ENERGY MANAGEMENT AND IMPROVEMENT STRATEGIES IN A LOCAL SPICE MANUFACTURING PLANT

JEYANTHAN SILVALINGGAM

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
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JEYANTHAN SILVALINGGAM

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ABSTRACT

Environmental impact and diminishing natural resources are global phenomenon confronted around the world including developing countries such as Malaysia. Increasing electricity tariff is influenced by this aggravated impact to curb demand side wastefulness of energy consumption. Specifically, the outcome of price increment and other derivative economical elements can further be observed in various industries such as spice manufacturing plant as focused in this thesis.

Generally, in spice processing industry, the cost of electricity synonymously referred to the uses of grinders and cooling equipment. As a result, the staggering operating cost of the process had triggered the key persons affiliated with technical exposure to look ways into minimize the cost of operation in this industry. In view of this, improving energy efficiency of the plant machineries and equipment by means of retrofit or control has become the primary concern that need to be seriously addressed.

In observing the situation, an audit has been carried out in a local spice processing plant. Tasks were initiated to list down the operating segments that exist in the plant and to identify the segment which consume most energy. Besides that, attention was also focused in areas where little energy is consumed but revealing a brighter prospect for improvement. Following that, alternative ways are looked at on how to reduce energy consumption based on the literatures and researches done in the past.

In this regard, the study of energy savings demonstrated in this thesis has focused from a broader perspective taking into account the less energy user too.

Throughout the study, an analysis performed on the energy billing for three years from 2014 to 2017 on the trend of growth of electricity consumption. Further data acquisition for seven months on the available energy meters made a solid path on the areas where the energy consumption can be saved while CO_2 emission can be reduced. Electrical motors, variable speed drives, compressed air system and lighting improvement are areas that are focused in detail in this study.

The analysis results have shown and concluded that the electricity energy can be saved efficiently in this industry. Indeed, the finding of the study has proposed to explore further in diverse field for more energy saving opportunity in the future.

ABSTRAK

Impak alam sekitar and susustan bahanapi semulajadi adalah fenomena global yang mendapat perhatian seluruh dunia termasuk di Negara membangun seperti Malaysia. Kenaikan tarif elektrik tidak dapat dibendung tetapi dilihat sebagai satu cara untuk mengurangkan pembaziran tenaga elektrik secara berleluasa di kalangan pengguna. Secara khususnya, susulan daripada kenaikan ini dan elemen terbitan ekonomi, kesannya dapat diperhatikan dalam pelbagai industri seperti industri memproses rempah.

Secara amnya, dalam industry memproses rempah, kos elektrik sering dikaitkan dengan pengisar dan alatan penyejukan. Hasilnya, kos operasi yang naik mendadak telah mendapat perhatian daripada pihak teknikal untuk mencari cara-cara untuk mengurangkan kos operasi di dalam industri ini. Melihat kepada keadaan ini, cara-cara ubahsuai atau kawalan untuk menaikkan kecekapan tenaga sesuatu mesin atau peralatan telah menjadi topik yang harus dibentangkan.

Melihat kepada situasi ini, satu audit telah dijalankan di kilang memproses rempah tempatan. Aktiviti yang dijalankan termasuklah menyenaraikan semua segmen operasi yang terdapat di dalam kilang berkaitan dan mengenalpasti segmen yang menggunakan tenaga yang banyak. Disamping itu, sektor dimana tenaga kurang digunakan tetapi mempunyai peluang yang cerah untuk diimprovasi juga dikenalpasti. Berikutan itu, pelbagai alternatif dikaji untuk mengurangkan penggunaan tenaga dengan berpandukan bahan literasi dan kajian yang pernah dijalankan.

Menyedari hakikat ini, kajian berikutan penjimatan tenaga yang dipaparkan di dalam tesis ini turut mengambilkira alatan yang menggunakan tenaga rendah. Disepanjang kajian ini, bil elektrik terkumpul dari tahun 2014 hingga 2017 telah dianalisa dalam mengkaji perkembangan penggunaan tenaga elektrik. Disamping itu, data-data telah dikumpul dari meter tenaga yang ada dalam masa tujuh bulan bagi mendapat halatuju yang jelas tentang dimana penjimatan dapat dilakukan disamping mengurangkan pembebasan gas karbon dioksida ke udara. Diantara litupan yang mendapat perhatian dalam kajian ini termasuklah motor elektrik, pengubah laju, sistem angin bertekanan tinggi dan lampu.

Hasil daripada kajian ini menyimpulkan bahawa penggunaan tenaga elektrik secara cekap dapat menjimatkan tenaga di dalam industri ini. Dapatan daripada kajian ini juga menyarankan supaya mengetahui kaedah penjimatan tenaga secara lebih mendalam dalam masa depan.

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LIST OF ABBREVIATIONS

$ABS_{CS\text{-}leak}$	Annual bill savings through leak repair
ABS_{HEM}	Annual bill savings when using high efficient motor
ABS_{ia}	Annual bill saving using outside intake air
ABS_{L}	Annual bill savings on lighting retrofit
ABS_{VSD}	Annual bill savings when using variable speed drive
AEC_{150W}	Annual energy consumption of 150W high pressure sodium lamp
AEC_{400W}	Annual energy consumption of 400W metal halide bulbs
$AER_{CS\text{-}leak}$	Annual emission reduction by leakage repair
AER_{HEM}	Annual emission reduction using high efficient motor
AER_{ia}	Annual emission reduction using outside intake air
AER_{L}	Annual emission reduction associated to lighting retrofit
AER_{VSD}	Annual emission reduction using variable speed drive
$AES_{CS\text{-}leak}$	Annual energy saving through leak prevention
AES_{HEM}	Annual energy saving using high efficient motor
AES_{ia}	Annual energy saving associated with the usage of outside intake air
AES_{L}	Annual energy saving on lighting retrofit
AES_{VSD}	Annual energy saving using variable speed drive
AEU	Annual energy use
AHU	Air Handling Unit
ASEAN	Association of Southeast Asian Nations
BAU	Business as Usual
Btu	British thermal unit
C	electricity charge (RM)
CAS	Compressed Air System
cfm	Cubic feet per minute
CO_2	Carbon dioxide
COP	Conference of Parties
EC	Energy Commission
E_{ee}	efficiency rating of high efficiency motor (%)
EDGAR	Emissions Database for Global Atmospheric Research
EE	energy efficiency
EF_{CO2}	emission factor for carbon dioxide
EMEER	Efficient Management of Electrical Energy Regulation
EnMS	energy management system
EnPI	Energy Performance Indicators
EPU	Energy Unit of Economic Planning Unit
ESL	Electron-stimulated Luminescence
E_{std}	efficiency rating of standard efficient motor (%)
FRL	Filter, Regulator and Lubricator
FG	Fine Grinding
FSD	Fixed Speed Drive
GDP	Gross Domestic Product
$GgCO_2$	Gigagramme carbon dioxide
GHG	Green House Gases
GWh	Gigawatthour

H	annual operating hours
HEM	High Efficiency Motor
HID	High Intensity Discharge
HT	High Tension
IRR	Internal rate of return
ICT	Information and Communication Technologies
KeTTHA	KementerianTenaga, TenagaHijaudan Air
$kgCO_2/kWh$	kilogram CO_2 / kilowatthour
$kgCO_2/US\$$	kilogram CO_2 / US Dollar
kPa	kiloPascal
ktoe	kilo tonnes of oil equivalent
kW	Kilowatt
kWh	Kilowatt hour
L	load factor
LCC	Life Cycle Cost
LED	Light Emitting Diode
LT	Low Tension
LV	Low Voltage
MD	maximum demand
MEGTW	Ministry of Energy, Green Technology and Water
MEPS	Minimum Energy Performance Standards
MNC	Multinational Corporation
Mtoe	million tonnes of oil equivalent
ODP	Open Drip-Proof
OECD	Organization for Economic Cooperation and Development
OLED	Organic Light Emitting Diode
P	motor rated horsepower
PG	Pre Grinding
RM	Ringgit Malaysia
RM/y	Ringgit Malaysia / year
PWM	Pulse Width Modulation
SEUs	significant energy users
SMEs	small- and medium- sized enterprise
SSL	solid state lighting
S_{SR}	percentage energy savings associated certain percentage speed reduction
T_0	annual average outside air temperature (°C)
T_1	average air temperature inside compressor room (°C)
TFEC	total final energy consumption
TNB	Tenaga Nasional Berhad
UNFCC	United Nations Framework Conventions on Climate Change
UteM	Universiti Teknikal Malaysia Melaka
VSD	Variable Speed Drive
W_R	fractional reduction in compressor work

CHAPTER 1: INTRODUCTION

1.1 Research Background

Globally, the upward trend of energy consumption, population and Gross Domestic Product (GDP) from the early 90's to present and forecasted up to year 2040 is inevitable. Fossil fuels such as natural gas, oil and coal are and are the major resources for energy consumption of 81% in 2014 and projected to be 78% in 2040 (Yanagisawa Akira, 2016). The decline in percentage showing that effort towards energy conservation has been addressed. However, utilization of these resources for modern society would also lead to increase in greenhouse gases (GHG) emission to the environment.

During the outlook period, the energy consumption growth from non-OECD (Organization for Economic Cooperation and Development) countries such as China, India and members of the Association of Southeast Asian Nations (ASEAN) countries surpassed other regions in the world including OECD countries. By early 2030s, China will become largest oil consumer compared to United States in current position. In the mid-2030s, India is projected to outdo European Union in oil consumption. At present technologies and economic efficiency, the proven reserves of fossil fuel will be sufficient to cover consumption for the next 25 years. However, fluctuations of crude oil and natural gas could impede the adequate supply investment.

In an effort to mitigate greenhouse gas emissions and climate change globally, a total of 160 countries (Parties) ratified Paris Agreement (United Nations, 2015) under the United Nations Framework Conventions on Climate

Hasanuzzaman, Selvaraj, Teo, & Chua, 2017). In many developed and developing countries, a lot of energy wastefulness situation occur due to the society take for granted of the capability of government in providing affordable and reliable energy. The government's policy and rationalization plan to remove energy subsidies gradually is unavoidable as a measure to dissuade energy wastage. A simulation study (Yusoff & Bekhet, 2016) conducted shows that the effect on final energy demands and energy savings is greater when both subsidy for fuel and fuel tax being gradually removed. In 2014, the removal of fuel subsidy by the Malaysian government as part of energy reform was seen necessary to fuel all relevant agencies to enforce common regulatory framework in order to safeguard a sustainable energy in future. This approach will stimulate demand-side preservation and efficiency measures by end-users.

Industrial and manufacturing sector in ASEAN countries reflects annual rate of 3.5% in expand of final energy consumption (Yanagisawa Akira, 2016), the fastest among any other sectors. Direct investment of foreign companies in Malaysia and other ASEAN countries due to abundance of cheap labor and development in machinery assembly will in turn increase the power demand. Accelerated industrialization process for the past two decades resulted in electricity demand growth. The energy intensity ratio of the nation has been always greater than 1.0 (KeTTHA, 2014), in techno-economics perspective, indicate inefficient use of energy. Towards sustainable energy path, energy efficiency (EE) improvement in the demand-side is one of the significant approach in addressing energy security issue and energy-related environmental impact.

Researches for the past twenty years in the field of energy management in manufacturing comprising 365 published journal articles in light of setting directions for policy-makers and a reference framework for energy managers in manufacturing facility to adopt key factors needed to integrate EE in manufacturing (May, Stahl, Taisch, & Kiritsis, 2016). Besides, the study outlined six scope of study in energy management: "i) drivers and barriers, ii) information and communication technologies, (iii) strategic paradigms, (iv) supporting tools and methods, (v) manufacturing process paradigms and (vi) manufacturing performances in the trade-off". The real challenge for energy managers is to adopt the wealth of knowledge in the findings into action plan towards energy efficient companies. Conceptual framework proposed (Schulze, Nehler, Ottosson, & Thollander, 2016), stressed on five key elements of energy management identified from previous researches (1979 to 2014) as "strategy/planning, implementation/operation, controlling, organization and culture", which focused on to reduce manufacturing processes energy consumption and energy cost. The content of the reviewed articles structured into concepts, themes and aggregate which forms the basis of the emergent framework.

One of the EE improvement initiative in industrial processes is the energy audit (Kluczek & Olszewski, 2017), which is a tool to analyze and energy usage and assessing saving potentials. In small- and medium- sized enterprise (SMEs), input energy cost was treated as overhead (Schulze et al., 2016) during the last two decades where the energy price was low and relatively stable. It only represents a small part of the total production cost (Kannan & Boie, 2003). In recent years, the situation has changed due to increasing electricity tariffs and number of firms actively concerned in energy management has risen, realizing that it is an effective way to enhance production and cost saving beneficial for plants. Implementation of energy management system (EnMS) is a tool to overcome barriers or efficiency gap (Trianni, Cagno, & Farné, 2016). The research carried out among manufacturing SMEs in Northern Italy in defining the relationship between drivers and barriers in the decision-making process involved in industrial energy efficiency measures.

In Malaysia, the institutions which promote EE are the Energy Unit of Economic Planning Unit (EPU), the Ministry of Energy, Green Technology and Water (MEGTW) and the Energy Commission (EC). EC's role as a regulatory agency for the electricity and gas supply industry also advises the ministry on matters relating to electricity, tariffs and EE promotion. EC is empowered to enforce Efficient Management of Electrical Energy Regulation (EMEER) 2008 , the regulation which states "all installations that consume or generate 3 million kWh or more of electricity over a period of six months will be required to engage an electrical energy manager who shall, among others, be responsible to analyze the total consumption of electrical energy, to advise on the development and implementation of measures to ensure efficient management of electrical energy as well as to monitor the effectiveness of the measures taken". This effort by government is a measure to control demand-side management so that energy is utilized wisely without wastages.

Hence, in this study, the criteria to oblige by the Act is met and attempts to analyze electricity consumption trend of a local SME plant and to identify opportunities or potentials to reduce the consumption.

1.2 Problem Statement

The diversity in Malaysian food industry offers wide range of processed food with Asian taste. It is dominated by Malaysian-owned SMEs although there are notable foreign multinational corporations (MNC). Spice mixes are essential ingredients in adding taste and flavorings in food preparation and are integral part of traditional Indian food which had gained popularity worldwide. Powdered spices are convenient to use and saves time and energy for preparing delicious dishes. Ina real production scale in a manufacturing environment, immense energy is needed for the grinding or comminution and cooling process of spices to retain the flavor and quality of the products (Singh & Goswami, 1999).

Preliminary data and findings are crucial towards in-depth audit plan. Utility bills, plant layout, circuit diagram, building design and factory process are necessary inputs for pre-audit. The gathered information together with manufacturing profile and production output scale hints the audit to possible conversion process.

A thorough study is needed to analyze the energy consumption in detail to determine and classify the energy users in the plant. Energy audit in a spice manufacturing plant involves task such as data collection by meters (Saidur & Mekhilef, 2010), measurements, characteristics of machinery and processed materials and energy flows (Kluczek & Olszewski, 2017).

Considering all the aspect above and the primary energy driver to gain first hand practical experience in the said facility, this project may impact the management to be more concerned in utilizing the input energy and how to manage efficiently without compromising the end result of the production output margin.

1.3 Research Objectives

The aim of the current research work is to carry out industrial energy efficiency measures in a local spice manufacturing plant to realize the savings potentials.

The objectives of this research are:

a) To investigate the total electrical energy consumption and to assess the breakdowns of energy usage of a local spice manufacturing plant

b) To analyze the data and to identify significant energy users (SEUs) which represent the main component of the total consumptions based on production output

c) To identify opportunities for energy conservation and cost-benefit analysis towards efficient management of the resources.

1.4 Thesis Outline

The thesis consists of five chapters and outline of each chapter is organized as follows:

Chapter 1 presents the scenario of world energy demand and the importance to mitigate climate change by improving energy efficiency in industrial sector. Besides that, it addresses the problem statement of current scenario in the spice manufacturing industry and finally, the objective of the research is clearly defined.

Chapter 2 consists of literature review on energy consumption in industrial sector focusing on food industry in Malaysia and brief description of energy components associated to spice manufacturing plant. Besides, the chapter summarizes the ways to improve industrial energy efficiency based on literatures and researches done in the past.

Chapter 3 focuses on the methodology of this project. The framework begins with overview of plant background and characterizing the energy blocks within the facility. Besides, it outlined the key process of gaining the data for further analysis using formulation based on researches.

