CHAPTER 1

INTRODUCTION

1.1 Energy efficiency

Malaysian government's vision is to turn Malaysia into a humane industrialized developed country by the year 2020 and hence demanding a noticeable energy consumption in industrial sector. Different industries include wood, food, cement, pulp and paper industries etc. Energy efficiency means using less energy to produce the same amount of useful work. Energy efficiency improvement is one of the most important functions to reduce energy cost as well as production cost in the food industry. Motors, boilers, air compressor systems, and lighting are major consumers of energy in food industrial sector in Malaysia.

Energy efficiency in food industrial sector can cause cutting down of energy losses. Through proper analysis and projection it can be possible to save energy and cost as much as possible. Furthermore in Malaysian food industry, electricity and fossil fuels are main sources of energy being used. Fossil fuels such as oil, gas, and coal are also used to generate electricity. These fossil fuels have impact on environment where carbon dioxide emission, contributes to green house effect and global warming. The industrial sector still remains as one of the major energy user, especially when compared to other sectors. This indirectly indicates the importance given to Malaysian industrial sector by the government.

Greenhouse gases such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxide (NO_x), carbon monoxide (CO) have been giving a tremendous effect on Earth's climate. The concentration of these gases has increased over the millennium. A major contributor of these gases is produced by burning fossil fuels. Burning fossil fuels release emissions of gases mentioned above which are known to cause the greenhouse gas emission effect, acid rain and other negative impacts on the environment and humankind.

CO_2 is a colorless, odorless gas, produced when any form of carbon is burned in an excess of oxygen. CO_2 greenhouse effect in the world is obvious where the atmosphere is trapping more heat and that has to escape to space. This is causing global warming as result melting of icebergs are observed in Arctic and Antarctica as mentioned by Mahlia (Mahlia, 2002).

Mahlia (2002) mentioned other gases like SO_2 is a colorless gas, from the family of sulfur oxides. Fossil fuel combustion is the main sources of SO_2 production by human activities such as industrial sector. NO_x is a collective term used to describe two types of oxides of nitrogen, namely nitric oxide (NO) and nitrogen dioxide (NO_2). NO is a colorless, flammable gas with a slight odor. NO_2 is a nonflammable gas with a detectable smell and in certain concentrations it is highly toxic, which in the long term can cause serious lung damage. NO_2 plays a major role in the atmosphere by producing ozone or smog.

In the atmosphere, NO_2 is mixed with water vapor producing nitric acids, which subsequently precipitate as acid rain. CO is a colorless, odorless, poisonous gas. Exposure to CO reduces the blood's ability to carry oxygen. CO is a product of incomplete burning of hydrocarbon based fuels.

Energy efficiency is significant in today's life to mitigate greenhouse gases to ensure the environment and health of fellow humankind of present and coming generation. If Malaysia puts herself in energy efficiency path, she will become one of green developing nation and would be a reputed country in international arena.

1.2 Worldwide energy consumption in Food industry

The food industry is present throughout Malaysia and contributes considerably to its economy. Typical food factories consume a considerable amount of energy from processing to preservation of food. Electric energy is required to run all the process machinery. Therefore improvement of energy efficiency is a very crucial factor in food industry to improve the environmental performance, emissions reduction and increase its profitability.

Malaysian food industrial sector is consuming about 14% of total industrial energy consumption (Mustaffah and Azma, 2006). Food industrial sector is one of the largest manufacturing sectors consuming energy. In the United States it consumes about 7% of the total electricity used by the manufacturing sector (Okos *et al.*, 1998). In the European Union energy used in food industry sector is about 8% of the energy used by the manufacturing sector or about 2.5% for the total energy demand in the year 2001 (Ramirez, 2005). Moreover, the energy consumption used in the food and tobacco sector in Netherlands accounted for about 9% of the final industrial energy demand (Ramirez *et al.*, 2006). In some developing countries, energy consumption in the food processing industry could be very high. In Thailand, the food and beverage manufacturing sector accounted for about 30% of the total energy consumption (Wang, 2008). In more industrialized countries like Brazil and India, less than 11% of the total commercial energy goes to the food production system.

In 2002 Organisation for Economic Cooperation and Development (OECD) countries energy consumption used for industrial sectors accounted about 70% for only four manufacturing sectors; the food industry shares only 6% of the industrial energy demand, accounting for about 2% of the total energy demand. Australia food industry accounted

13% for the total energy used for manufacturing sectors (Ramirez, 2005). However, it should be noted that the share of energy consumed in the food industrial sectors is considerable; therefore reducing these energy can improve energy efficiency and reduce the impact of emission to the environment.

1.3 Objectives of the study

The industrial sector is known as the largest consumer of energy in Malaysia, and has proven the need and the importance of improving the energy performance of the industrial processes. This research and dissertation will exhibit and show the importance of the methods to improve food industrial sector in terms of energy saving, emissions reduction, cost-benefit analysis and payback period as well. To achieve these improvements a case study has been undertaken to investigate the following aspects.

a) High efficiency motors and variable speed drives.

b) Heat recovery systems for the boilers.

c) High efficiency lamp (T-5) for the lighting.

d) And repairing leakages of air compressor systems.

The outcome of this investigation is expected to give the operators many useful choices in many applications.

1.4 Scope of the study

The overall aim of this dissertation is to examine the development of energy use in food industrial sector in Malaysia. Specific goals are:

a) High efficiency motors installation.

(i) The data of electrical motors by watt hours for food industry in Malaysia is obtained from literatures.

(ii) Emission guide and fuel prices in Malaysia are all obtained from literatures.

(iii) The bill saving and payback period are included in this study.

(iv) Types of greenhouse gases have been considered to estimate emissions reduction are CO_2, SO_2, NO_x and CO.

b) Variable speed drives installation.

(i) The data of electrical motors by watt hours and the emission guide for food industry in Malaysia is obtained from literatures.

(ii) The percentage of speed reduction by using VSDs ranges from 10-60%.

(iii) The cost benefits analysis and payback period have been considered in this study.

(iv) Types of greenhouse gases have been considered to estimate emissions reduction are CO_2, SO_2, NO_x and CO.

c) Heat recovery systems installation.

(i) Seven food and beverage factories in Malaysia have been considered to study the benefits of installing heat recovery system.

(ii) Emission guide and fuel prices in Malaysia are all obtained from literatures.

(iii) The bill saving and payback period are included in this study.

(iv) Types of greenhouse gases have been considered to estimate emissions reduction are CO_2, SO_2, NO_x and CO.

d) High efficiency lamp T5 installation for the lighting.

(i) Ten food and beverage factories in Malaysia have been considered to study the benefits of installing high efficiency lamp T5.

(ii) Emission guide and fuel prices in Malaysia are all obtained from literatures.

(iii) The bill saving has been considered in this study.

(iv) Types of greenhouse gases have been considered to estimate emissions reduction are CO_2, SO_2, NO_x and CO.

e) Repairing leaks of air compressor systems.

(i) Ten food and beverage industries in Malaysia have been considered to study the benefits of repairing leakage.

(ii) Emission guide and fuel prices in Malaysia are all obtained from literatures.

(iii) The cost benefits analysis has been considered in this study.

(iv) Types of greenhouse gases have been considered to estimate emissions reduction are CO_2, SO_2, NO_x and CO.

1.5 Organization of dissertation

This dissertation comprises five chapters. The chapters are organized as follows:

Chapter 1 discusses the energy efficiency and emission issue. It includes effect on environment, due to operation of worldwide food industry. It shows the energy consumption in Malaysia and around the world especially in food industrial sector and finally objectives and scope of the study.

Chapter 2: this chapter provides a literature review for the study. It has started by giving a historical overview of energy demand trend in Malaysia, specifically demand in industrial sector followed by comprehensive definitions of motors, high efficiency motors, variable speed drives, boilers, heat recovery approaches, lighting, air compressor systems, and repairing leakages of air compressor systems. The next part of each approach gives a background for all of these applications, and energy saving associated with these approaches.

Chapter 3 explains in detail, the research methodology and design. This chapter provides an explanation of methods applied to calculate energy saving, emission reduction, cost benefit analysis and payback period while the five concepts; high efficiency motors, VSDs, heat recovery, lighting, and repairing leakages methods in the food industrial sector being provided in Malaysia.

Chapter 4 is dedicated to present all the results being obtained from the input data and present the findings of the study are presented systematically. A detailed discussion and analysis of all the findings and comparison with the existing results included in the literature are incorporated here.

Chapter 5 provides a summary of the key findings of the research and some suggestions for the future studies.

CHAPTER 2

LETERATURE REVIEW

2.1 Introduction

Present literature review attempts to discover major publications, those will provide an insight understanding about the topic and related issues. The review also reveals the limitations encountered in the area of research which is related to the Malaysian food industrial sector.

This chapter emerges with an overview of energy demand trend in Malaysia, especially for the industrial sector. This part is dedicated to show the importance of tracing and tracking energy demand in Malaysia and combining it with the efforts towards improving energy efficiency by the methods, which will be covered later in this study. This will be followed by describing motors, with high efficiency and variable speed drive, technical description of them and benefits. Part three is describing boiler which use heat recovery system (economizer) and benefits. Part four is about lighting. In this part we begin with types of lamp and secondly we reveal how to save energy by replacing lamps. Finally is the benefit of replacement of new lamps is incorporated. Last part of this chapter will be specific on talking about repairing leakage for air compressed system.

2.2 Energy demand trend in Malaysia

Over the past few years, rapid growth of industrial sector has resulted in overall increase in energy demands in Malaysia. One of the recent study reveals that; Malaysian energy consumption grew at a rate of 5.6 percent between 2000 and 2005 to reach 38.9 Mtoe in 2005 (APEC, 2006) and expected to increase the overall energy demand at an average rate about 6% per annum in 2010 (Saidur *et al.*, 2009c). Figure 2.1 shows the energy demand in Malaysia in the year 1999 to 2010. It can be seen that the energy demand in Malaysia increases rapidly, almost 20% within 3 years periods (from 1999 to 2002) (Mohamed and Lee, 2006). Another study has been reported, Malaysia's final energy demand is projected to grow at 3.9 percent per year, reaching 98.7 Mtoe in 2030 (APEC, 2006).

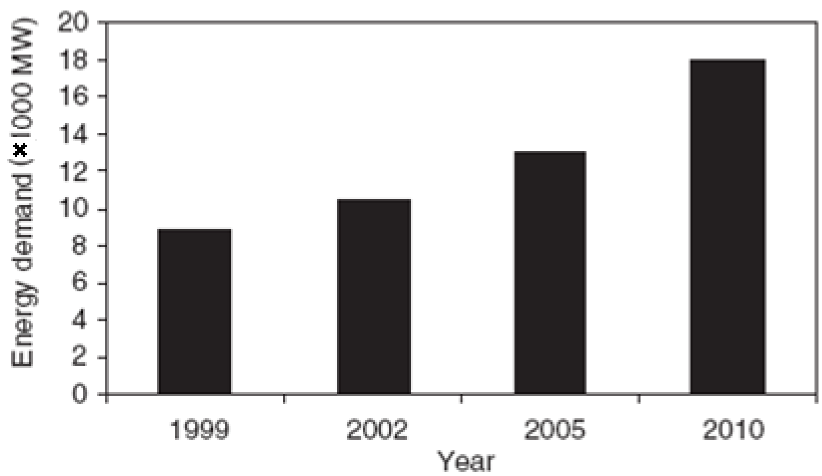

Figure 2.1: Energy demand in Malaysia (Mohamed and Lee, 2006).

The industrial sector has the highest growth rate of 4.3 percent, followed by transport at 3.9 percent, residential at 3.1 percent and commercial at 2.7 percent as shown in Figure 2.2. Energy demand in the industrial sector is projected to grow at an average annual rate of 4.3 percent until 2030, lower than its average annual growth of 7.5 percent over the past two decades (APEC, 2006). Industrial sector is highest energy consumer among all Malaysian sectors as shown in Figure 2.3 (Saidur *et al.*, 2009d) and overall factories have been tabulated in Table 2.1 (Saidur *et al*., 2009b).

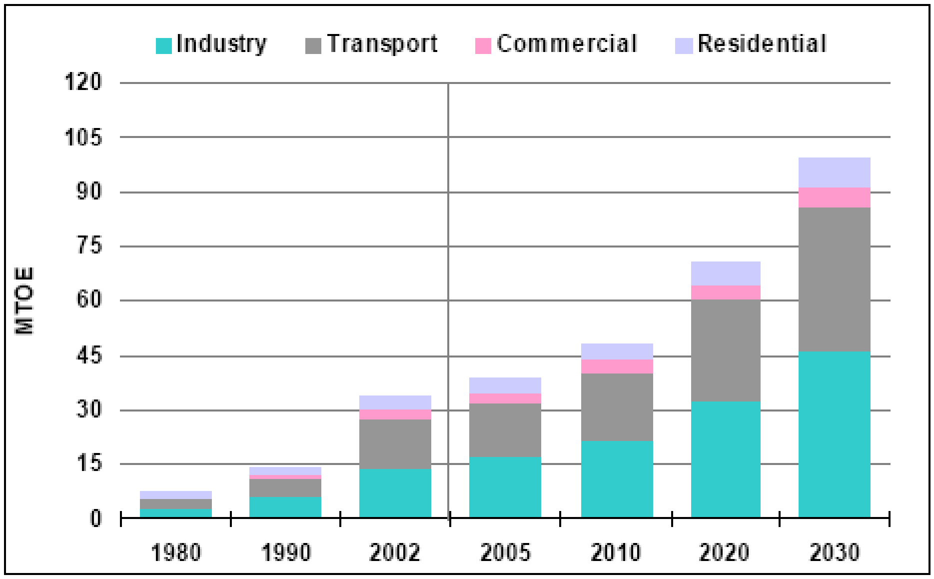

Figure 2.2: Final Energy Demands (APEC, 2006).

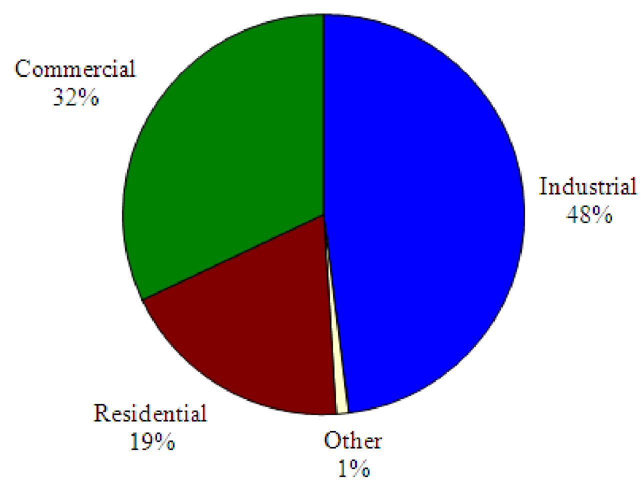

Figure 2.3: Final energy uses in Malaysia (Saidur *et al*., 2009b)

Table 2.1 Locations and number of factories in all Malaysian industrial sectors (Saidur *et al*., 2009b)

Location	Number of audit factories
Central (Selangor, Kuala Lumpur)	41
North (Perak, Penang, Kedah and Perlis)	25
South (Johor, Melaka and Negeri Sembilan)	14
East (Pahang and Terengganu)	11
Total (East coast of Malaysia)	91

2.3 Motor

A motor is an apparatus used to convert electrical energy into mechanical energy to transform it into useful work. Industrial electric motors have been available for nearly a century. In that time, there have been made a great many changes (Cowern, 2010). Refrigerators, vacuum cleaners, air conditioners, fans, pumps, and multitudes of other appliances and devices all use electric motors to convert electrical energy into useful mechanical energy. Electricity is the main energy source used in the food industry. In food industrial sectors, about 48% of the electricity is used for driving motors (Wang, 2008). Motors, which are used to drive refrigerators, fans, compressors, and pumps, are the main consumer of electricity in the food industry. It is most important to consider the energy efficiency of motors and the purchase of electricity used to drive motors as well. The electricity bill may be estimated from power demand, electricity consumption, power factor, and ratchet charge. The process of converting electrical energy to mechanical energy is never perfect. As much as we would like to have a 100% efficiency motor, it is impossible to make a machine that convert all electrical energy into mechanical output. The output intake is always less than 100% (Cowern, 2010).

In Malaysia, approximately 48% of total energy is used to drive industrial motors, as shown in Figure 2.4, Table 2.2 shows the results of motors used in Malaysian industrial sectors (Saidur *et al.*, 2009b). The energy consumed to drive electric motors used in industries is about 65% of the total energy consumption in the European Union and Turkey (Saidur *et al.*, 2009b). In many industrialized countries, more than 70% of the total energy is consumed by electric motors (Saidur *et al.*, 2009b). This means that, the impact of energy consumption by using electric motors is very scary and the energy saving can be achievable. There are many ways to save energy from consumption of that electrical motor. In this study we will introduce two ways to save energy from consumption of motor such as using high efficiency motors and variable drive speed.

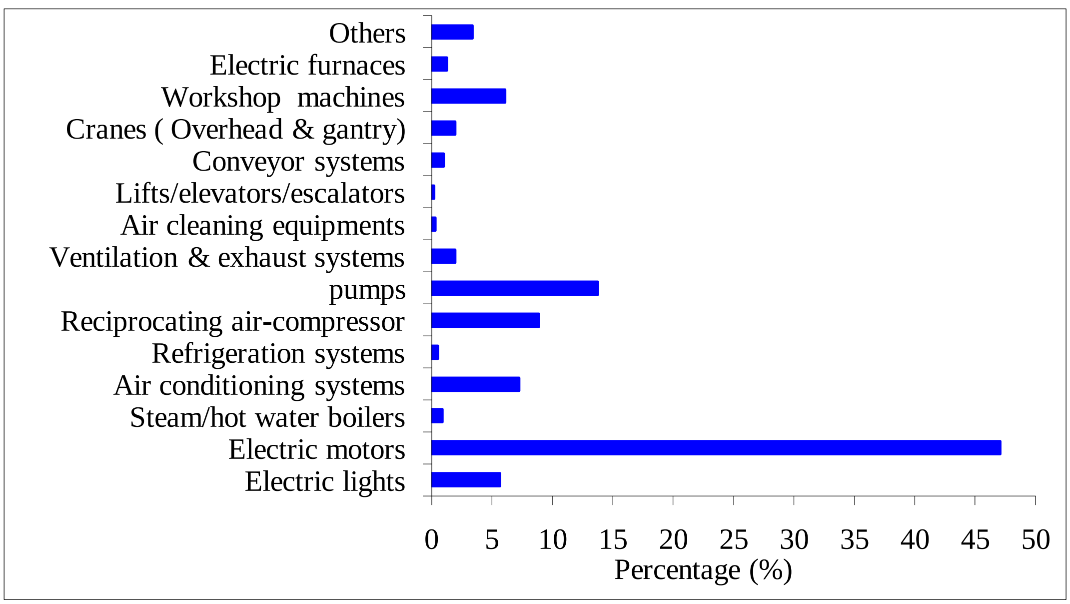

Figure 2.4: End use energy breakdowns in Malaysian industrial sector (Saidur *et al.*, 2009b).

Table 2.2 Results of industrial Malaysian energy audit (Saidur *et al*., 2009b)

Motors (HP)	Number of motors	Operating hours (Hours)
1	3968	
1.5	331	
2	1653	
3	2976	
4	13,556	
5.5	331	
7.5	661	6000
15	165	
20	3306	
25	992	
30	331	
40	661	
50	331	
60	827	
75	165	

2.3.1 High efficiency motors

The escalation in the cost of electric power that began in 1972 made it increasingly expensive to use inefficient electric motors (Emadi and Andreas, 2005). The majority of electrical energy consumed in most industrial sectors is used to run electric motors. Energy efficiency motor is of higher quality than standard motor. Most electric motors are designed to operate at 50% to 100% of their rated load. Optimum efficiency is generally achieved at 75% of the rated load since motors are usually designed for their starting requirement of high load (Wang, 2008). Motor operates under loaded (mean less than 50%) are working inefficiently. This is good to replace. Replacement of inefficient motor with efficient one can decrease energy consumption. The standard motors have a substantial amount of losses which occur during the operation like magnetic core loss, windage and friction, stator power losses, rotor power losses, and stray load losses. Table 2.3 shows types of losses in different motor power (McCoy *et al*., 1993; Saidur, 2009). Making improvements in efficiency of motor for all of these losses by replacing inefficient motor with high efficiency motor can save significant amount of energy and cost. Reduced losses means an energy efficiency motor produces a given amount of work with less energy input than that of a standard motor (McCoy and Douglass, 1996). The cost of high efficiency motor is about 10 to 25% more than that of standard motors (Garcia *et al.*, 2007).

