice. The table below presents the luminous efficiency of various lamps.

The luminous intensity of various lamps and the standard illumination required in various working stations are required to evaluate whether the current installation system is appropriate and are given in table 4.1 and 4.2 below consequently.

Table 4.1 Luminous Intensity of Various Lamps [18]

No.	Lamp Type	Luminous Intensity (Lumens/watt)
1	Incandescent	15
2	Fluorescent tube	60-85
3	High Pressure Hg vapor lamps – 80W	2,880
4	High Pressure Hg vapor lamps – 400W	14,400
5	High Pressure Na – 70W	5,740
6	High Pressure Na – 400W	46,800
7	Low Pressure Na – 10W	1,000
8	Low Pressure Na – 18W	3,150
9	CFL Up to & including 7W	45
10	CFL 8-10W	50
11	CFL 11-15 W	55
12	CFL 16-24 W	60

Table 4.2: Illumination Required in Various Working Stations [1]

No.	Activity	Illumination required (LUX)	Remark
1	Workshop	200 - 750	
2	Office	500	

The lighting point's data in each section of the factory has been collected and analyzed as in table 4.3 below. Currently 696 fluorescent lamps are installed with each 40 W of power rating and the fluorescent tubes are T-12 tubes (T-12 lighting tubes are 12/8 inches in diameter and the "T-"designation refers to a tube's diameter in terms of 1/8 inch increments). It can be observed from the table that the total installed capacity of the lighting system is about 27.84 kW with a daily energy consumption of 435.5 kWh.

The key descriptions and discussions of the results of the lighting data of table 4.3 are given below.

4.1.2 Analyzing Lighting Data

As we have seen in the above table, all the lamps found at Mughar cement factory are florescent lamps with ratings 40 W. The symbols used in the table are explained as;

NL – number of lamps installed in the department

TP – Total power ratings of the lamps installed in the department given in watts and obtained as follows:

$$TP = LR \times NL \quad , \qquad (4.1)$$

where LR is lamp rating which is 40watts.

TL – Total lumens output of lamps installed in the department.

$$TL = NL \times Lo \qquad (4.2)$$

Lo – is the luminous output of each fluorescent lamp which is 85lumens/watt obtained in the table for fluorescent lamps.

RA – Room area of each department measured in square meter.

IL – The illumination produced by the installed lamps expressed in lux and is obtained by dividing the total lumens to the room area (1 lux is equivalent to 1lumens/m^2)

$$IL = \frac{TL}{RA} \qquad (4.3)$$

OH – Operating hours per day and explains the time each department is devoted to the factory works.

ALR – The actual lamps required for proper illumination which is used to analyze energy wastes due to improper illumination. Let us calculate the actual number of lamps with the same ratings at the factory.

$$ALR = \frac{ILR}{IL} * NL \qquad (4.4)$$

where,

ILR is the illumination required in each office (department) which is 500 Lux from table 3.3 above and this figure is compared with the actual lux produced in each office. The actual florescent lamp required (ALR) are calculated for each department and compared with number of lamps (NL) currently installed. energy utilization (EU) for the lighting systems can be calculated using equation and compared with the energy required (ER) after a proper illumination as shown in table the energy difference(ED) explains the energy utilization and the energy required after proper illumination.

$$EU = NL \times LR$$

$$ER = ALR \times LR \qquad (4.5)$$

$$ED = EU - ER$$

Table 0.3: Lighting data summary

No	Department	NL	TP	TL	RA	IL	ALR	OH	EU	ER	ED	AS
1	Guard	6	240	20400	34	600	5	24	5760	4800	960	0
2	Time Keeper	3	120	10200	17.5	582.86	3	24	2880	2880	0	0
3	Eng. Dep.	46	1840	156400	290	539.3	43	24	44160	41280	2880	-255.744
4	Adm. Bdg	115	4600	391000	717	545.32	105	8	36800	33600	3200	-106.56
5	Finance bdg	112	4480	380800	616	618.18	91	8	35840	29120	6720	106.56
6	Substation	10	400	34000	45.5	747.25	7	16	6400	4480	1920	-298.368
7	Workshops	34	1360	115600	70	880.00	28	8	10880	8960	1920	85.248
8	Latrines	30	1200	102000	120	833.33	18	24	28800	17280	11520	85.248
9	Production control rooms	18	720	61200	72	850.00	11	24	17280	10560	6720	0
10	Water Pump	4	160	13600	28	485.71	4	24	3840	3840	0	0
11	Maintenances.	20	800	68000	60	1133.33	13	16	12800	8320	4480	127.872
12	Kiln control rooms	33	1320	112200	155	723.87	23	24	31680	22080	9600	42.624
13	Clinker prep.	19	760	64600	93.5	690.9	14	24	18240	13440	4800	42.624
14	Raw materials stores	26	1040	88400	138.5	638.27	20	24	24960	19200	5760	255.744
15	Finishing control rooms	36	1440	122400	266.5	459.28	39	24	34560	37440	-2880	0
16	General Service	15	600	51000	158.5	321.18	23	8	4800	7360	-2560	-85.248
17	Garage	13	520	44200	60.5	730.58	9	8	4160	2880	1280	63.936
18	Kibebs	24	960	81600	216	377.78	32	8	7680	10240	-2560	0
19	Packing & transport	42	1680	142800	385	370.55	57	16	26880	36480	-9600	-85.248

20	Crushing	12	480	40800	108	377.77	16	24	11520	15360	-3840	0
21	Oil Pump Room	5	200	17000	33	515.15	5	16	3200	3200	0	0
22	Cement Stores	25	1000	85000	102	833.33	15	24	24000	14400	9600	42.624
23	Library	6	240	20400	50	408	7	8	1920	2240	-320	AS
24	Clinic	6	240	20400	58	351.72	9	8	1920	2880	-960	-85.248
25	Raw mills control rooms	36	1440	122400	266	460.15	39	24	34560	37440	-2880	0
	Total	696					636		435,520	389,760	45,760	

The lighting data of each department of the factory is collected and analyzed in the table. There are around 696 florescent lamps currently installed in the factory with power rating of 40 W of each. The total installed capacity of the lighting system is about 27.84kw and a daily energy consumption of 435.52 kWh.the actual florescent lamps required in the factory should be around 936 lamps. Therefore there are unnecessary lamps installed. There are a significant energy differences (ED) between the energy utilization (EU) due to currently installed florescent lamps and the actual energy required(ER). This shows that there are energy losses due to lighting systems in the factory.

4.2 Energy Efficiency opportunities Opportunity in Lighting System

As shown above, there exists an opportunity to conserve energy within this lighting system. Therefore, it is important to examine whether the light source is utilized in the most efficient way and take energy saving measures. In the next sub-sections energy saving opportunities of the lighting system that should implement in the factory will be discussed.

4.2.1 Lighting controls

Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors that turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10-20% of facility lighting energy use. SystemManual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches to allow occupants to control lights. It is also important to make employees aware of the importance of turning off lights in Other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight. [7]

4.2.2 Improvement of the Installation System

There must be sufficient and appropriate illumination for varieties of operation in the factory. The illumination required for various operations and the luminous intensity of various lamps are given in table 4.1 and 4.2. As explained in section 4.1, currently, there are 696 lighting points installed in the factory all fitted with 40W fluorescent lamps. In certain office segments the illumination is not significant and additional lamps needs to be installed to bring the appropriate brightness. On the other hand, there is more than sufficient illumination in the other offices indicating possibility of reducing the number of lamps installed in these offices. After the appropriate illumination has been checked, only 636 lamps of the same ratings would be required. This results in reduction of 60 lamps which is equivalent to 2.4 kW of power. It also results in energy saving of 16,698.75 kWh and in money savings of 6,679.5 Birr annually.

In addition to proper illumination, the fittings of luminaries should be cleaned periodically from dust traps and soot which causes depreciation in illumination. [7]

4.2.3 Replacing T-12 Tubes with T-8 Tubes

In many industries including Mughar cement factory T-12 tubes florescent lamps have been found. A T-12 tube refers to the diameter in 1/8 inch increment (T-12 means 12/8 inch or 3.8 cm diameter tubes). The initial output and energy consumption of these lights is high. These also have extremely poor efficiency, lamp life, lumen depreciation, and color rendering index. Because of these maintenance and energy costs of T-12 tubes are high. Replacing T-12 lamps with T-8 (smaller diameter) lamps approximately doubles the efficiency of the former. Also, T-8 tubes generally last 60% longer than T-12 tubes, which lead to savings in maintenance costs. Typical energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30% [9].

As we have been discussed earlier, there are 696 lamps currently installed in the factory indicating that there are 696 T-12 fluorescent tubes. After the corrected installation, however, only 636 lighting points would be required.