Chapter 4 presents the trend usage of current electricity consumption and the potential saving results by applying the methods underpinning industrial energy efficiency. The savings are presented and discussed.

Chapter 5 elaborates the conclusions of the research and recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Present literature review covers an insight on understanding the topic in a systematic way by exploring related publications available in the globe. Scarcity and limitations pertinent to the scope of this research outdone by adopting general key concepts applicable in industrial sector as a whole.

This chapter begins as top-down approach on overview on trend of energy consumption in industrial sector globally before zoom into ASEAN and later specifically, Malaysia covering subsector of food industry. The utility breakdowns in a spice manufacturing plant uncovered to provide a brief description to readers. Following that, the importance of improving energy efficiency in industrial sector and the standardized method for conserving energy is covered later in this study. Finally, the aspects where opportunities on energy saving alternatives are briefly studied in sections based on reviews of researches in present and past.

2.2 Energy Consumption in Industrial Sector

The world industrial sector is the most energy consuming sector about 54% of total delivered energy worldwide. According to projections, energy usage in this sector will increase from 222 quadrillion British thermal units (Btu) in 2012 to 309 quadrillion Btu in 2040 at a rate of increase of 1.2%/year, (EIA, 2016). This long-term growth in energy consumption is significantly contributed by non-OECD countries. Specifically, electricity usage accounts

different from the global statistics where the transportation sector covers 45% of final energy consumption whereas industrial sector in the second rank holding 27% of share (Energy Commission, 2015). In terms of electricity consumption, the nation's industrial sector consumed 5,218 ktoe or 45.9% of a total of 132,199 GWh as reported by Energy Commission taking up the largest proportion followed by commercial and residential sector. Although there is a steady growth from 1990's, the sector's transformation to more economical mode of operation reducing intake of fossil fuels (Oh et al., 2017).

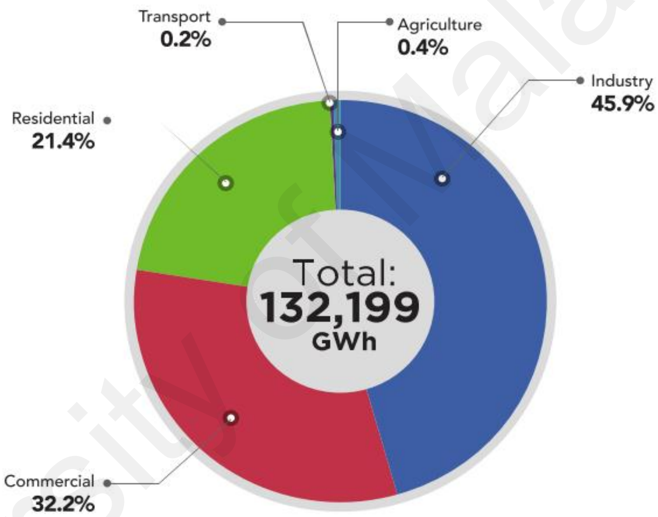

Figure 2.2: Electricity Consumption by Sectors in Malaysia. Source: National Energy Balance 2015

2.3 Food Industry in Malaysia

The development of food industry in terms of technology started a few hundred years ago and undergone a rapid pace of trade and commercial systems (Knoerzer, 2016). It induced civilization through centralized processing and specialization of different type of foods to be manufactured. The rising demand of a more diverse food products manufacture attributed to explosive human population growth, changes in lifestyle and public health concerns of the modern world. This in turn triggers the process of manufacturing into more complex operation to produce good taste and quality products (Weaver et al., 2014). Hence, energy intake to produce or manufacture will substantially increase. Emerging technologies in food process and improving resource efficiency describes the increasing role of manufacturers to apply latest technology in order to boost quality of food and at the same time processing efficiency as one of the possibilities to optimize food supply chain (Augustin et al., 2016). This will lead to reduced energy and water intake, reduced environmental impacts and minimize wastage.

According to US Energy Information Administration, the industrial sector is distinctively sub-divided into three main categories: energy-intensive manufacturing, nonenergy-intensive manufacturing and non-manufacturing. Food manufacturing or industry is classified under energy-intensive manufacturing. Food industry is not considered as energy-intensive due to lower energy cost compared to profit account however the case might be intensive if all direct and indirect energy drivers taken into account (Biglia, Fabrizio, Ferrara, Gay, & Aimonino, 2015). Combined energy of 'plant' level and 'process' level or in other terms, direct and indirect energy drivers such as lighting for the required process environment provides a greater insight into energy consumption in manufacturing (Rahimifard, Seow, & Childs, 2010).

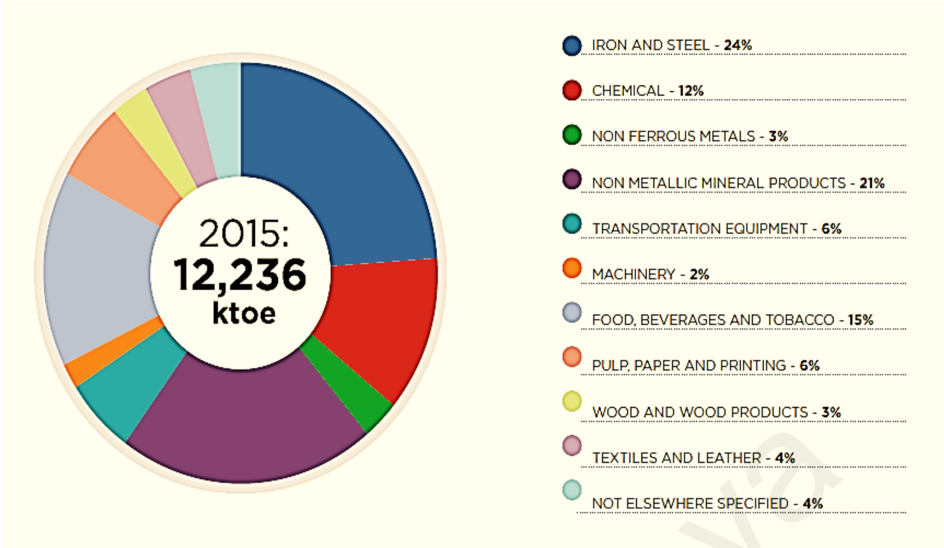

Figure 2.3: Final Energy Consumption by Sub-Sectors in Malaysian Manufacturing Sector. Source: National Energy Balance 2015

Food industry as specified under Malaysian Standard of Industrial Classification (2008) is a sub-sector of manufacturing sector. Food processing sector is grouped under food, beverage and tobacco products which accounts for 15% of final energy consumption in manufacturing sector in Peninsular Malaysia (Energy Commission, 2015) or 1,868 ktoe which represents energy consumptions based on monthly data provided by 73 food processing manufacturers out of 520 manufacturing plants surveyed in Peninsular Malaysia. A study article (Ali, Saidur, Hasanuzzaman, & Ward, 2013), audited 10 food factories in Malaysia and reveals potential of emission and consumption reduction by applying efficiency measures.

2.4 Standardized Methods for Conserving Energy

2.4.1 Energy Audit

Energy management although defined in different interpretation in selected literatures (Schulze et al., 2016) encompasses sole purpose which is the strategy to plan and operate energy using systems and procedures in order to reduce consumptions while maintaining the production output, goods or services. The difference in understanding on industrial energy management is due to different approach in terms of strategy and tactical level of a company in achieving various objectives. Energy management is multidisciplinary which coalesces engineering, management skills and good housekeeping too to maximize profits and optimize EE in process in a judicious and effective manner (Kannan & Boie, 2003).

Due to the fact that industrial activity among primary energy consumers and undeniably large CO_2 emitter of the world (Abdelaziz, Saidur, & Mekhilef, 2011), the political and social pressure has mounted, emphasizing the way industrial firms consume energy and considering energy awareness (Okereke, 2007) who also researched motivational factors, drivers and barriers in carbon management program among 100 most capitalized blue-chip companies in UK. The empirical findings show that there are various reasons a company opted for carbon management programs and obstacles that might be faced. One of the activities mentioned by the companies involved in response to climate change is increasing energy efficiency by energy management.

EE contribution towards sustainable manufacturing benefits the companies in economic, environmental and societal aspects (Bunse, Vodicka, Schönsleben, Brülhart, & Ernst, 2011; Kannan & Boie, 2003). One of the key enablers of energy management in manufacturing is supporting tools and method besides information and communications technologies (ICT), manufacturing paradigms and strategic paradigms. Improving EE in manufacturing facilities is a real challenge for not only managers but academicians and practitioners (May et al., 2016). Proper tools are needed to assess energy consumption behavior so that decision making is supported by energy-based analysis. Energy assessment tools is one of the criteria and in the literature, the most used approach by research articles compared to less common simulation and benchmarking tools.

Energy consumption in manufacturing facilities is becoming more prevalent topic of interest in manufacturing facilities planning and operating structures. Traditionally, this criterion is often sidelined as other contributing factors such as raw material cost, labor costs and productivity are of importance in decision making to meet market demand (O'Driscoll & O'Donnell, 2013). For decades, researches proposes methods to link production to energy consumption and it has become widespread nowadays that importance of measurement and monitoring in real production scale become significant. Prior to efficiently manage electricity consumption, an understanding of where and how energy is being used within a plant must be accurately quantified. Power and energy measurement technologies provide an insight on understanding the daily usage in a quantitative perspective.

Energy audit is a well-known method and in fact the most comprehensive tool to achieve energy savings in industry by minimizing the wasteful energy (Kluczek & Olszewski, 2017). The goal of energy audit is to fill up efficiency gap or barriers faced by industries for instance organizational, behavioral and economic point of view (May et al., 2016). In terms of manageability, among top three operating expenses: raw material, labor and energy (electrical and thermal); energy reflects a strategy for saving opportunities. This reliable and systematic approach helps any organization to zoom in areas where possible energy reduction and wastages identified, plan and implement feasible techniques so as to enhance energy efficiency (R. Saidur, 2010). According to ISO 50002, "energy audit comprises a detailed analysis of energy performance of an organization, equipment, system(s) or process(es)". The details of usage patterns gathered from measurement and observation are then analyzed, prioritized and the outputs include ranked recommendations to improve energy performance and financial benefits.

The depth or focus of analysis depending on the potential at a specific site for energy and cost reductions and the project parameters set by the client. Although in the literatures, the types of energy audit categorized in different terminologies, the stages are of standard structure. There are three distinct types of energy audits

1. Preliminary audit / Walk-through

2. General audit

3. Detailed audit

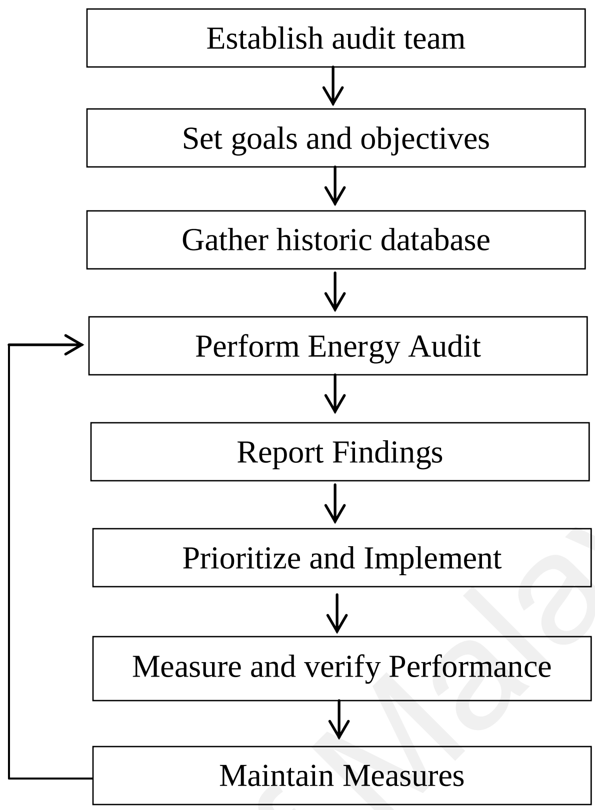

Figure 2.4: Typical energy audit program. Source: Saidur, 2010

Preliminary audit is where the audit process starts and the quickest type of audit which involves interviews with non-energy oriented engineering staff on information regarding manufacturing profile, production input and output, facility utility bills and the most energy intensive machines/processes (Kluczek & Olszewski, 2017). This information hints the auditor on familiarization of energy conversion process in the plant and identifies areas where low-cost/no-cost measures can be immediately implemented and areas which need detailed study. The outcome of this audit is to furnish the energy costs and pointing out the wastages in major processes so that optimization of energy consumption can be prioritized (Abdelaziz et al., 2011). In a walk-through audit conducted by (Saidur & Mekhilef, 2010) in selected Malaysian rubber industries, based on necessary inputs, the breakdowns of end-use equipment analyzed and potential energy savings and emission reduction calculated using formulation. Following the strategies recommended, a significant amount utility bills can be saved and the payback period within three years.

One step further of preliminary audit is called general audit, a more detailed approach where additional information on plant operation is collected for evaluation of efficiency measures identified. The factory's energy usage profile and energy/output are rate obtained by analyzing the utility bills for a period of 12-36 months. This data is supported by additional metering points of specific processes and operating parameters garnered from interviews with plant operating personnel. As a whole, this information provides a better understanding of plant daily and annual energy consumption trend.

Detailed audit or investment-grade audit as it name describes focuses on capital investment decision on projects identified from previous audit. This task requires more field data and rigorous analysis. Based on recorded data from sub-metering of major energy consuming process, the characteristic with conservation measures applied are modeled and compared with actual utility data (baseline) and its operating characteristics. Situation on which load profile variation taken into consideration in order to calculate savings on proposed measures. A detailed audit on aluminum industry (Arya et al., 2017), recommended efficiency measures based on review papers of past audits. From a top down approach, the author begins with overall energy consumption for a period of three years and synthesized the breakdowns of the energy components involved. Power consumption can be reduced by 29.54% following the following the implementation of suggested measures.

2.4.2 Energy Baseline

Improving energy efficiency continuously in an organization requires development and documentation of relevant methodology classified as outlined in ISO 50001. This aspect of energy planning process is shown in Figure 2.5. In industry, energy review begins with identification of past and present energy consumption covering all types of energy inputs and SEUs. Besides that, available improvement opportunities shall be prioritized accordingly at defined period taking into account of major changes in equipment or process. SEU are defined as equipment or process consuming large portion of energy or large number of savings opportunities as per ISO 50001. Variables affecting significant energy uses need to be carefully determined prior to energy review so that precise correlation with SEU could be obtained. Otherwise, variations of other variables such as weather and production mix may distort the SEUs indirectly.

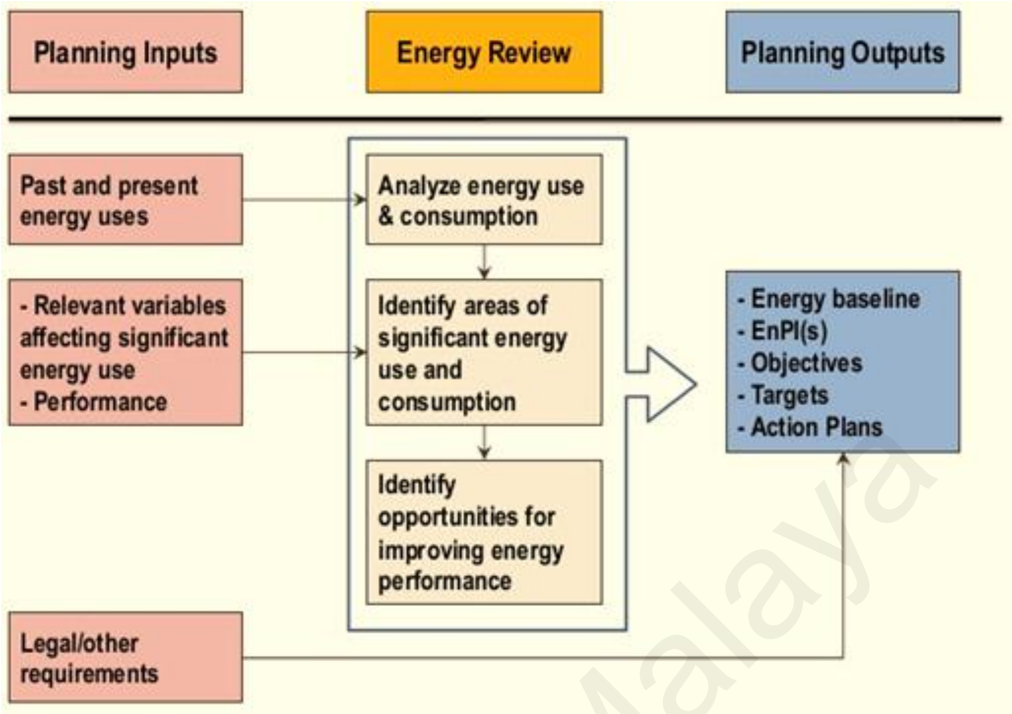

Figure 2.5: Energy planning process. Source: ISO 50001:2011

Quantitative analysis of energy consumption of a facility prior to evaluate the successfulness of energy efficiency improvement strategies is referred to as developing baseline. Figure 2.6 shows an example of monthly electrical consumption for one year with first six month represents baseline period. Initiatives taken on the seventh months onwards resulted in decreased electricity consumption relative to the expected baseline shown in dotted lines. Efficiency measures made during the period is referred as reporting period. In this project, the study encompasses baseline period only due to limited time frame and obligations to maintain existing operating conditions.