Table 2.3 Typical losses at different motor power 1800RPM (McCoy *et al*., 1993; Saidur, 2009)

Types of loss	Motor (HP) 25	Motor (HP) 50	Motor (HP) 100
Stator	42	38	28
Rotor	21	22	18
Core losses	15	20	13
Windage and friction	7	8	14
Stray load	15	12	27

2.3.1.1 Energy saving through high efficiency motors

A high efficiency motor uses materials prone to low loss to reduce core and copper losses. Therefore, it generates less heat and requires a smaller and more energy efficient cooling fan (Saidur *et al.*, 2009b). However, energy efficiency motors can reduce significant amount of energy losses and operating costs. The efficiency gains are obtained through the use of refined design, better materials, and improved construction (McCoy *et al.*, 1993).

Use of energy efficient motor is a most important method to improve motor efficiency and reduce motor losses. Even though standard motors operate efficiently, with typical efficiencies ranging between 83 and 92 percent, energy efficiency motors perform significantly better. An efficiency gain from only 92 to 94 percent results in a 25 percent reduction in losses (McCoy *et al.*, 1993) Table 2.4 shows the efficiency for standard and high efficiency motors at different motor load (Saidur and Mahlia, 2009; Saidur *et al.*, 2009d). Since motor losses result in heat rejection into the atmosphere, reduction of losses can significantly reduce cooling loads in an industrial facility's air conditioning system. The replacement by energy efficiency motor translates into substantial energy and dollar savings are very large amount.

One of the recent studies has been made by Saidur and Mahlia (2009) they found that the energy saving on replacement of standard motors with high efficiency motors is a considerable amount. Based on estimation, it has been found that 15,111, 6,507 and 4,295 MWh of energy can be saved for 50, 75 and 100% motor loadings, respectively. These energy savings correspond to cost savings of US$967,074, US$416,461 and US$274,892, respectively. It was also found that 7,562,070 kg of CO_2, 45,266 kg of SO_2, 21,326 kg of NO_x and 4,599 kg of CO could be avoided by using energy efficiency motors at 50% load.

Table 2.4: Efficiency for standard and high efficiency motors at different loads (Saidur and Mahlia, 2009; Saidur *et al.*, 2009d)

Motor (HP)	Load (50%)		Load (75%)		Load (100%)	
	E_{std}	E_{ee}	E_{std}	E_{ee}	E_{std}	E_{ee}
1	70.05	75.28	74.43	79.49	77	80.97
1.5	76.04	80.06	78.03	81.28	78.5	82.55
2	77.2	80.02	79.29	83.07	81	83.55
3	77.78	82.44	79.87	84.55	81.5	85.01
4	81.07	83.69	82.39	85.24	82.9	85.96
5.5	81.15	84.35	84.73	86.5	85.3	87.75
7.5	84.07	85.51	86.23	87.58	86.61	89.5
15	84.92	88.32	86.45	89.85	87.94	90.44
20	86.03	88.51	87.58	91.05	88.95	91.64
25	87.61	90.26	88.39	91.66	89.5	91.8
30	88.43	90.89	89.32	91.73	90.7	91.83
40	88.15	90.39	90.54	91.91	90.36	92.85
50	89.63	91.16	89.86	92.58	92.06	93.28
60	87.89	90.07	91.31	92.09	91.78	93
75	88.77	90.86	90.19	92.72	92.44	93.02

U.S industrial sector performed study in northwest of U.S. and found that the potential energy savings is about 52.7 MWa by replacing standard motors with high efficiency motors. This savings is annually worth of US$13.8 million considering electricity price of only US$0.03/kWh (McCoy *et al.*, 1993).

Another published case study has been conducted at the Odwalla Juice Company's facility in Dinuva, California. The found that the installation of more energy efficiency motors would lead to US$6,300 in annual cost savings with a simple payback period of only eight months (Masanet *et al.*, 2008).

Saidur *et al.*, (2009b) have performed study for energy and emission analysis for industrial motors in Malaysia. They found that the energy savings when replacing standard motor with high efficiency motor is about 1765, 2703 and 3605 MWh of total energy for 50%, 75% and 100% motor loading, respectively. Similarly, the bill savings are US$115,936, US$173,019 and US$230,693, respectively for the payback period between 0.53 to 5.05 years for different percentages of motor loading.

2.3.1.2 Benefits of high efficiency motors

Benefits of installing energy efficiency motors can reduce operating costs in several ways. Not only saving energy does reduce monthly electrical bill, it can also eliminate the need to expand the electrical supply. Besides that, high efficiency motors run at lower temperatures than that of equivalent standard motors. Consequently, increases motor insulation, bearing life, and elongates periods between scheduled maintenance actions. Thus generating less waste heat in the space around the motor which causes reduced building ventilation and air conditioning requirements (Cowern, 2010; McCoy *et al.*, 1993). They have inherent design character of ability to tolerate wider voltage variations and when necessary to operate at higher ambient temperatures. Additional benefits typically associated with energy efficiency motors include (European IPPC Bureau, 2008; McCoy *et al.*, 1993):

(i) Extended lubrication cycles due to cooler operation

(ii) Better tolerance to thermal stresses resulting from stalls or frequent starting

(iii) The ability to operate in higher ambient temperatures

(iv) Increased ability to handle overload conditions due to cooler operation and a 1.15 service factor

(v) Fewer failures under conditions of impaired ventilation

(vi) More resistance to abnormal operating conditions, such as under and over voltage

(vii) More tolerance to poorer voltage and current wave shapes

(viii) A slightly higher power factor in the 100 hp and lower size range, which reduces distribution system

(ix) Losses and utility power factor penalty changes

(x) Noise is reduced

(xi) Ability to handle overload condition improves

These benefits however, depend on many factors. Based on manufacturer design practices, energy efficiency motors may have higher or lower power factors than their standard efficiency counterparts (McCoy *et al*., 1993).

2.3.2 Variable speed drives

Nowadays, technology requires different speeds in many applications where electric motors are used. Electric motors using traditional control methods have mainly two states stop and operate at maximum speed. In most motor installation, motors are sized to provide the maximum power output required. If the rotational speed is constant at its maximum value to provide the maximum designed load, the power input to the motor remains constant at the maximum value. However, if the load decreases, significant energy savings can be achieved if the rotational speed of the motor is decreased to match the load requirement of the device driven by the motor (Hordeski, 2003). Nevertheless, the majority of motors operate only at 100% speed for short periods of time. This often results in many systems operating inefficiently during long periods of time. Consequently, there are significant energy losses occurring during the operation time. Thus, the potential of reduction of this loss can be achievable by installing variable speed drives (VSDs) system to match speed with the related load. VSD has become very popular because of their advantages over traditional control methods. Using VSD, the speed of a motor or generator can be controlled and adjusted to any desired speed. Besides adjusting the speed of an electric motor, VSD can also keep an electric motor speed at a constant level where the load is variable (Emadi and Andreas, 2005).

Variable speed drives can change the speed of the motor by changing the voltage and frequency of the electricity supplied to the motor based on the requirement of load. This is accomplished by converting the AC to DC and then by inverting the DC to a synthetic AC output with controlled voltage and frequency based on various switching mechanisms (Wang, 2008).

2.3.2.1 Variable speed drives systems

Variable speed drives or variable frequency drives are electronic devices, which match motor speed to that required for the application. To vary the frequency of motor is more convenient, cost efficient and of precise design. The output voltage and frequency are determined by actual power needs of the motor. Whether the speed of the drive is set manually by an operator or automatically by a control system, most motor can benefit from VSD. A drive provides many different frequency outputs. A variable speed drives essentially consists of a rectifier which convert the AC voltage to DC and the inverter, convert DC voltage to the desirable AC current as shown in Figure 2.5. Controls of the VSD enables exchange of data between VSD and peripherals, gathers and reports fault messages and carry out protective functions of the VSD (Jayamaha, 2006).

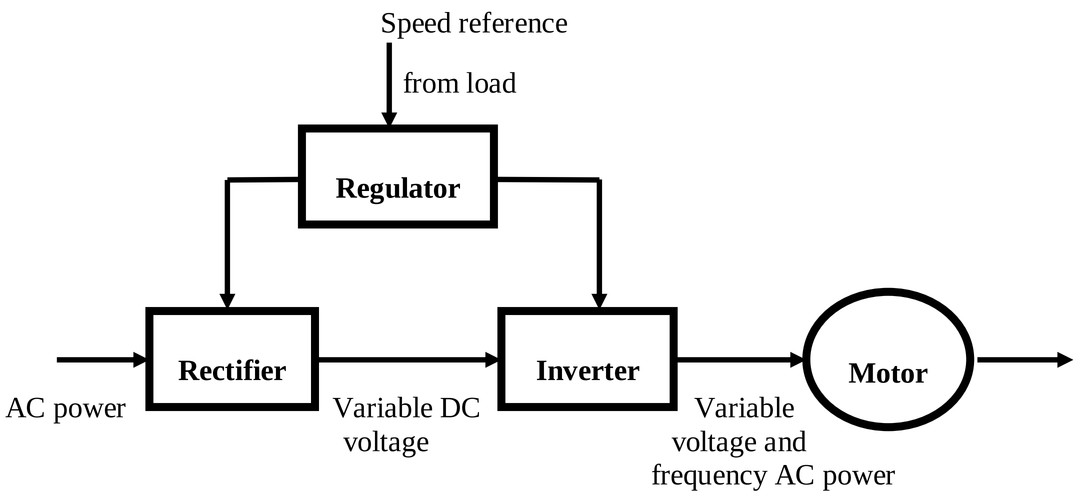

Figure 2.5: Components of a variable speed drives (Saidur, 2009).

2.3.2.2 Energy savings through VSDs

Variable speed drives is a best way to reduce energy consumption of motors. Energy used by electric motors generally represents up to 75% of a plant's entire energy use and about two-thirds of the motors in industrial use are for fans and pumps which do not need constant motor speeds (Saidur, 2009). A small change in motor speed can cause a significant change in energy consumption as shown in Figure 2.6. VSD can save about 15–40% of the energy (in many cases) and extend equipment life by allowing gentle start-up and shutdown (Saidur *et al*., 2009b).

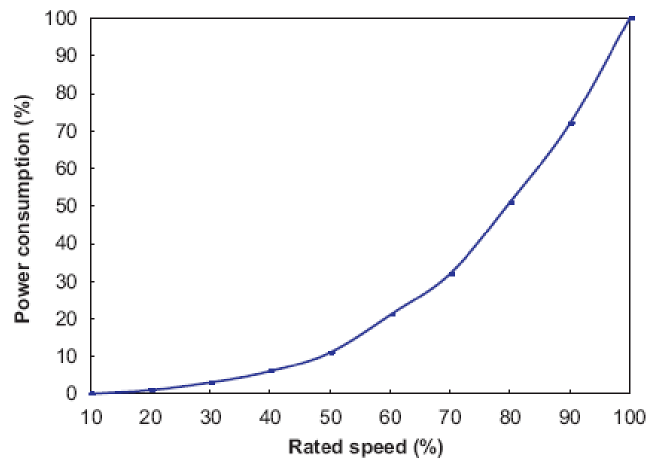

Figure 2.6: Relationship between motor power reduction and rated speed (Saidur *et al*., 2009b).

The department of energy estimated that replacing conventional motors with adjustable speed motors in appropriate applications would result in saving 41% of the energy used in industrial motors. Power consumption actually drops far more than the drop in motor speed, so the savings can accumulate quickly. For example a 10% reduction in shaft speed results in a 27% decrease in power consumption (Saidur, 2009). Table 2.5 shows the energy savings associated with the speed reductions as a result of using VSD.

Table 2.5 potential of energy saving from VSD (Saidur, 2009)

Average speed reduction (%)	Potential energy savings (%)
10	22
20	44
30	61
40	73
50	83
60	89

A study conducted in china by Nadel *et al*, (2001), presents that the potential of energy saving through variable speed control can be achievable. The annual energy saving is as high as 40 billion kWh annually. The percentage of energy savings in VSD applications typically ranges from 20 to 40% and the payback period can be recovered in 1-3 years.

Another published case study on a fruit and vegetable industry, at Odwalla Juice Company Dinuva, California, showed that the installation of VSD on the pump's motor could save about US$31,500 in electricity costs per year with a payback period of six months (Masanet *et al*., 2008).

2.3.2.3 Benefits of variable speed drives

Most motors are designed to operate at a constant speed and provide a constant output. While in many cases this may be more than adequate, it is not the all. Installing variable speed drive can improve energy efficiency of motors. There are many advantages of installing VSD like (Saidur, 2009):

(i) Energy cost savings

(ii) Reliability improvements

(iii) Simplified pipe systems (elimination of control valves and bypass lines)

(iv) The soft start characteristic of VSD eliminates voltage dip and reduces starting shock on motor.

(v) Reducing maintenance.

VSDs installation can increase energy efficiency at the same time savings energy consumption, improve power factor and process precision as well, and afford other performance benefits such as soft starting and over speed capability. They also eliminate throttling mechanisms and frictional losses affiliated with mechanical or electromechanical adjustable speed technologies and expensive energy-wasting. The other benefits of variable speed drives include prolonging the life of the equipment, by adjusting motor speed to meet load requirements. Generally, these energy savings translate into cost savings and reduction in greenhouse gas emissions for a given level of production (Mustaffah and Azma, 2006).

2.4 Boiler

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process (Bureau of Energy Efficiency, 2010a). The steam is used for heat process concentrating liquid foods, drying, sterilizing, and generate mechanical power and electricity for some food processing facilities. Typically boiler steam generation is used for food processing facilities. In the food industry, about 57% of the fossil fuel consumption is used to generate steam. Steam is used in many important applications throughout the typical food processing facility. Boilers consume significant amounts of energy in food industry, and energy losses through flue gas are very huge. Thus minimizing these losses is absolutely essentially.

The heat produced by the burning fuel cannot be fully transferred to the boiler. Since most of the heat losses from the boiler appear as heat in the flue gas (Bujak, 2008). Typically, the flue gases leaving a boiler are at high temperature. Thus, there is a potential to recover heat from these gases. The essential is a quality of heat not the amount but rather its “value”. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized. Also the potential for energy saving depends on the type of boiler installed and the fuel used (Bureau of Energy Efficiency, 2010a).

Table 2.6 shows fuel consumption used in Malaysian food industries (PTM, 2009). In many boilers, the flue gases still have useful amounts of energy even after they have passed through the boiler. Heat can be recovered from the flue gas by passing it through a heat exchanger (commonly called an economizer) installed after the boiler, as shown in Figure 2.7 (Jayamaha, 2006). In many applications, economizers provide effective method to increase boiler efficiency by transferring heat of the flue gases to incoming feed water.

2.4.1 Heat recovery systems (economizer)

Economizer is a heat exchanger that transfers energy from the boiler exhaust gas to the boiler feed water in the form of "sensible heat." Sensible heat is created by the transfer of the heat energy of one body; in this case “exhaust gas” to another cooler body the boiler feed water. This reduces a boiler exhaust temperature while preheating boiler feed water and increasing overall efficiency. Economizer is one of the effective methods of heat recovery from flue gas to save energy in a boiler as shown in Figure 2.7.

Table 2.6 Results of the Malaysian food industrial energy audit (PTM, 2009)

Factory name	Location	Diesel consumption (Liter/year)
A	Pahang (East)	11,245,000
B	Pahang (East)	2,124,000
C	Melaka (central)	1,559,000
D	Perak (North)	560,000
E	Penang (North)	452,000
F	Penang (North)	150,000
G	Sarawak	86,000
Total		**16,176,000**

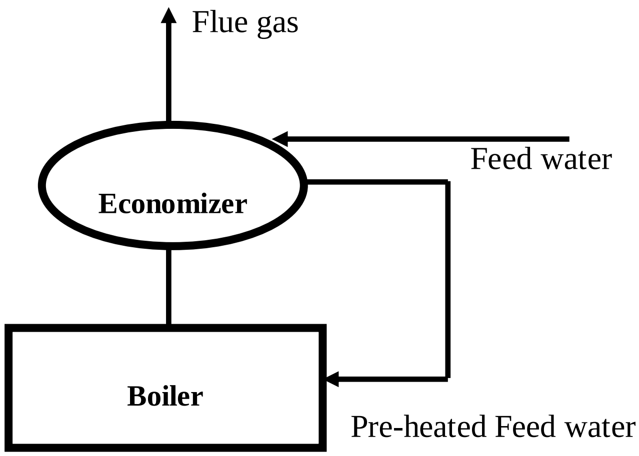

Figure 2.7: A typical block diagram of economizer system (Jayamaha, 2006)

2.4.2 Energy savings through heat recovery systems (economizer)

A heat produced by the burning fuel cannot be completely transferred to water or steam in the boiler. There a significant amount of energy loss through flue gases appear as heat (Bujak, 2009).The recovery of this heat by economizer results in substantial energy savings and minimization of heat losses. About 10 to 20 percent of the total heat energy is normally exhausted from the boiler through the stack without a waste heat recovery unit (Jayamaha, 2006). The energy loss from flue gas increases with the increase in excess air. Depending on the fuel, the temperature of leaving gases can be in the range of 150°C to 250°C (Jayamaha, 2006).

Economizers typically increase boiler efficiency by 2.5% to 4%, depending on the type of heat transfer surfaces and the allowable pressure drop. As per general rule, for every 40°C reduction in boiler gas temperature, 1% efficiency is gained (European IPPC Bureau, 2008; Willems and Pipkin, 2007). By recovering through waste heat economizer one can often reduce the fuel requirement about 5 to 10% and the payback period less than 2 years (European IPPC Bureau, 2008).

One of studies has been conducted for a small boiler. The result of the study shows, the energy savings roughly about 5 GWh/y and cost savings about EUR 60,000/y and about 1000 tones of CO_2 can be attained (European IPPC Bureau, 2008).

2.4.3 Benefits of heat recovery system (economizer)

Benefits of waste heat recovery by using economizer can be generally classified in two groups:

a) Direct Benefits

Recovery of waste heat has a direct effect on the efficiency of the process. This is reflected by reduction in the utility consumption & costs, and process cost (Bureau of Energy efficiency, 2010b).

b) Indirect Benefits

(i) Reduction in pollution: A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off gases, oil sludge etc, released to atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels.

(ii) Minimum maintenance required

(iii) Reduction in equipment sizes: Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes of all flue gas handling equipments such as fans, stacks, ducts, burners, etc.

(iv) Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption like electricity for fans, pumps etc (Bureau of energy efficiency, 2010b).

2.5 Lighting

Currently, lighting consumes a significant amount of electrical energy in industrial sectors in Malaysia. Although, many industrials think cost of light means the purchase price of the lamps. In reality, the lamp purchase represents only a small fraction of the overall cost of light. Power usage is the biggest expense for the light as shown in Figure 2.8 (Lighting, 2003b).

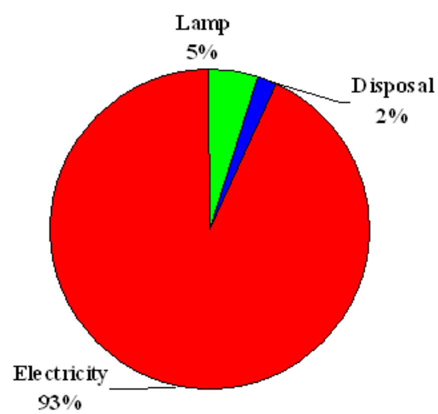

Figure 2.8: Lighting cost comparison (Lighting, 2003b)

Lighting systems not only consume power directly to generate light, in air-conditioned buildings they also indirectly account for some of the power consumed by air conditioning systems, as the heat added by lighting has to be removed by the building cooling systems (Jayamaha, 2006). Most importantly, for some building over 90 percent of lighting energy consumed can be an unnecessary expense through over-illumination

(European IPPC Bureau, 2008). Thus, the lighting in food industry has achieved additional power savings and emission reductions by increasing the efficiency of lighting products such as new efficiency lamps. In Malaysian industrial sector the percentage of electrical energy used for lighting is about 10 to 20% of total energy consumption (Al-Mofleh *et al.*, 2009) and the electrical energy consumption in Malaysian food industries have been shown in Table 2.7 (PTM, 2009). Lighting offers several opportunities to conserve energy. Improving energy efficiency of lighting by effective way, which will also improve the lighting quality whilst reducing maintenance and operating costs, can be achieved by installing a new high efficiency lamp. In summary, the improvement of lighting in food industry has contributed to significant reductions in the emissions of greenhouse gases, ozone depletion, acid rain precursors and carbon monoxide.