Replacing these 636 T-12 lamp tubes with T-8 lamps tubes, therefore, we obtain:

Power demand saving (PDS):

$$PDS = \frac{0.30 \times ALR \times LR}{1000} = \frac{0.30 \times 636 \times 40 watts}{1000} = 7.632 kW \qquad (4.6)$$

Energy Saving (ES):

$$ES = \frac{0.30 \times ER \times 365}{1000} = \frac{0.30 \times 90{,}864{,}000 watt - hours}{1000} = 42{,}678.72 kWh \quad (4.7)$$

Birr Saving (BS):

$$BS = ES \times R = 42{,}678.72 \frac{kWh}{year} \times 0.50 \frac{Birr}{kWh} = 21{,}339.09 \quad \frac{Birr}{Year} \quad (4.8)$$

4.2.4 Replacement with CFL

The existing florescent lamps which have 40kW power rating can be replaced by with energy efficient compact florescent lamps (CFL) with 11kW power ratings. It should be noted, however, that energy saving is not realized in replacement of the existing fluorescent lamps with CFL lamps because the luminous intensity of fluorescent lamps is better than that of the CFL as we can see in the table.. Therefore it is recommended that the existing fluorescent lamps should be replaced by the CFL of small rating in the rooms with sufficient day lighting and in the offices that are unused and locked at night as the day lighting and the small rating CFL supplements each other. In this regard much higher saving could be realized in the lighting system. [7]

4.2.5 Turning off Lights in Unoccupied Areas

An easy and effective measure to minimize the lighting load at the factory is to encourage personnel to turn off lights in unoccupied building spaces. An energy management program that aims to improve the awareness of personnel with regard to energy use can help staff get in the habit of switching off lights and other equipment when not in use. This may be achieved by shutting off lights during non-working hours by automatic controls, such as occupancy sensors that turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10-20% of facility lighting energy use [10].

4.2.6 Day Lighting

Daylighting is the efficient use of natural light in order to minimize the need for artificial light in buildings. Increasing levels of daylight within rooms can reduce electrical lighting loads. Efficient daylighting system may provide evenly dispersed light without creating heat gains. Daylighting differs from other energy efficiency measures because its features are integral to the architecture of a building, and so it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can be cost-effectively refitted with daylighting systems. Various daylighting systems are available on the market; some of which can be supplied as kits to retrofit an existing building. Daylighting can be combined with lighting controls to maximize its benefits. Because of its variability, daylighting is usually combined with artificial lighting to provide the necessary illumination on cloudy days or after dark. Daylighting technologies include properly placed and shaded windows, atria, angular or traditional (flat) rooflights, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts utilize angles of the sun and redirect light with walls or reflectors.

Not all parts of a facility may be suitable for the application of daylighting. Daylighting is most appropriate for those areas that are used in daytime hours by people. In office spaces, daylighting may save between 30 and 70%. The savings will vary widely depending the facility and buildings. Some problems associated with daylighting in industrial buildings have been identified due to the structure of the building. Various companies offer daylighting technologies. Daylighting systems will have a payback period of around 4 years, although shorter paybacks have been achieved.[24]

Although all the installed lamps are lighting throughout the working hours at mughar cement factory, most of the offices are suited with windows appropriate for day lighting. The offices that are unused and locked at night are equipped with fluorescent lights. In engineering building offices, in part of factory controlling rooms, there is sufficient day lighting.

By combining several of the lighting measures above, light system improvements can be the most effective and comprehensive way to reduce lighting energy.

4.3 Electric Motors

4.3.1 Introduction to electric motor

An electric motor is an electromechanical device that converts electrical energy to mechanical energy. This mechanical energy is used for, for example, rotating a pump impeller, fan or blower, driving a compressor, lifting materials, driving mills etc. Electric motors are used at home (mixer, drill, fan) and in industry. Electric motors are sometimes called the "work horses" of industry because it is estimated that motors use about 70% of the total electrical load in industry.

The general working mechanism is the same for all motors such as:[8]

1. An electric current in a magnetic field will experience a force.
2. If the current carrying wire is bent into a loop, then the two sides of the loop, which are at right angle to the magnetic field, will experience forces in opposite directions.
3. The pair of forces creates a turning torque to rotate the coil. (note: a "torque" is the force that causes the rotation)
4. Practical motors have several loops on an armature to provide a more uniform torque and the magnetic field is produced by electromagnet arrangement called the field coils

In understanding a motor it is important to understand what a motor load means. Load refers to the torque output and corresponding speed required. Loads can generally be categorized into three groups:

- **Constant torque loads** are those for which the output power requirement may vary with the speed of operation but the torque does not vary. Conveyors, rotary kilns, and constant-displacement pumps are typical examples of constant torque loads.
- **Variable torque loads** are those for which the torque required varies with the speed of operation. Centrifugal pumps and fans are typical examples of variable torque loads (torque varies as the square of the speed).

- **Constant power loads** are those for which the torque requirements typically change inversely with speed. Machine tools are a typical example of a constant power load.[8]

4.4 Energy efficiency oportunities on electric motors

The motor system energy efficiency can be improved by different measures . These measures include;

4.4.1 Replace standard motors with energy efficient motors

High efficiency motors have been designed specifically to increase operating efficiency compared to standard motors. Design improvements focus on reducing intrinsic motor losses and include the use of lower-loss silicon steel, a longer core (to increase active material), thicker wires (to reduce resistance), thinner laminations, smaller air gap between stator and rotor, copper instead of aluminum bars in the rotor, superior bearings and a smaller fan, etc. Energy efficient motors cover a wide range of ratings and the full load. Efficiencies are 3% to 7% higher compared with standard motors as shown in Figure 4.1. Table 4.4 describes the improvement opportunities that are often used in the design of energy efficient motors.[6]

As a result of the modifications to improve performance, the costs of energy efficient motors are higher than those of standard motors. The higher cost will often be paid back rapidly through reduced operating costs, particularly in new applications or end-of-life motor replacements. But replacing existing motors that have not reached the end of their useful life with energy efficient motors may not always be financially feasible, and therefore it is recommended to only replace these with energy efficiency motors when they fail.

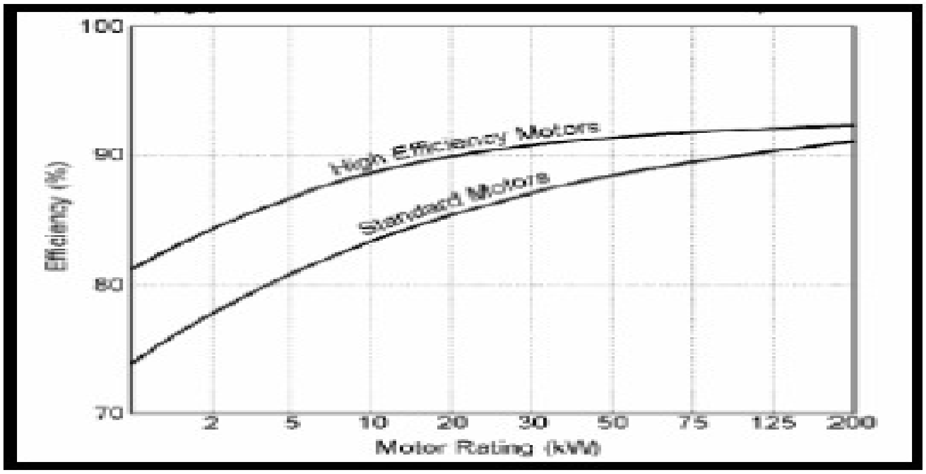


Fig. 4.1 Efficiency Improvement of Energy Efficient Motors over Standard Motors [6]

4.4.2 Analyzing Electric Motors of MCF with Software

There are more than 600 electric motors installed at Mughar cement factory. These are used for raw material tretment, crusher, raw mills, cement mills, finish grinding, etc. Those motors consume more than 90% of electrical energy in the factory. By improving the efficiencies of these motors or by replacing with energy efficient motors, we can save 5% to 15% of electrical energy.

Many motors of different power ratings are currently in operation in the factory (See Appendix A for operating loads in the factory.) Most of these motors are old, rewound, not regularly maintained and efficiency loss is common to the motors that are rewound. Currently the motor technology is improved. Energy efficient motors are being designed to transfer the input energy to the shaft very efficiently. Efficient motors also tend to have a better relative performance at part load, which is of increased benefit for applications with variable load requirements. In this regard there is a high opportunity to save energy in the factory.

4.4.2.1 Motor master+ international (IMSSA) software

This software, the International Motor Selection and Analysis (IMSSA), supports motor management functions and designed for utility auditors, industrial energy coordinators, and plant or consulting engineers, Motor Master+ international supports motor and motor systems improvement planning through identifying the most efficient action for a given repair or motor purchase decision. It can also be used to identify inefficient or oversized inventory motors and compute the energy and demand savings associated with selection of a replacement energy-efficient model. [21]

In this thesis work, I used motor master+ international software to evaluate the performance of the existing motor with the energy efficient motors. The input parameters to this software are: Power in kilowatts, speed in revolutions per minute, percentage loading, efficiency, annual operating hours, and energy and purchase price of the energy efficient motor in dollars of both the operating motors and the energy efficient motors.

The output parameters of the software are: Energy and demand savings, and a simple back period.

4.4.2.2 Determining input parameters

- **Estimating motor loads**

Operating efficiency and motor load values must be assumed or based on field measurements and motor nameplate information. The motor load is typically derived from a motor's part-load input kW measurements as compared to its full-load value (when kW or voltage, amperage, and power factor readings are available), from a voltage compensated amperage ratio, or from an operating speed to full-load slip relationship.