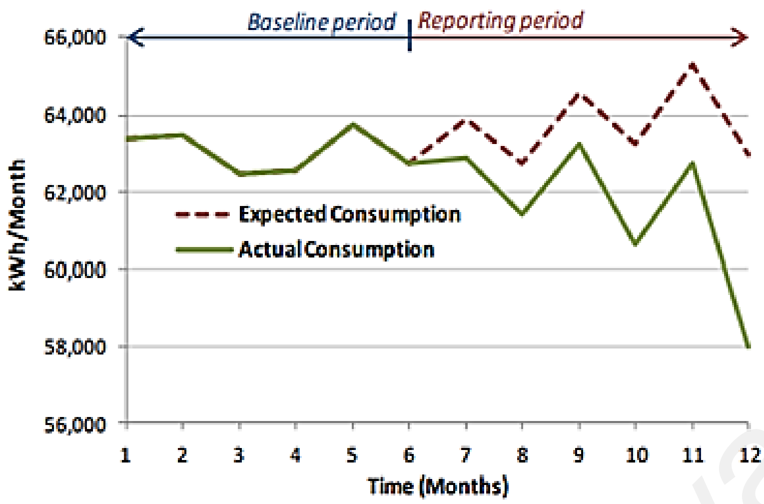

Figure 2.6: Improved performance over time relative to baseline. Source: Northwest Energy Efficiency Alliance (2013)

The performance of energy consumption of a facility is quantitatively defined by energy performance indicators (EnPI). This indicator is the ratio of energy input over output units. The normally used energy inputs are kWh and Btu whereas for outputs, it is more complex for instance, units produced, tons processed and clients served. EnPI assessed within the factory boundaries and there are no specific guidelines for choosing the units but a suitable EnPI has minimum cost and effort to monitor and yields acceptable feedback on effectiveness of improvement strategy (Energy Baseline Methodologies for Industrial Facilities, 2013). One of the criteria of EnPI in industrial facility is minimizing kWh/unit produced without affecting product quality to meet business objectives and to increase shareholder value.

2.5 Electrical Motor

A motor is equipment which converts electrical energy into useful mechanical energy. The invention of electric motor dated back in the 1800s and at present, there are various types of electric motors as shown in Figure 2.7, worldwide used in diverse applications everywhere from consumer products to industrial. Motors can be divided into two primary categories which are AC motor and DC motor. The most common type of motors found in the industries are poly phase squirrel cage induction motors used to drive components such as fans, blowers, compressors, pumps and process equipment. Their use in industrial activity is indispensable and has significant impact on industrial development and technological progress.

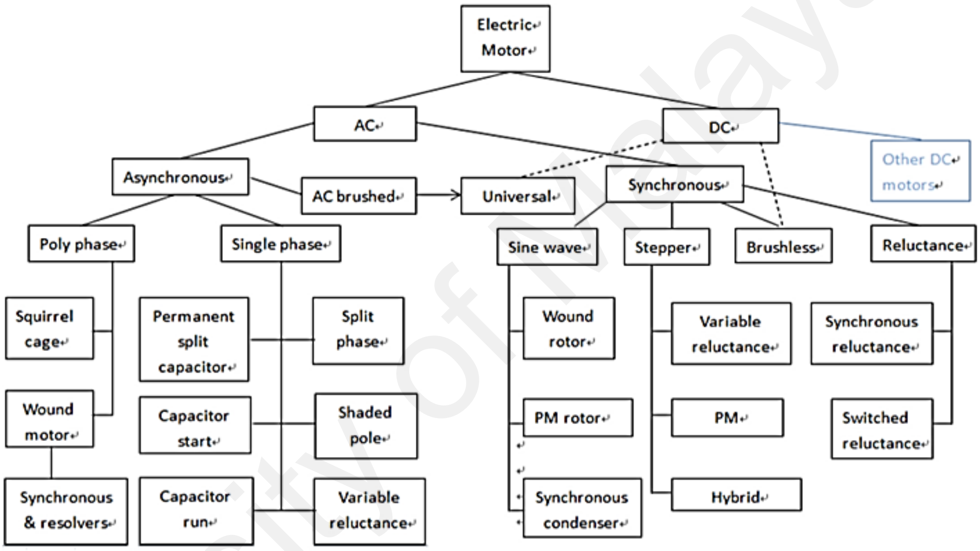

Figure 2.7: Types of electric motors (Lu, 2016)

A large proportion of industrial electricity consumption is by electric motors (Abdelaziz et al., 2011). Applications such as grinding, mixing, refrigeration, blowing and conveying heavily relies on electric motors. As shown in Figure 2.8, electric motors cover approximately 48% of end use energy in Malaysian industry. This in turn indicates that, significant amount of energy consumption contributed by electric motors and many ways to reduce the amount. In this study, upgrading to higher efficiency motors opportunities is studied.

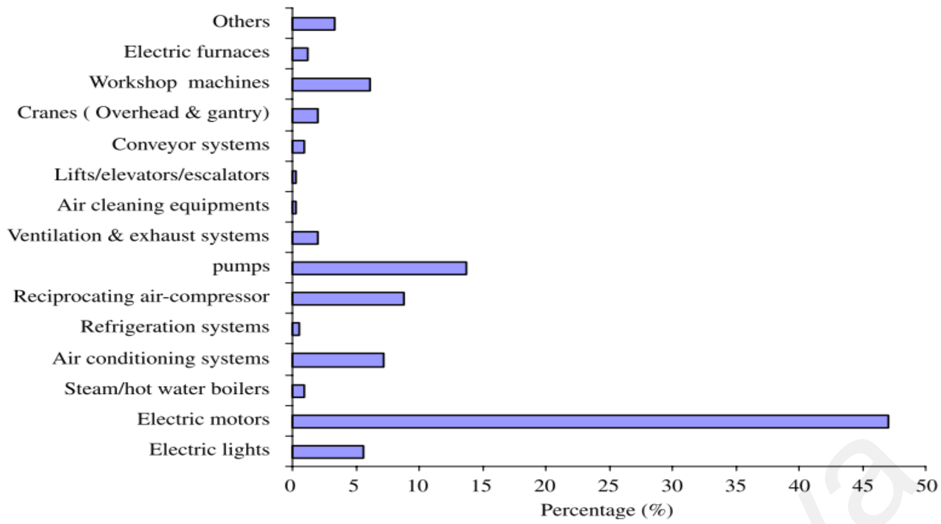

Figure 2.8: End-use energy consumption in Malaysian audited industrial sector (R. Saidur, 2010)

2.5.1 High Efficiency Motor

Industrialization and commercialization of induction motors boomed since the three phase AC power was invented (Lu, 2016). Due to its simple structure, easy maintenance and cheaper cost, induction motors suited industrial equipment quite well with fixed rotation speeds in the initial stage. The global sales market of electric motors experienced a compound annual growth every year. The demand for a more innovative and energy efficient product together with a rise in minimum energy efficiency standards has led to increase in demand for higher performance and efficient motors. This is also seconded by the needs to reduce energy wastages resulted by inefficient operation of electrical motors.

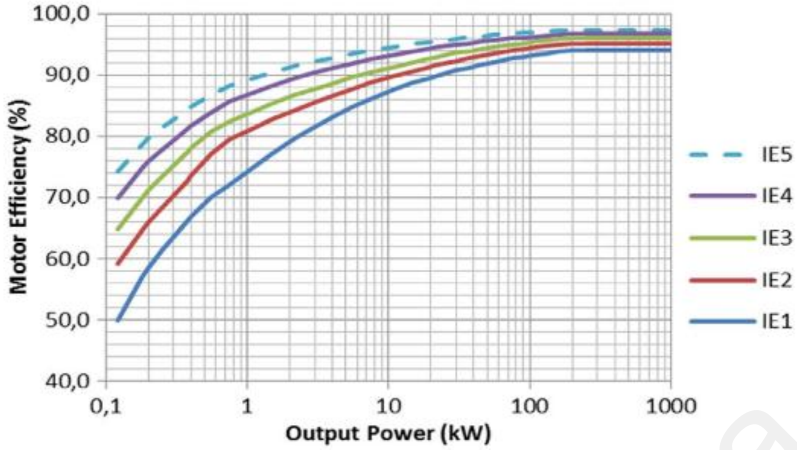

Figure 2.9: Efficiency levels for poly-phase motors. Source: IEC 60034-30-1 (2014)

In Figure 2.9, energy efficiency classification standard has been updated with IE4 (Super-Premium) which was envisaged previously but is defined in the current market and technology. The spectrum output power was also broadened to cover motors up to 1000kW. Many countries have adopted Minimum Energy Performance Standards (MEPS) for mandatory compliance of minimum efficiency levels for motor sold in the respective countries.

Electrical motors usually operated at 50-100% rated load and optimum efficiency at approximately 75% of rated load. At loads under 50%, motors run inefficiently and its best to replace with suitable sized more efficient motor in order to reduce energy consumption. Losses in a standard efficiency induction motor are substantial and can only be reduced in motor design(R. Saidur, 2010; Saidur & Mahlia, 2010).Table 2.1 shows the types of losses of a standard open drip-proof (ODP) enclosed motor.

Table 2.1 Typical motor losses (%) for 1800RPM ODP Motor (McCoy, Litman, & Douglass, 1990)

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

Motor losses can be divided into fixed losses and variable losses. Core losses, windage and friction losses are permanent losses when the motor is energized and independent of motor load. These losses can be minimized by using improved permeability of magnetic material such as ferrosilicon alloys, thinner steel laminations, improvement in core head, bearing, airflow and fan dimensional design. Variable losses include stator losses, rotor losses and stray load losses. These losses are dependent of motor load and appeared as heating of the stator and rotor windings. Stray load losses are the resultant of the leakage fluxes induced by load currents. Variable losses are minimized by modifying the stator slot design and increasing the size of rotor bar and end rings to produce lower resistance.

Standard motors operate at a typical efficiencies ranging from 83-92% which is considered efficient but HEM motors runs more efficient in the range of 92-94% depending on the power of the motor (McCoy et al., 1990). This small efficiency gain will reduce the losses by 25% in the form of heat dissipated to the ambient which will abruptly reduce cooling loads in an air conditioned industrial facility. A more efficient motor produces same work as that of standard efficient with less energy input hence reducing amount of energy and cost. HEM costs more than 10 to 25% expensive compared to standard efficient counterpart but the payback period on the investment is within few years depending on the running hours and loading capacity.

2.5.2 High Efficiency Motor Savings Opportunities

In Malaysia, the industrial sector is the second largest final energy user (*Malaysia Energy Statistics Handbook 2016*). An energy audit in 91 industrial sites classified by 11 types of products manufactured according to International Standard Industrial Classification (ISIC) in Peninsular Malaysia were selected based on response received (Saidur et al., 2009). The study reveals that electrical motor as the highest end-use energy consumer followed by pumps, air compressor and others. From the surveyed data, most of the companies still and continue using standard motors for few reasons. Significant potential for energy saving exists by tapping the advances in technology and researches current and past. Savings opportunities using this approach uncovered from past literatures.

A walk-through audit in a garment factory in Bangladesh (Habib, Hasanuzzaman, Hosenuzzaman, Salman, & Mehadi, 2016), investigated that 70% of the factory's energy consumption dominated by electrical motors, hence reveals a potential of savings. Upgrading of standard efficiency motors to high efficiency motor (HEM) and evaluation under different motor loading condition were based on formulas from literatures. Savings reaped and payback period from such measures varies and depends on operating conditions and capacity from motor to motor. Analysis in terms of 50%, 75% and 100% motor loadings yields significant energy savings of 28,311 kWh, 41,713 kWh and 57,080 kWh respectively.

A study conducted on food and beverage industries in Nigeria (Ogunjuyigbe, Ayodele, & Ogunmuyiwa, 2015) for energy conservation opportunities spotted that bulk of electricity usage involved utilizing low efficient electric motors. Approximately 71% of the energy usage in this industry governed by motors to drive processes involved grinding, mixing, material conveying and others. Implementing high efficiency on the electric motors considered a viable choice since almost 60% of the running motors have been rewound according to Operation Manager. The efficiency of the motors degraded in the range of 1-2% when it is rewound in most studies. However, advances in materials and craftsmanship yields that a properly planned rewound can meet the original efficiency (Hasanuzzaman, Rahim, Saidur, & Kazi, 2011). For case industry B in the literature, annual savings of 4.5% achieved from a total 3,605,436 kWh annually and the payback period in replacing with market available high efficiency motor is 36 months.

2.6 Variable Speed Drive

In the past, most application in the industry using motors were designed to operate at constant speed, however in modern technology, speed variation is seems inevitable in many applications. Traditionally, electric motors were controlled by switching it on, off and run at constant speed to provide maximum designed load. The power input to the motor remains constant at the maximum value. However, in most cases, if the load decreases, huge amount of energy is wasted due to the motor running at full speed, hence, systems operating inefficiently. To reduce the losses, variable speed control methods has been used to enhance the flexibility and consistency of manufacturing processes.

2.6.1 Types of VSD

Variable speed drives (VSD) are incorporated in the system to regulate the speed or output torque of the rotational equipment. Speed controlling method in the industrial sector can be categorized as electrical, mechanical and hydraulic.

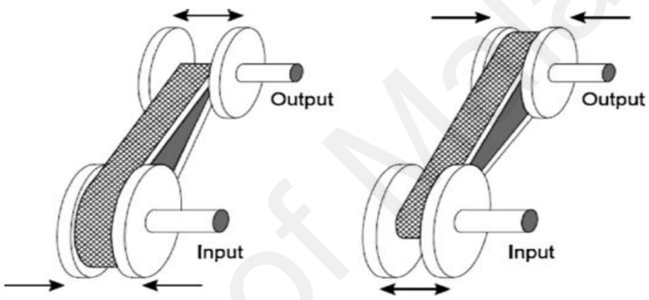

Figure 2.10: Mechanical VSD - adjustable sheave belt-type (Saidur, Mekhilef, Ali, Safari, & Mohammed, 2012)

In some applications for example light commercial air balancing, mechanical VSDs are still used due to its simple construction and low cost. There are a number of methods where the speed of the equipment driven varied mechanically such as traction drive, gearbox and belt drives. In Figure 2.10, the speed of the output shaft is varied by adjusting the tapered section of adjustable sheave which is normally fixed at the motor shaft. When the sheave is moved closer, the belt is forced outside of the pulley causing to travel greater distance hence increasing the output speed. In traction drives, the speed ratio is adjusted by varying the diameter of contact path between two metal rollers of different shapes and designs.

Another method available in the industries for controlling the speed of equipment is hydraulic VSDs. These types of VSDs more often used in heavy-duty application which requires large forces and high torques for example tilting a bucket laden with raw materials at opposing gravity in a lift system. Varying pump pressure and volume of fluid in the coupling will change the speed of the driven shafts. In Figure 2.11, the losses in a hydraulic system in nature are depicted in Sankey diagram. Presence of resistive components such as throttling valves and pressure reducing valves lower the system efficiency and increases the amount of heat transferred to fluid. Elimination of these components by introducing more efficient volumetric control dictates the overall system efficiency.