Table 2.7 Results of the Malaysian food industrial energy audit (PTM, 2009)

Factory name	Location	Energy consumption (kWh)
A	Johor (south)	26,820,000
B	Melaka (central)	13,366,000
C	Pahang (East)	13,307,000
D	Pahang (East)	11,958,000
E	Perak (North)	4,295,000
F	Penang (North)	1,517,000
G	Penang (North)	1,137,000
H	Perak (North)	648,000
I	Penang (North)	483,000
J	Sarawak	175,000
Total		**73,706,000**

2.5.1 Types of electrical lamp

Several types of lighting systems are used in industrial sectors. There are benefits and considerations associated with each type of lighting. Some of the most common types of lighting found in industrial sectors include incandescent, fluorescent and high-intensity discharge, or HID.

2.5.1.1 Incandescent lamp

Incandescent lamp is one of the most commonly used lamps as shown in Figure 2.9. It has low efficacy because, incandescent lamps convert about 92 percent of the energy into heat and only 8 percent is converted to useful light. They also have a relatively short life of only about 1000 hours (Jayamaha, 2006). However, they have good color rendering and a warm color temperature, which make them the preferred choice for many special applications.

Figure 2.9: Incandescent lamp (Jayamaha, 2006)

2.5.1.2 Linear fluorescent lamp

Linear fluorescent lamps are one of the most common types of lamps used for industrial lighting and have higher efficacy than incandescent lamps. They come in varying lengths as shown in Figure 2.10. The tubes are classified by a T, number which refers to the tube diameter in 1/8 of an inch. For example T12 refers to 12 ×1/8 =1-inch (38 mm) as same as T8 and T5 lamps. The lamp life is about 12,000 hours, which is much more than the life of incandescent lamp (Jayamaha, 2006). Linear fluorescent lamps are used for many general applications. These lamps have more energy efficiency than compact fluorescent lamps.

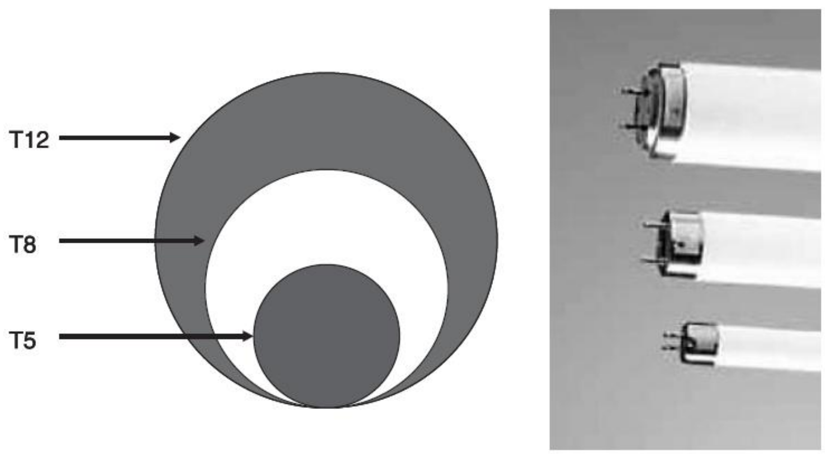

Figure 2.10: Different sizes of linear fluorescent lamps (Jayamaha, 2006).

2.5.1.3 Compact fluorescent lamp

Compact fluorescent lamps fold the discharge path and are therefore smaller in size compared to linear fluorescent lamps as shown in Figure 2.11. They have a much higher lamp efficacy compared to incandescent lamps and use only about 20 to 25 percent of electrical power (compared to incandescent lamps) to produce the same amount of light. Compact fluorescent lamps also have a life span of about eight times of that of incandescent lamps (8000 hours compared to 1000 hours). Also compact fluorescent lamps have extra cost more than incandescent lamps (Jayamaha, 2006).

Figure 2.11: Compact fluorescent lamp (Jayamaha, 2006).

One of recent study has shown that the replacement of incandescent lamps with compact fluorescent lamps (CFL) can make considerable amount of energy savings, and the reduction of energy consumption is about 80% of that used in incandescent lamp (Mahlia *et al.*, 2005).

2.5.1.4 High intensity discharge (HID) lamp

HID lamp is an electric arc and the gases in a small bulb create a high amount of light in a small package when compared to fluorescent and incandescent lamps as shown in Figure 2.12. HID lamps are commonly used when high levels of light are required over large areas and efficiency and long life are important, as in gymnasiums, warehouses, parking lots, etc (Lighting, 2003a). HID lights produce visible light when an arc or electricity is drawn through gases. These types of light bulbs produce extremely generous light outputs but require a considerable amount of energy to operate. They can take several minutes to warm up and reach full brightness. They are also more expensive than most other types of industrial lights available in the market.

Figure 2.12: High intensity discharge (Lighting, 2003a)

2.5.2 Energy saving through replacing T12 and T8 lamps with T5 lamp

In many industries, it is common to find T12 and T8 lamps in use (Masanet *et al.*, 2008). T12 and T8 tubes consume huge amount of electrical energy compared with efficient one. Energy savings from lighting systems can be achieved by many advanced lighting methods, improving the efficiency of lighting systems through replacing T12 and T8 with T5 lamps and electronic ballasts is an excellent method to conserve energy consumption in food industrial sector. T5 compact lighting has given T8 and T12 consumers an energy efficiency option to fluorescent lighting. T8 and T12 are now becoming obsolete. The new T5 lamp reduces consumption of power by 50% while still providing the same output of light as T8 and T12 lamps (Hendricks, 2010). Table 2.8 shows the comparison between various lighting T5, T8 and T12 lamps. Lights can be saved by 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 energy use for facility lighting up to 10% to 20% (Masanet *et al.,* 2008).

Table 2.8 the comparison between T5, T8 and T12 lamps (products, 2010)

Type	Watt			
T5	14	21	28	35
T8	17	25	32	58
T12	27	38	48	73

2.5.3 Benefits of replacing T12 and T8 lamps with T5 lamps

The strategy is to replace high wattage lamps with lower wattage lamps in a most effective way. The replacements of lighting can improve the efficiency of lighting system. The benefits obtained by replacement of lighting include:

(i) Save energy and cost.

(ii) These lamps require fewer toxic chemicals.

(iii) They emit less heat (thus reducing air conditioning costs) and generate less environmental impact.

(iv) They provide better quality of light.

(v) Reducing maintenance and operating costs.

2.6 Air compressor system

A compressor is the mechanical device that takes in ambient air and increases its pressure (Kemp, 2010). Compressed air is one of the major utilities in industrial food processing. Compressed air is used in different operations such as aerating, conveying, dehydration, spraying coatings, cleaning, vacuum packing and pneumatic control in a food processing industry (Wang, 2008). Compressed air systems are important areas to improve energy efficiency in industrial sectors especially in food industry.

The compressed air system utilizes a major amount of electrical energy. It is worth noting that the running cost of a compressed air system is far higher than the cost of a compressor itself as seen in Figure 2.13 (ECompressedAir, 2010). Proper improvements to compressors and compressed air systems can save 20%–50% of the energy consumed by the systems (Wang, 2008). For many facilities this is equivalent to thousands, or even hundreds of thousands of dollars of potential annual savings, depending on use. A properly managed compressed air system can save energy, reduce maintenance, decrease downtime, increase production output, and improve product quality. The production of compressed air can be one of the most expensive processes in manufacturing sectors. Therefore, energy saving for compressed air systems should be an important part of the energy conservation project in industrial food processing.

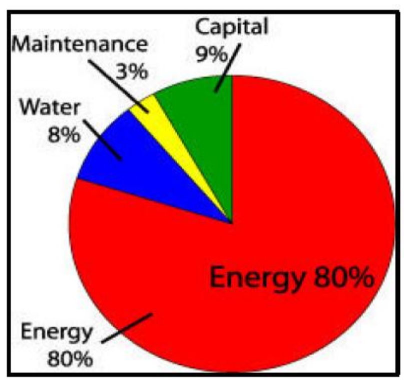

Figure 2.13: Cost components in a typical compressed air system (ECompressedAir, 2010)

Compressed air is usually supplied by several air compressors through a pipe system. In order to meet the varying air demands, air storage systems are usually installed. Extra filters and air driers are also required to supply food grade quality air as shown in Figure 2.14.

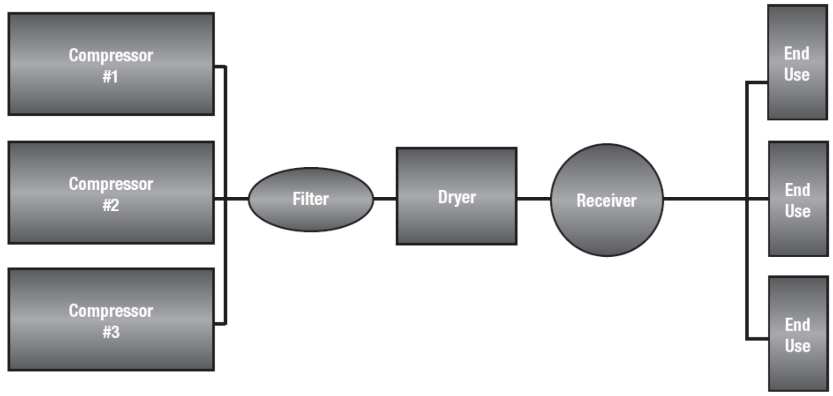

Figure 2.14: Compressed air system block diagrams (Kemp, 2010).

There is a huge energy loss from a compressed air system through leakage. Partial load decreases the energy efficiency of a compressor. All compressed air systems have some uncontrolled air leakage and inappropriate uses of compressed air. Savings leakage can improve the performance of compressor system and overall efficiency of system.

2.6.1 Leakage of air compressor systems

Air leakage is the greatest single cause of energy loss from a compressed air system in industrial sectors. Consequently, sometimes the range of energy loss is about 20 to 30 percent of the output of an industrial compressed air system. A typical plant that has not been well maintained will likely have a leakage rate equal to 20 percent of total compressed air production capacity (Kemp, 2010). On the other hand, eliminating air leakage totally is impractical, and a leakage rate of 10% is considered acceptable in practice (Wang, 2008). In addition to being a source of wasted energy, leaks can also contribute to other operating losses. Leakage causes a drop in system pressure, which can cause loss efficient functioning of air tools, and affect production adversely (Kemp, 2010). Besides that, by forcing the equipment to run longer, leakage shorten the life of almost all system’s equipment of the compressor. Increased running time can also lead to additional maintenance requirements and increased unscheduled downtime. Finally, leakage can lead to adding unnecessary compressor capacity (ECompressedAir, 2010). The loses of compressed air through leakage increases exponentially with the increase in leak diameters, as shown in Figure 2.15.

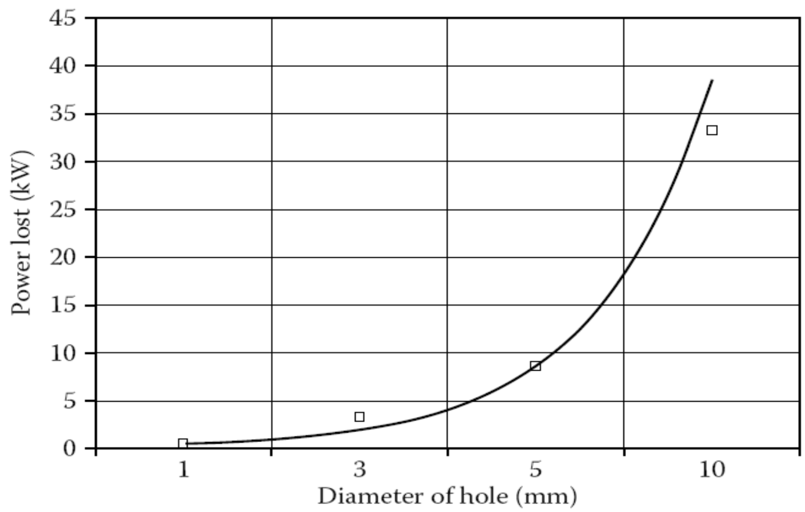

Figure 2.15: Power losses as a function of leakage through varied hole diameter at 600 kPa pressure (Saidur et al., 2009b; Wang, 2008).

While leakage can come from any part of the system. The most common problem areas include couplings, hoses, tubes, fittings, pressure regulators, open condensate traps, shut-off valves, pipe joints, disconnects, and thread sealants (Kemp, 2010). Leakage is usually inexpensive and could be easily repaired, but allowing a leakage to persist can be very costly and inefficient as indicated in Figure 2.16.

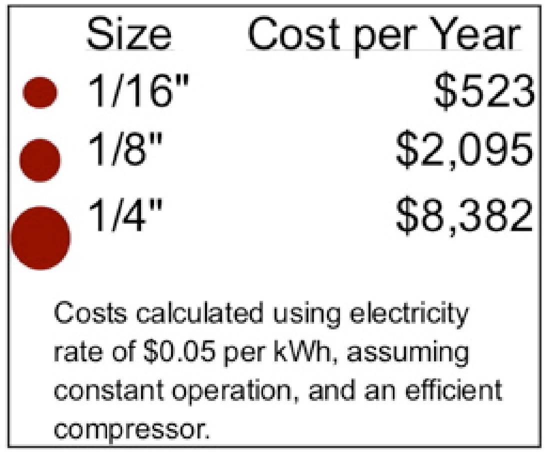

Figure 2.16: Cost of waste energy due to leak (Saidur *et al.*, 2009b).

2.6.2 Leakage Detection

Air leakages are almost impossible to see, other methods must be used to locate them. The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize the high-frequency hissing sounds associated with air leakage (Kemp, 2010). These portable units consist of directional microphones, amplifiers, and audio filters, and usually have either visual indicators or earphones to detect leakage. A simpler method is to apply soapy water with a paint brush to suspected areas. Although reliable, this method can be time consuming (Kemp, 2010).

2.6.3 Fixing the leakage

Leakage occurs most often at joints and connections at end-use applications. Stopping leakage can be as simple as tightening a connection or as complex as replacing faulty equipment such as couplings, fittings, pipe sections, hoses, joints, drains, and traps. In many cases leakage are caused by bad or improperly applied thread sealant. Select high quality fittings, connectors, hose, tubing, and install them properly with appropriate thread sealant (CompressedAir, 2010). Another way to reduce leakage is to lower the demand of air pressure of the system. The lower the pressure differential across an orifice or leak, the lower the rate of flow, so reduced system pressure will result in reduced leakage rates. Stabilizing the system header pressure at its lowest practical range will minimize the leakage rate for the system.

2.6.4 Energy savings through repairing leakage of air compressor systems

Energy savings through leakage prevention. Leakage can be a significant source of wasted energy in an industrial compressed-air system, sometimes wasting 20–50% of a compressor's output. An unmaintained plant will likely to have a leakage-rate equal to 20% of total compressed-air production capacity (Saidur *et al.*, 2009b). Reducing air leakage can save thousands of dollars annually. Compressed air is one of the most expensive forms of energy used in industry. Repairing leakage can save a significant amount of energy; the percentage of energy savings represents about 42 percent (Saidur *et al.*, 2009b) as shown in Figure 2.17.

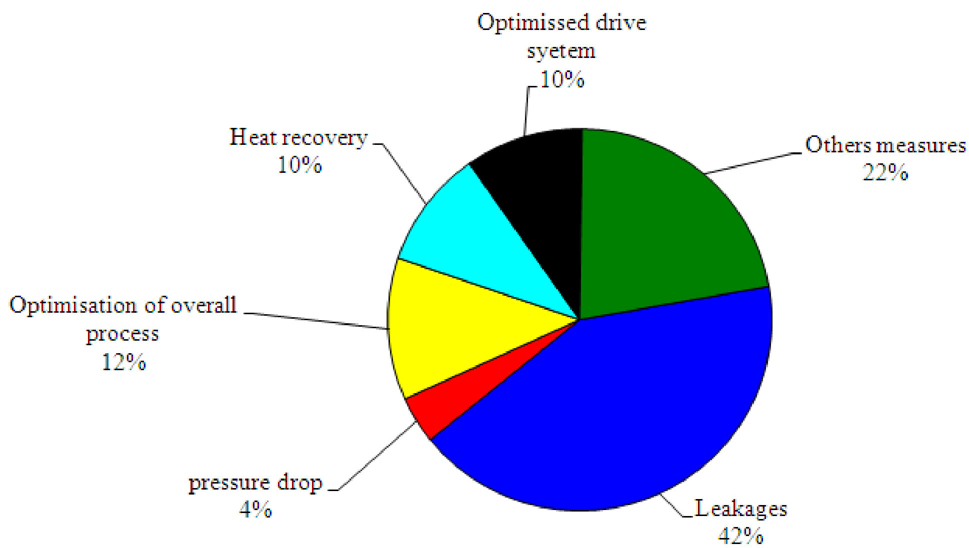

Figure 2.17: Different options of compressed-air energy savings (Saidur *et al.*, 2009b)

2.6.5 Benefits of fixing Leaks of air compressor systems

The benefits of fixing leaks are obvious including cost saving and prolong life of equipment. Additional benefits include:

(i) Potential of reducing emissions

(ii) Reduced compressor run time.

(iii) Reduced maintenance.

(iv) Reduced demand for new compressor capacity.

(v) Increased equipment life.

(vi) Save energy and reduce costs.

(vii) Helps to reduce carbon footprint.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, data collection procedure and mathematical formulations of energy consumption, energy savings, emission reductions and cost benefits analysis are involved. The target of this study is of energy savings food industrial sector by high efficiency motors (HEMs), variable speed drives (VSDs) of motors, heat recovery system (economizer) for the boilers, Lighting system and repairing leakages of air compressor systems and the payback period of all these application.

3.2 High efficiency motors

3.2.1 Targeted manufacturing factories and audit data collection

The targeted food industry in this section have been taken from a previous survey that focused on the overall industrial sectors in Malaysia in different regions within Peninsula Malaysia as shown in Table 2.1. The results of the energy audit are shown in Table 2.2.

3.2.2 Energy consumption of motors

The annual energy consumption of motors can be calculated by the following formula as

$$AEC = n \times 0.746 \times H_{avg\text{-}usage} \times LF \times P \qquad (3.1)$$

Where 0.746 is conversion factor from horsepower to (kW), LF is load factor and which is approximately about 60% (Jayamaha, 2006).