Equations used to estimate motor load are summarized below. The kilowatt technique should be used whenever input kilowatt measurements are available. Use the slip technique only when strobe tachometer readings are at hand and kilowatt values are not available. The full-load or synchronous speed for the existing motor may be extracted from the nameplate, whereas speed characteristics for new motors are obtained from manufacturers' catalogs.[23]

Motor load estimation techniques are:

- Kilowatt ratio technique

$$Motor\ \ load = \frac{KW_{INPUT}}{(hp * 0.746)/\eta_{fl}} = \frac{\sqrt{3} * volts_{avg} * amps_{avg} * pf}{1000 * hp * 0.746/\eta_{fl}} * 100\% \qquad (4.9)$$

- Voltage compensated slip technique

$$\text{Motor load} = \frac{rpm_{synch} - rpm_{measured}}{(rpm_{synch} - rpm_{nameplate}) * \left(\frac{voltage_{rated}}{voltage_{measured}}\right)^2} \qquad (4.10)$$

Another technique used to calculate motor loads is amperage ratio technique as suggests that loads be estimated by comparing a motor's true root-mean-square (rms) amperage draw against its full-load or nameplate value. Thus, the load on a motor is defined as:

- Amperage ratio technique:

$$\text{Motor load} = \frac{amps_{measured}}{amps_{nameplate}} * \left(\frac{volts_{measured}}{volts_{nameplate}}\right) \qquad (4.11)$$

where;

kW (input) – input power in Kilowatt

Volts(avg) – average three phase voltage

Volts (nameplate) – nameplate three phase voltage

Amps (avg) – average three phase current

Amps (nameplate) – nameplate three phase current

Pf – power factor

Hp – horse power (rated power)

η (fl) – full load efficiency

rpm (sych) – synchronous speed in revolution per minute

Rpm (measured) - measured speed in revolution per minute

Rpm (nameplate) nameplate speed in revolution per minute

❖ **Determining motor efficiency**

The efficiency of a motor can be defined as “the ratio of a motor’s useful power output to its total power output.” Motors convert electrical energy to mechanical energy to serve a certain load. In this process, energy is lost as shown in the figure below.The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design and operating condition. Losses can vary from approximately two percent to 20 percent.

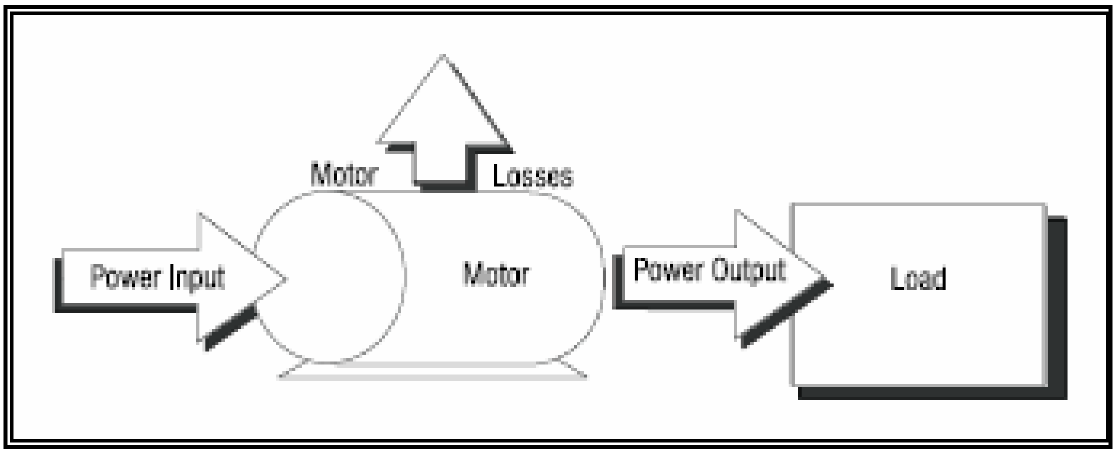


Fig. 4.2 Motor losses [23]

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design and operating condition. Losses can vary from approximately two percent to 20 percent. Table 1 shows the types of losses for an induction motor.[23]

Table 4.5 types of motor losses[23]

Type of loss	Percentage of total loss(100%)
Fixed loss or core loss	25
Variable loss; stator loss(I*I*R)	34
Variable loss; rotor loss(I*I*R)	21
Friction & rewinding loss	15

Stray load loss	5

The efficiency of a motor can be defined as "the ratio of a motor's useful power output to its total power output."

Factors that influence motor efficiency include:

- Age. New motors are more efficient.
- Capacity. As with most equipment, motor efficiency increases with the rated capacity.
- Speed. Higher speed motors are usually more efficient.
- Type. For example, squirrel cage motors are normally more efficient than slip-ring motors.
- Temperature. Totally-enclosed fan-cooled (TEFC) motors are more efficient than screenprotected drip-proof (SPDP) motors.
- Rewinding of motors can result in reduced efficiency.
- Load, as described above.

There is a clear link between the motor's efficiency and the load. Manufacturers design motors to operate at a 50-100% load and to be most efficient at a 75% load. But once the load drops below 50% the efficiency decreases rapidly as shown in Figure 4.3. Operating motors below 50% of rated loads has a similar, but less significant, impact on the power factor. High motor efficiencies and power factor close to 1 are desirable for an efficient operation and for keeping costs down of the entire plant and not just the motor.[8]

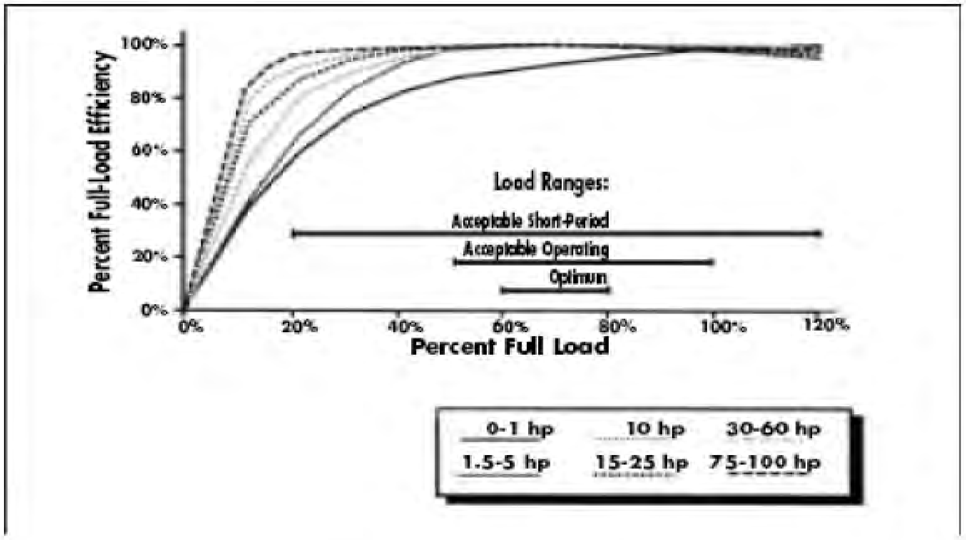


Fig.4.3 motor part load efficiency(as a function of % full load)

For this reason, it is useful to determine both the load and efficiency when assessing a motor's performance. In most countries it is a requirement for manufacturers to display the full-load efficiency on the motor's nameplate. However, when a motor has been in operation for a long time, it is often not possible to determine its efficiency because nameplates of motors are often lost or painted over.

The definition of energy efficiency is the ratio of its useful power output to its total power input and is usually expressed in percentage, as shown in equation 4.12 [12].

$$\eta = \frac{0.7457 \times hp \times Load}{p_i} \qquad (4.12)$$

where:

η = Efficiency as operated in %

Hp = Nameplate rated horsepower

Load = Output power as a % of rated power

P_i = Three phase power in kW

And the three phase input power can be directly measured or can be calculated by using equation 4.13.

$$P_i = \frac{V \times I \times PF \times \sqrt{3}}{1000} \tag{4.13}$$

where:

P_i = Three-phase power in kW
V = RMS voltage, mean line-to-line of 3 phases
I = RMS current, mean of 3 phases
PF = Power factor

Using line current estimation technique to estimate motor loading and equation 4.12 to estimate motor efficiency, the MCF motors data are summarized in table 4.6 .

- Therefore loading, efficiency, nameplate speed (rpm), voltage rating (v) and power rating (kW) are the input of the software which are taken from the existing motors at MCF.
- Power rating(kW), loading, efficiency, voltage rating(v), nameplate speed(rpm) and the purchase price under the energy efficient motors column are the specifications of the energy efficient motors taken from the **Motor master + international** software catalogue. These values are selected in such a way to improve the loadings of the existing operation.