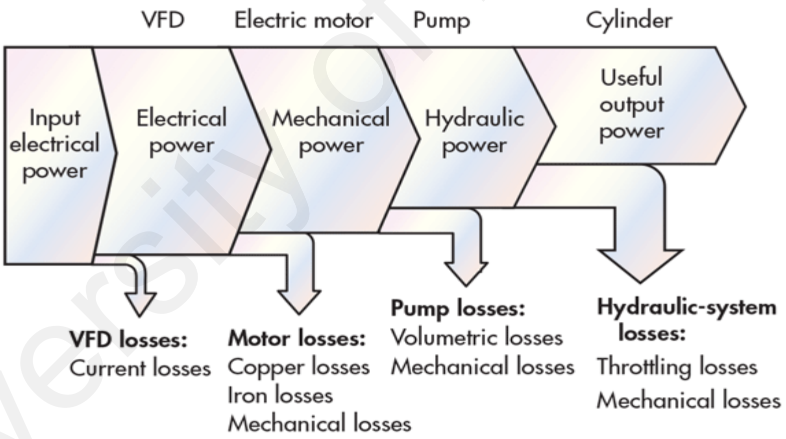

Figure 2.11: Energy losses in hydraulic systems. Source: www.hydraulicspneumatics.com

Among all the types of VSD, electrical VSD is in fact the most effective controller and energy saver in the industry. Most industrial processes require adjustment for optimum performance and usually accomplished with VSD. Inherently, electrical VSD has the advantage of setting any desired speed and keep the speed at constant level even if the load is variable (R. Saidur, 2010). In modern world today, most VSDs able to create variable output voltage, current and frequency using pulse width modulation (PWM). Three main components of a VSD are rectifier, regulator and inverter as can be seen in Figure 2.12.

Inside the VSD, the rectifier converts from AC voltage to DC using three phase bridge configuration, conditioned the DC link voltage and invert back to desired AC current before feeding into motor by switching the IGBTs or power switches in a sequential manner. The regulator controls the VSD by interacting with peripherals such as resolvers, synthesizes collected data and performs protective attributes.

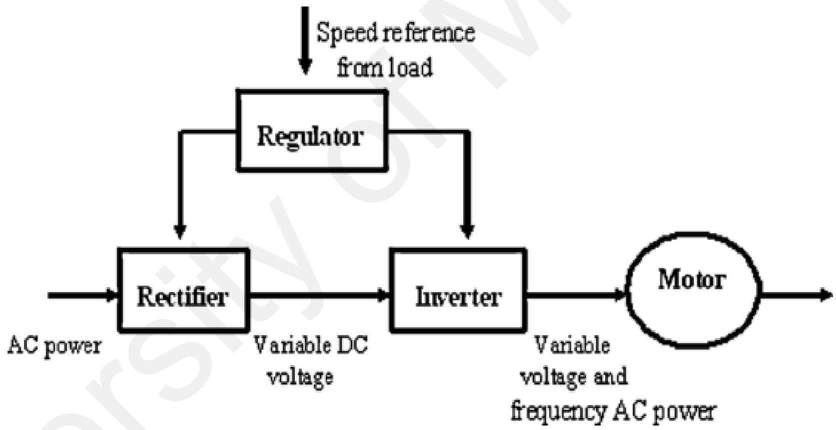

Figure 2.12: Electrical VSD components (Saidur et al., 2012)

2.6.2 VSD application in industry

Application of VSD and its benefits in wide areas translate into energy cost savings and reduction in greenhouse gas emissions provides an opportunity in this project to look into such prospects exists in the plant. The contribution of VSD in fans, pumps, compressors and air-conditioning systems (Saidur et al., 2012) are remarkable and immense potential of savings in the industry.

Table 2.2 Potential energy saving of VSD by speed reduction (Abdelaziz et al., 2011)

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

Fans are important equipment in building and manufacturing process. Fans comes in wide variety of design suited for different application, for example building air handling unit (AHU), process fan for cooling system and ventilation systems. More often, fan speed need to vary to match load requirement. Traditional method of varying fan speed including gearing between motor shaft and driven shaft, pitch control of blade angle and on-off switching (Al-Bahadly, 2007) besides throttling methods(Almeida, Ferreira, & Both, 2005) such as using mechanical damper. Reducing speed of a fan with VSD method will result in reducing the power drawn as shown in Figure 2.13. Fans obey the power cube law, where the input power is proportional to the cube of the speed. Hence, a little speed reduction saves a lot of energy.

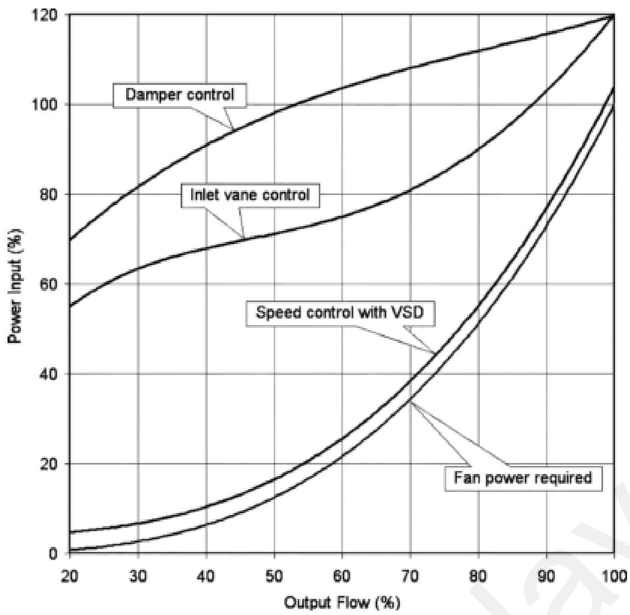

Figure 2.13: Input power for different flow control methods of a centrifugal fan (Almeida et al., 2005)

Pumps are the essential part of pumping system which accounts for 25-50% of industrial facility energy usage (Saidur et al., 2012). Energy consumption reduction in pumping system is possible through smart design, retrofitting and operation practices. In most cases, variable-duty requirement of pumps often met by controlling the flow via bypass lines, throttle valves or pump speed adjustment. The efficiency of the pumping system can be enhanced in three ways which are component selection, system dimensioning; and control and adjustment (Arun Shankar, Umashankar, Paramasivam, & Hanigovszki, 2016). VSD control is among one of the most efficient technique to improve process control and system reliability. In Figure 2.14, VSD reduces the amount of energy needed to produce same flow rate. By analogy, it is similar to applying new pump with smaller impeller which constitutes new pump curve. The area shaded in blue shows the energy saved by using VSD compared to speed adjustment using throttle valve.

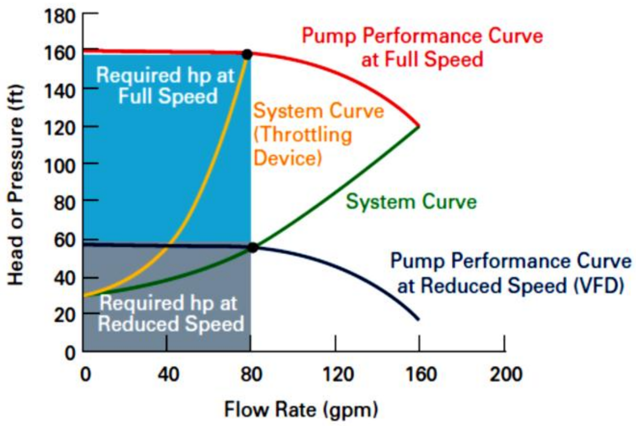

Figure 2.14: The difference in energy consumption using throttling method and VSD (Khushiev & Ishnazarov, 2015)

In practical, energy losses occur at each element of pumping system as shown in Table 2.3. Losses mostly occur in piping system which must be properly designed during the initial stage. The contribution of other losses is relatively lower. The efficiency of the whole pumping system can be enhanced by implementing VSD and efficient pump as shown in Figure 2.15. By using VSD to control the acceleration or deceleration of pump, degradation of piping internal surface due to "water hammer" effect is possible to be controlled (Almeida et al., 2005). For the same amount of 60% rated flow, reconfiguration of the components in the system yields 132% increase in overall pumping efficiency especially by introducing VSD in the system.

Table 2.3 Losses in pumping system (Arun Shankar et al., 2016)

SI.	Component in pumping system	Efficiency (%)	Losses (%)
1	Piping system	50-60	40-50
2	Pumps	85-90	10-15
3	Coupling	~99	~1
4	Motors	>90	<10
5	VSD cables	~98	~2
6	VSDs	95-98	2-5
7	Transformers	~99	~1

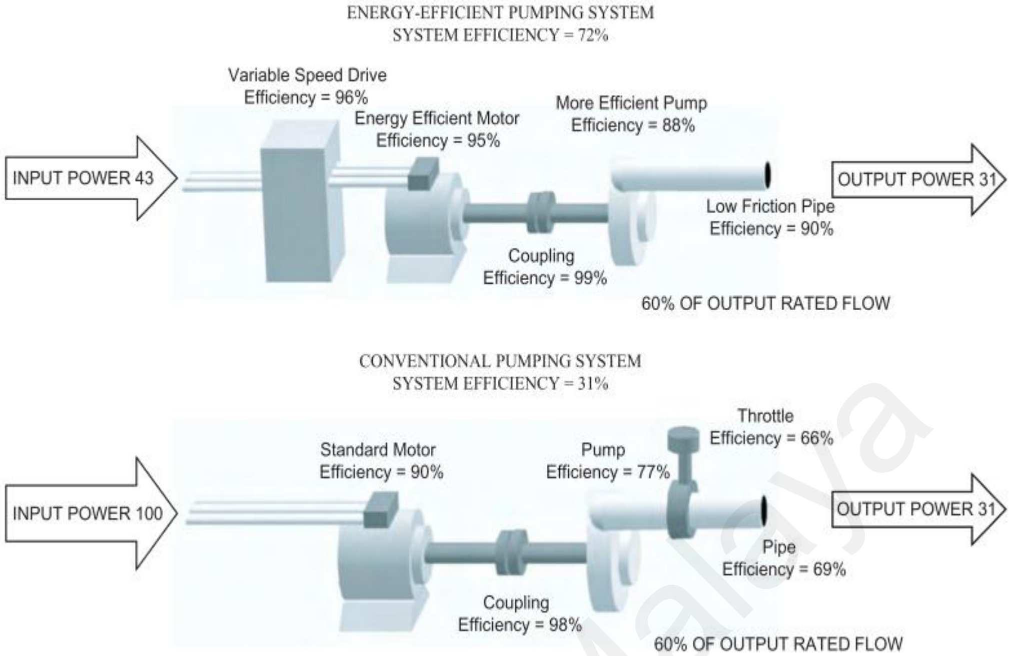

Figure 2.15: Reconfiguration of pumping system to improve efficiency (Almeida et al., 2005)

There are many inherent benefits of installing electrical VSD in place where speed control is necessary. Although there are issues pertaining to motor efficiency, power quality and electromagnetic interference (EMI) (Almeida et al., 2005; Saidur et al., 2012), mitigation to avoid such issues with technological advancement already taking place with development of more improved and sophisticated drive in the market. It is a cost-effective solution which leads to reduced maintenance, less wear in mechanical equipment, better and reliable process control, less acoustical noise and many more which add up to significant energy savings.

2.6.3 Variable Speed Drive Savings Opportunities

Almost every industrial process requires speed adjustment for optimum performance of the machines. Although speed can be adjusted in various ways by using mechanical and hydraulic approach, electrical means emerged as a viable choice when it comes to ease of controllability. Many literatures report the use of VSD benefits almost all sectors. A few selected to investigate the findings or analysis reported to ascertain the needs for VSD.

In an audit conducted on 20 sites of deep mine cooling systems in South Africa (Du Plessis, Liebenberg, & Mathews, 2013), studied on potential savings and feasibility indicators on chilled water supply system and mine surface cooling. The existing system chillers, pumps and cooling tower axial fans were operated without VSD. A feasibility study on the system yields that following the implementation of VSD in a large scale results in annual electricity saving of 32.2% from a total of 1,318,225 MWh and 132 Mton of CO_2 emission reductions. A pilot implementation of the proposed method on one of the mines which involves transition of valve flow control to VSD control on water pumps evaluated for a period of one month. The final result indicates that a saving of 30% on electricity for the particular month with a payback period of 1.8 years which could possibly reduce to one year if pumps operated for longer period.

Another feasible strategy proposed during the walk-through audit in a garment factory (Habib et al., 2016) is speed reduction of motors using VSD. Calculated annual energy savings garnered from 20%, 40% and 60% speed reduction from rated speed resulted in savings of 137,003 kWh, 319,673 kWh and 502,343 kWh respectively. The payback period however, reasonable for larger motors with higher operating hours and greater speed reduction.

Building air-conditioning system generally operated as centralized system involving chillers, pumps and cooling towers. It is a common adoption in large commercial, industrial or institutional buildings. A walkthrough energy audit in 16 faculties of University Malaya (Saidur, Hasanuzzaman, Mahlia, Rahim, & Mohammed, 2011) covered preliminary analysis of energy consumption and savings opportunities in space conditioning system. Data collected through questionnaires and interview with technicians of respective faculties on number of components in the system with their cooling capacity and power rating. Additionally, monthly energy billing and hours of chiller loading at different capacity is recorded for the analysis. In conclusion drawn from the study, the highest annual savings achievable by implementing speed reduction techniques up to 60% using VSD for chilled water pumps, condenser water pumps and cooling tower fans, is 23,532 MWh and associated CO_2 emission reduction of 2,426,769 kg per year. The payback period for this strategy is only few months and regarded as economically viable strategy. As for chillers, implementation of VSD from 25% to 100% loading capacity and its savings were also analyzed. The payback periods calculated (ranging from 2 months to 10.55 years) is dependable on the loading percentage and related running hours. This strategy is feasible in a readily installed and running VSD chiller however, upgrading in an existing chiller requires utmost attention in integration study as it involves capital investment.

A detailed audit in a cement industry on Low Tension (LT) and High Tension (HT) motors with under loaded running condition (Thirugnanasambandam et al., 2011) was estimated for optimization using application of VSD to match load requirement. Using speed reduction, the payback period is in terms of only days rather than months due to longer annual operating hours. The study also found that installation of power capacitors to improve power factor is not a viable economical solution due to low rate of savings. It is estimated that for LT motors alone, annual energy savings estimated is 1,865,925 MWh and 2,122,675 tons of CO_2 emission reduced for 60% speed reduction.

2.7 Compressed Air System

Compressed air is vital in industry and is considered one of the utility in plants. It is among one of the most expensive processes in manufacturing plants. From a small machine shop to large industries, all levels utilized some type of compressed air system (CAS). It is of absolute necessity that in some cases, factories cannot operate without it. The capacity varies from small size to huge systems according to the load size. The system consists of components shown in block diagram in Figure 2.16. Compressor, prime mower, controls, treatment equipment and distribution systems are major sub-system of CAS. The compressor is a mechanical device driven by prime mower such as motor that takes in ambient air and increase the pressure. The amount of compressed air produced to meet the demand regulated by controls. The treatment equipment such as driers and filters remove contaminants like oil and dirt, stored in receiver tank before the plant is supplied with food grade quality air at specified dew point. Distribution system includes piping layout to transfer the compressed air to end-users, ranging from machineries to hand operated pneumatic tools.

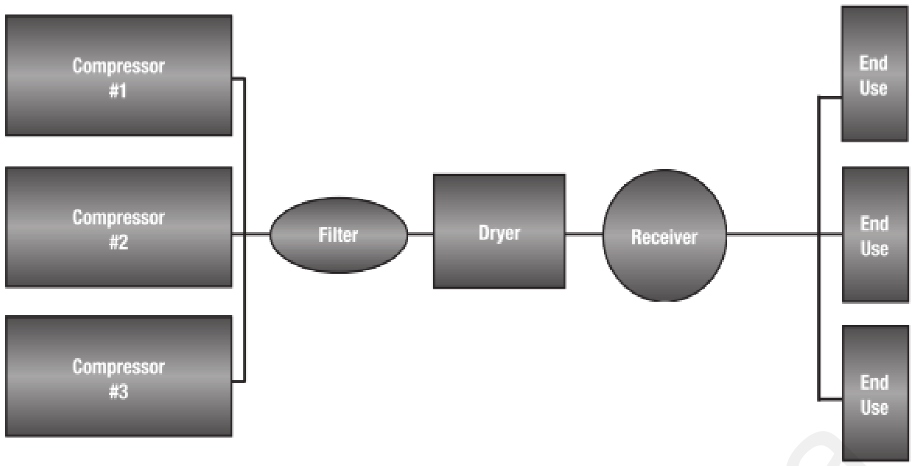

Figure 2.16: Block diagram of CAS (Beals et al., 2003)

CAS is one of the significant energy users in industrial plants (Benedetti et al., 2017). In manufacturing and service sectors, the use of compressed air is vital because it is safe and easy to be produced, handled and utilized. CAS is widely used in food industries for different end-use operations such as bag house purging in silos, aerating rotary purge valves, rejection unit as in metal detectors, pneumatic vibrators or hammers for product hoppers and various pneumatic controls in packaging such as pick and place application, glue injection nozzles and carton box forming and sealing. For a typical CAS application, the operating cost of running the equipment by far exceeds the investment and maintenance cost by approximately 75% over total life cycle cost (LCC) as depicted in Figure 2.17. In this standpoint, efforts to reduce energy consumption by applying simple conservation measures immediately pay for themselves.