3.2.3 Estimate energy savings using HEMs.

Annual energy savings (*AES*) attained by replacing standard efficiency motors with high energy efficiency motors can be estimated using the methodology described in Table 4.1 (Saidur and Mahlia, 2009; Saidur *et al*., 2009d)

$$AES = P \times 0.746 \times H \times L \times (\frac{1}{E_{\text{std}}} - \frac{1}{E_{\text{ee}}}) \times 100 \quad (3.2)$$

3.2.4 Cost benefit analysis when using HEMs

The Annual bill savings associated with the above energy savings can be calculated as (Mahlia, 2002; Mahlia et al., 2004; Saidur and Mahlia, 2009)

$$Annual\ Bill\ Savings\ (ABS) = AES \times C \quad (3.3)$$

3.2.5 Emissions reduction when using HEMs

The emission is a crucial factor because it has a negative impact on the environment. Thus reduction of emission is very important for protection of the environment. The common potential reductions in emission in this study include carbon dioxide CO_2, sulfur dioxide SO_2, nitrogen oxide NO_x and carbon monoxide CO. This study is concerned with all these emissions. Thus emissions reduction when using HEM can be calculated using the following Equations (Mahlia, 2002; Saidur and Mahlia, 2009; Saidur et al., 2009d):

$$AER_{CO2} = AES_{HEM} \times \Sigma\ (EF_{CO2} \times F\%) \quad (3.4)$$

$$AER_{SO2} = AES_{HEM} \times \Sigma\ (EF_{SO2} \times F\%) \quad (3.5)$$

$$AER_{NOx} = AES_{HEM} \times \Sigma\ (EF_{NOx} \times F\%) \quad (3.6)$$

$$AER_{CO} = AES_{HEM} \times \Sigma \, (EF_{CO} \times F\%) \quad (3.7)$$

3.2.6 Payback period when using HEMs

Payback period is the function of the incremental cost of HEM divided by the annual bill savings of HEM in a particular year. Thus Payback period can be expressed mathematically from the following Equation (Saidur *et al.*, 2009d):

$$Payback\ period\ (years) = \frac{Incremental\ cost\ (IC_{HEM})}{Annual\ bill\ savings\ (ABS_{HEH})} \quad (3.8)$$

3.3 Variable speed drives

3.3.1 Targeted manufacturing factories and audit data collection

The targeted food industry in this section have been taken from a previous survey that focused on the overall industrial sectors in Malaysia in different regions within Peninsula Malaysia as shown in Table 2.1. The results of the energy audit are shown in Table 2.2 in literature review section 2.2.

3.3.2 Energy savings when using VSDs

The energy savings of motors when installing (VSDs) can be calculate as (Saidur and Mekhilef, 2010)

$$AES_{VSD} = n \times P \times 0.746 \times H_{avg\text{-}usage} \times S_{SR} \quad (3.9)$$

3.3.3 Cost benefit analysis when using VSDs

The annual cost savings is related to annual energy savings and price of fuel. The annual bill savings of motor when using (VSDs) can be calculated as

$$Annual\ Bill\ Savings\ (ABS_{VSD}) = AES_{VSD} \times C \quad (3.10)$$

3.3.4 Emissions reduction when using VSDs

The emissions reduction is a function of energy saving, percentage of fuel used and emission factor of the particular fuel has been taken from Tables 4.2 and 4.3. Thus annual emissions reduction when using (VSDs) can be calculated using the following Equations (Mahlia, 2002):

$$AER_{CO2} = AES_{VSD} \times \Sigma \; (EF_{CO2} \times F\%) \quad (3.11)$$

$$AER_{SO2} = AES_{VSD} \times \Sigma \; (EF_{SO2} \times F\%) \quad (3.12)$$

$$AER_{NOx} = AES_{VSD} \times \Sigma \; (EF_{NOx} \times F\%) \quad (3.13)$$

$$AER_{CO} = AES_{VSD} \times \Sigma \; (EF_{CO} \times F\%) \quad (3.14)$$

3.3.5 Payback period when using VSDs

Payback period is the function of the incremental cost of VSDs divided by the annual bill savings of VSDs in a particular year. Incremental prices of VSDs are shown in Table 4.5. Thus Payback period can be expressed mathematically from the following Equation:

$$Payback\ period\ (years) = \frac{Incremental\ cost\ (IC_{VSD})}{Annual\ bill\ savings\ (ABS_{VSD})} \quad (3.15)$$

3.4 Heat recovery systems using economizer

3.4.1 Targeted manufacturing factories and audit data collection

The targeted food industry in this section has been taken from Pusat Tenaga Malaysia (PTM) as shown in Table 2.6.

3.4.2 Energy savings when using heat recovery systems (economizer)

Energy consumption of boiler without using heat recovery system can be expressed mathematically by the formulation as

$$AEC_{\mathrm{HR}}\,(kWh) = \frac{ADC \times \rho \times EHC}{3600} \quad (3.16)$$

Estimation of energy savings associated with boiler heat recovery system can be expressed mathematically by the formulation as

$$AES_{\mathrm{HR}} = AEC \times \%_{\mathrm{PRH}} \times \eta_{\mathrm{ECN}}(\%) \quad (3.17)$$

Percentage of increasing efficiency of boiler due to installation of economizer system can be calculated from the following Equation

$$\eta_{\mathrm{th}} = \frac{AES_{\mathrm{HR}}}{AEC_{\mathrm{HR}}} \quad (3.18)$$

3.4.3 Cost benefit analysis when using heat recovery systems (economizer)

Total annual bill savings associated with the above energy savings equals to total annual energy saving multiplied by diesel fuel price. It can be calculated from the following Equation (Mahlia *et al.*, 2004):

$$ABS_{\mathrm{HR}} = AES_{\mathrm{HR}} \times FP \quad (3.19)$$

3.4.4 Emissions reduction when using heat recovery systems (economizer)

The environmental impact of the heat recovery system is a potential reduction of greenhouse gasses or other element that give negative impact to the environment. The emission factors and percentage of fuels of all gases are shown in the Tables 4.2 and 4.3. The annual emissions reduction is a function of total annual energy saving and the emission factor of the particular fuel. Emissions reduction when using heat recovery systems can be calculated as follows (Mahlia, 2002):

$$AER_{CO2} = AES_{HR} \times EF_{CO2} \quad (3.20)$$

$$AER_{SO2} = AES_{HR} \times EF_{SO2} \quad (3.21)$$

$$AER_{NOx} = AES_{HR} \times EF_{NOx} \quad (3.22)$$

$$AER_{CO} = AES_{HR} \times EF_{CO} \quad (3.23)$$

3.4.5 Payback period when installing economizer systems

Knowing that installation cost of economizer is RM 30,000 (Manan, 2003), payback period equals to the installation cost of heat recovery divided by total annual bill saving when using heat recovery systems. Payback period of this application can be calculated from the following Equation (Saidur *et al.*, 2009d):

$$PBP_{HR} = \frac{IC_{HR}}{ABS_{HR}} \quad (3.24)$$

3.5 Energy conservation for lighting system

3.5.1 Targeted manufacturing factories and audit data collection

The targeted food industry in this section has been taken from Pusat Tenaga Malaysia (PTM) as shown previously in Table 2.7.

3.5.2 Energy savings when replacing T12 and T8 lamps with T5 lamps

Based on that assumption the food industrial sector are used T12 and T8 lamps for lighting system. Energy savings when replacing T12 and T8 lamps with T5 lamps can be expressed mathematically by the following Equation:

$$AES_{L} = AEC_{T(12\text{-}8)} \times \%_{T\text{-}5} \quad (3.25)$$

Where AES_L is annual energy savings, $AEC_{T(12\text{-}8)}$ is annual energy consumption by using T12 and T8 lamps, $\%_{T\text{-}5}$ is percentage of energy saving by using T5 lamps is equal to 50% according to reference (Hendricks, 2010).

3.5.3 Cost benefit analysis

The bill savings when replacing T12 and T8 lamps with T5 lamps is a function of energy savings and the average price of electricity. The potential bill savings by replacing lighting is calculated by the following Equation (Saidur *et al.*, 2009d):

$$ABS_L = AES_L \times C \quad (3.26)$$

3.5.4 Emissions reduction

The environmental impact is potential reduction of greenhouse gasses or other element that cause negative impact to the environment. The common emission reductions are usually reductions of CO_2, SO_2, NO_x and CO. The emission reduction is a function of energy savings. The emission factors and percentage of fuel of all these gases are shown in the Tables 4.2 and 4.3. The annual emission reduction can be expressed mathematically by the following Equations (Mahlia *et al*., 2005):

$$AER_{CO2} = AES_L \times EF_{CO2} \quad (3.27)$$

$$AER_{SO2} = AES_L \times EF_{SO2} \quad (3.28)$$

$$AER_{NOx} = AES_L \times EF_{NOx} \quad (3.29)$$

$$AER_{CO} = AES_L \times EF_{CO} \quad (3.30)$$

3.6 Energy conservation when repairing leakage of air compressor system

3.6.1 Targeted manufacturing factories and audit data collection

The targeted food industry in this section has been taken from Table 2.7 in section 2.5.

3.6.2 Energy savings by repairing leakage

Total annual energy saving by repairing leaks of air compressor system in food industry that have been calculated from the data shown in Table 4.7 (PTM, 2009) equals to total annual leakage energy consumption of compressor in (kWh) multiplied by the percentage of repairing leakage. Energy savings through leakage prevention can be expressed as (Saidur *et al.*, 2009a).

$$AES_{\text{CS-Leak}} = AEC_{CS} \times \%ES \qquad (3.31)$$

Where AEC_{CS} is compressor annual energy consumption, $AES_{CS\text{-}Leak}$ annual energy savings, and is $\%ES$ percentage of energy saving by repairing a leakage of air compressor system represent about 42% according to (Saidur *et al*., 2009b).

3.6.3 Cost benefit analysis

The bill savings by repairing leakage is a function of energy savings and the average price of electricity. The potential bill savings by repairing leakage is calculated by the following Equation (Mahlia *et al.*, 2004):

$$ABS_{\text{CS-Leak}} = AES_{\text{CS-Leak}} \times C \qquad (3.32)$$

3.6.4 Emissions reduction

The environmental impact due to repairing of leakage has potential reduction of greenhouse gasses or other element that cause negative impact to the environment. The common emission reductions are usually, CO_2, SO_2, NO_x and CO. The emission reduction is a function of energy savings. The annual emission reduction can be expressed mathematically by the following Equations (Mahlia, 2002):

$$AER_{CO2} = AES_{CS\text{-}Leak} \times EF_{CO2} \quad (3.33)$$

$$AER_{SO2} = AES_{CS\text{-}Leak} \times EF_{SO2} \quad (3.34)$$

$$AER_{NOx} = AES_{CS\text{-}Leak} \times EF_{NOx} \quad (3.35)$$

$$AER_{CO} = AES_{CS\text{-}Leak} \times EF_{CO} \quad (3.36)$$

CHAPTER 4

RESULTS AND DISUCUSSION

4.1 Introduction

This chapter discusses the results of installation of high efficiency motors and variable speed drives of motors, heat recovery systems for boilers, replacing inefficient lamps with high efficiency lamps, and repairing leakage of air compressor in the food industrial sector in Malaysia. The energy savings, economic benefits, emissions reduction and payback period are all calculated to examine the potential of all these approaches.

4.2 Results of installation of high efficiency motors

Based on the fact that motors represent about 47.1% of the overall Malaysian industrial sector's energy consumption as previously shown in Figure 2.4 and the food industries represent about 14% of all industrial energy consumption in Malaysia as shown in Figure 4.1 (Mustaffah and Azma, 2006). The results of energy audit for food industrial sector are shown in Table 4.1.

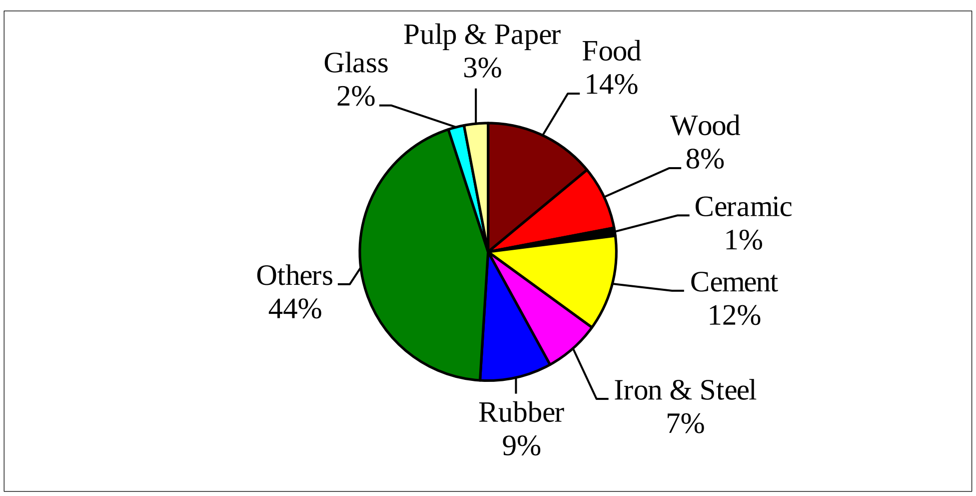

Figure 4.1: Energy Consumption in Malaysian Industrial Sector (Mustaffah and Azma, 2006).

Table 4.1 Results of food industrial Malaysian energy audit

Motors (HP)	Number of motors	Operation hour (Hours)
1	262	
1.5	22	
2	109	
3	196	
4	894	
5.5	22	
7.5	44	6000
15	11	
20	218	
25	65	
30	22	
40	44	
50	22	
60	55	
75	11	

4.2.1 Energy saving when using high efficiency motors

Energy saving when installing high efficiency motors in the food industry which have already been shown in Table 4.1 and based on the Equation 3.2 and data taken from Table 2.4, the results of total annual energy saving in (kWh) of this application has been calculated and presented in Figures 4.2 and also the relevant data are shown in Table F.2 (Appendices).

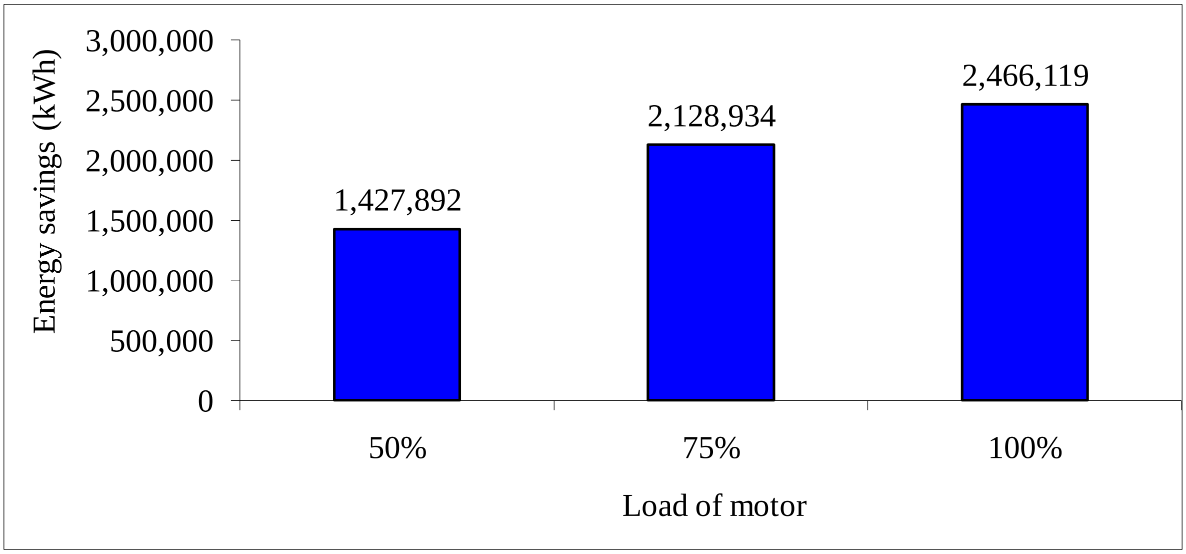

Figure 4.2: Total annual energy savings when installing HEMs

The results from Figure 4.2 show that the total annual energy savings in food industrial sector covered in this study can be increased significantly when increasing the load of motors. For example, Annual energy saving increased about 1,427,892 kWh, 2,128,934 kWh and 2,466,119 kWh for 50%, 75% and 100% load of motors. These results represent a huge amount of energy savings that can be achieved when replacing standard motors with high efficiency motors. These results indicate that energy savings in food industrial sector can be achieved by replacing standard motors with high efficiency motors.

These results is similar to that have already been found in the literature review as the HEMs can increase energy savings by 1765, 2703 and 3605MWh for 50%, 75% and 100% load of motors (Saidur *et al.*, 2009d).

4.2.2 Cost benefit analysis when using HEMs

Bill saving when installing HEMs in the food industry associated with above energy saving has been calculated by the Equation 3.3, the results of total annual bill savings in US$ of this application has been illustrated in Figure 4.3 and also the relevant data are shown in Table F.3 (Appendices).

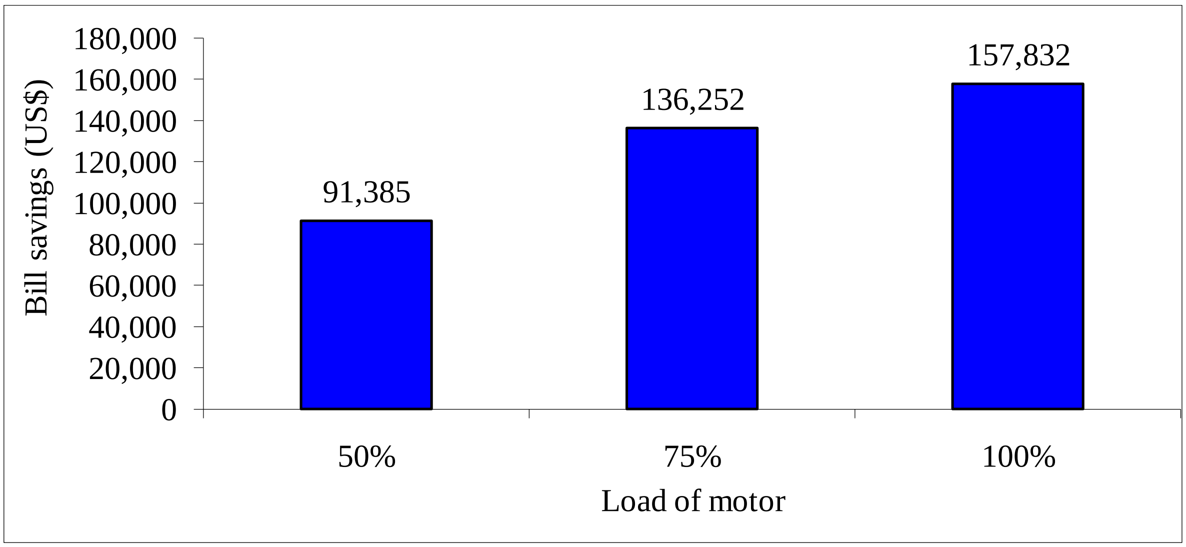

Figure 4.3: Total annual Bill savings when using HEMs

The results from Figure 4.3 show that the total annual bill savings when installing high efficiency motors in the food industry. In this study about US$91,385, US$136,252 and US$157,832 could be saved at 50%, 75% and 100% load of motors. These results represent a huge amount of bill saving that can be achieved when installing high efficiency motors in food industrial sector in Malaysia.

These results is similar to that have already been found in the literature review as the HEMs can increase bill savings by US$262,216, US$241,931 and US$136,460 for 50%, 75% and 100% load of motors (Saidur and Mekhilef, 2010).

4.2.3 Emissions reduction when using HEMs

Emissions reduction when installing HEMs have been calculated by Equations (3.4 – 3.7) and the emission factors of all these gases and the percentage of electricity generation based on fossil fuel types are shown in the Tables 4.2 and 4.3. The results can be illustrated in Figure 4.4 and also the relevant data are shown in Table F.4 (Appendices).

Table 4.2 Emission factors from fossil fuel for a unit electricity generation (Mahlia, 2002)

Fuels	Emission (kg/kWh)			
	CO_2	SO_2	No_x	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Gas	0.53	0.0005	0.0009	0.0005
Hydro	0	0	0	0
other	0	0	0	0

Table 4.3 Percentage of electricity generation based on fuel types (Mahlia, 2002)

Fuel type	Coal	Petroleum	Gas	Hydro
Percentage (%)	15	5	70	10

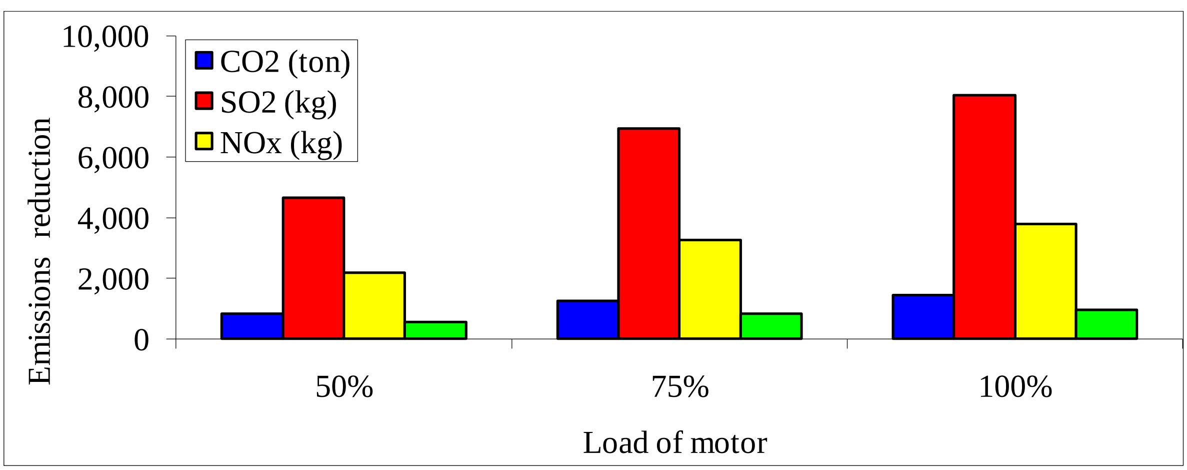

Figure 4.4: Emissions reduction when installing HEMs

The results from Figure 4.4 show that the emissions reduction when installed HEMs are increased with increasing the load of motors for 50%, 75% and 100% load of motors in food industrial sector. It can be observed that emissions reduction with increasing the load of motors. The results also show that emissions can be substantially reduced by installing high efficiency motors strategy to food industrial sector.