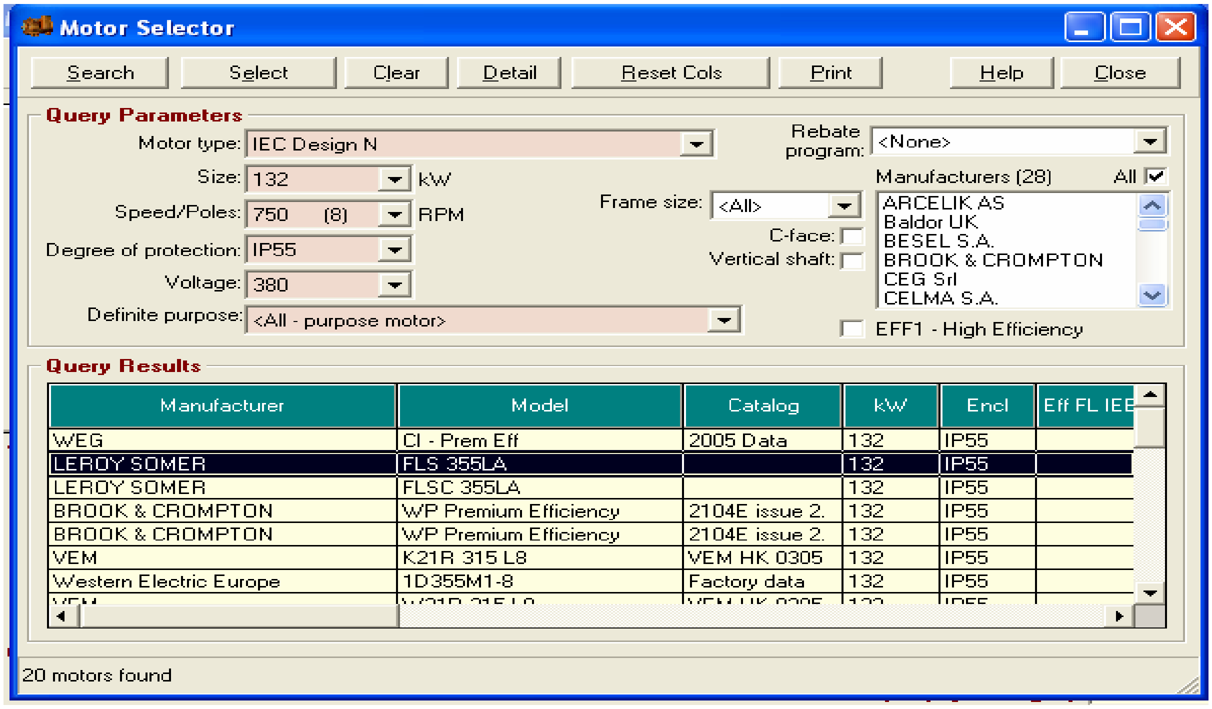


Fig.4.4 motor selection [21]

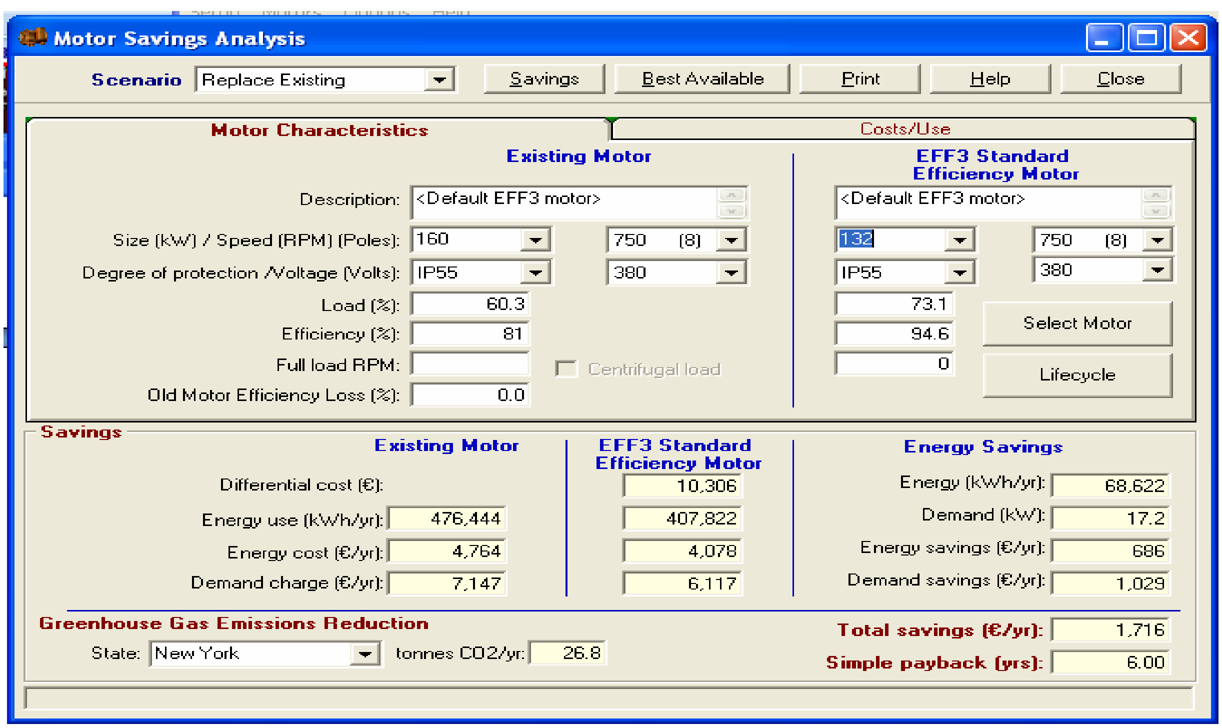


Fig. 4.5 motor saving analysis [21]

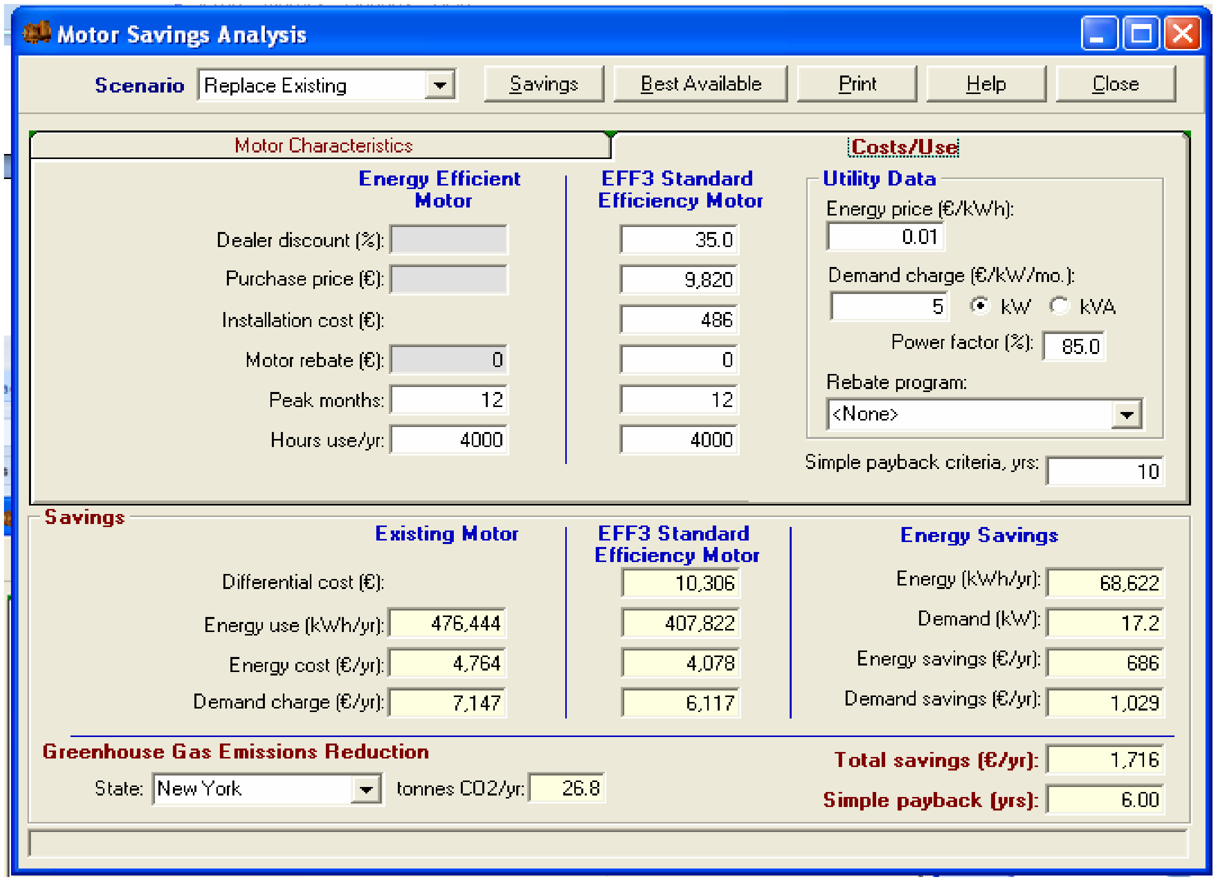


Fig. 4.6 motor purchasing price data [21]

Motor Savings Analysis - Replace Existing

Page: 1

INPUTS

Motor Characteristics

	Existing Motor		EFF3 Standard Efficiency Motor	
Description:	<Default EFF3 motor>		<Default EFF3 motor>	
Size (kW) / Speed (RPM) (Poles):	160.0 kW:	750 RPM	132.0 kW:	750 RPM
Degree of protection /Voltage (Volts):	IP55	380 Volts	IP55	380 Volts
Load (%):	60.3		73.1	
Efficiency (%):	81.0		94.6	
Full load RPM:	0 RPM		0 RPM	
Centrifugal load:	False			
Old Motor Efficiency Loss (%):	0			

Costs/Use

	Existing Motor	EFF3 Standard Efficiency Motor	Utility Data	
Dealer discount (%):	N/A	35	Energy price (€/kWh):	0.04
Purchase price (€):	N/A	9,820	Demand charge (€/kW/mo.):	5
Installation cost (€):	N/A	486	Power factor (%):	N/A
Motor rebate (€):	N/A	0	Rebate program:	<None>
Peak months:	12	12	Simple payback criteria, yrs:	10
Hours use/yr:	4000	4000		

RESULTS - SAVINGS

	Existing Motor	EFF3 Standard Efficiency Motor	Energy Savings	
Differential cost (€):		10,306	Energy (kWh/yr):	68,622
Energy use (kWh/yr):	476444	407822	Demand (kW):	17.2
Energy cost (€/yr):	19,058	16,313	Energy savings (€/yr):	2,745
Demand charge (€/yr):	7,147	6,117	Demand savings (€/yr):	1,029
Greenhouse Gas Emissions Reduction			Total savings (€/yr):	3,774
State:		tonnes CO2/yr.: 0.00	Simple payback (yrs):	2.7

Fig. 4.7 motor saving analysis [21]

- The motor saving analysis is summarized in table 4.6 and the above figures are sample output of the software in figures 4.2 through 4.5.
- The energy saving and back pay period columns explain the kilowatt hour energy savings per year and the number of years required to recover the investment in energy efficient motors respectively.