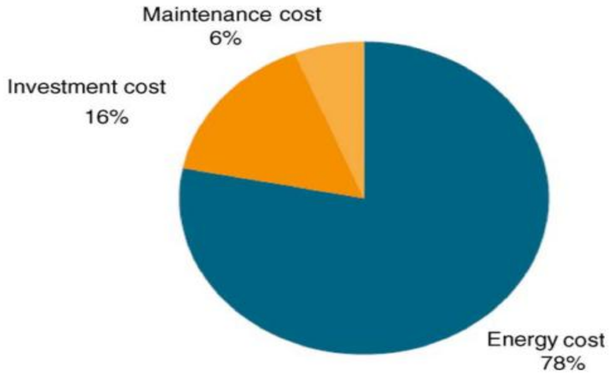

Figure 2.17: Life cycle costs of compressed air energy use (Saidur, Rahim, & Hasanuzzaman, 2010)

A savings potential of 32.9% can be achieved in 15 years when energy saving measures such as system installation or renewal of components and system operation and maintenance properly carried out (Radgen & Blaustein, 2001). According to the study, the significant amount of savings can be realized by measures such as reducing air leaks, better system design, use of variable speed controllers and recovery of waste heat.

The operating pressure in a typical manufacturing environment is normally in the range of 600kPa to 800kPa. Pressure at the downstream equipment more often regulated to meet requirement by using a combination of filter, regulator and lubricator (FRL). There are many components within the system hence proper management of the system saves energy, reduced maintenance and downtime, increases productions output and at the same time the product quality. It is an utmost important part of the energy conservation.

Compressed air leaks as researched from many literatures are a significant source of energy wastage amounting 20-50% of compressor's output (Saidur et al., 2010). Leaks leads to pressure drop in the system and in severe cases, affects production where unwanted major breakdowns bound to happen when the pneumatic components fails to operate efficiently. Leaks, generally occurs at flange connections, hoses, faulty regulators and equipment connected to the system. The volume of air lost in the leak depends on the size of orifice, the temperature of the expelled air and line pressure. The bigger the hole, the more wastage it will be and the lost increases exponentially as shown in Figure 2.18. In terms of compressor capacity lost in percentage, a properly maintained plant will have an acceptable level of 10% due to complete leak reduction is impractical in nature. The rate at which leakage in cubic feet per minute (cfm) occurs is proportional to the square of the orifice diameter and is shown in Table 2.4.

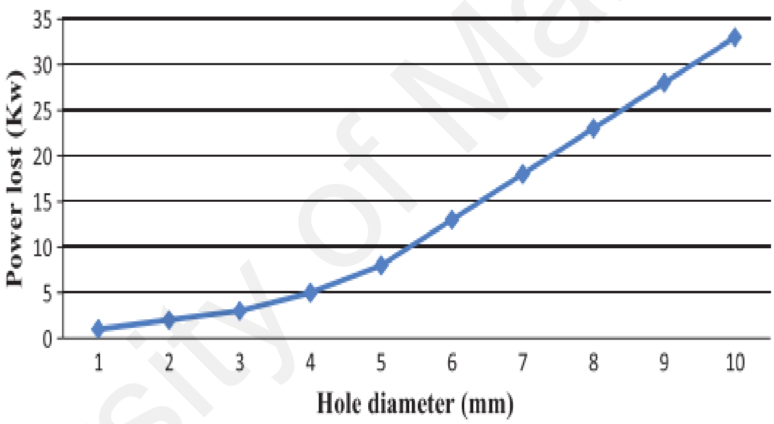

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Figure 2.18: CAS power loss with leakage hole diameter at 600kPa, (Abdelaziz et al., 2011)

Table 2.4 Leakage rate (cfm) at different supply pressures and approximate orifice size (Abdelaziz et al., 2011)

Pressure	Orifice diameter (in.)					
(psig)	1/64	1/32	1/16	1/8	1/4	3/8
70	0.3	1.2	4.8	19.2	76.7	173
80	0.33	1.3	5.4	21.4	85.7	193
90	0.37	1.5	5.9	23.8	94.8	213
100	0.41	1.6	6.5	26.0	104	234
125	0.49	2.0	7.9	31.6	126	284

Locating a leakage in the system requires careful attention and with proper tools such as ultrasonic acoustic detectors, the point of leak regardless of ambient noise level can be detected. Other method includes application of soapy water to detect the area but is time consuming. The leakage can be repaired temporarily or during planned shutdown. The system needs to be re-evaluated after the leak has been arrested to verify the system performance (Saidur et al., 2010).

In many industrial plants, operating pressure of CAS commonly raised to meet end-use requirement without looking at root of the problem. At exaggerated cases, larger compressor is installed to cater pressure drops instead of preliminary checking of the system which is supposed to be the first hand approach. This issue can be tackled by systems approach in design and maintenance of CAS (Beals et al., 2003). There are many ways to minimize pressure drop such as selection of components with best performance characteristics at the lowest pressure differential at actual rate of flow, reduced air travel in a properly designed distribution system, periodic maintenance of air treatment components and more. Significant savings can be achieved by minimizing pressure drops in the system whilst allowing the air compressor discharged pressure to lowest functional pressure that meets production requirements and taking into account large changes in demand. This measure results in cascading effect by improving overall system performance, reduce stress and prolong service life of components and air compressor itself. However, this approach incurs cost involving modifications of components and operating equipment which can be recouped from ongoing savings later.

A high percentage of electrical energy used to produce compressed air is wasted as heat energy to atmosphere. Depending on the practical worth of this energy in industrial plants, a properly designed heat recovery system can recover between 50-90% of thermal energy to be reused in heating water or air. The usage includes industrial process heating, indoor makeup air heating for colder climates and heating food and beverage products for instance. Heat recovery unit is available for both air-cooled and water-cooled air compressors. Waste heat extracted from aftercooler and lubricant cooler using recuperator or heat exchanger. System modification in terms of addition of ducts, controls and fans to handle duct loading to channel the energy for use involves capital investment hence a good business decision will yield attractive payback.

In industrial facility, compressors are usually located inside compressor room. The air being supplied for compression is within the room, more often hotter than outside air. At higher temperatures, air molecules expand and the air compressor will have to work extra to compress the air. The amount of work can be reduced by taking cooler outside air hence increasing the compression efficiency. The compressor energy saved by 1% for each 3°C (Saidur et al., 2010).

The performance of CAS is critical at part-load condition because most air compressors works at part-load for longer duration compared to full-load in a typical facility demand profile. Hence, to meet this requirement, compressors are equipped with control strategies designed for a particular type of compressor and load profile (Beals et al., 2003). The complexity of the controls varies from simple for a single compressor with steady demand to a more complex control with multiple compressors and varying demand. In determining CAS performance and efficiency, careful consideration must be taken into account when selecting both control strategy and type of compressor. For individual compressors, the control strategy developed over the years are start/stop, load/unload, modulating control of inlet valve, variable displacement control, capacity control and VSD. Using VSD offers a continuous control of speed of motor and thus matching actual load requirements by varying the capacity of the air compressor. Besides, it allows gentle start-up and shutdown of the air compressor hence prolong the equipment life. Table 2.5 shows the various methods of compressed air savings in summary which adopted in industries to improve CAS.

Table 2.5 Compressed air energy savings option (Radgen & Blaustein, 2001)

Energy saving measures	Potential savings
Reducing air leaks	42%
Pressure drop	4%
Recovering waste heat	10%
Adjustable speed drive	10%
Overall system design	12%
Other measures	22%

2.7.1 Compressed Air Savings Opportunities

Researches both documented and published reveal various approaches in enhancing efficiency of CAS as described from previous section. Measures such as reducing air leaks, minimizing pressure drop, recovering waste heat, using VSD compressors and others yields significant amount of energy consumption reduction. Energy audit in CAS and potential savings via different measures are mentioned in this section.

An energy audit carried out by (Safdar, Ilyas, & Malik, 2017) in a brewery plant in Pakistan shows that compressors usable energy use only accounts 10 - 30%. The remaining balance is wasted in the form of heat, misuse, friction and noise to a lesser extent. The result of the audit reveals that annual energy loss due to unidentified leakages in the system was 65674.872 kWh/y. The proposed method to identify the leakages in pipelines, manifolds and under insulated coverings are by deploying ultrasonic leak detector. The recommendation to purchase "SDT LexUS Ultrasonic Leak Detector" yields a payback period in less than two months provided leak management program implemented as a business as usual function. Secondly, a reduction of 3°C inlet air temperature yields 1% reduction in amount of energy required to produce same output. Hence, alternatives to induce cooler air in compressor room may incur initial investment.

A review of CAS improvements in cement industries (Madlool, Saidur, Hossain, & Rahim, 2011) which can be adopted in this project were also considered. Reducing air leaks and sizing the pipe diameter correctly in CAS results in reduction of 20% annual energy consumption respectively (Radgen & Blaustein, 2001). In New Zealand, the best practice program in CAS (Neale & Kamp, 2009) focused on demand-side savings for six categories of different installed capacity sites across the country comprising 6500 sites. The major savings opportunities targeted is to address losses from leaks and artificial demand (inappropriate use of compressed air). Another identified method is to reduce system pressure which results in 1-3% power consumption saving by simply reducing the discharge pressure set point at compressor console.

Compressed air system dynamics are essentially important key for high performance system where the energy is managed efficiently to meet peak requirements and at part-load (Mousavi, Kara, & Kornfeld, 2014). The multiple compressors in a system are controlled in a logical manner using fixed speed drive (FSD) and variable speed drive (VSD) compressors. The author proposed state-based model in a pharmaceutical plant in Sydney to show that sequencing the compressors by simulation under different scenarios results in potential energy consumption reduction of the system. In Figure 2.19, a VSD compressor is inherently more efficient at part-load condition and a promising choice under fluctuating load condition and more often used as top-up capacity. FSD compressor on the other hand, works on either load or unloads conditions at constant rate although possible to throttle the air flow to the compressor which is considered inefficient. This compressor consumes less energy at full-load.

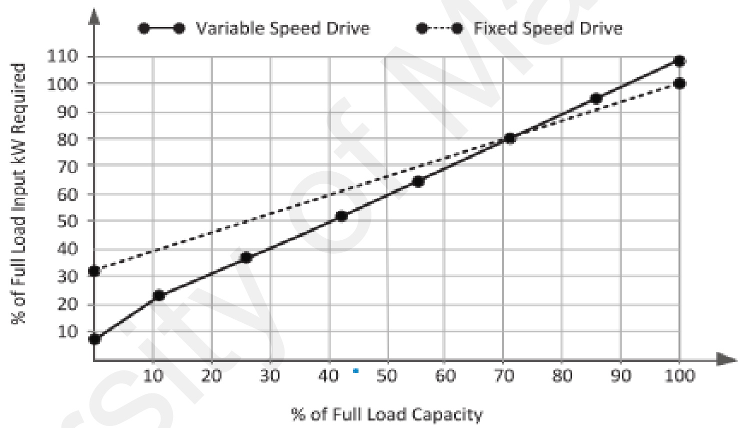

Figure 2.19: Comparison of VSD and FSD compressors energy efficiency (Mousavi et al., 2014)

The data collected on site are used to study the load profile of the operation and the relationship of compressor operating modes to time. Experimental design conducted using simulation models based on compressor priority determination and base-load compressor capacity determination shows that energy efficiency improvements is feasible by integrating this model in said plant.

An audit in an aluminium casting plant reveals that pressure fluctuation caused by consumption in the process leads to frequent load/unload of the

100kW compressor (Olszewski & Borgnakke, 2016). Further auditing direction by the authors proposed that installation of additional receiver tank in vicinity to the consumption end would reduce the peak flow rates and intense pressure drop, subsequently, allowing pressure reduction of the system.

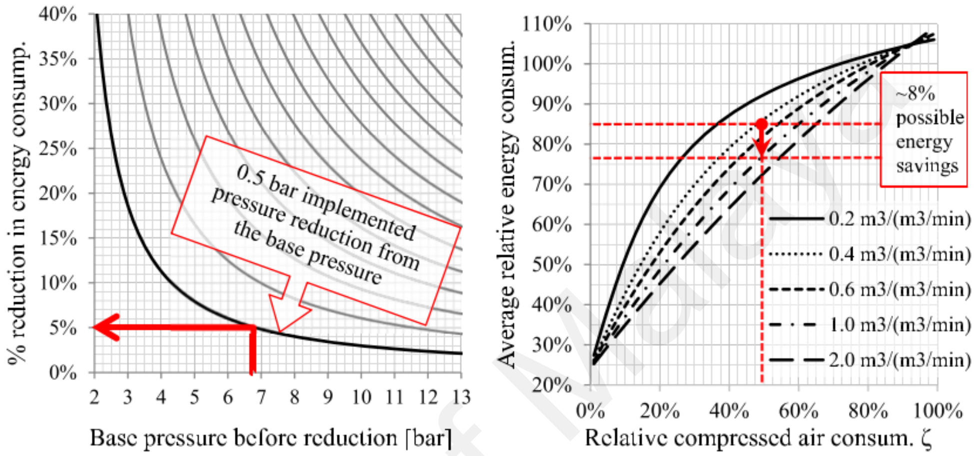

Figure 2.20: Energy saving assessment for pressure reduction (left) and installation of additional receiver tank (right) for aluminium casting plant (Kluczek & Olszewski, 2017)

Based on the methodology proposed, an estimated energy savings of approximately 8% is anticipated for the installation of additional receiver tank. Power consumption of the compressor's motor is reduced when the short and intense blowing process supported by the tank installed nearby. System base pressure of 6.75bar with average power consumption of 84.28kW as shown in Figure 2.20, a reduction by 0.5bar following the implementation of the first method would also results in further energy saving of 5%.

2.8 Lightings

Lighting can be considered as one of the basic human right (Chitnis, Thejo kalyani, Swart, & Dhoble, 2016) in everyday lives. Artificial lighting to attain a realistic visual effect is a precious commodity to look at as huge amount of energy is invested to generate it. In industrial sector, lighting consumes 10-20% of total energy consumption (Al-Mofleh, Taib, Mujeebu, & Salah, 2009). Lighting in industrial facilities most often sidelined due to fractionally amount to purchase it rather than looking at the expenses of power usage. Besides that, lighting systems indirectly add heat load to the building air conditioning system. This will cause additional effort of cooling systems to remove the radiant heat from lighting. In some cases, unnecessary energy being wasted by over-illumination, glare and light clutter which may lead to discomfort and adverse health effects. Thus, by adopting latest technology of high efficiency lamps and control methods, improving efficiency and quality of lighting has positive outcome together with reduced maintenance and operating cost.

Artificial lighting or electrically powered light sources categorized by two distinctive types as shown in Figure 2.21. Traditional lighting system using incandescent and halogen lamps is diminishing progressively and been replaced by more energy efficient lighting globally. The use of fluorescent and high intensity discharge (HID) lamps is the most popular for many years in the industries. However, development and technology maturity on solid state lighting (SSL) for instance, light emitting diode (LED) lamps offers a window of opportunity for cost effective and eco-friendly lighting choice. Lighting performance and effects varies with different light sources employed to suit requirements based on architectural design, colour rendering index, temperature and stability.