4.2.4 Payback period when using HEMs

The annual payback period when using HEMs can be calculated by Equation 3.8 and the incremental prices of HEMs are shown in Table 4.4 (Saidur *et al.*, 2009d). The results of calculation can be depicted in the Figure 4.5 and also the relevant data are shown in Table F.5 (Appendices).

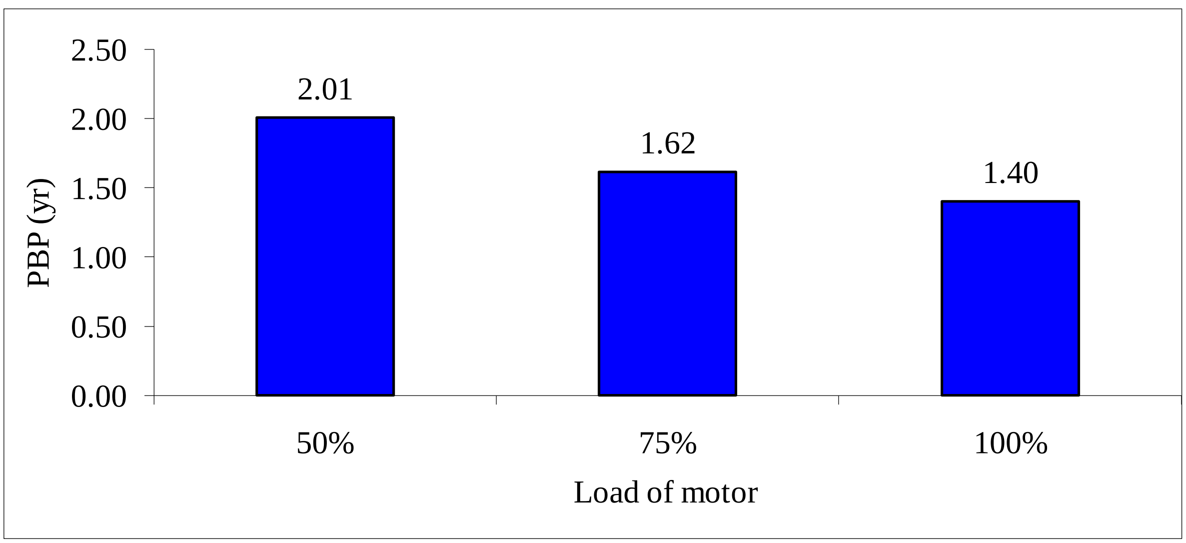

Figure 4.5: Payback period when using HEMs

Table 4.4 Incremental costs of HEMs (Saidur *et al*., 2009d)

Motor power (HP)	Increment cost (US$)
1	24
1.5	21
2	25
3	27
4	60
5.5	65
7.5	91
15	147
20	197
25	246
30	257
40	231
50	281
60	574
75	518

The results from Figure 4.5 show that the average payback periods are about 2.01 year, 1.62 year and 1.40 year for 50%, 75% and 100% load of motors in food industrial sector. It can be observed that payback period decreased with increasing the load of motors. These results indicate that the implementation of high efficiency motors would be cost-effective, as their payback periods are less than one third of the motor life.

4.3 Results of variable speed drives

4.3.1 Energy savings when using variable speed drives

Energy savings with installed variable speed drives of motors in the food industry have shown in Table 4.1 and based on the Equation 3.9, the results of total annual energy savings in kWh of this application has been shown in Figures 4.6 and also the relevant data are shown in Table F.6 (Appendices).

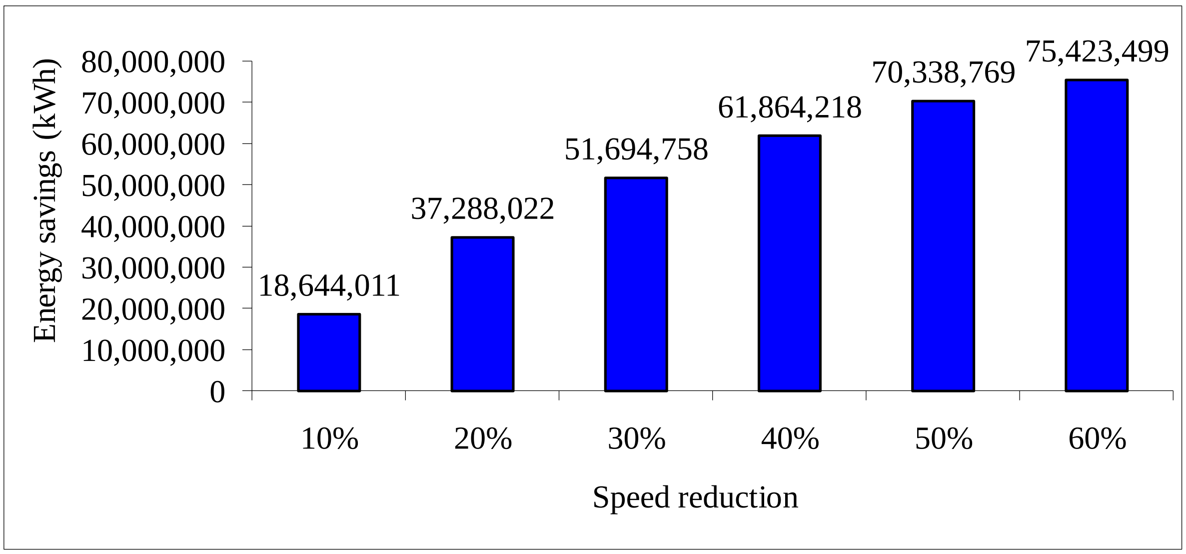

Figure 4.6: Energy savings when using VSDs

The results from Figure 4.6 show that the total annual energy savings in the food industrial sector covered in this study can be increased significantly with increasing the speed reduction percentage of motors. For example, Annual energy saving increased from 18,644,011 kWh in 10% speed reduction to 75,423,499 kWh in 60% speed reduction. More energy can be saved for higher speed reductions. These results represent a substantial amount of energy saving can be achieved by applying VSDs in food industrial sector.

4.3.2 Cost benefits analysis when using VSDs

Bill savings with installed variable speed drives of motors in the food industry can be calculated by using Equation 3.10. The results of total annual bill savings in US$ for this application have been illustrated in Figure 4.7 and also the relevant data are shown in Table F.7 (Appendices).

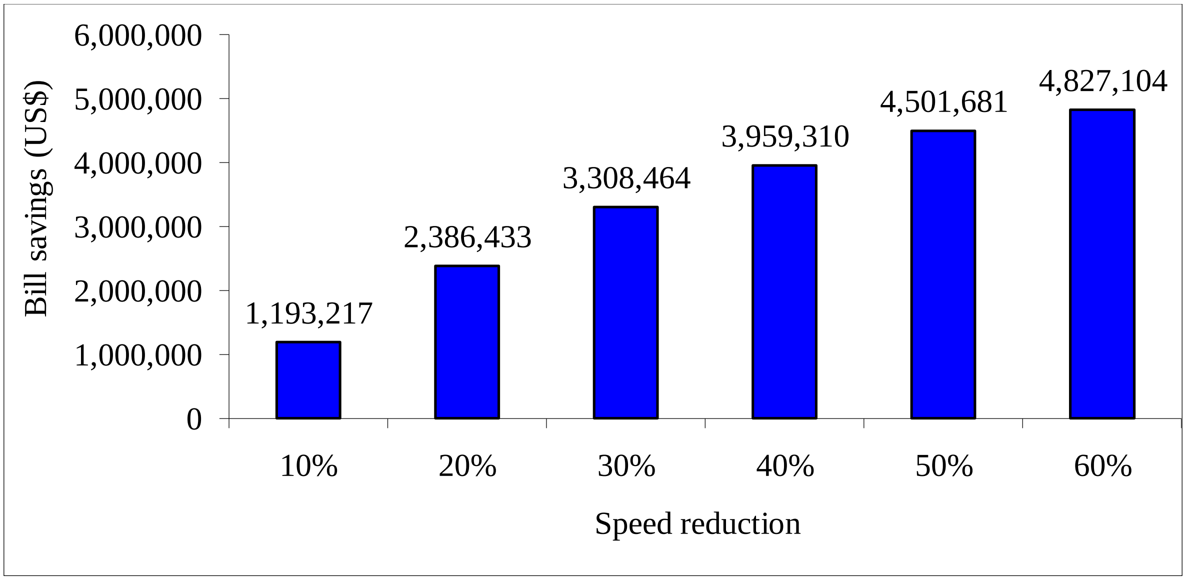

Figure 4.7: Bill savings when using VSDs

The results from Figure 4.7 show that the total annual bill savings with installing VSDs in the considered food industrial sector are about US$1,193,217 in 10% speed reduction, to US$4,827,104 in 60% speed reduction. These results represent a substantial amount in expense can be saved, these can be achieved by applying VSDs strategy in food industrial sector in a small developing country like Malaysia.

4.3.3 Emissions reduction when using VSDs

Emissions reductions with installed VSDs have been calculated by Equations (3.11 – 3.14) and data from Tables 4.2 and 4.3, the result have been illustrated in Figure 4.8 and also the relevant data are shown in Table F.8 (Appendices).

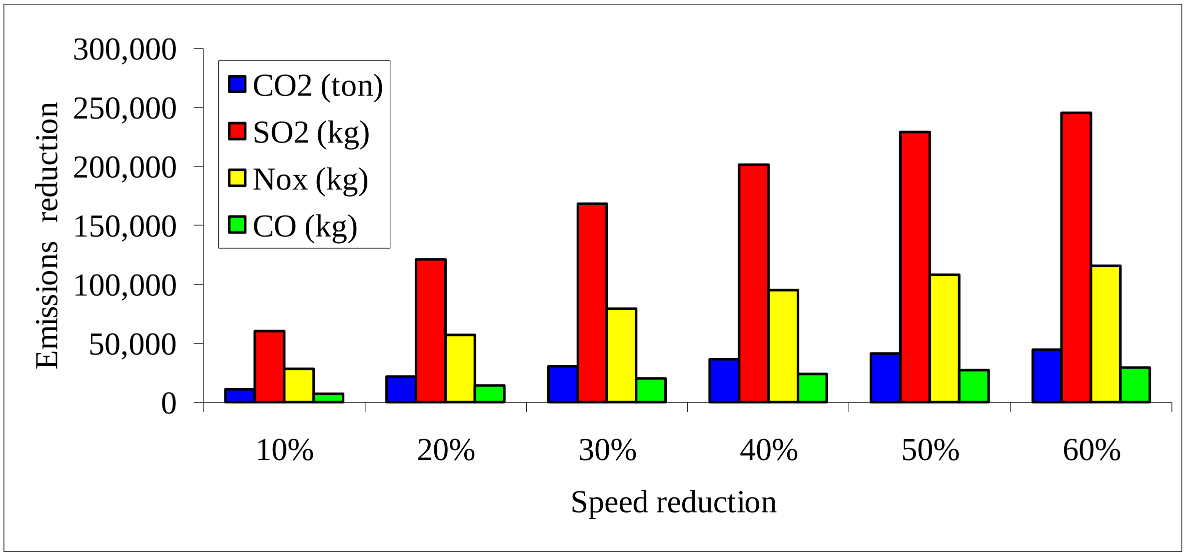

Figure 4.8: Emissions reduction when installing VSDs

The results from Figure 4.8 indicate that the total emissions reduction is increased from 10% speed reduction to 60% speed reduction in the food industry. Along with energy savings, a substantial amount can be saved associated emissions reduction, this can be achieved by using VSD for food industrial sector in Malaysia

4.3.4 Payback period when using VSDs

The annual payback period with using variable speed drives can be estimated from Equation 3.15 and the data from Table 4.5, the results are illustrated in Figure 4.9 and also tabulated in Table F.9 (Appendices).

Table 4.5 Incremental costs of VSDs (Saidur *et al.*, 2009b)

Motor power (HP)	Increment cost (US$)
3	2216
5	2461
7.5	3376
10	3349
15	4176
20	5316
25	6123
30	6853

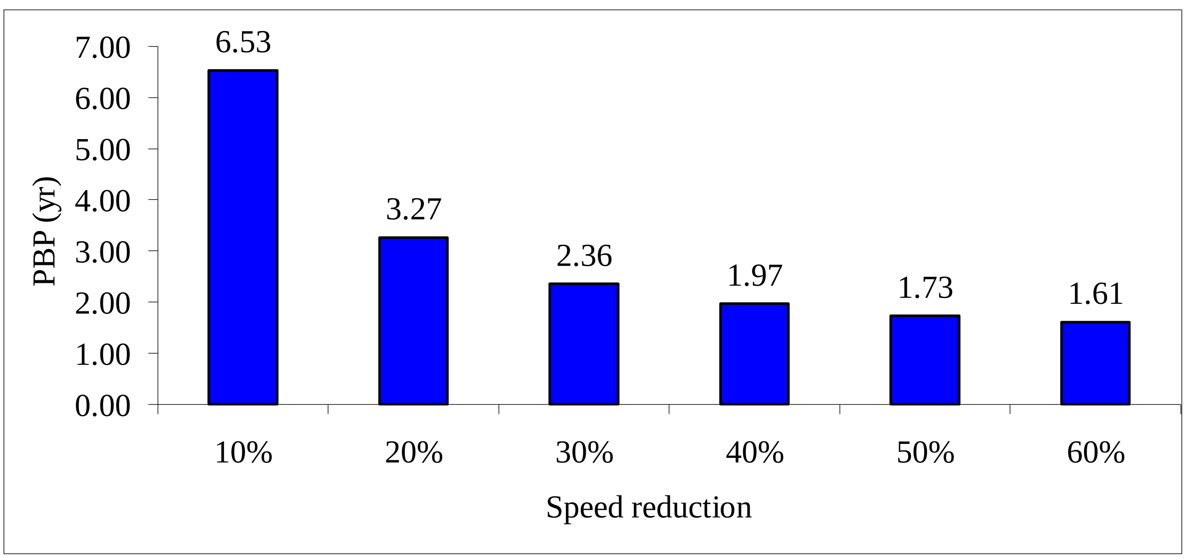

Figure 4.9: Payback period when using VSDs

The result from Figure 4.9 show that the average payback periods are about 6.53 year in 10% speed reduction and 1.61 year in 60% speed reduction of motors in food industrial sector. These results can observe that payback period decreased when increasing speed reduction. It can be seen that the payback period for VSDs is economically very viable, since the payback period is very short.

4.4 Heat recovery results

4.4.1 Energy savings when using economizer

Energy savings of boiler by installing economizer is calculated by Equation 3.17 and data from Table 2.6 and Table F.1 (Appendices) respectively. Annual energy saving of boiler for different factories has been illustrated in Figure 4.10 and tabulated in Table F.10 (Appendices).

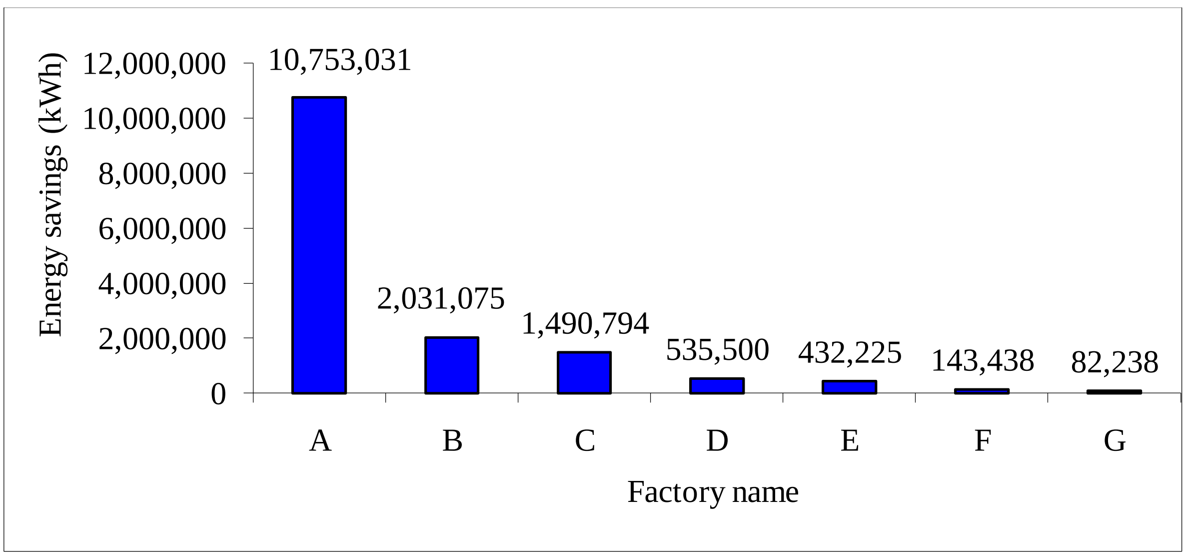

Figure 4.10: Energy savings when using economizer

The results from Figure 4.10 show that the total annual energy savings with installed economizer in all factories is 15,468,300 kWh. These results represent a considerable amount of energy savings that can be achieved with installation of economizer in boilers. It can be seen that the annual energy savings are different among all factories, however the energy consumption is also different among them. Based on Equation 3.18 the Percentage of increase in thermal efficiency of boiler due to installation of economizer has been found about 9%. This result indicates that the economizer is very useful and can save a huge amount of energy and cost as well.

4.4.2 Cost benefits analysis with using economizer

Bill savings with installed economizer for boilers in food industry has been calculated by the Equation 3.19 and data from Table F.1 (Appendices). The results of total annual bill savings in US$ (US$1 = RM3.2) for this application has been illustrated in Figure 4.11 and also the relevant data are shown in Table F.11 (Appendices).

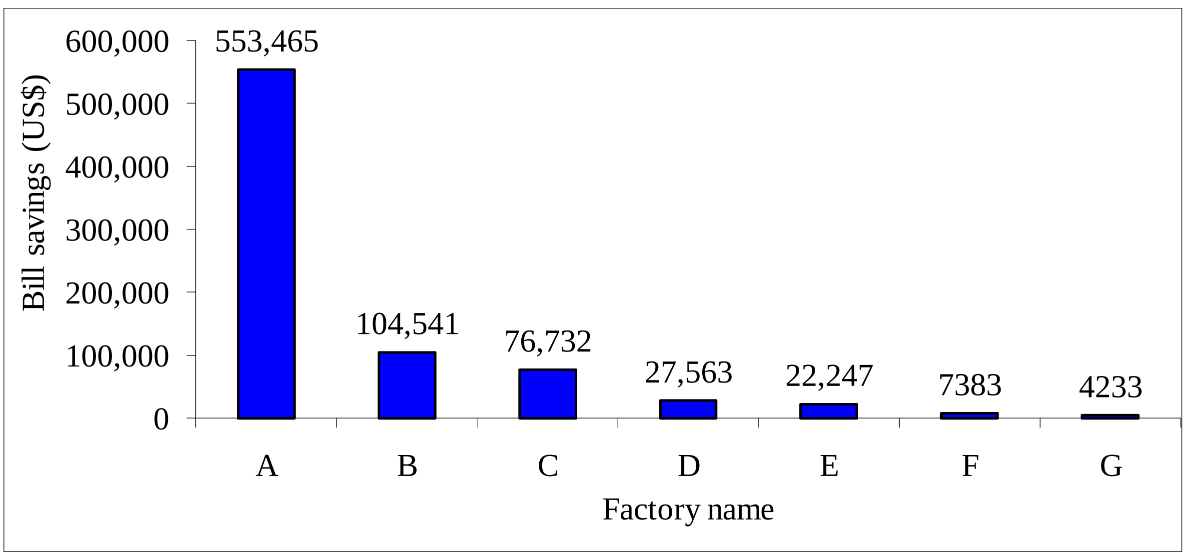

Figure 4.11: Bill savings when economizer is used

The results from Figure 4.11 show that annual bill savings when economizer is used in food industrial sector about US$553,465 in A factory to US$4233 in ***G*** factory. It can be observed that annual bill savings is quite high in ***A*** factory in comparison to other factories. This is due to annual energy consumption of these factories are lower than ***A*** factory. These results indicate that economizer can be a useful device for purposes in Malaysian food industries when the annual energy consumption of boiler is very high and the bill saving is high.