As we have seen in table 4.6, where energy saving analysis based on replacing standard motors with energy efficient motors are more effective when we apply at MCF. But it needs investment cost to buy those energy efficient motors. For example, to buy an energy efficient motor for mill waste- gas blower on line one plant, we should have 9820 dollar to purchase the motor, 456 dollar for the installation. But these costs will be back after 6 years with energy savings of 68,622kwh per year. Therefore, this method should be implemented in the factory to use electric energy more efficiently.

4.4.3 Reduce under-loading and over-sized motors

Under-loading increases motor losses and reduces motor efficiency and the power factor. Under-loading is probably the most common cause of inefficiencies for several reasons:

- Equipment manufacturers tend to use a large safety factor when selecting the motor.
- Equipment is often under-utilized. For example, machine tool equipment manufacturers provide for a motor rated for the full capacity load of the equipment. In practice, the user may rarely need this full capacity, resulting in under-loaded operation most of the time.
- Large motors are selected to enable the output to be maintained at the desired level even when input voltages are abnormally low.
- Large motors are selected for applications requiring a high starting torque but where a smaller motor that is designed for high torque would have been more suitable.

The motor size should be selected based on a careful evaluation of the load. But when replacing an oversized motor with a smaller motor, it is also important to consider the potential efficiency gain. Larger motors namely have inherently higher rated efficiencies than smaller motors. Therefore, the replacement of motors operating at 60 – 70% of capacity or higher is generally not recommended. On the other hand there are no rigid rules governing motor selection and the savings potential needs to be evaluated on a case-by-case basis. For example, if a smaller motor is an energy efficient motor and the existing motor not, then the efficiency could improve.[23]

4.4.4 Sizing to variable load

Industrial motors frequently operate under varying load conditions due to process requirements. A common practice in this situation is to select a motor based on the highest anticipated load. But this makes the motor more expensive as the motor would operate at full capacity for short periods only, and it carries the risk of motor under-loading.

An alternative is to select the motor rating based on the load duration curve of a particular application. This means that the selected motor rating is slightly lower than the highest anticipated load and would occasionally overload for a short period of time. This is possible as manufacturers design motors with a service factor (usually 15% above the rated load) to ensure that running motors above the rated load once in a while will not cause significant damage.[23]

The biggest risk is overheating of the motor, which adversely affects the motor life and efficiency and increases operating costs. A criterion in selecting the motor rating is therefore that the weighted average temperature rise over the actual operating cycle should not be greater than the temperature rise under continuous full-load operation (100%). Overheating can occur with:

- Extreme load changes, such as frequent starts / stops, or high initial loads
- Frequent and/or long periods of overloading
- Limited ability for the motor to cool down, for example at high altitudes, in hot environments or when motors are enclosed or dirty where loads vary substantially with time, speed control methods can be applied in addition to proper motor sizing[12] .

4.4.5 Improving Power Quality

Motor performance is affected considerably by the quality of input power, which is determined by the actual volts and frequency compared to rated values. Fluctuation in voltage and frequency much larger than the accepted values has detrimental impacts on motor performance.

Voltage unbalance can be even more detrimental to motor performance and occurs when the voltages in the three phases of a three-phase motor are not equal. This is usually caused by the supply different voltages to each of the three phases. It can also result from the use of different cable sizes in the distribution system. An example of the effect of voltage unbalance on motor performance is shown in table 4.7.

A voltage unbalance degrades the performance and shortens the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of a motor's winding insulation. Voltage unbalances may be caused by faulty operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1%. Even a 1% unbalance will reduce motor efficiency at part load operation, while a 2.5% unbalance will reduce motor efficiency at full load operation.[22]

The voltage of each phase in a three-phase system should be of equal magnitude, symmetrical, and separated by 120°. Phase balance should be within 1% to avoid derating of the motor and voiding of manufacturers' warranties. Several factors can affect voltage balance: single-phase loads on any one phase, different cable sizing, or faulty circuits. An unbalanced system increases distribution system losses and reduces motor efficiency.

Table 4.7 Effect of voltage unbalance in induction motors[18]

	Example 1	Example 2	Example 3
Percentage unbalance in voltage (%)	0.30	2.3	5.4
Unbalance in current(%)	0.4	17.7	40.0
Increase in temperature(oC)	0	30	40

- ❖ Percent unbalance in voltage = (maximum deviation from mean voltage / mean voltage)*100

Voltage unbalance can be minimized by:

- balancing any single phase loads equally among all the three phases
- segregating any single phase loads which disturb the load balance and feed them from a separate line / transformer.

4.4.6 Rewinding

It is common practice in industry to rewind burnt motors. The number of rewound motors in some industries exceeds 50% of the total number of motors. Careful rewinding can sometimes maintain motor efficiency at previous levels, but in most cases results in efficiency losses. Rewinding can affect a number of factors that contribute to deteriorated motor efficiency; winding and slot design, winding material, insulation performance, and operating temperature. For example, when heat is applied to strip old windings the insulation between laminations can be damaged, thereby increasing eddy current losses. A change in the air gap may affect power factor and output torque.[23]

However, if proper measures are taken, the motor efficiency can be maintained after rewinding, and in some cases efficiency can even be improved by changing the winding design. Using wires of greater cross section, slot size permitting, would reduce stator losses and thereby increasing efficiency. However, it is recommended to maintain the original design of the motor during the rewind, unless there are specific load-related reasons for redesign.

When rewinding motors it is important to consider the following:

- Motors less than 40 HP in size and more than 15 years old (especially previously rewound motors) often have efficiencies significantly lower than currently available energy-efficient models. It is usually best to replace them. It is almost always best to replace non-specialty motors under 15 HP.

- If the rewind cost exceeds 50% to 65% of a new energy-efficient motor price, buy the new motor. Increased reliability and efficiency should quickly recover the price premium

4.4.7 Power factor correction

Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. A low power factor may result in increased power consumption, and hence increased electricity costs. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium-efficient motors.

By definition power factor is a ratio of true power (useful power) expressed in kilo watts and apparent power expressed in kilo volt amperes. Because true power and apparent power form the adjacent and hypotenuse sides of a right triangle, respectively, the power factor ratio is also equal to the cosine of that phase angle and is a unit less parameter.

$$Powerfactor = \left(\frac{truepower}{apparentpower}\right)$$

Capacitors connected in parallel (shunted) with the motor are often used to improve the power factor. The capacitor will not improve the power factor of the motor itself but of the starter terminals where power is generated or distributed. The benefits of power factor correction include reduced kVA demand (and hence reduced utility demand charges), reduced I*I*R losses in cables upstream of the capacitor (and hence reduced energy charges), reduced voltage drop in the cables (leading to improved voltage regulation), and an increase in the overall efficiency of the plant electrical system.[23]

At mughar cement factory the power factor is with in the acceptable range that is above 0.85 which is Ethiopian electric power coorporation (EEPCO's) acceptable range as we have seen in table 3.5.

4.4.8 Improving maintenance

The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventative or predictive. Preventative measures, the purpose of which is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to replace a motor before failure occurs.The savings associated with an ongoing motor maintenance program are significant, and could range from 2% to 30% of total motor system energy use. [21]

Appropriate maintenance is needed to maintain motor performance. A checklist of good maintenance practices would include:

- Inspect motors regularly for wear in bearings and housings (to reduce frictional losses) and for dirt/dust in motor ventilating ducts (to ensure proper heat dissipation)
- Check load conditions to ensure that the motor is not over or under loaded. A change in motor load from the last test indicates a change in the driven load, the cause of which should be understood
- Lubricate appropriately. Manufacturers generally give recommendations for how and when to lubricate their motors. Inadequate lubrication can cause problems, as noted above. Over-lubrication can also create problems, e.g. excess oil or grease from the motor bearings can enter the motor and saturate the motor insulation, causing premature failure or creating a fire risk

- Check periodically for proper alignment of the motor and the driven equipment. Improper alignment can cause shafts and bearings to wear quickly, resulting in damage to both the motor and the driven equipment
- Ensure that supply wiring and terminal box are properly sized and installed. Inspect regularly the connections at the motor and starter to be sure that they are clean and tight
- Provide adequate ventilation and keep motor cooling ducts clean to help dissipate heat to reduce excessive losses. The life of the insulation in the motor would also be longer.