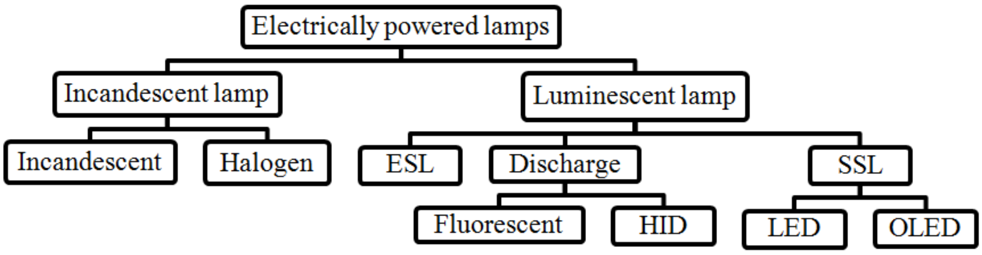

Figure 2.21: Flowchart of electrically powered lamps (Chitnis et al., 2016)

2.8.1 Types of industrial lighting and retrofits

In the industrial sector, the common lighting systems that can be found are fluorescent lights (both compact and linear) and HID lamps. The purpose of such selection depends on consideration and benefits at the time of installation.

Linear fluorescent lamps comes in different lengths and tube sizes denoted by T(number) which refers to tube diameter in 1/8 of an inch, for example T12, T8 and T5. Compared to incandescent lamps, fluorescent tubes reflect higher efficacy and last longer about 10,000h (Chitnis et al., 2016). Generally, these lamps occupy a lot of space and mounted on walls, production offices, plant rooms and platforms. Light emission is time consuming and physically fragile.

Compact fluorescent lamps (CFL) is a lamp similar in principle of operation of linear fluorescent lamps but the tubes are curved or folded, with electronic ballast compacted at the base of the lamp. This fluorescent bulb is easily fitted into standard incandescent light sockets makes CFL offer better choice in terms of power consumption and lamp life compared to incandescent. The purchase price however, is higher but recovered with operating cost within its lifetime. In industry, CFL are used in workbenches, process lines and intricate machinery where visibility is important aspect. The main drawback of fluorescent lamps is it releases toxic mercury if broken and hazardous to humans and environment. Hence, emergence of green lighting technology will overcome these alarming problems.

Some manufacturing buildings are of high bay type with ample of overhead space over floor area especially for overhead facilities such as crane. This type of building needs high level of lights for productions. HID lamps such as metal halide, mercury vapor, and high pressure sodium in the range of few hundred watts often utilized to shine large areas. Flood lights, high bay lights and street lights are examples where HID lamps used in industrial plants and building perimeter. The lamps are specially designed with pressurized glass tubes with gaseous mixture and include tungsten electrodes for electrical arc. Auxiliary equipment such as ignitor and ballast are required for operation of each bulb. In summary, all HID lamps produce large quantity of light but with a considerable amount of energy. The warm up time to reach full light output is several minutes.

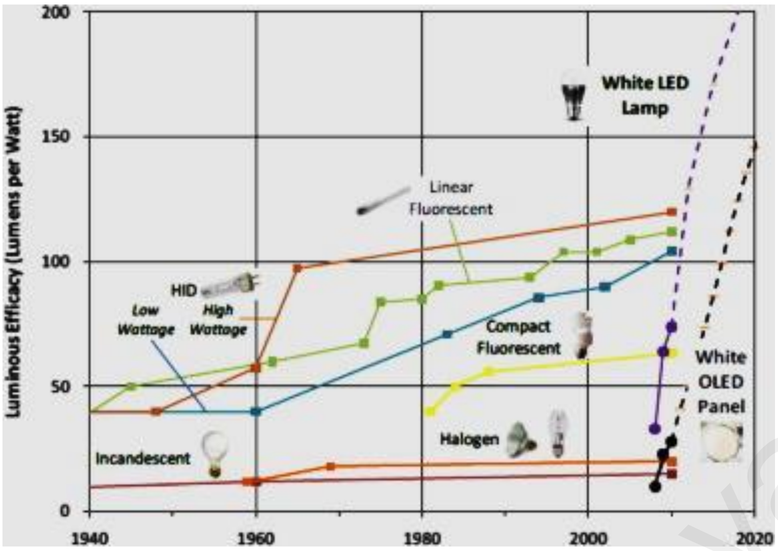

Figure 2.22: Efficacy of light sources, historical and predicted (De Almeida, Santos, Paolo, & Quicheron, 2014)

SSL lighting technology evolves in a rapid pace overtaking conventional lighting technologies as shown in Figure 2.22 and slowly dominating the marketplace. It is this technology that takes the lighting system to a new level. LED lamps are built to suit wide array of applications due to its reliability, colour rendition, visibility and long life aspects. In the beginning, LED lights only found in small appliances such as automotive lighting, large display and signal lighting until in a few years recently starting to replace high powered discharge lamps and fluorescents. As shown in Table 2.6, LED lamps have the highest efficacy compared to the conventional lightings.

Table 2.6 Luminous flux number for common light sources (Gan, Sapar, Mun, & Chong, 2013)

Lamps	Lamps Wattage	Lumens
Incandescent lamp	75W	950
Compact fluorescent lamp	15W	810
Fluorescent lamp	36W	2,400
LED	18W	1,600

There are several advantages of LED in industrial buildings and street lighting. LED significantly lowers waste heat to reduce air conditioning requirements and lower maintenance costs in buildings. For street lighting, about 50% reduction in energy cost could be anticipated by replacing High Pressure Sodium Vapour (HPSV) lamps, increased lifetime with well-designed LED luminaires, increased visual acuity and safety; and less light pollution due to directional light output (De Almeida et al., 2014).

2.8.2 Types of Lighting Controls

Researches show that there are various types of lighting control scheme besides retrofit options as described earlier. The main aim of such controls is to achieve better efficiency in lighting by using less energy as possible without compromising the optimum lighting condition. Manual lighting control is one of the conventional method been practiced with savings awareness in mind. It requires constant human intervention to strategies controls based on occupancy pattern and occupant behavior (Yun, Kim, & Kim, 2012). Automatic lighting control on the other hand offers flexibility over the controls with sophisticated building automation system available today. For a successful commissioning of control scheme to take place, an in-depth study on selection of right luminaires, types of workspace and varying occupancy activity must be surveyed. Hence, providing a clear picture on the energy used pattern in a specified workspace.

Occupancy-based control scheme is one of the technologies widely used in this field and employs occupancy sensors which works on specific algorithm designed either on motion-based switching or motion-based dimming. Detection technique in this scheme includes ultrasonic sensors, passive infrared (PIR) sensors and new technology such as radio frequency identification (RFID) detections and digital imaging. Time delay, sensitivity of sensor, positioning and coverage zone is factors that determine the overall performance and savings of this type of control (Haq et al., 2014).

Provision to receive daylight into premises considerably decrease lighting loads by linking to control systems using switching or dimming method and open or close loop method. Factors involved in lighting control and design linked to optimum use of daylight are ideal window area, shading and obstructions. Excessive penetration of daylight can cause visual discomfort and increased heat load for air conditioning system particularly in tropical climates. Proper tuning of lux level and delay settings of controller, placement of photosensor based on open loop or close loop ensures optimum performance and user acceptance.

Time-based control or scheduling is a simple control by fixing operating time of light fixtures. This control switches the lights on and off based on a pre-fixed schedule derived from accurately predictable occupancy pattern usually a fixed routine. Time switches and time clocks are devices used in this control and manual override capability provided for users beyond scheduled periods.

2.8.3 Lightings Savings Opportunities

Technology advancement in lighting is rapid and viable adoption due to relatively lower investment cost compared to equipment and machineries in industry, offers attractive energy saving with faster paybacks. Furthermore, such savings is concretely evident because one can visually experience the quality rendered. Upgrading luminaires and improving lighting controls are methods towards energy savings. Literatures presented in the following shows economically feasible approach.

In a detailed audit carried out in a small aluminium industry in India, the lighting system shows a potential for improvement (Arya et al., 2017). Energy consumption of tube lights constitutes 13% of the factory's annual energy consumption translated to 163,320 kWh annually. Suggested measures recommends replacing identified tube lights and bulbs to LED bulbs of same lumens resulted in a power reduction of 39% out of current consumption of 66.3kWh/day.

Energy conservation measures devised through an audit conducted in four food and beverage industries in Nigeria (Ogunjuyigbe et al., 2015) shows that load classification of lighting system is approximately 4.5%. The retrofit exercise proposed by the author shows that the quality of lighting maintained and light intensity is improved in the process lines and workbench. Replacement of existing fittings of incandescent, halogen and fluorescent to LED and compact fluorescent lights (CFL) shows possible reduction in energy consumption and payback period varies from 12-16 months. For instance, energy saved per annum for company A is 133,680 kWh. Area of focus is given on the 400W halogen fixtures of existing system retrofit to 100W LED wall light with same luminous flux that could be implemented in this project.

Another case study conducted in Universiti Teknikal Malaysia Melaka (UTeM) at selected faculty buildings lighting system proposed different combination of lighting and controls reveals bill savings up to 76% by using

LED tubes and motion sensor (Gan et al., 2013). The experiment conducted in a lab showed the LED's light distribution and illuminance intensity is greater compared to fluorescent lights using photometry at different angles and encouraging electrical performance. Table 2.7 shows different energy saving strategies proposed and the electricity bill reduction in percentage. In terms of initial cost, it was noted that LED T8 costs five times more expensive compared to existing lighting system. However, sensitivity analysis shows that longer operating hours will result in shorter payback period.

Table 2.7 Energy consumption reduction using various strategies (Gan et al., 2013)

Saving Strategies	Power (kW)	Electricity bill (RM/year)	Reduction (%)
T8 (Existing Lighting)	243	270,764	0
T8 + Sensor	243	173,411	36
T5 Retrofit	145	154,860	43
T5 Retrofit + Sensor	145	103,240	62
LED T8	91	97,272	64
LED T8 + Sensor	91	64,848	76

2.9 Summary

Globally, industrial sector has been growing constantly over the years due to economic and demographic growth. On the other hand, concern about depletion of natural reserves and related global emission has increased among nations. Malaysia, a rapidly growing country realized the importance of managing energy usage prudently for a sustainable future. Energy audit is a systematic and powerful analysis tool to identify potential savings and estimate reduction of energy and GHG. Savings opportunities in industrial sector are deeply explored in this chapter and feasibility of the methods will be applied in the following chapter.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The chapter illustrates the audit procedure in brief for the manufacturing plant chosen. It also covers data collection procedure, analysis and the limitation observed during the study. Mathematical formulations on calculation related to energy are clearly defined based on literatures.

3.2 Preliminary energy audit

The study propagated the necessity of a systematic approach to understand the steps involved in auditing an industrial plant from scratch. The scope of the audit considers the resources available at site such process flowcharts, metering equipment; energy bills to define the share of processes of plant's total energy use (Hasanbeigi & Price, 2010). Figure 3.1 shows the flowchart of beginning of an energy audit. The aim of preliminary approach is to develop an understanding on how energy is being used in a plant by data gathering exercise.

General information on the nature of business, plant location and layout and production capacity is the basic data that can be retrieved by interviewing key people for instance, facility managers. In the process, compilation of monthly energy bills for at least one year required to analyze the energy consumption and cost trend. Besides, it is equally important to check and verify the presence of metering equipment in the plant in order to quantify the amount of energy used for processes (O'Driscoll & O'Donnell, 2013). Hence, energy reduction via identified measures is calculable.

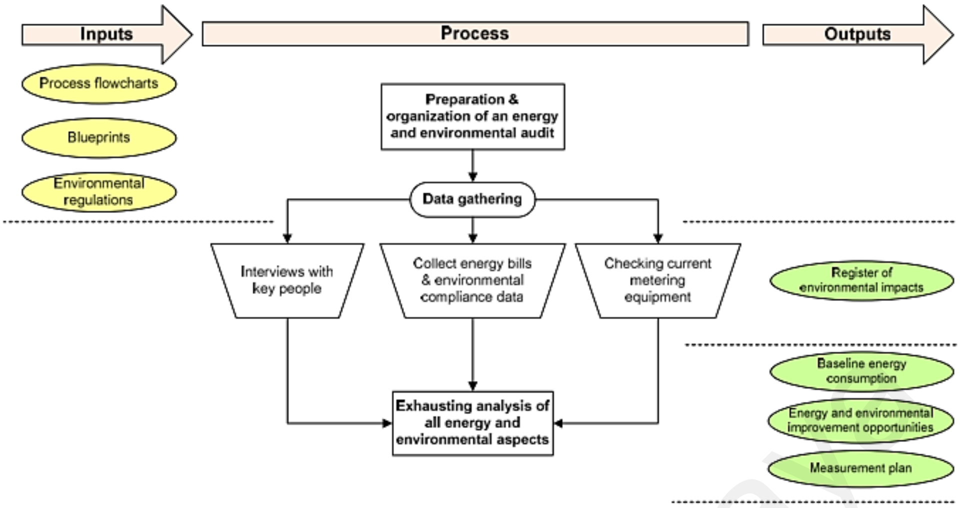

Figure 3.1: Flowchart of Preliminary Energy Audit (Morvay & Gvozdenac, 2008)

3.3 Plant Description

3.3.1 Overview of Culinary Spice Manufacturing Plant Energy Utilization

The industry studied in this project is a manufacturer of premium blended spice ingredients or masala mix and pure spice powders of assorted cuisine in Malaysia. The process includes grinding of raw ingredients procured from overseas (cleaned and decontaminated in different plant) and packaging. The said facility is fully-air conditioned operating in real production scales. The main energy utilized in this plant is electricity which is used to drive process motors such as granulators and grinders, compressed air system, heating and cooling process, packaging machines, bulk material handling, building air-conditioning and lighting.

The plant is receiving 11kV electrical supply from Tenaga Nasional Berhad (TNB) grid and registered under tariff E2 for medium voltage peak or off-peak industrial tariff. Energy unit price for peak hours is higher than off-peak hours. The average monthly consumption of electricity for the factory is approximately 521, 654 kWh and maximum demand of 1644kW which is considered high for a medium enterprise. Hence, it is utmost important to study the trend of electricity consumption and identify opportunities to reduce the consumption without compromising the quality and quantity of end production output. This initiative is the core aspect of this study in improving process efficiency and managing the resources frugally.

3.3.2 Layout of the Plant

The factory is located in Rawang district in the state of Selangor, Malaysia and has been in operations since year 2004.The gross factory floor area is approximately 9600 m^2 and divided into 9 bays denoted A1, A2, A3, B1, B2, B3, C1, C2 and C3 as shown in Figure 3.2. It is a modern industrial facility equipped with fire suppression system, card access system, surveillance system and building automation system.

Utility rooms such as switchgear rooms, transformer rooms, chiller rooms and compressor room are located on two-storey mechanical floor. An 850kVA standby generator set stood outside this two-storey building to supply essential loads in case of local grid power interruption. The main 11kV supply comes from a remote sub-station located 200m from the building before energizing two units of 2.5MVA dry-type cast resin transformer. The low voltage switchgear room is located on the first floor. Three units of busducts supply power to the machinery in the production bays.

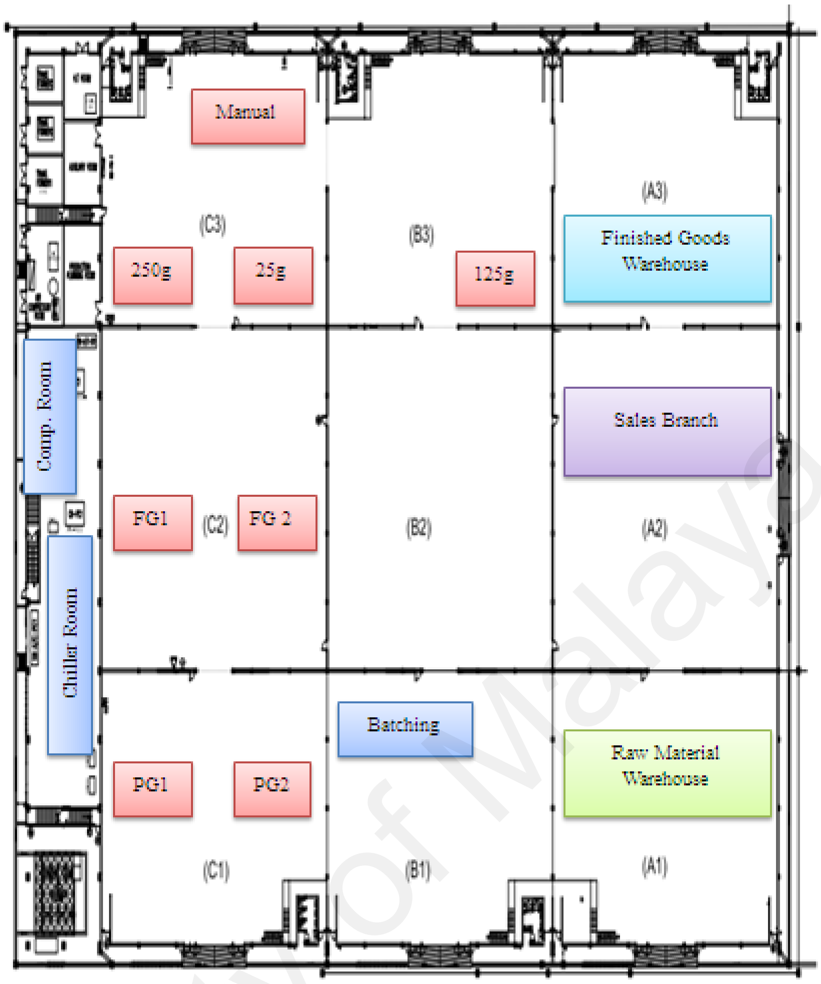

Figure 3.2: Plant Layout

An insight into chiller plant room reveals energy users such as chillers, chilled water pumps and condenser water pumps which interconnected as shown in Figure 3.3. There are four units of 200 refrigerant tonnage helical rotary liquid chillers and twelve units centrifugal water pumps either in standby or duty mode operations. Only two chillers are operating at any point of time. One for the building air conditioning or referred to as comfort cooling from hereon. Another chiller supplies chilled water at 4°C for fine grinding process. Four of the bays, C1, C2, C3 and B3 are used for production process while the rest are utilized to store raw materials, finished goods and machinery parts. Production bays are fully air-conditioned at temperature set-point 24°C by means of chilled water system in the primary loop and air handling units. The open rooftop of the two-storey floor houses eight units of cooling towers of type induced draft counterflow and domestic water tanks.