4.4.3 Emissions reduction when using economizer

Emissions reductions with installation of economizer in the boilers have been calculated by Equations (3.20 – 3.23) and data from Tables 4.2 and 4.3, the results are illustrated in Figure 4.12 and presented in Table F.12 (Appendices):

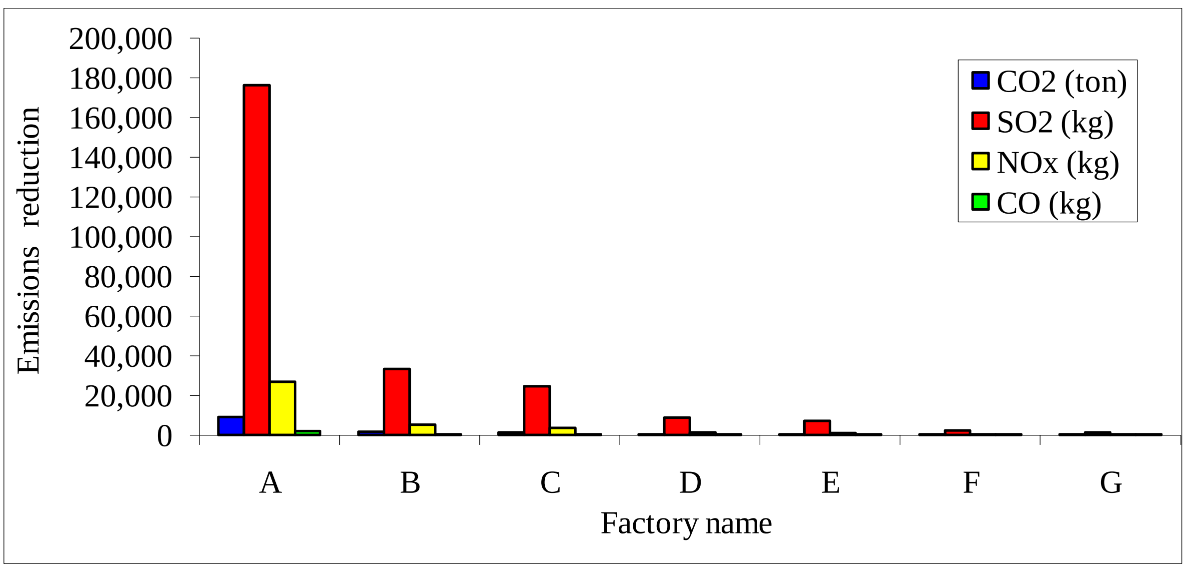

Figure 4.12: Emissions reduction with installation of economizer

The results from Figure 4.12 show that the emissions reduction when installed economizer is represented a significant amount of reduction in food industrial sector. It observed that the emissions reduction can be substantially reduced by installing economizer in boilers food industrial sector. These results indicate that economizer can be a useful device for this purpose in Malaysia when the annual energy consumption of boilers is very high and the emissions reduction is high too.

4.4.4 Payback period when economizer is used

The annual payback period when economizer is used has been calculated by Equation 3.24, and the result is illustrated in Figure 4.13. The average payback period is less than one year.

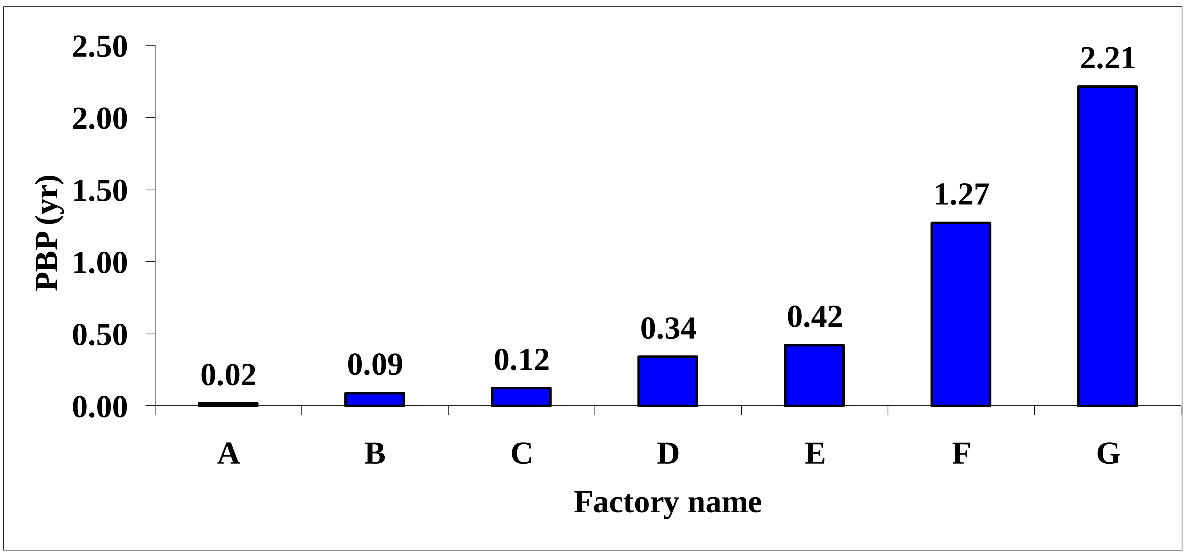

Figure 4.13: Payback period when economizer is used

The results from Figure 4.13 show that payback period with economizer being installed in the food industrial sector from 0.02 years in ***A*** factory to 2.21 years in ***G*** factory. It can be observed that payback period is quite high in ***G*** factory in comparison to other factories. This is due to annual energy consumption of these factories are lower than G factories. However in other factories like A, B, C, D, and E the payback periods are very suitable and enhance installation of this application. These results indicate that economizer can be a useful device for short term purposes in Malaysia when the annual energy consumption of boilers is very high and the payback period is short.

4.5 Lighting results

Based on the fact that the average percentage of lighting represent about 15% of the total electrical industrial sector's consumption in Malaysia (Al-Mofleh *et al.*, 2009) and the total of electrical energy consumption for food industry has been tabulated in Table 2.7 (PTM, 2009). The results of the lighting's energy audit for food industrial sectors are shown in Table 4.6.

Table 4.6 Results of the lighting's of food industrial energy audit

Factory name	Location	Energy consumption (kWh)
A	Johor (south)	4,023,000
B	Melaka (central)	2,004,900
C	Pahang (East)	1,996,050
D	Pahang (East)	1,793,700
E	Perak (North)	644,250
F	Penang (North)	227,550
G	Penang (North)	170,550
H	Perak (North)	97,200
I	Penang (North)	72,450
J	Sarawak	26,250
Total		**11,055,900**

4.5.1 Energy savings from lighting

Energy savings by replacing T12 and T8 lamps with T5 lamps in all the food factories can be estimated by the Equation 3.25. The lighting will save 50% when installed T5 lamp, the results of total annual energy savings in kWh has been tabulated in Table F.13 (Appendices) and has been illustrated in Figure 4.14.

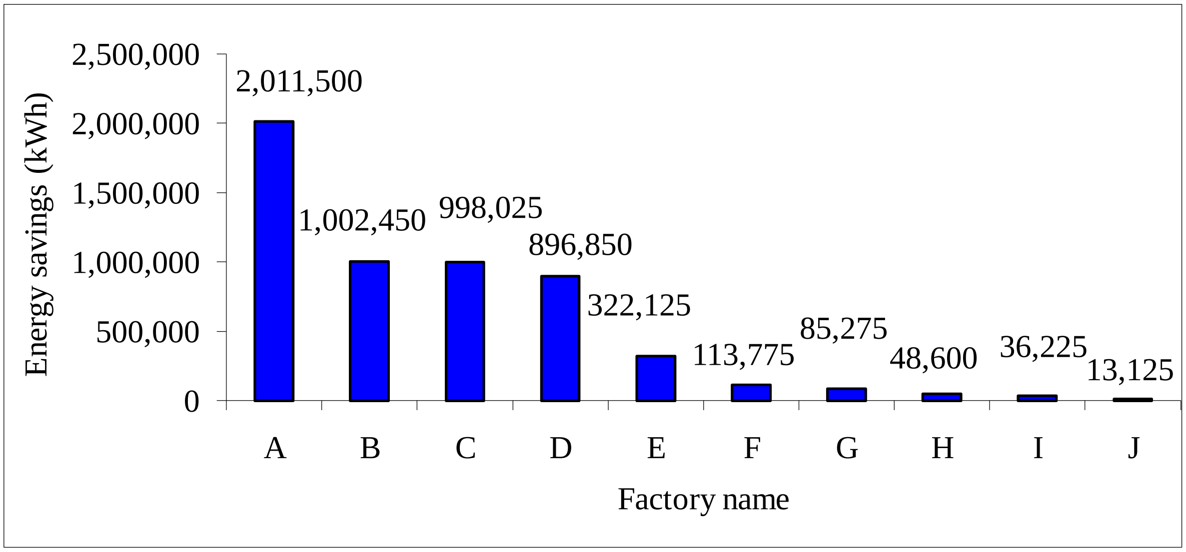

Figure 4.14: Energy savings by replacing lighting with T5

The results from Figure 4.14 show that annual energy savings by replacing T12 and T8 lamps with T5 in food industrial sector from 2,011,500 kWh in ***A*** factory to 13,125 kWh in ***J*** factory. It can be observed that annual energy savings is quite high in ***A*** factory in comparison to other factories. This is due to annual energy consumption of these factories are lower than ***A*** factory. These results indicate that T5 lamp can be a useful device for purposes in Malaysian food industries when the annual energy consumption of lighting is very high and the energy saving is high.

4.5.2 Cost benefits analysis of lighting

Bill savings by replacing T12 and T8 lamps with T5 lamps in Malaysian food industry has been calculated by the Equation 3.26 and data from Table F.1 (Appendices). The results of total annual bill savings in US$ of this application has been illustrated in Figure 4.15 and also shown in Table F.14 (Appendices).

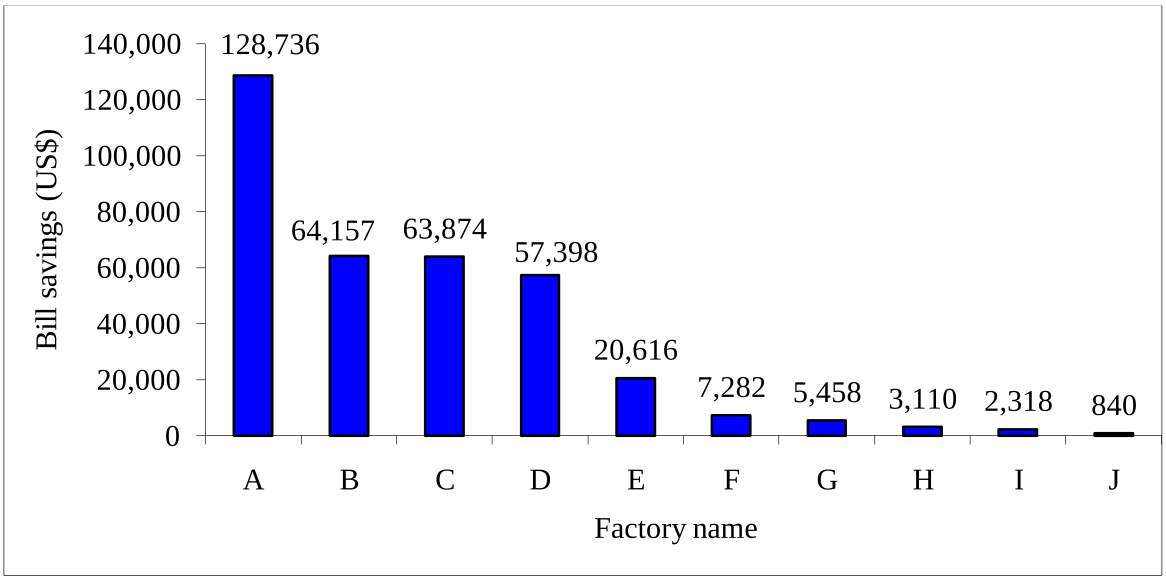

Figure 4.15: Bill savings by replacing lighting with T5

The results from Figure 4.15 show that annual bill savings by replacing T12 and T8 lamps with T5 in food industrial sector range from US$128,736 in ***A*** factory to US$840 in ***J*** factory. It can be observed that annual bill savings is quite high in ***A*** factory in comparison to other factories. This is due to annual energy consumption of these factories are lower than ***A*** factory. These results indicate that there is a huge amount of bill savings can be achieved with installing new lamps in Malaysian food industrial sector.

4.5.3 Emissions reduction for lighting

Emissions reduction by replacing T12 and T8 lamps with T5 lamp in all the food factories have been calculated by Equations (3.27 – 3.30) and data from Tables 4.2 and 4.3, the results can be illustrated in Figure 3.16 and tabulated in Table F.15 (Appendices):

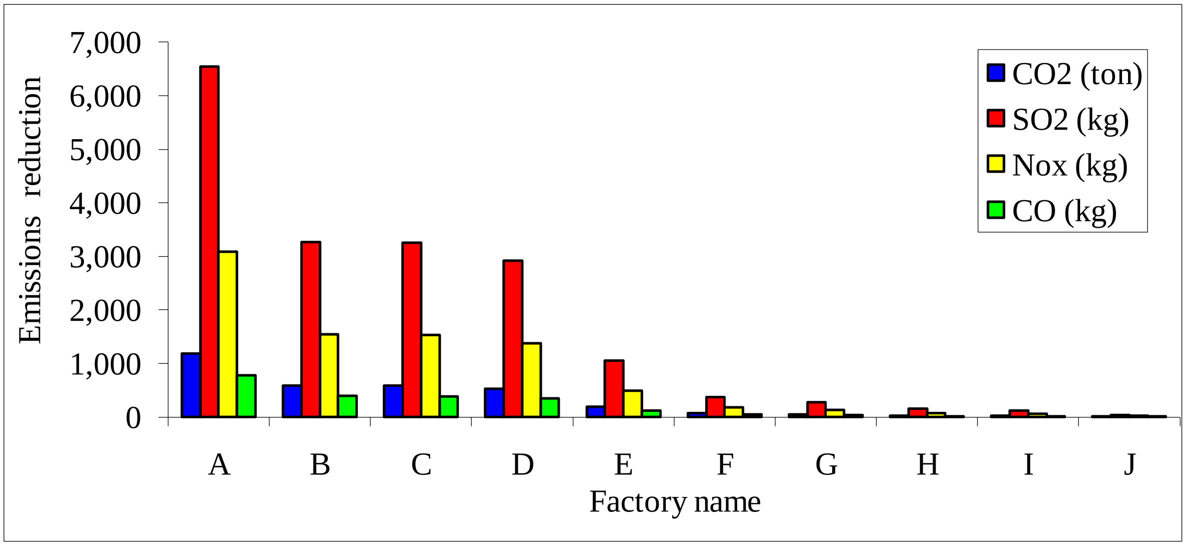

Figure 4.16: Emissions reduction by replacing lighting with T5 lamps

The results from Figure 4.16 show that the emissions reduction by installed installing new lamps (T5) is represented a significant amount of reduction in food industrial sector. It observed that the emissions reduction can be substantially reduced by installing T5 lamps for lighting in food industrial sector. These results indicate that T5 lamps can be a valuable device for lighting in Malaysian food industries when the annual energy consumption of lighting is very high and the emissions reduction is high too.

4.6 Results of air compressor systems

Based on the fact that, air compressor systems represent about 18% of the electrical industrial sector's consumption (Saidur, 2009) and leakage of air compressor systems consume about 35% of energy consumption (Saidur *et al.*, 2009b). The results of air compressor system energy audit for food industrial sectors are shown in Table 4.7.

Table 4.7 Results of air compressor system's food industrial energy audit (PTM, 2009)

Factory name	Location	Energy consumption (kWh)
A	Johor (south)	4,827,600
B	Melaka (central)	2,405,880
C	Pahang (East)	2,395,260
D	Pahang (East)	2,152,440
E	Perak (North)	773,100
F	Penang (North)	273,060
G	Penang (North)	204,660
H	Perak (North)	116,640
I	Penang (North)	86,940
J	Sarawak	31,500
Total		**13,267,080**

4.6.1 Energy savings from air compressor systems

Energy savings by repairing leakage of air compressor system based on the Equation 3.31 and data from Table 4.8, the results of total annual energy saving in kWh has been shown in Table F.16 (Appendices) and illustrated in the Figure 4.17.

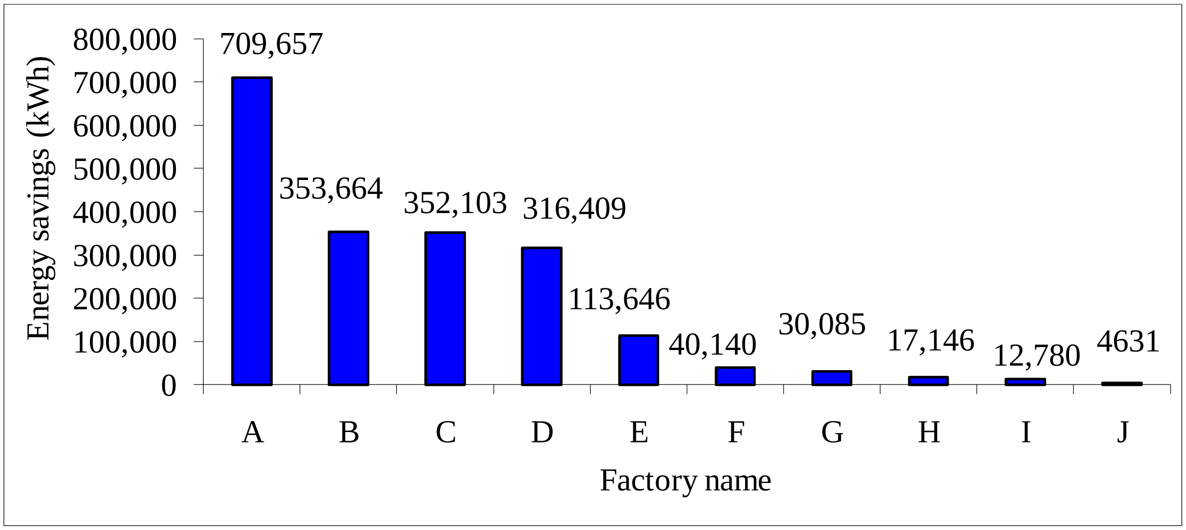

Figure 4.17: Energy savings when repairing leaks of air compressor systems

The results from Figure 4.17 show that annual energy savings by repairing leakage in food industrial sector about 709,657 kWh in ***A*** factory to 4631 kWh in ***J*** factory. It can be observed that annual energy savings is extremely high in ***A*** factory in comparison to other factories. This is due to annual energy consumption of these factories are lower than ***A*** factory. These results indicate that repairing leakage of air compressor system can be a useful technique to save energy consumption Malaysian food industrial sector.