4.4.9 Motor management

A motor management is an essential part of a plant's energy management strategy. Having a motor management plan in place can help companies realize longterm motor system energy savings and will ensure that motor failures are handled in a quick and cost effective manner. The following sugestions are a key elements for a sound motor management plan

- Creation of a motor survey and tracking program.
- Development of guidelines for proactive repair/replace decisions.
- Preparation for motor failure by creating a spares inventory.
- Development of a purchasing specification.
- Development of a repair specification.
- Development and implementation of a predictive and preventive maintenance program.

In general several factors are important when selecting a motor, including motor speed, horsepower, enclosure type, temperature rating, efficiency level, and quality of power supply. When selecting and purchasing a motor, it is also critical to consider the life-cycle costs of that motor rather than just its initial purchase and installation costs. Up to 95% of a motor's costs can be attributed to the energy it consumes over its lifetime, while only around 5% of a motor's costs are typically attributed to its purchase, installation, and maintenance. Life cycle costing is an accounting framework that allows one to calculate the total costs of ownership for different investment options, which leads to a more sound evaluation of competing options in motor purchasing and repair or replacement decisions. [23]

The selection of energy-efficient motors can be an important strategy for reducing motor system life-cycle costs. Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also run cooler (which may help reduce facility heating loads) and have higher service factors, longer bearing life, longer insulation life, and less vibration.

The choice of installing a premium efficiency motor strongly depends on motor operating conditions and the life cycle costs associated with the investment. In general, premium efficiency motors are most economically attractive when replacing motors with annual operation exceeding 2,000 hours/year. Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period.

4.5 Opportunities to improve the use of fuel oil consuption reduction at MCF

Improving energy efficiency should be approached from several directions. A strong, corporate-wide energy managment program is essential. Cross-cutting equipment and techinologies such as motors and compressed air, common to most plants and manufacturing industries, present well- documented opportunities for improvment. Equally important ,the production process can be fine-tubed to produce even greater energy as well as money savings. Below are some measures concerning these and other geeneral crosscutting utilities that apply to the cement industry.[22]

Several technologies and measures exist that can reduce the energy intensity (i.e. the electricity or fuel consumption per unit of output) of the various process stages of cement production. This section provides fuel oil consumption reduction technologies and measures, their costs, and potential for implementation on the factory Table 4.7 lists the technologies and measures that we consider in our analysis.

Table 4.7 Energy – efficient practices and technologies in cement production.[22]

<table>
<tr><td colspan="2">Raw Material Preparation
• Efficient transport system
• Raw meal blending systems(dry process)
• High – efficiency roller mills (dry cement)
• High – efficiency classifiers (dry cement)</td></tr>
<tr><td>Clinker production (wet)
• Kiln combustion system improvements
• Kiln shell heat loss reduction
• Use of waste fuels
• Conversion to modern grate cooler
• Conversion to pre – heater, pre – calciner kilns
• Conversion to semi – wet kilns

General measures
• Preventative maintenance (insulation, compressed air losses, maintenance)
• Reduced kiln dust wasting
• Energy management and process control
• High efficiency motors

Efficient fans with variable speed drives</td><td>Clinker production (dry)
• Kiln combustion system improvements
• Kiln shell heat loss reduction
• Use of waste fuels
• Conversion to modern grate cooler
• Heat recovery for power generation
• Low pressure drop cyclones for suspension pre – heaters
• Long dry kiln conversion to multi – stage pre – heater kiln
• Long dry kiln conversion to multi – stage pre – heater, pre – calciner kiln.
• Addition of pre – calciner to pre – heater kiln.</td></tr>
<tr><td>Finish grinding (applies to both wet and dry cement production)
• Improved grinding media (ball mills)
• High – pressure roller press
• High efficiency classifiers
• Improve mill internals</td><td>Product changes
• Blended cements
• Reducing the concentration of C3S in cements
• Reducing fineness of cement for selected uses</td></tr>
</table>

Not all measures in table above will apply to all plants. Applicability will depend on the current and future situation in individual plants. For example, expansion and large capital projects are likely to be implemented only if the company has about 50 years of remaining limestone reserve onsite. Plants that have a shorter remaining supply are unlikely to implement large capital projects and should rather focus on minor upgrades and energy management measures.

4.5.1 Clinker Production

Kiln combustion system improvements. Fuel combustion systems in kilns can be contributors to kiln inefficiencies with such problems as poorly adjusted firing, incomplete fuel burn-out with high CO formation, and combustion with excess air. Improved combustion system aims to optimize the shape of the flame, the mixing of combustion air and fuel and reducing the use of excess air. Various approaches have been developed. One technique developed in the UK for flame control resulted in fuel saving of 2 – 10% depending on the kiln type. Fuel savings of up to 10% have been demonstrated for the use of flame design techniques to eliminate reducing conditions in the clinkering zone of the kiln.[22]

Kiln shell heat loss reduction. There can be considerable heat losses through the shell of a cement kiln, especially in the burning zone. The use of better insulating refractory (e.g. Lytherm) can reduce heat losses. The coating refractory choice is the function of insulating qualities of the brick and the ability to develop and maintain coating. The coating helps to reduce heat losses and to protect the burning zone refractory bricks. Estimates suggest that the development of high-temperature insulating linings for the kiln refractory can reduce fuel use by 0.1-0.34 GJ/tone. Costs for insulation systems are estimated to be $0.23/ annual tone clinker capacity. Structural considerations may limit the use of new insulation materials. The use of improved kiln-refractories may also lead to improve reliability of the kiln and reduced downtime, reducing production costs considerably, and reducing energy needs during start-ups.

Use of Waste Derived Fuels. Waste fuels can be substituted for traditional commercial fuels in the kiln. In 1999 tires accounts for almost 5% of total fuel in the U.S. cement industry, while all wastes are about 17% of all fuel inputs. The trend towards increased waste use will likely increase after successful testes in Europe and North America. New waste streams include carpet plastic wastes, filter cake, paint residue and sewage sludge. Cement kilns also use hazardous wastes. Waste derived fuels may replace the use of commercial fuels, and are hence accounted as energy savings. The carbon dioxide emission reduction depends on the carbon content of the waste derived fuel, as well as the alternative use of the waste and efficiency of use. [24]

Conversion to Grate Cooler. Four main types of coolers are used in the cooling of clinker: shaft, rotary, planetary and grate cooler. The grate cooler is the modern variant and is used in almost all modern kilns. The advantages of the grate cooler are its large capacity (allowing large kiln capacities) and efficient heat recovery (the temperature of the clinker leaving the cooler can be as low as 83°C, instead of 120-200°C which is expected from planetary cooler). Tertiary heat recovery (needed for pre-canciners) is impossible with planetary coolers, limiting heat recovery efficiency. Modern grate coolers recover more heat than do the other types of coolers. For large capacity plants, grate coolers are the preferred equipment. For smaller plants the grate cooler may be too expensive. [23]

Seals: seals are used at the kiln inlet and outlet to reduce false air penetration, as well as heat losses. Seals may start leaking, increasing the heat requirement of the kiln. Most often pneumatic and lamella-type seals are used. Although seals can last up to 10,000 to 20,000 hours, regular inspection may be needed to reduce leaks. Energy losses resulting from leaking seals may vary, but are generally relatively small. Philips kiln services report that upgrading the inlet pneumatic seals at a relatively modern plant in India (Maihar cement), reduced fuel consumption in the kiln by 0.4% (0.01 MBtu/tone clinker). The payback period for improved maintenance of kiln seals is estimated at 6 months or less. [24]

Refractories: refractories protect the steel kiln shell against heat, chemical and mechanical stress. The choice of refractory material depends on the combination of raw materials, fuels and operating conditions. Extended life time of the refractories will lead to longer operating periods and reduced lost production time between relining of the kiln, and hence, offset the costs of higher quality refractrories. It will also lead to additional energy savings due to the relative reduction in start-up time and energy costs. The energy savings are difficult to quantify, as they will strongly depend on the current lining choice and management. [24]

Low Pressure Drop Cyclones for Suspension Pre-heaters. Cyclones are a basic component of plants with pre-heating systems. The installation of newer cyclones in a plant with lower pressure losses will reduce the power consumption of the kiln exhaust gas fan system. Depending on the efficiency of the fan 0.6-0.8 kWh/tone clinker can be saved for each 50 mm

W.C. (water column) the pressure loss is reduced. For most old kilns this amounts to savings of 0.6-1.0 kWh/tone. [24]

Heat Recovery for Cogeneration. Waste gas discharged from the kiln exit gases, the clinker cooler system, and the kiln pre-heater system all contain useful energy that can be converted into power. Cogeneration systems can either be direct gas turbines that utilize the waste heat, or the installation of a waste heat boiler system that runs a steam turbine system. The steam turbine systems are more economical and these systems have been installed in many plants world-wide. While electrical efficiencies are still relatively low (18%) and the average power generation may vary between 10-20 kWh/t clinkers. And the average electricity savings is around 17kWh/tone of clinker. The estimated installation costs for such a system at $2-4/tone of clinker capacity with operating costs of $0.2-0.3/tone of clinker. [23]

Installation of pre-calciners on dry pre-heater kiln. An existing preheater kiln may be converted to a multi-stage preheater precalciner kiln by adding a precalciner and, when possible an extra preheater. The addition of a precalciner will generally increase the capacity of the plant, while lowering the specific fuel consumption. Using as many features of the existing plant and infrastructure as possible, special precalciners have been developed by various manufacturers to convert existing plants, e.g. Pyroclon®-RP by KHD in Germany.