Figure 3.3: Pictorial view of chiller plant room

Figure 3.4: Pictorial view of cooling tower area

Compressor room houses two units of 200hp centrifugal turbo air compressor, a 6.615 m^3 receiver tank and adsorption air dryer in series connection. Figure 3.5 shows the placement of the equipment inside the room. Air intake duct for the compressor is packaged close to the compressor as can be seen in the image. Compressed air is used throughout the factory machineries.

Figure 3.5: Pictorial view of air compressor room

The building ceiling height is 50 feet from the ground and the ceiling consist of high bay lights fixtures, ducting for cold air outlet and exhaust system louvers. Overhead utilities such as crane and lifts are dry bulk material handling equipment utilized in the plant. The operation of this type of equipment is cyclic due to batch processing method. Machineries in the production lines installed on structured steel platform in pre-grinding and fine grinding sections as shown in Figure 3.6 and Figure 3.7.

Figure 3.6: Pre-grinding section

Figure 3.7: Fine grinding section

3.3.3 Factory Operation

In general, a food industry's main input is raw unprocessed materials. This input will further undergo initial processes such as cleaning, sorting, disinfection and decontamination before processed into canned, packaged or bottled end-user products. Figure 3.8 shows the operation of spice processing industry into marketable product. The raw input to the plant is mainly spices from oversea besides finishing items such as corrugated carton boxes, film rolls and label stickers which procured locally.

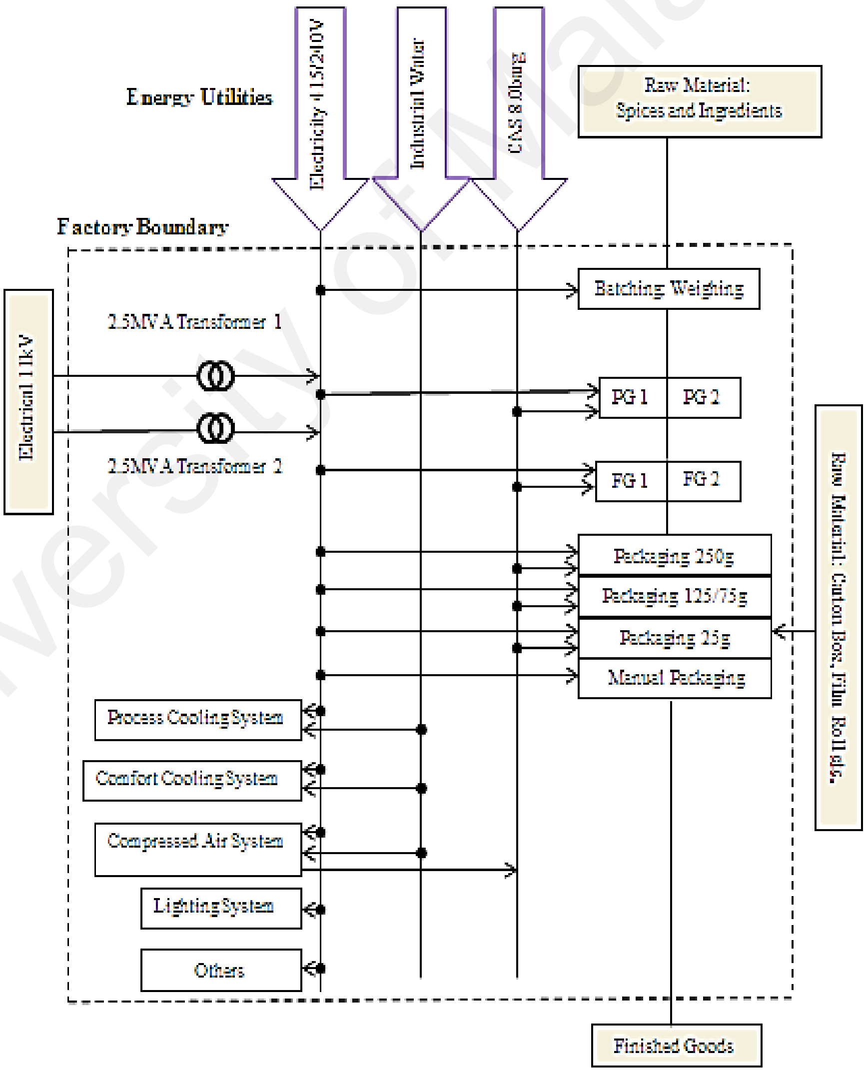

Figure 3.8: Scheme of production process

The process begins in batching section where high quality raw materials are sorted, weighed and arranged in pallets by lot basis. In production terms, one lot is equivalent to approximately 550kg of raw material ingredients. Most of the work here is labour intensive and only weighing scales are used in this section. In this factory, there are two processing lines with similar operating characteristics but with different production capacity and products.

Lots are transferred to pre-grinding section (denoted PG1 and PG2) where the materials are fed into pre-crushing and cutting granulator to shear into sizes from 500µm to 4000µm. The granulator is driven by a 132kW motor running at an optimum frequency of 70Hz and a fixed capacity of 1.2 ton/hour. The pre-grinded powder form is subsequently transported by a product container to fine grinding process where immense energy is used.

Fine grinding is the process where the particle size of the material is further reduced to requirements using air swept pulveriser mill. The mill is driven by a 450hp high efficiency inverter-duty motor for line 1 and 400hp for line 2. Both motors are running at different frequencies to obtain required tip speed of the machine. To maintain the quality of the product, process cooling system plays an important role in cooling off the heat generated during grinding process. The cooling system or process AHU consists of primary stage cooling using chilled water system, two dehumidifiers and a series of semi-hermetic refrigeration compressors in the secondary stage. The idea is to supply cold dry air with a relatively low dew point temperature for cooling purpose. The fine particle is then sucked to a dust collector or baghouse by a 75kW centrifugal suction fan before sieved and transferred to packaging lines.

Coarser particles would be directed back into the system for re-grinding process.

The packaging lines are dictated by the weight of the packaged products namely 250g, 125g/75g, 25g and 1kg/3kg. The first three respective lines are fully automated machineries and mostly embedded fractional kW motors or servomotors optimized to meet low energy demand. Energy saving option is part of bundled packaging machines and the performance most often optimized for production. Tweaking the machines for energy reduction may detrimentally effects the performance of the lines because the operation is synchronized along the line. Manual packaging is another labour intensive with single phase loads such as sealing machines, weighing scales and laser printers. The final output of the packaging lines, packed products in carton boxes transferred to finished goods warehouse for storage before distribution to market.

Another important aspect to ponder is the lighting system of the plant. The present luminaire of high bay light is 400W metal halide consisting 24 units in each outer bays and 30 units in each center bays. These fixtures radiate high level of luminance but also add heating loads for the cooling system. Flood lights and street lights outside the building illuminated by 150W HPSV lamps and operated 12 hours a day, 365 days reflects a great potential for energy savings. There are 33 units of external flood lights and 27 units of street lights surrounding the factory.

3.4 Measurement and Data Collection

As outlined in the auditing procedure, electricity bills for the plant have been collected for the past three years since 2014.This data is sufficient to investigate the trend of growth of the facility based on the production output. Through billing analysis, it is also feasible to determine whether the plant has to abide by the law EMEER 2008, providing a basis for the auditing direction towards demand side management.

Secondly, the energy data is manually recorded on a daily basis before and after the production period on available energy meters in the plant. The energy meter illustrated in Figure 3.9 is of make Schneider Electric and type PM5100 with a class accuracy of 0.5S. Data were collected for the period of seven months for energy share by process pie chart. A total of 16 points were recorded during the process. However, there is limitation observed due to absence of energy meters for sub-distribution boards such as utility and lighting distribution boards. Assumption was made on the process share on these sub-boards due to relatively low energy consumption compared to other major equipment. This period is aimed to recognize SEUs in the plant.

Figure 3.9: Pictorial view of Digital Power Meter

To understand further on the usage pattern of process or sub systems, sampling was taken using digital power quality analyzer of make Kyoritsu and type KEW6315 (Figure 3.10) with accuracy of ±0.3% on energy readings. The data however, has been recorded randomly at a user specified period. Using a single analyzer it is only feasible to display some of the energy consuming characteristic of the plant systems due to time limitation. The operating hours of equipment is derived based on statistical data for the year 2016. Plant production hours and public holidays were taken into account based on assumptions that unscheduled breakdowns were neglected.

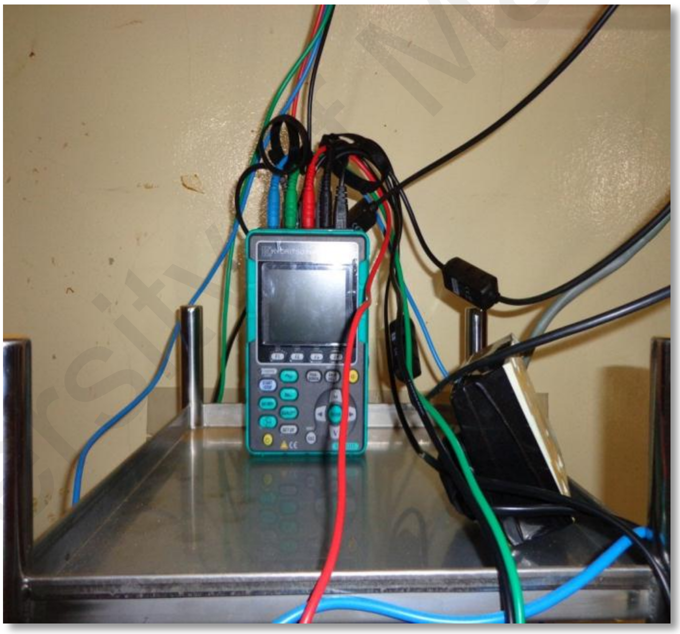

Figure 3.10: Pictorial view of Digital Power Quality Analyzer

3.5 Mathematical formulation for energy saving methods

3.5.1 Electrical motors

The following expressions define the energy performance calculation of electrical motors (Saidur & Mahlia, 2010). The evaluation based on different percentage of motor loadings for 50%, 75% and 100%.

Annual energy use (AEU) of an electrical motor can be estimated as

$$AEU = P \times 0.746 \times H \times L \tag{3.1}$$

where 0.746 is a conversion factor from horsepower to kW (Saidur & Mekhilef, 2010).

The calculation for kilowatt saved (kW_{saved}) and annual energy savings (AES_{HEM}) of replacing standard efficiency motors with HEM motors are given by the following methodology (McCoy et al., 1990; Shaikh, Memon, & Hussain, 2016)

$$kW_{saved} = P \times 0.746 \times L \times \left(\frac{100}{E_{std}} - \frac{100}{E_{ee}}\right) \tag{3.2}$$

$$AES_{HEM} = P \times 0.746 \times H \times L \times \left(\frac{1}{E_{std}} - \frac{1}{E_{ee}}\right) \times 100 \tag{3.3}$$

The associated annual bill savings (ABS_{HEM}) related to the energy savings above calculated as

$$ABS_{HEM} = (AES_{HEM} \times C) + (kW_{saved} \times 12 \times MD) \tag{3.4}$$

where C is the peak hour electricity rate of RM0.355/kWh and MD is the maximum demand charge of RM37.00/kW.

Indirectly, energy savings in industrial facilities reduce electricity generation from power plant. Hence, CO_2 emission reduction can be estimated using the following equation

$$AER_{HEM} = AES_{HEM} \times EF_{CO2} \qquad (3.5)$$

The emission factor for Peninsular Malaysia is 0.694 tCO_2/MWh (Sustainable Energy Development Authority).

3.5.2 Variable Speed Drives

VSD is suitable for many industrial application especially involving fans and pumps. There are many ways to calculate estimated energy savings through VSD. In this study, the following formulation is employed to calculate energy savings (Saidur & Mekhilef, 2010).

The annual energy savings (AES_{VSD}) when using VSD can be calculated as

$$AES_{VSD} = P \times 0.746 \times H \times S_{SR} \qquad (3.6)$$

The associated annual bill savings (ABS_{VSD}) when using VSD can be estimated as

$$ABS_{VSD} = AES_{VSD} \times C \qquad (3.7)$$

CO_2 emission reduction related to energy savings by means of VSD is calculated using the following formula

$$AER_{VSD} = AES_{VSD} \times EF_{CO2} \qquad (3.8)$$

3.5.3 Compressed Air System

In this study, energy savings by repairing air leaks in CAS is estimated based on the percentage obtained in previous research (Bashir, 2010). Annual energy savings through leak prevention ($AES_{CS-Leak}$) in CAS is given by the following

$$AES_{CS-Leak} = AEU \times \%ES \qquad (3.9)$$

where %ES represents the savings percentage of about 20% (Saidur et al., 2010).

The associated annual bill savings ($ABS_{CS\text{-}Leak}$) is calculated by the following expression

$$ABS_{CS-Leak} = AES_{CS-Leak} \times C \tag{3.10}$$

The annual emission reduction as a function of energy savings through leak repair is given by

$$AER_{CS-Leak} = AES_{CS-Leak} \times EF_{CO2} \tag{3.11}$$

Another feasible method of CAS energy saving is by using outside intake air temperature. Annual energy savings related to usage of outside intake air is given by

$$AES_{ia} = P \times L \times 0.746 \times H \times W_R \tag{3.12}$$

where W_R is the fractional reduction in compressor work and can be estimated by the following formula

$$W_R = \frac{T_1 - T_0}{T_1 + 273} \tag{3.13}$$

where T_1 is the average air temperature inside compressor room and T_0 is the annual average outside air temperature.

The associated annual bill savings (ABS_{ia}) using outside intake air temperature method is calculated as following

$$ABS_{ia} = AES_{ia} \times C \tag{3.14}$$

Annual CO_2 emission reduction related by using this approach can be mathematically expressed as

$$AER_{ia} = AES_{ia} \times EF_{CO2} \tag{3.15}$$

3.5.4 Lighting system

The study shows that lighting energy consumption can be reduced by upgrading to LED type luminaires. For high bay lighting scheme, it is proposed to replace selected 400W metal halide fixtures to 150W LED high bay lights. Perimeter flood lights and street lights operated throughout the year using 150W HPSV lamps are proposed to be replaced by 60W LED SSL street lights.

The annual energy savings (AES_L) of lighting method is estimated using the following

$$AES_L = AEC_{400W} \times \%_{150W} + AEC_{150W} \times \%_{60W} \tag{3.16}$$

where $\%_{150W}$ and $\%_{60W}$ are percentage of energy saving by using 150W LED and 60W LED respectively.