4.6.2 Cost benefit analysis by repairing leaks of air compressor systems

Bill savings by repairing leaks of air compressor system in all the industrial food factories has been calculated by the Equation 3.32 and data from Table F.1 (Appendices). The results of total annual bill savings in US$ with this application is illustrated in Figure 4.18 and presented in Table F.17 (Appendices).

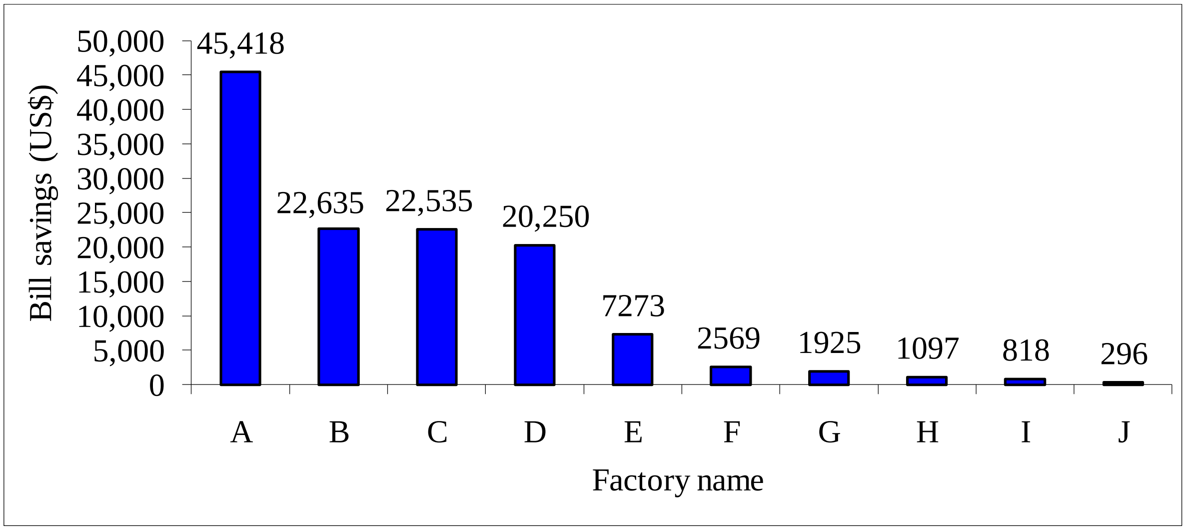

Figure 4.18: Bill savings by repairing leaks of air compressor system

The results from Figure 4.18 show that annual bill savings from repairing leakage in food industrial sector is varying between all factories. It can be seen that annual bill savings is quite high in ***A*** factory in comparison to other factories. This is due to annual energy consumption of these factories are lower than ***A*** factory. These results indicate that there is a considerable amount of bill savings can be achieved with repairing leakage of air compressor system in Malaysian food industrial sector.

4.6.3 Emissions reduction by repairing leaks of air compressor systems

Emissions reduction by repairing leaks of air compressor system in all the food factories has been calculated by Equations (3.33 – 3.36) and data from 4.2 and 4.3. The results have been illustrated in Figure 4.19 and also tabulated in Table F.18 (Appendices):

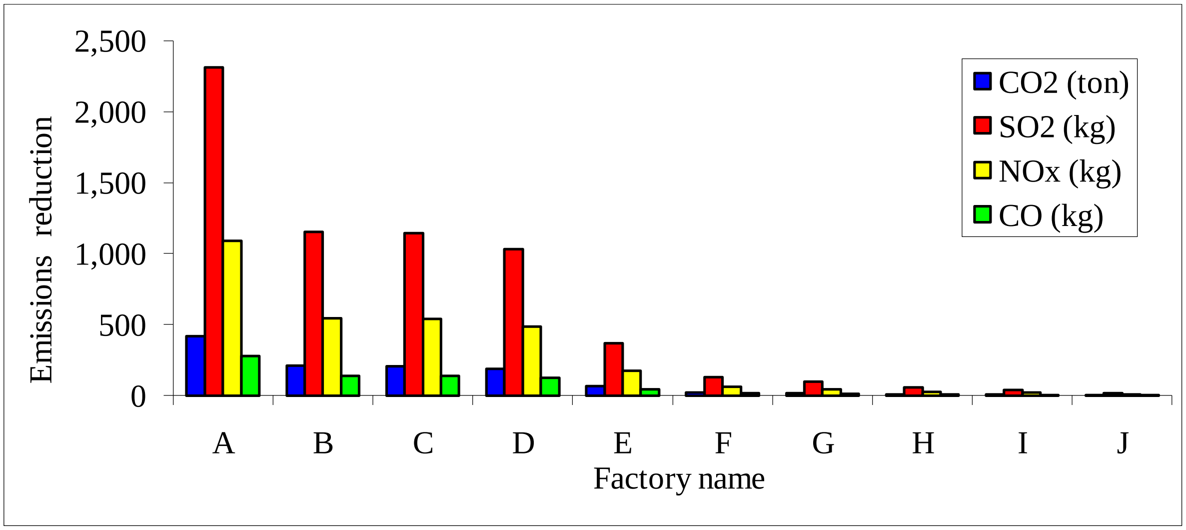

Figure 4.19: Emissions reduction by repairing leaks of air compressor systems

The results from Figure 4.19 show that the emissions reduction by repairing leakage is represented a significant amount of reduction in food industrial sector. It observed that the emissions reduction can be significantly reduced by repairing leakage of compressor in food industrial sector. These results indicate that repairing leakage can be a helpful method for air compressor systems in Malaysian food industries when the annual energy consumption of air compressor systems is very high. These results show similar trend as found in the literature and represent a huge amount of emissions reduction that can be achieved by repairing leakage of air compressor in food industry.

CHAPTER 5

CONCLUSIONS AND SUGGESIONS FOR FUTURE WORK

5.1 Conclusions

Total annual amount of 1,427,892 kWh of energy savings, 843 ton of CO_2 emissions reduction, US$91,385 bill savings and 2.01 year average of payback period could be achieved when installing high efficiency motors at 50% motor load. Similar results are obtained for 75% and 100% motor loads. These results indicate that high efficiency motor is an energy saving, economically viable and emissions reduction application specially when increasing the of load motor. This can be used in small developing country like Malaysia.

Energy savings in motors can be achieved by installing variable speed drive. It has been found that by installing variable speed drives in these motors, the total annual amount of 75,423 MWh of energy saving, 44,538 tons of CO_2 emission reduction, US$4,827,104 bill savings and 1.61 year average of payback period could be achieved when reducing the speed of motors by 60%. These results indicate that VSDs are energy saving, economically viable and emissions reduction application specially when increasing the speed reduction percentage of motors. This can be used in small developing country like Malaysia.

It has been found that total amount of 15,468,300 kWh energy savings, US$796,163 bill savings and 13,148 tons of CO_2, 253,680 kg of SO_2, 38,671 kg of NO_x and 3,094 kg of CO emission reductions could be achieved annually by installing economizes in boilers and the average of payback period is less than one year. These results indicate that economizer is an energy saving, economically viable and emissions reduction application. It can be used in small developing countries like Malaysia.

Energy saving can be achieved by installing T5 lamps. It has been found that total annual amount of 5,527,950 kWh energy saving, US$353,789 bill saving and 3,264 tons of CO_2, 17,993 kg of SO_2, 8,485 kg of NO_x and 2,256 kg of CO emission reductions could be achieved annually. These results indicate that a new lamp is an energy saving, economically viable and emissions reduction application. It can be used in small developing countries like Malaysia.

Energy saving can be achieved by repairing air compressor leaks. It has been found that total annual amount of 1,950,261 kWh of energy saving, US$124,817 bill saving and 1,152 tons of CO_2, 8,348 kg of SO_2, 2,994 kg of NO_x and 761 kg of CO emission reductions could be achieved annually. These results indicate that repairing leakage is an energy saving, economically viable and emissions reduction application. It can be used in small developing countries like Malaysia.

5.2 Suggestions for future work

This dissertation has focused on the energy analysis, emission analysis, and bill savings food industrial sector. The findings of this study proved the viability of all the methods used. Nevertheless, it is suggested that further studies can be carried out for refrigeration system, air conditioning, heat recovery from compressor, conveyor and boiler energy analysis.

There are several methods which can be used to improve and reduce energy consumption in food industrial sector in Malaysia.

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APPENDICES

APPENDIX A

SAMPLE OF CALCULATIONS WHEN HIGH EFFICIENCY MOTORS ARE USED

1. **Energy savings when HEMs are used:**

From Equation 3.2, annual energy savings by using high efficiency motors at 50% motor load of 1 HP can be calculated as follow:

$AES_{HEM} = n \times HP \times 0.746 \times H \times L \times \left(\frac{1}{Estd} - \frac{1}{Eee}\right) \times 100$ = 262 × 1 × 0.746 × 6000 × 0.5 × $(\frac{1}{70.05} - \frac{1}{75.28}) \times 100$ = ***58,153 kWh.***

When repeating the same calculations for other motors those have been shown in Table 3.3 and using Equation 3.2 and data from Table 2.4, the results of annual energy savings at 50% motor load are as follow:

For 1.5 HP, AES_{HEM} = 4,877 kWh

For 2 HP, AES_{HEM} = 22,272 kWh

For 3 HP, AES_{HEM} = 95,635 kWh

For 4 HP, AES_{HEM} = 309,047 kWh

For 5.5 HP, AES_{HEM} = 12,660 kWh

For 7.5 HP, AES_{HEM} = 14,794 kWh

For 15 HP, $AES_{HEM} = 16,740$ kWh

For 20 HP, $AES_{HEM} = 317,802$ kWh

For 25 HP, $AES_{HEM} = 122,647$ kWh

For 30 HP, $AES_{HEM} = 45,209$ kWh

For 40 HP, $AES_{HEM} = 110,733$ kWh

For 50 HP, $AES_{HEM} = 46,098$ kWh

For 60 HP, $AES_{HEM} = 203,381$ kWh

For 75 HP, $AES_{HEM} = 47,843$ kWh

Thus, total annual energy saving in all motors at 50% load is equal to:

58,153 + 4,877 + 22,272 + 95,635 + 309,047 + 12,660 + 14,794 + 16,740 + 317,802 + 122,647 + 45,209 + 110,733 + 46,098 + 203,381 + 47,843 = ***1,427,892 kWh.***

2. **Cost benefit analysis when using HEMs**

From Equation 3.3, annual bill savings by using HEMs, 1 HP of 50% motor load can be calculated as:

$Annual\ Bill\ Savings\ (ABS_{HEMs}) = AES_{HEM} \times C$= 58,153 × 0.064 = ***US$ 3,722***

Repeating the same calculations for other motors those have been shown in Table 4.1 and using Equation 3.3, the result of annual energy saving at 50% motor load are as follow:

For 1.5 HP, $ABS_{HEMs} =$ US$ 312

For 2 HP, ABS_{HEMs} = US$ 1,425

For 3 HP, ABS_{HEMs} = US$ 6,121

For 4 HP, ABS_{HEMs} = US$ 19,779

For 5.5 HP, ABS_{HEMs} = US$ 810

For 7.5 HP, ABS_{HEMs} = US$ 947

For 15 HP, ABS_{HEMs} = US$ 1,071

For 20 HP, ABS_{HEMs} = US$ 20,339

For 25 HP, ABS_{HEMs} = US$ 7,849

For 30 HP, ABS_{HEMs} = US$ 2,893

For 40 HP, ABS_{HEMs} = US$ 7,087

For 50 HP, ABS_{HEMs} = US$ 2,950

For 60 HP, ABS_{HEMs} = US$ 13,016

For 75 HP, ABS_{HEMs} = US$ 3,062

Thus, total annual bill saving in all motors in 50% motor load is equal to:

3,722 + 312 + 1,425 + 6,121 + 19,779 + 810 + 947 + 1,071 + 20,339 + 7,849 + 2,893 + 7,087 + 2,950 + 13,016 + 3,062= ***US$ 91,385.***

3. **Emissions reduction when using HEMs:**

By using Equations (3.4-3.7) and the data from Tables 4.2 and 4.3 respectively, the total annual emissions reduction of CO_2, SO_2, NO_X and CO could be obtained by using HEMs, those have been shown in Table 3.3 and in 50% motor load:

$AER_{CO2} = AES_{\ HEMs} \times \sum(\%F \ \times \ EF_{CO2})$=

1,427,892 × (1.18 × 0.15 + 0.85 × 0.05 + 0.53 × 0.70) / 1000 = ***843 ton.***

$AER_{SO2} = AES_{\ HEMs} \ \times \sum(\%F \times EF_{SO2})$=

1,427,892 × (0.0139 × 0.15 + 0.0164 × 0.05 + 0.0005 × 0.70) = ***4,648 kg.***

$AER_{NOx} = AES_{\ HEMs} \ \times \ \sum(\%F \ \times \ EF_{NOx}) =$

1,427,892 × (0.0052 × 0.15 + 0.0025 × 0.05 + 0.0009 × 0. 70) = ***2,192 kg.***

$AER_{CO} = AES_{\ HEMs} \ \times \ \sum(\%F \ \times \ EF_{CO})$=

1,427,892 × (0.0002 × 0.15 + 0.0002 × 0.05 + 0.0005 × 0.70) = ***557 kg.***

4. **Payback period when using HEMs**

Based on Equation 3.8 and incremental costs of HEMs showed in Table 4.4, payback period, when HEMs used are shown in Table 4.1 and at 50% motor load are as follows:

$$Payback\ period\ (PBP_{HEMs}) \ = \frac{Incremental\ cost\ of\ motors\ (IC_{HEMs})}{Annual\ bill\ savings\ (ABS_{HEHs})}$$

For 1 HP, $PBP_{HEMs} = \frac{6288}{3722}$ = ***1.69 years***

When repeating the same calculations for other motors those have been shown in Table 4.1 and using Equation 3.8 and Table 4.4 respectively, the result of payback period at 50% motor load are as follow:

For 1.5 HP, $PBP_{HEMs} = 1.48$ years

For 2 HP, $PBP_{HEMs} = 1.91$ years

For 3 HP, $PBP_{HEMs} = 0.86$ years

For 4 HP, $PBP_{HEMs} = 2.71$ years

For 5.5 HP, $PBP_{HEMs} = 1.76$ years

For 7.5 HP, $PBP_{HEMs} = 4.23$ years

For 15 HP, $PBP_{HEMs} = 1.51$ years

For 20 HP, $PBP_{HEMs} = 2.11$ years

For 25 HP, $PBP_{HEMs} = 2.05$ years

For 30 HP, $PBP_{HEMs} = 1.95$ years

For 40 HP, $PBP_{HEMs} = 1.43$ years

For 50 HP, $PBP_{HEMs} = 2.10$ years

For 60 HP, $PBP_{HEMs} = 2.43$ years

For 75 HP, $PBP_{HEMs} = 1.86$ years

The average payback period in this study is equal to:

$$\frac{1.69+1.48+1.86+0.86+2.71+1.76+4.23+1.51+2.11+2.05+1.95+1.43+2.10+2.43+1.86}{15}$$

= ***2.1 years***

Similarly we can repeat all this calculations for 75% and 100% load of motors.

APPENDIX B

SAMPLE CALCULATIONS WHEN VARIABLE SPEED DRIVES ARE USED.

1. Energy savings when using VSDs:

From Equation 3.9, annual energy saving when variable speed drive is used at 10% speed reduction for a motor of 1 HP, could be calculated as follow:

$AES_{VSD} = n \times P \times 0.746 \times H_{avg\text{-}usage} \times S_{SR} =$

262 × 1 × 0.746 × 6000 × 0.22 = ***257,997 kWh***

When repeating the same calculations for other motors those have been shown in Table 4.1 and using Equation 3.9, the result of annual energy saving at 10% speed reduction are as follows:

For 1.5 HP, $AES_{VSD} =$ 32,496 kWh

For 2 HP, $AES_{VSD} =$ 214,669 kWh

For 3 HP, $AES_{VSD} =$ 579,015 kWh

For 4 HP, $AES_{VSD} =$ 3,521,359 kWh

For 5.5 HP, $AES_{VSD} =$ 119,151 kWh

For 7.5 HP, $AES_{VSD} =$ 324,958 kWh

For 15 HP, $AES_{VSD} =$ 162,479 kWh

For 20 HP, $AES_{VSD} =$ 4,293,379 kWh

For 25 HP, $AES_{VSD} = 1{,}610{,}324$ kWh

For 30 HP, $AES_{VSD} = 649{,}915$ kWh

For 40 HP, $AES_{VSD} = 1{,}733{,}107$ kWh

For 50 HP, $AES_{VSD} = 1{,}083{,}192$ kWh

For 60 HP, $AES_{VSD} = 3{,}249{,}576$ kWh

For 75 HP, $AES_{VSD} = 812{,}394$ kWh

Thus, total annual energy saving in all motors and at 10% speed reduction is equal to:

257,995 + 32,496 + 214,669 + 579,015 + 3,521,359 + 119,151 + 324,958 + 162,479 + 4,293,379 + 1,610,324 + 649,915 + 1,733,107 + 1,083,192 + 3,249,576 + 812,394 = ***18,644,011 kWh.***

2. Cost benefit analysis when using VSDs:

Based on Equation 3.10, annual bill savings when using VSD in motors that have been showed in Table 4.1 and in 10% speed reduction are as follow:

$Annual\ Bill\ Savings\ (ABS_{VSD}) = AES_{VSD} \times C$= 257,995 × 0.064= ***US$ 16,512***

For 1.5 HP, $ABS_{VSD} =$ US$ 2,080

For 2 HP, $ABS_{VSD} =$ US$ 13,739

For 3 HP, $ABS_{VSD} =$ US$ 37,057

For 4 HP, ABS_{VSD} = US$ 225,367

For 5.5 HP, ABS_{VSD} = US$ 7,626

For 7.5 HP, ABS_{VSD} = US$ 20,797

For 15 HP, ABS_{VSD} = US$ 10,399

For 20 HP, ABS_{VSD} = US$ 274,776

For 25 HP, ABS_{VSD} = US$ 103,061

For 30 HP, ABS_{VSD} = US$ 41,595

For 40 HP, ABS_{VSD} = US$ 110,919

For 50 HP, ABS_{VSD} = US$ 69,324

For 60 HP, ABS_{VSD} = US$ 207,973

For 75 HP, ABS_{VSD} = US$ 51,993

Thus, total annual bill saving in all motors and at 10% speed reduction is equal to: 16,512 + 2,080 + 13,739 + 37,057 + 225,367 + 7,626 + 20,797 + 10,399 + 274,776 + 103,061 + 41,595 + 110,919 + 69,324 + 207,973 + 51,993 = ***US$ 1,193,217***

3. Emissions reduction when using VSDs:

By using Equations (3.11- 3.14) and Tables 4.2 and 4.3, the total annual emissions reduction of CO_2, SO_2, NO_X and CO can be obtained when VSD in motors have been used as shown in Table 4.1 and at 10% speed reduction:

$AER_{CO2} = AES_{VSD} \times \sum(\%F \times \mathrm{EF}_{CO2})$=

18,644,011 × (1.18 × 0.15 + 0.85 × 0.05 + 0.53 × 0.70) / 1000 = ***11,009 ton.***

$AER_{SO2} = AES_{VSD} \times \sum(\%F \times EF_{SO2})$=

18,644,011 × (0.0139 × 0.15 + 0.0164 × 0.05 + 0.0005 × 0.70) = ***60,686 Kg.***

$AER_{NOx} = AES_{VSD} \times \sum(\%F \times EF_{NOx}) =$

18,644,011 × (0.0052 × 0.15 + 0.0025 × 0.05 + 0.0009 × 0. 70) = ***28,619Kg.***

$AER_{CO} = AES_{VSD} \times \sum(\%F \times EF_{CO})$=

18,644,011 × (0.0002 × 0.15 + 0.0002 × 0.05 + 0.0005 × 0.70) = ***7,271 Kg.***

4. **Payback period when using VSDs**

Based on Equation 3.15 and incremental costs of VSDs showed in Table 4.5, payback period when VSDs are used in motors those have been shown in Table 3.3 and at 10% speed reduction are as follows:

$$Payback\ period\ (PBP_{VSD}) = \frac{Incremental\ cost\ of\ motors\ (IC_{VSD})}{Annual\ bill\ savings\ (ABS_{VSD})}$$

For 1 HP, $PBP_{VSD} = \frac{109{,}542}{16{,}512} =$ ***6.63 years***

When repeating the same calculations for other motors those have been shown in Table 4.1 and using Equations 3.8, Table 4.5, the result of annual energy saving at 10% speed reduction are calculated as:

For 1.5 HP, $PBP_{VSD} = 6.63$ years

For 2 HP, $PBP_{VSD} = 6.63$ years

For 3 HP, $PBP_{VSD} = 6.62$ years

For 4 HP, $PBP_{VSD} = 6.62$ years

For 5.5 HP, $PBP_{VSD} = 6.61$ years

For 7.5 HP, $PBP_{VSD} = 6.60$years

For 15 HP, $PBP_{VSD} = 6.57$ years

For 20 HP, $PBP_{VSD} = 6.54$ years

For 25 HP, $PBP_{VSD} = 6.52$ years

For 30 HP, $PBP_{VSD} = 6.5$ years

For 40 HP, $PBP_{VSD} = 6.4$ years

For 50 HP, $PBP_{VSD} = 6.4$ years

For 60 HP, $PBP_{VSD} = 6.35$ years

For 75 HP, $PBP_{VSD} = 6.28$ years

The average payback period in this study is equal to:

$$\frac{6.63+6.63+6.63+6.62+6.62+6.61+6.60+6.57+6.54+6.52+6.5+6.4+6.4+6.35+6.28}{15}$$

= ***6.53 years***

Similarly we can repeat all this calculations for 20% to 60% speed reduction of motors as shown.