Generally, the kiln, foundation and towers are used in the new plant, while cooler and preheaters may be replaced. Cooler replacement may be necessary in order to increase the cooling capacity for larger production volumes. The conversion of a plant in Italy, using the existing rotary kiln, led to a capacity increase of 80-100%, while reducing energy use from 3.56 to 3.06-3.19 GJ/tone clinker, resulting in a saving of 11-14%. Fuel savings will depend strongly on the efficiency of the existing kiln and on the new process parameters (e.g. degree of precalcination, cooler efficiency). The average savings of new calciners can be 0.4 GJ/tone of clinker. It is assumed a cost of $15/annual tone of clinker. The increased production capacity is likely to save considerably in operating costs, estimated around $1/ tone of clinker. [23]

Conversion of long dry kilns to dry pre-heater, pre-calciner kilns. In some cases it may be feasible to upgrade a long dry kiln to the more current state of the art multi-stage pre-heater, precalciner kiln. The average energy savings are estimated 1.2 GJ/tone of clinker for the conversion. This savings reflects the difference between the average dry kiln fuel intensity and the energy intensity of a modern preheater, pre-calciner kiln based on a study of the Canadian cement industry and the retrofit of an Italian plant. The estimated investment cost is $25/one of clinker capacity. [22]

CHAPTER FIVE

5. Conclusion and Recommendation

5.1. Conclusion

In Ethiopian cement factories proper attention is not give on energy distribution and utilization assessments to improve energy consumption efficiency, but for the sake of survival and to contribute their part to the country's energy development and also to save foreign currency due to the imported furnace oil, the factories must assess their energy losses and use the suggested opportunities in this thesis to save energy losses.

Results of energy saving in the lighting systems were mainly obtained through improving the installation systems, replacement of accessories, use of energy efficient lamps, and an efficient use of day lighting. Replacement of energy efficient motors with the standard motors has achieved significant results in the study with small payback periods.

By implementing the energy efficiency improvement opportunities in this thesis work, the factories can get the following benefities:

- As we have seen on the energy loss assessment part, 15 – 20 % of cost of energy is due to inefficient use of energy both electric and furnace oil. So, by reducing these losses the factories will reduce their energy costs.
- Reducing energy consumption without affecting the production means reducing carbon dioxide emission – reduces environmental pollution
- By reducing their energy intensity, the factories will be competent with the world market. Which means the factory will produce products with minimum cost.

Some of the energy savings opportunities in this work are quick and low cost measures that can be implemented in the existing systems. The high cost or capital intensive measures may need further detailed audit and analysis. However, the results of the study should be used as a guide line for future expansions and purchases of new machineries.

5.2. Recommendation

While the study is mainly focused on cement industries particularly Mughar cement factory, which is the largest energy consuming industry in the country, it would also apply to any industry.

The concept of energy efficiency improvement in the Ethiopian industries has been analyzed in this paper as a case study in the Mughar cement factory (MCF).the paper has analyzed the historic trends for energy efficiency at MCF and cost – effective energy saving measures that can be implemented in the near and far future. The report focused on the detailed analysis of energy use by process, specific energy technologies and measures to reduce energy use and to improve the energy efficiency without affecting the production potential for the cement industry.

The following recommendations are made based on the study that has been conducted.

- There should be a responsible section in the factory to supervise, monitor and report the energy utilization of the factory. The tasks performed by this section include: assess performances and set goals, look for any energy efficiency improvement opportunities, formulate action plans for implementing efficiency improvement measures, coordinate the implementation of the action plan, supervise and control the implementation, evaluate and report performance.
- The implementation of the energy efficiency measures has also a positive impact on the environment and socio – economy of the local, national and international society
- The retrofit energy efficiency measures require a substantial amount of investment, but the measures are very vital hence should be implemented by attaining appropriate project financing either through bank loan or government support.

APPENDICES

Appendix A; Electric motors and drives description at MCF

Ser. N0.	Item no.	Drive no.	Type	Description	Qty	Drive no.	Type	Qty
35	303.4	223214	3-ph slip-ring motor Type DSSAI 5627-6 1600kw,6kv,50Hz,IP23, IN 1001, N=1000rpm	Mill main drive	1	223014	3-ph slip-ring motor Type DSSAL 5627-6 1600kw,6kv,50Hz,IP23, IN 1001, N=1000rpm With built- in resistance thermometers 3xpt 100	1
26	303.4	223202	3-ph slip-ring motor DSRAI 4015-6 225kw, 6kv, 50Hz, IP44 IM 1001, n=1000rpm	Impact drier	1	223001	3-ph slip-ring motor DSRAI 4015-6 225kw, 6kv, 50Hz, IP44 IM 1001, n=1000rpm	1
42	315	223226	3-ph squirrel-cage motor Type IMRAI 4516-6 250kw, 6kv,50Hz, IP44, IM 1001, n=1000rpm	Circulating gas fan	1	223026	3-ph squirrel-cage motor Type IMRAI 4516-6 250kw, 6kv,50Hz, IP44, IM 1001, n=1000rpm	1
66	801	340201	3-ph slip-ring motor Type DSR AJ 5023-6 710kw,6kw,50Hz,IP44, IM 1001,n=1000rpm With built in pt 100 resistance thermometers (2 thermometers per phase)	Hot gas fan	1	340001	3-ph slip-ring motor Type DSR AJ 5023-6 710kw,6kw,50Hz,IP44, IM 1001,n=992rpm With built in 1xpt x100 thermometers per phase	1
70	802.5	340205	3-ph squirrel-cage motor Type DKRAJ5023-10 250kw,6kv, 50Hz,IP44,IM 1001, n=600rpm With built- in resistance thermometers 3xpt 100	Waste gas fan	1	340005	3-ph squirrel-cage motor Type DKRAJ5023-10 250kw,6kv, 50Hz,IP44,IM 1001, n=600rpm With built- in resistance thermometers 3xpt 100	
16	301.1	473201	3-ph slip-ring rotor motor Type DSS 1526-8 2500kw,6kv,50Hz,IP44,IM 732, n=750rpm	Separators cement mill main drive	1	473001	3-ph slip-ring rotor motor Type DSE 1526-8 2500kw,6kv,50Hz,IP44,IM 732, n=750rpm	

44	316	223229	3-ph squirrel -cage motor Type 2AHR 355-8 160kw,380v,50Hz,IP44,IM 1001,n=750rpm	Mill waste-gas blower	1	223029	3-ph squirrel -cage motor Type 2 AHR 355-8 150kw,380v,50Hz,IP44,IM 1001,n=750rpm	1
9	117	320223/ 320225	3-ph slip-ring motor Type ARU455-10 132kw,380v,50Hz,IP44,IM 1001,n=600rpm	Piston ring blower	2	320023/ 320025	3-ph slip-ring motor Type ARU455-10 125kw,380v,50Hz,IP44,IM 1001,n=600rpm	2
24	301.7	333201	D.C. shunt motor Type GMMBW 45 14-600 180kw,440v,DC,IP 44,IM1001,n=750-180rpm	Thirstier controlled rotary kiln main drive	1	333001	D.C. shunt motor Type GMMAW 45 14-600 180kw,440v(armature voltage),DC,n=750-180rpm exciting voltage 220vDC	1
41	401.8	334201	D.C. shunt motor Type GMMBW 45 14-600 180kw,440v,DC,IP 44,IM1001,n=750-180rpm	Thirstier controlled rotary cooler main drive counter	1	334001	D.C. shunt motor Type GMMAW 45 14-600 180kw,440v(armature voltage),DC,n=750-180rpm exciting voltage 220vDC	1
47	810	488269	3-phase squirrel-cage motor, type ZG3 KMR 80 G8, 0.55kw, 380v, 50HZ, TP44 G310, n=20/100rpm	Shut off valve	2	486234	3- phase squirrel – cage motor,45kw,380v,50Hz,n=1000rpm	3
9	703	117203	3-phase squirrel- cage motor, type KMR 132 M6 7.6kw, 380v,50HZ, IP54 TM 1001, n=1000rpm	Belt conveyer drive	1	488201	3- phase geared motor,1.5kw,380v,50Hz,	12
8	702	117202	3-phase squirrel- cage motor, type KMR 180 M6 22kw, 380v, 50HZ, IP54, IM= 1001, n=1000rpm	Belt conveyer drive	1	488213	Ventil with magnetic coil,0.12kw,220v,50Hz,	6
7	701	117201	Installed power about 140kw,380v,50hz	Bridge scraper	1	488219	3- phase squirrel – cage motor,0.18kw,380v,50Hz,n=1500rpm	6
6	504	115206	Installed power about 80kw, 380v,50hz	Stack depositing device	1	488001	3- phase squirrel – cage motor,0.52kw,380v,50Hz,n=1500rpm	4
		115205	3-phase squirrel-cage motor, type	Belt		488050	3- phase squirrel – cage	

5			KMR 200 M6 30kw,380v 50hz, IP54,IM 1001, n=1000rpm	conveyer drive	1		motor,42.5kw,380v,50Hz,n=600rpm	2
3	502	115203	3-phase squirrel-cage motor, type KMR 132 M6 7.5kw, 380v, 50hz, IP54 IM 1001, n= 1000rpm	Belt conveyer drive	1	486218	3- phase squirrel – cage motor,11kw,380v,50Hz,n=3000rpm	3
10	704	172041	3-phase squirrel-cage motor, type KMR 132 M6 7.5kw, 380v,50hz, IP54 IM 1001, n=1000rpm	Belt conveyer drive	1	486223	3- phase squirrel – cage motor,0.18kw,380v,50Hz,n=1500rpm	6
12	705	117206	3-phase squirrel-cage motor, type KMR 132 M6 7.5kw, 380v,50hz, IP54 IM 1001, n=1000rpm	Belt conveyer drive	1	486005	Serve drive MAW type motor, 0.18kw,380v,50Hz,n=1500rpm	7
45	832	488267	3- phase squirrel- cage motor, 4kw, 380v,50Hz,n= 1500rpm	Monorail single – phase conveyor	1	4880583	3 – phase squirrel – cage motor, 3.8kw, 380v, 50Hz,n = 1500rpm	1
46	840	488268	3- phase squirrel- cage motor, 30kw,380v, 50Hz,n = 1000rpm	Electric heist and connected to lighting and power circuit	1	488059	3- phase squirrel- cage motor, 30kw,380v, 50Hz,n = 1000rpm	1
36	826	488257/1	3 – phase Squirrel –cage motor, 6.25kw, 380v,50Hz, n = 1500rpm	Bag leading conveyor	2	488044	3 – phase squirrel – cage motor, 6kw, 380v, 50Hz, n = 1500rpm	2
37	826	488251	3- phase squirrel – cage motor, 2.2kw, 380v, 50Hz, n = 1500rpm	Lifting drive	2	488045	3 – phase squirrel – cage motor, 1.1kw, 380v, 50Hz, n = 1500rpm	2
38	826	488257/2	3- phase squirrel – cage motor,0.75kw, 380v, 50Hz, n = 1000rpm	Moveable drive	2	488038	3- phase squirrel – cage motor, 0.8kw, 380v, 50Hz,n = 750rpm	2
39	826	488257/3	3- phase squirrel – cage motor,2.2kw, 380v, 50Hz, n = 1500rpm	Feeding belt	2	488040	3- phase squirrel – cage motor, 2.05kw, 380v, 50Hz, n = 1000rpm	2
40	826	488257/4	3- phase squirrel – cage motor, 1.1kw, 380v, 50Hz,n = 1500rpm	Stacker belt	2	488042	3- phase squirrel – cage motor, 1.5kw, 380v, 50Hz, n = 1000rpm	2

41	830	488259	Central device for control of solenoid valves, 0.35kw, 220v, 50Hz	Bag dust filter control	2	488052	Central cabient , 0.9kw, 380v, 50Hz	2
42	830	488261	3- phase squirrel – cage motor,1.5kw,380v, 50Hz, n = 1500rpm	Reversible screw conveyor	2	488054	3- phase squirrel – cage motor, 1.4kw, 380v, 50Hz, n=1500rpm	2
43	830	488263	3- phase squirrel – cage motor, 0.55kw, 380v, 50Hz, n= 1000rpm	Rotary air lack	2	488055	3- phase squirrel – cage motor, 0.50kw, 380v, 50Hz, n=1000rpm	2
44	831	488265	3- phase squirrel – cage motor, 55kw, 380v, 50Hz, n = 1500rpm	Radial blower with heavy starting duty	2	488056	3- phase squirrel – cage motor, 52kw, 380v, 50Hz, n=1500rpm	2
28	816	488247/1	3- phase squirrel – cage motor, 1.1kw,380v,50Hz,n=1500rpm	Rotary air lack	2	488018	3- phase squirrel – cage motor, 1kw, 380v, 50Hz, n=1500rpm	2
29	816	488247/2	3- phase squirrel – cage motor, 3kw, 380v, 50Hz, n=1500rpm	Vessel for packing machine	2	488019	3- phase squirrel – cage motor,1.5kw, 380v, 50Hz, n=1500rpm	2
30	816	488247/3	3- phase squirrel – cage motor,0.18kw,380v, 50Hz, n=3000rpm	Serve drive	2	488022	3- phase squirrel – cage motor,0.18kw,380v, 50Hz, n=3000rpm	2
31	816	488247/4	3- phase squirrel – cage motor,3kw, 380v, 50Hz, n=1500rpm	Bag discharging conveyor	2	488021	3- phase squirrel – cage motor,2.8kw, 380v, 50Hz, n=1500rpm	2
32	817	488249	3- phase squirrel – cage motor,2.2kw, 380v, 50Hz, n=1500rpm	Sack conveyor	2	488031	3- phase squirrel – cage motor, 2.05kw, 380v, 50Hz, n=1500rpm	2
33	820	488251	3- phase squirrel – cage motor,1.1kw,380v,50Hz,n=750rpm	Bag cleaning set	2	488048	3- phase squirrel – cage motor,1.1kw,380v,50Hz,n=1500rpm	2
34	821	488253	3- phase squirrel – cage motor,3kw,380v,50Hz,n=1500rpm	Screw conveyor	2	488029	3- phase squirrel – cage motor,2.8kw,380v,50Hz,n=1500rpm	2
35	824	488255	3- phase squirrel – cage motor,4kw,380v,50Hz,n=1500rpm	sack conveyor	2	488046	3- phase squirrel – cage motor,3.8kw,380v,50Hz,n=1500rpm	2
22	807	488231	3- phase squirrel – cage motor,4kw,380v,50Hz,n=3000rpm	Radial blower with heavy duty	4	488009	3- phase squirrel – cage motor,3.8kw,380v,50Hz,n=1500rpm	4
23	808	488235	3- phase squirrel – cage	Screw		488013	3- phase squirrel – cage	

			motor,22kw,380v,50Hz,n=1500rpm	conveyor	2		motor,22kw,380v,50Hz,n=1500rpm	2
24	809	488237	3- phase squirrel – cage motor,15kw,380v,50Hz,n=1500rpm	Screw conveyor	4	488015	3- phase squirrel – cage motor,15kw,380v,50Hz,n=1500rpm	4
25	811	488241	3- phase squirrel – cage motor,22kw,380v,50Hz,n=1000rpm	Bucket elevator drive	2	488013	3- phase squirrel – cage motor,20kw,380v,50Hz,n=970rpm	2
26	811	488243	3- phase squirrel – cage motor,4kw,380v,50Hz,n=1500rpm	Maintenance drive	2	488014	3- phase squirrel – cage motor,3.8kw,380v,50Hz,n=1000rpm	2
27	812	488245	3- phase squirrel – cage motor,1.1kw,380v,50Hz,n=1000rpm	Vibration screen	2	488014	3- phase squirrel – cage motor, 1.1kw,380v,50Hz,n=1000rpm	2

Appendix B: Support Programs for Industrial Energy Efficiency Improvement

This appendix provides a list of energy efficiency support available to industry. A brief description of the program or tool is given, as well as information on its target audience and the URL for the program.

Tools for Self-Assessment

Steam System Assessment Tool

Description: Software package to evaluate energy efficiency improvement projects or steam
. Systems. It includes an economic analysis capability.

Target Group: Any industry operating a steam system

Format: Downloadable software package (13.6 MB)

URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Steam System Scoping Tool

Description: Spreadsheet tool for plant managers to identify energy efficiency opportunities in industrial steam systems.

Target Group: Any industrial steam system operator

Format: Downloadable software

URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Optimization of Insulation of Boiler Steam Lines

Description: Downloadable software to determine whether boiler systems can be optimized through the insulation of boiler steam lines. The program calculates the most economical thickness of industrial insulation for a variety of operating conditions. It makes calculations using thermal performance relationships of generic insulation materials included in the software.

Target Group: Energy and plant managers

Format: Downloadable software

URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Motor Master+

Description: Energy-efficient motor selection and management tool, including a catalogue of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.

Target Group: Any industry

Format: Downloadable software

URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

ASDMaster: Adjustable Speed Drive Evaluation Methodology and Application

Description: Software program helps to determine the economic feasibility of an adjustable speed drive application, predict how much electrical energy may be saved by using an ASD, and search a database of standard drives.

Target Group: Any industry

Format: Software package

URL: http://www.epri-peac.com/products/asdmaster/asdmaster.html

Approach to Motor Management

Description: A step-by-step motor management guide and spreadsheet tool that can help motor service vendors, utilities, energy-efficiency enters, organizations, and others convey the financial benefits of sound motor management

Target Group: Any industry

Format: Downloadable Microsoft Excel spreadsheet

URL: http://www.motorsmatter.org/tools/123approach.html

AirMaster+: Compressed Air System Assessment and Analysis Software

Description: Modelling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices

Target Group: Any industry operating a compressed air system

Format: Downloadable software

URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Fan System Assessment Tool (FSAT)

Description: The Fan System Assessment Tool (FSAT) helps to quantify the potential benefits of optimizing a fan system. FSAT calculates the amount of energy used by a fan system, determines system efficiency, and quantifies the savings potential of an upgraded system.

Target Group: Any user of fans

Format: Downloadable software

URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Combined Heat and Power Application tool (CHP)

Description: The Combined Heat and Power Application Tool (CHP) helps industrial users evaluate the feasibility of CHP for heating systems such as fuel-fired furnaces, boilers, ovens, heaters, and heat exchangers.

Target Group: Any industrial heat and electricity user

Format: Downloadable software

URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

Pump System Assessment Tool 2004 (PSAT)

Description: The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.

Target Group: Any industrial pump user

Format: Downloadable software

URL: http://www1.eere.energy.gov/industry/bestpractices/software.html

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