APPENDIX C

SAMPLE CALCULATIONS WHEN HEAT RECOVERY SYSTEMS ARE USED

1. Energy savings when heat recovery systems (Economizer) are used

Based on Equation 3.16 and data from Table F.1 (Appendices), total energy consumption in all factories without using economizers in the factories have been presented in Table 2.6, are calculated as follows:

$$TAEC_{\mathrm{HR}}\,(KWh) = \frac{ADC \times \rho \times EHC}{3600} = \frac{16176000 \times 850 \times 45000}{3600 \times 1000} = \boldsymbol{171{,}870{,}000\ kWh}$$

Based on Equations 3.17 and 3.18 and Table F.1, total energy savings in all factories when economizers are used in the factories those have been shown in Table 2,6 can be calculated as follows:

$$AES_{\mathrm{HR}} = AEC \times \%_{\mathrm{PRH}} \times \eta_{\mathrm{ECN}}(\%) = 171{,}870{,}000 \times 0.20 \times 0.45 = \boldsymbol{15{,}468{,}300\ kWh.}$$

Increasing efficiency of boilers by using economizer can be calculated as:

$$\%\eta_{th} = \frac{TAES_{HR}}{TAEC_{KWH}} = \frac{15{,}468{,}300}{171{,}870{,}000} = \boldsymbol{9\%.}$$

2. Cost benefits analysis when heat recovery systems (Economizer) are used

Based on Equation 3.19 total of annual bill savings when economizers are used in all factories can be calculated as follow:

$$TABS_{HR} = TAES \times PF = \frac{15{,}468{,}300 \times 3600 \times 1000}{(850 \times 45000)} \times \left(\frac{RM1.75}{US\$3.2}\right)$$

= ***US$ 796,163***

3. **Emissions reduction when heat recovery systems (Economizer) are used**

Based on the Equations (3.20- 3.23) and data from Table 4.2, annual emissions reduction can be calculated as follow when economizer is used:

$AER_{CO2} = TAES_{HR} \times EF_{CO2}$ = 15,468,300 × $\frac{0.85}{1000}$ = ***13,148 tons.***

$AER_{SO2} = TAES_{HR} \times EF_{SO2}$ = 15,468,300 × 0.0164 = ***253,680 kg.***

$AER_{NOx} = TAES_{HR} \times EF_{NOx}$ = 15,468,300 × 0.0025 = ***38,671 kg.***

$AER_{CO} = TAES_{HR} \times EF_{CO}$ = 15,468,300 × 0.0002 = ***3,094 kg.***

4. **Payback period when Economizer system is installed**

Based on the Equation 3.24 the payback period could be calculated as follow when economizers in factories were used:

PBP_A $\frac{IC_{HR}}{ABS_{HR}}$ = $\frac{9,375}{553,465}$ = ***0.02 year.***

Repeating the same calculations for other factories as shown in Table 2.6 and by using Equation 3.24, the results of payback period could be calculated as follows:

PBP_B = 0.09 years.

PBP_C = 0.12 years.

PBP_D = 0.34 years.

PBP_E = 0.42 years.

PBP_F = 1.27 years.

PBP_G = 2.21 years.

APPENDIX D

SAMPLE CALCULATIONS ON INSTALLING T5 LAMP

1. Energy saving when T5 lamp are used

Based on Equation 3.25, total energy savings in all factories when using T5 lamps can be calculated as follows for the factories those have shown in Table 4.6:

$AES_L = AEC_{T(12\text{-}8)} \times \%_{T\text{-}5} = 11{,}055{,}900 \times 0.5 =$ **5,527,950 kWh.**

2. Cost benefits analysis when T5 lamp is used

Based on Equation 3.26 total annual bill saving can be calculated as follows when economizers in all factories are used:

$TABS_L = AES_L \times PF = 5{,}527{,}950 \times 0.064 =$ **US$ 353,789**

3. Emissions reduction when T5 lamp is used

Based on the Equations (3.27- 3.30) and data from Tables 4.2 and 4.3, annual emissions reduction can be calculated as follows when T5 lamp is used:

$AER_{CO2} = AES_L \times \sum(\%F \times EF_{CO2}) =$

$5{,}527{,}950 \times (1.18 \times 0.15 + 0.85 \times 0.05 + 0.53 \times 0.70) \times \frac{1}{1000} =$ ***3,264 tons.***

$AER_{SO2} = AES_L \times \sum(\%F \times EF_{SO2}) =$

5,527,950 × (0.0139 × 0.15 + 0.0164 × 0.05 + 0.0005 × 0.70)= ***17,993 kg.***

$AER_{NOx} = AES_{L} \times \sum(\%F \times EF_{NOx}) =$

5,527,950 × (0.0052 × 0.15 + 0.0025 × 0.05 + 0.0009 × 0. 70)= ***8,485kg.***

$AER_{CO} = AES_{L} \times \sum(\%F \times EF_{CO})$=

5,527,950 × (0.0002 × 0.15 + 0.0002 × 0.05 + 0.0005 × 0.70)= ***2,156 kg.***

APPENDIX E

SAMPLE CALCULATIONS WHEN LEAKAGE ARE REPAIRED

1. Energy savings when Leakage are repaired

Based on Equation 3.31, total annual energy savings in all factories can be calculated as follows on repairing of leaks of air compressor in the factories those have been in Table 4.7:

$AES_{\text{CS-Leak}} = \text{AEC}_{\text{CS}} \times \%EC_{\text{Leak}} \times \%\text{ES}$ = 13,267,080 × 0.35 × 0.42= ***1,950,261 kWh.***

2. Cost benefits analysis after repairing leakage

Based on Equation 3.32, total of annual bill saving after repairing Leakage in all factories can be calculated as follow:

$ABS_{\text{CS-Leak}} = AES_{\text{CS-Leak}} \times EP = 1{,}950{,}261 \times 0.064$ = **US$ 124,817**

3. Emissions reduction after repairing leakage

Based on the Equations (3.33-3.36) and data from Tables 4.2 and 4.3, annual emissions reduction can be calculated as follow after repairing leakage:

$AER_{CO2} = AES_{\text{CS-Leak}} \times \sum(\%F \times \text{EF}_{CO2})$=

$1{,}950{,}261 \times$ (1.18 × 0.15 + 0.85 × 0.05 + 0.53 × 0.70) / 1000 = ***1,152 ton.***

$AER_{SO2} = AES_{\text{CS-Leak}} \times \sum(\%F \times EF_{SO2})$=

$1{,}950{,}261 \times (0.0139 \times 0.15 + 0.0164 \times 0.05 + 0.0005 \times 0.70) =$ ***6,348 kg.***

$AER_{NOx} = AES_{\text{CS-Leak}} \times \sum(\%F \times EF_{NOx}) =$

$1{,}950{,}261 \times (0.0052 \times 0.15 + 0.0025 \times 0.05 + 0.0009 \times 0.70) =$ ***2,994 kg.***

$AER_{CO} = AES_{\text{CS-Leak}} \times \sum(\%F \times EF_{CO}) =$

$1{,}950{,}261 \times (0.0002 \times 0.15 + 0.0002 \times 0.05 + 0.0005 \times 0.70) =$ ***761 kg.***

APPENDIX F

TABLES OF CALCULATIONS

Table F.1 Diesel properties, prices of electricity, percentage of recoverable heat and efficiency of economizer (Ben, 2010; (David, 2010;PTM, 2009; aidur et al., 2009a;Saidur *et al.*, 2009d; Wang, 2008)

Description	Value
Average percentage of recoverable heat	20%
Density of diesel (kg/m^3)	850
Efficiency of economizer	45%
Energy content of diesel (kJ/kg)	45,000
Price of diesel (RM/Lit)	1.75
Prices of electricity (US$/kWh)	0.064

Table F.2 Annual energy savings when installing HEMs

Motor (HP)	Number of motors	Energy savings (kWh)		
		50%	75%	100%
1	262	58,153	75,222	74,674
1.5	22	4877	5677	9232
2	109	22,272	41,999	36,767
3	196	95,635	136,797	133,336
4	894	309,047	487,165	687,319
5.5	22	12,660	9810	17,727
7.5	44	14,794	19,803	55,069
15	11	16,740	24,245	23,215
20	218	317,802	636,916	644,018
25	65	122,647	221,573	204,905
30	22	45,209	65,171	40,079
40	44	110,733	97,271	233,800
50	22	46,098	120,734	69,949
60	55	203,381	102,761	211,122
75	11	47,843	83,790	24,908
	Total	**1,427,892**	**2,128,934**	**2,466,119**

Table F.3 Bill savings when using HEMs

Motor (HP)	Number of motors	Bill savings (US$)		
		50%	75%	100%
1	262	3722	4814	4779
1.5	22	312	363	591
2	109	1,425	2688	2353
3	196	6121	8755	8533
4	894	19,779	31,179	43,988
5.5	22	810	628	1135
7.5	44	947	1267	3524
15	11	1071	1552	1486
20	218	20,339	40,763	41,217
25	65	7849	14,181	13,114
30	22	2893	4171	2565
40	44	7087	6225	14,963
50	22	2950	7727	4477
60	55	13,016	6577	13,512
75	11	3062	5363	1594
Total		**91,385**	**136,252**	**157,832**

Table F.4 Emissions reduction when installing HEMs

Emissions reduction	Total of emissions reduction		
	50%	75%	100%
CO_2 (ton)	843	1257	1456
SO_2 (kg)	4648	6930	8027
NO_x (kg)	2192	3268	3785
CO (kg)	557	830	962

Table F.5 Payback period when installing HEMs

Motor (HP)	Motors load		
	50%	75%	100%
1	1.69	1.31	1.32
1.5	1.48	1.27	0.78
2	1.91	1.01	1.16
3	0.86	0.60	0.62
4	2.71	1.72	1.22
5.5	1.76	2.28	1.26
7.5	4.23	3.16	1.14
15	1.51	1.04	1.09
20	2.11	1.05	1.04
25	2.05	1.14	1.23
30	1.95	1.36	2.21
40	1.43	1.63	0.68
50	2.10	0.80	1.38
60	2.43	4.80	2.34
75	1.86	1.06	3.58
Average	**2.01**	**1.62**	**1.40**

Table F.6 Energy savings when using VSDs

Motor	Energy savings (kWh)					
(HP)	10%	20%	30%	40%	50%	60%
1	257,997	515,993	715,354	856,080	973,351	1,043,714
1.5	32,496	64,992	90,102	107,827	122,598	131,460
2	214,669	429,338	595,218	712,311	809,887	868,434
3	579,015	1,158,031	1,605,452	1,921,278	2,184,467	2,342,380
4	3,521,359	7,042,717	9,763,767	11,684,508	13,285,126	14,245,497
5.5	119,151	238,302	330,374	395,365	449,525	482,020
7.5	324,958	649,915	901,019	1,078,268	1,225,976	1,314,601
15	162,479	324,958	450,509	539,134	612,988	657,301
20	4,293,379	8,586,758	11,904,370	14,246,213	16,197,749	17,368,670
25	1,610,324	3,220,649	4,464,990	5,343,349	6,075,315	6,514,494
30	649,915	1,299,830	1,802,038	2,156,537	2,451,953	2,629,202
40	1,733,107	3,466,214	4,805,434	5,750,765	6,538,541	7,011,206
50	1,083,192	2,166,384	3,003,396	3,594,228	4,086,588	4,382,004
60	3,249,576	6,499,152	9,010,188	10,782,684	12,259,764	13,146,012
75	812,394	1,624,788	2,252,547	2,695,671	3,064,941	3,286,503
Total	**18,644,011**	**37,288,022**	**51,694,758**	**61,864,218**	**70,338,769**	**75,423,499**

Table F.7 Bill savings when using VSDs

Motor (HP)	Bill savings (US$)					
	10%	20%	30%	40%	50%	60%
1	16,512	33,024	45,783	54,789	62,294	66,798
1.5	2080	4159	5767	6901	7846	8413
2	13,739	27,478	38,094	45,588	51,833	55,580
3	37,057	74,114	102,749	122,962	139,806	149,912
4	225,367	450,734	624,881	747,809	850,248	911,712
5.5	7626	15,251	21,144	25,303	28,770	30,849
7.5	20,797	41,595	57,665	69,009	78,462	84,134
15	10,399	20,797	28,833	34,505	39,231	42,067
20	274,776	549,553	761,880	911,758	1,036,656	1,111,595
25	103,061	206,122	285,759	341,974	388,820	416,928
30	41,595	83,189	115,330	138,018	156,925	168,269
40	110,919	221,838	307,548	368,049	418,467	448,717
50	69,324	138,649	192,217	230,031	261,542	280,448
60	207,973	415,946	576,652	690,092	784,625	841,345
75	51,993	103,986	144,163	172,523	196,156	210,336
Total	**1,193,217**	**2,386,433**	**3,308,464**	**3,959,310**	**4,501,681**	**4,827,104**

Table F.8 Total annual emissions reduction when using VSDs at different speed reduction

Emissions	Speed reduction					
	10%	20%	30%	40%	50%	60%
CO_2 (ton)	11,009	22,019	30,526	36,531	41,535	44,538
SO_2 (kg)	60,686	121,373	168,266	201,368	228,953	245,503
NO_x (kg)	28,619	57,237	79,351	94,962	107,970	115,775
CO (kg)	7271	14,542	20,161	24,127	27,432	29,415

Table F.9 Payback period at different speed reduction when using (VSDs)

Motor (HP)	Payback period (year)					
	10%	20%	30%	40%	50%	60%
1	6.63	3.32	2.39	2.00	1.76	1.64
1.5	6.63	3.32	2.39	2.00	1.76	1.64
2	6.63	3.31	2.39	2.00	1.76	1.64
3	6.62	3.31	2.39	2.00	1.76	1.64
4	6.62	3.31	2.39	2.00	1.75	1.64
5.5	6.61	3.31	2.38	1.99	1.75	1.63
7.5	6.60	3.30	2.38	1.99	1.75	1.63
15	6.57	3.28	2.37	1.98	1.74	1.62
20	6.54	3.27	2.36	1.97	1.73	1.62
25	6.52	3.26	2.35	1.96	1.73	1.61
30	6.50	3.25	2.34	1.96	1.72	1.61
40	6.45	3.22	2.33	1.94	1.71	1.59
50	6.40	3.20	2.31	1.93	1.70	1.58
60	6.35	3.18	2.29	1.91	1.68	1.57
75	6.28	3.14	2.26	1.89	1.66	1.55
Average	**6.53**	**3.27**	**2.36**	**1.96**	**1.73**	**1.61**

Table F.10 Energy savings when installing economizer system

Factory name	Location	Energy savings (kWh)
A	Pahang (East)	10,753,031
B	Pahang (East)	2,031,075
C	Melaka (central)	1,490,794
D	Perak (North)	535,500
E	Penang (North)	432,225
F	Penang (North)	143,438
G	Sarawak	82,238
Total		**15,468,300**

Table F.11 Bill savings with installed economizer system

Factory name	Location	Bill savings (US$)
A	Pahang (East)	553,465
B	Pahang (East)	104,541
C	Melaka (central)	76,732
D	Perak (North)	27,563
E	Penang (North)	22,247
F	Penang (North)	7383
G	Sarawak	4233
Total		**796,163**

Table F.12 Emissions reduction when installing economizer

Factory name	Emissions reduction			
	CO_2 (ton)	SO_2 (kg)	No_x (kg)	CO (kg)
A	9140	176,350	26,883	2151
B	1726	33,310	5078	406
C	1267	24,449	3727	298
D	455	8782	1339	107
E	367	7088	1081	86
F	122	2352	359	29
G	70	1349	206	16
Total	**13,148**	**253,680**	**38,671**	**3094**

Table F.13 Energy savings when installing T5 lamp

Factory name	Location	Energy savings (kWh)
A	Johor (south)	2,011,500
B	Melaka (central)	1,002,450
C	Pahang (East)	998,025
D	Pahang (East)	896,850
E	Perak (North)	322,125
F	Penang (North)	113,775
G	Penang (North)	85,275
H	Perak (North)	48,600
I	Penang (North)	36,225
J	Sarawak	13,125
Total		**5,527,950**

Table F.14 Bill saving when replacing lighting with T5

Factory name	Location	Bill savings (US$)
A	Johor (south)	128,736
B	Melaka (central)	64,157
C	Pahang (East)	63,874
D	Pahang (East)	57,398
E	Perak (North)	20,616
F	Penang (North)	7282
G	Penang (North)	5458
H	Perak (North)	3110
I	Penang (North)	2318
J	Sarawak	840
Total		**353,789**

Table F.15 Emissions reduction by replacing Lighting with T5

Factory name	Location	Emissions reduction			
		CO_2 (ton)	SO_2 (kg)	NO_x (kg)	CO (kg)
A	Johor (south)	1188	6547	3088	784
B	Melaka (central)	592	3263	1539	391
C	Pahang (East)	589	3249	1532	389
D	Pahang (East)	530	2919	1377	350
E	Perak (North)	190	1049	494	126
F	Penang (North)	67	370	175	44
G	Penang (North)	50	278	131	33
H	Perak (North)	29	158	75	19
I	Penang (North)	21	118	56	14
J	Sarawak	8	43	20	5
Total		**3264**	**17,993**	**8485**	**2156**

Table F.16 Energy savings when repairing leaks of air compressor system

Factory name	Location	Energy savings (kWh)
A	Johor (south)	709,657
B	Melaka (central)	353,664
C	Pahang (East)	352,103
D	Pahang (East)	316,409
E	Perak (North)	113,646
F	Penang (North)	40,140
G	Penang (North)	30,085
H	Perak (North)	17,146
I	Penang (North)	12,780
J	Sarawak	4631
Total		**1,950,261**

Table F.17 Bill savings by repairing leaks of air compressor systems

Factory name	Location	Bill savings (US$)
A	Johor (south)	45,418
B	Melaka (central)	22,635
C	Pahang (East)	22,535
D	Pahang (East)	20,250
E	Perak (North)	7273
F	Penang (North)	2569
G	Penang (North)	1925
H	Perak (North)	1097
I	Penang (North)	818
J	Sarawak	296
Total		**124,817**

Table F.18 Annual emissions reduction when repairing leaks of air compressor systems

Factory name	Location	Emissions reduction			
		CO_2 (ton)	SO_2 (kg)	NO_x (kg)	CO (kg)
A	Johor (south)	419	2310	1089	277
B	Melaka (central)	209	1151	543	138
C	Pahang (East)	208	1146	540	137
D	Pahang (East)	187	1030	486	123
E	Perak (North)	67	370	174	44
F	Penang (North)	24	131	62	16
G	Penang (North)	18	98	46	12
H	Perak (North)	10	56	26	7
I	Penang (North)	8	42	20	5
J	Sarawak	3	15	7	2
Total		**1152**	**6348**	**2994**	**761**