The annual bill savings (ABS_L) for the proposed lighting scheme is calculated by

$$ABS_L = AES_L \times C \tag{3.17}$$

The calculated annual CO_2 emission reduction by lighting energy savings is given by

$$AER_L = AES_L \times EF_{CO2} \tag{3.18}$$

3.6 Summary

In summary, the systematic approach of auditing procedure is adopted in this study and essential information has been collected for analysis. Mathematical formulation for each potential savings and emission reduction described in this chapter will be used in the following chapter to display the significance of energy saving analysis in industry.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

A synergic study from previous, this chapter discusses the electrical energy consumption history of the plant and analyses the contribution from each processes in energy standpoint. Furthermore, results from the methodology described earlier are calculated to examine the significance of savings towards protecting the environment and for the benefits of the plant.

4.2 Trend of Electricity Consumption and Breakdowns

As a preliminary step, electricity consumption of the plant tracked back to 2014. Bills collected for the period to date to analyze the consumption growth as shown in Figure 4.1. The period starts from 2015 taking into account annualized amounts from the previous year.

The annualized method shows the trend of consumption in a systematic way. It can be noted that there is a steady growth from the year 2015 to 2016 before reaching steady state average above 6.2MWh mark in 2017. This is because the second production line was commissioned in late 2015. A lot of effort in trial and error on optimization of new process line to meet stringent food quality requirement resulted in immense consumption of electrical energy per unit output depicted as peaks and valleys in the year 2016 as shown in Figure 4.2. The number of lots however, fluctuates from month to month might due to certain factors such as market and seasonal demand, raw input shortage, line breakdowns and unplanned maintenance works.

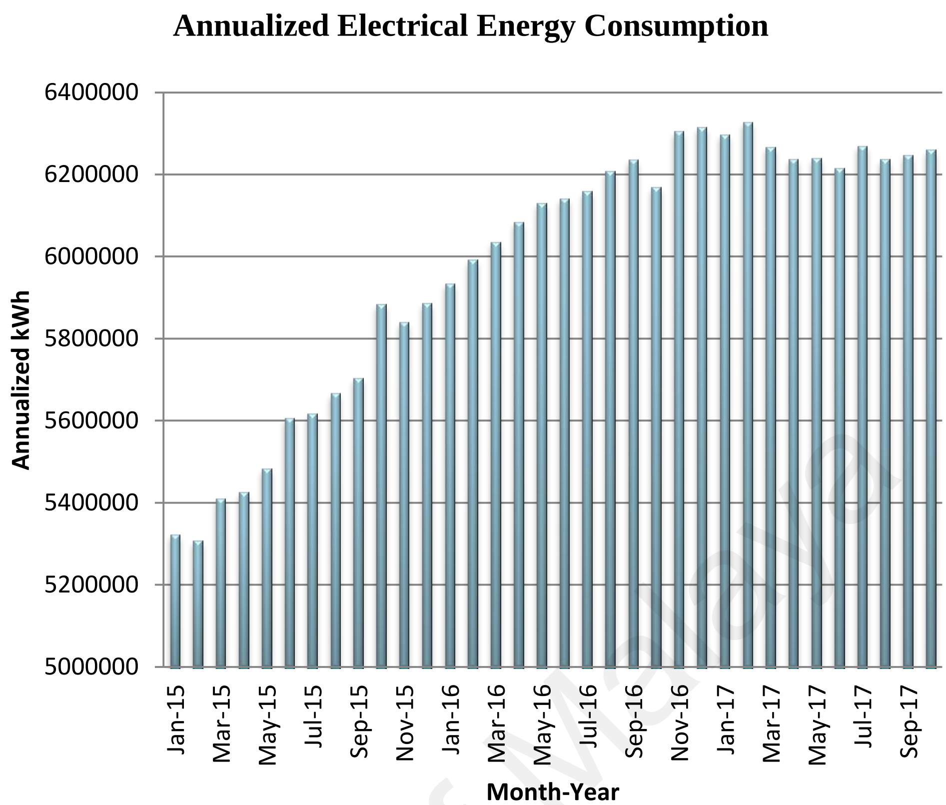

Figure 4.1: Annualized electricity consumption for period 2015-2017

The energy performance index of the overall plant operation based on the production output calculated using Table A.1 (Appendices) and depicted as purple lines as shown in Figure 4.2. The energy used per lot output has been decreasing in the year 2017 reaching below 350kWh/lot. This is because simple no cost measures such as shutting off equipment after the end of process and during non-productive hours yields a small amount of saving. Besides, a testing was carried out by reducing the speed of certain AHU units to monitor the effect of production bay temperature. Such initiative propelled by legislative procedure enforced by Energy Commission to appoint Energy Manager for the company following the electricity usage exceeds the pre-determined ceiling level of 3MWh over a period of six consecutive months.

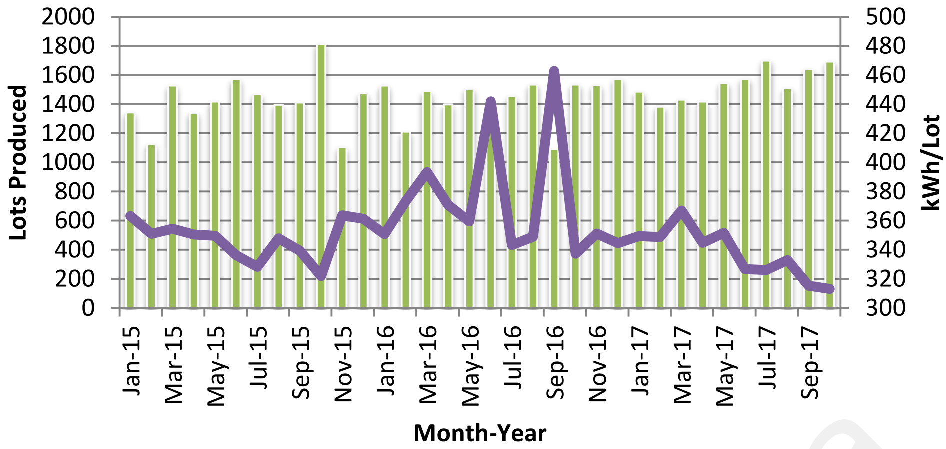

Figure 4.2: Production Output and Energy Performance for period 2015-2017

Energy consumption recorded at sub-main distribution boards are shown in Table A.2 (Appendices). Due to limitation of energy meters available at site, the remaining energy is classified under 'Others'. Most of the loads involved under this sector are single phase loads such as lightings, office equipment, card access system and building automation system. Figure 4.3 shows the pie chart derived from the recordings of seven months.

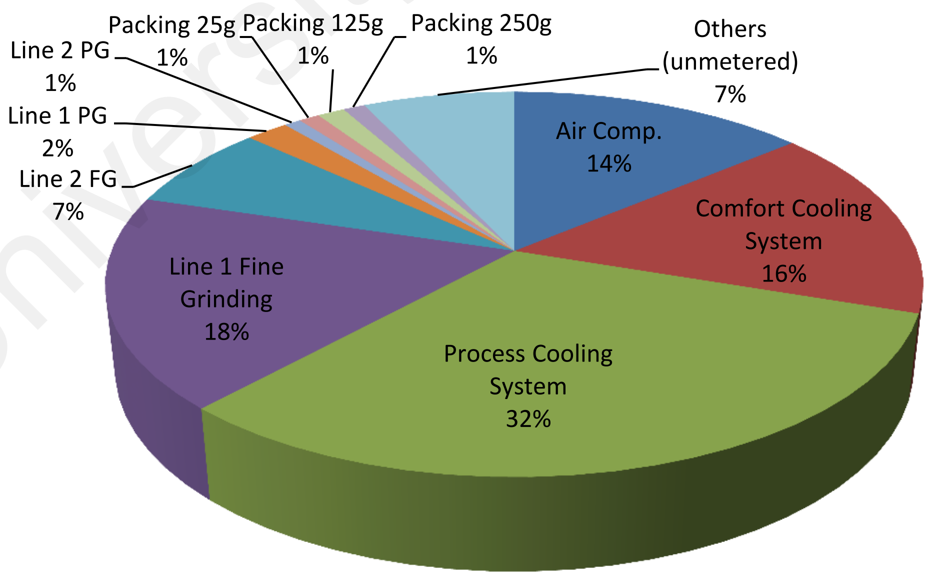

Figure 4.3: Electricity consumption by processes share

It is noted that the most significant energy user is process cooling system comprising 32% of the total electricity consumption followed by line 1 fine grinding (18%), comfort cooling system (16%), compressed air system (14%) and so on. Data recorded for process cooling system and comfort cooling system consist of three and five sub-main panels respectively as indicated in Table A.3 (Appendices). The main energy user in this category is chillers, centrifugal water pumps, fans and process heaters.

Line 1 fine grinding constitutes 18% of the total electricity consumption. In fact, the largest single load of the plant is the 450hp high efficient motor driven by 12 pulse inverter used for grinding. The second largest energy consumer is the 400hp high efficient motor in line 2 fine grinding. However, upgrading or speed adjustment for these motors is not feasible as the performance is already optimized to meet the capacity and finesse of the products.

Compressed air encompasses 14% of the electricity consumption or approximately 73.765 MWh on average which is considered high because it is running on a 200hp high efficient motor and the first one to start before production and the last to stop after production. Hence, targeting CAS yields significant savings which will be calculated later in this chapter.

4.3 Savings and Emission Reduction on HEM

For this study, the criteria considered for the upgrade to a higher efficient motor is annual operating hours more than 2000 hours (Hasanbeigi & Price, 2010), more than 1hp or 0.75kW and standard efficient motor. Table A.5 (Appendices) lists out the motor database of the plant where the selection is made. From the selection, Table A.6 (Appendices) estimates the potential annual savings on energy and utility bills. Also emission reduction for CO_2 is calculated for different percentage of motor loadings.

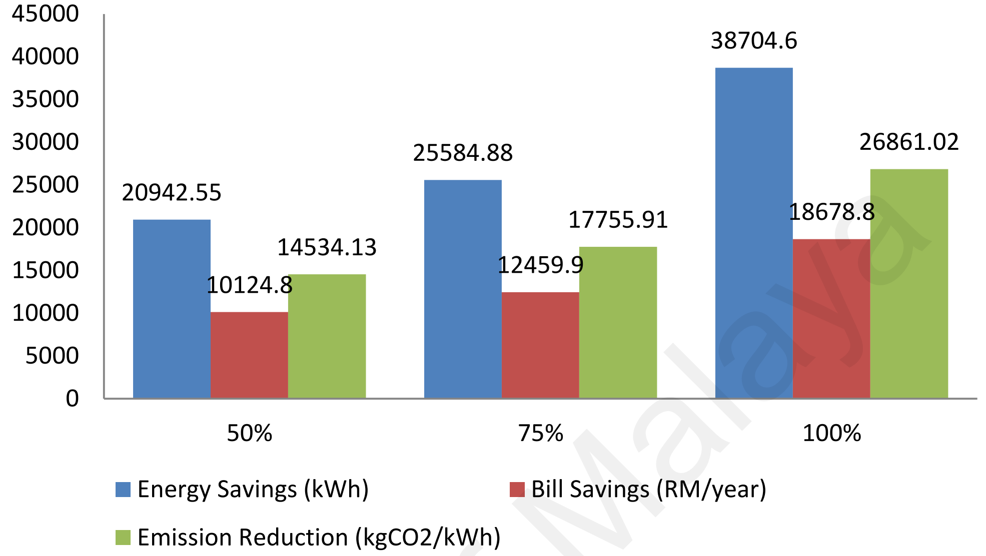

Figure 4.4: Annual energy savings, bill savings and emission reduction for different load of motor when upgrading to HEM

Based on the calculation, the result shown in Figure 4.4 summarized the savings potential and emission reduction when upgrading to higher efficiency motor. It is to be noted that upgrading to a higher efficient motor not only involve capital investment but the energy savings attained would not be sufficient to be exempted from EMEER 2008. At present, the annual energy consumption exceeds 6.2MWh. However, this method does yield savings for the benefits of the company and environment.

4.4 Savings and Emission Reduction using VSD

In this study, energy savings using VSD is focused on centrifugal loads such as fan and pumps. This is because most motors in production lines are running at reduced speed to meet process flow. Speed reduction in these systems may pose inadvertent affect to the process such as delayed transfer, clogging and temperature rise.

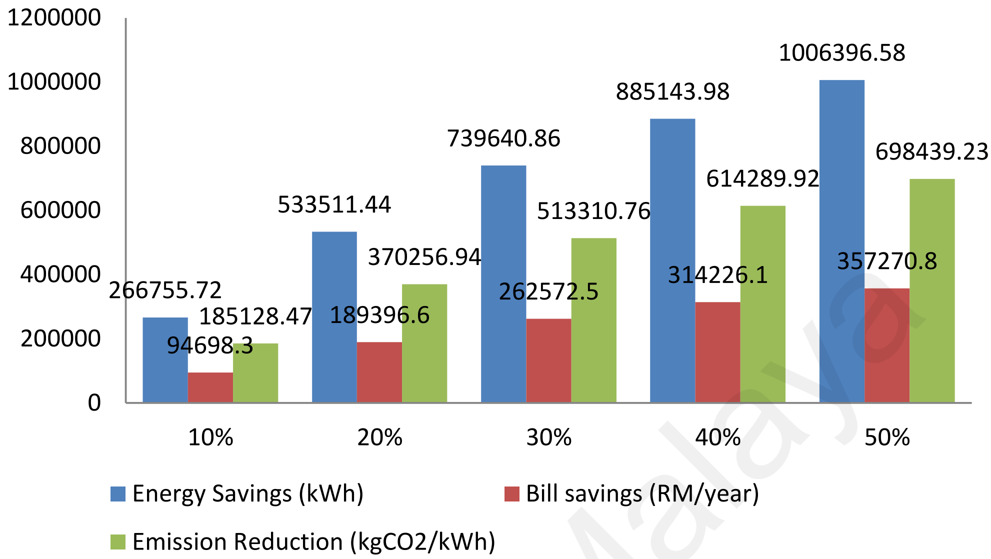

Figure 4.5: Annual energy savings, bill savings and emission reduction for different percentage of speed reduction using VSD

In the food industry, speed reduction with the use of VSD shows significant amount of saving even for just 10% as shown in Figure 4.5. For example, by reducing the speed by 50%, annual energy consumption can be reduced by 16% from 6,260,232 MWh. The data calculated is compiled in Table A.7, Table A.8 and Table A.9 (Appendices). Furthermore, the amount of CO_2 emission reduction increased 3.77 times from 10% to 50% speed reduction. This method is a viable choice for the industry.

4.5 Savings and Emission Reduction on CAS

CAS consumes about 14% of the total energy consumption. This figure constitutes other components in the system such as air dryer, water pumps and cooling tower. To study the energy consumed by air compressor alone, data has been recorded using digital power quality analyzer for one production day as shown in Figure 4.6 and Figure 4.7.

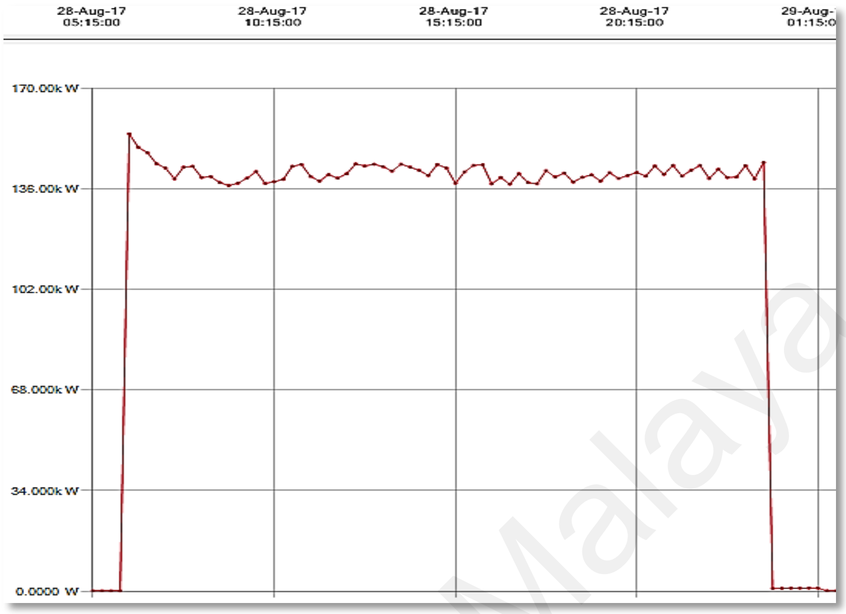

Figure 4.6: Load profile of air compressor for one production day

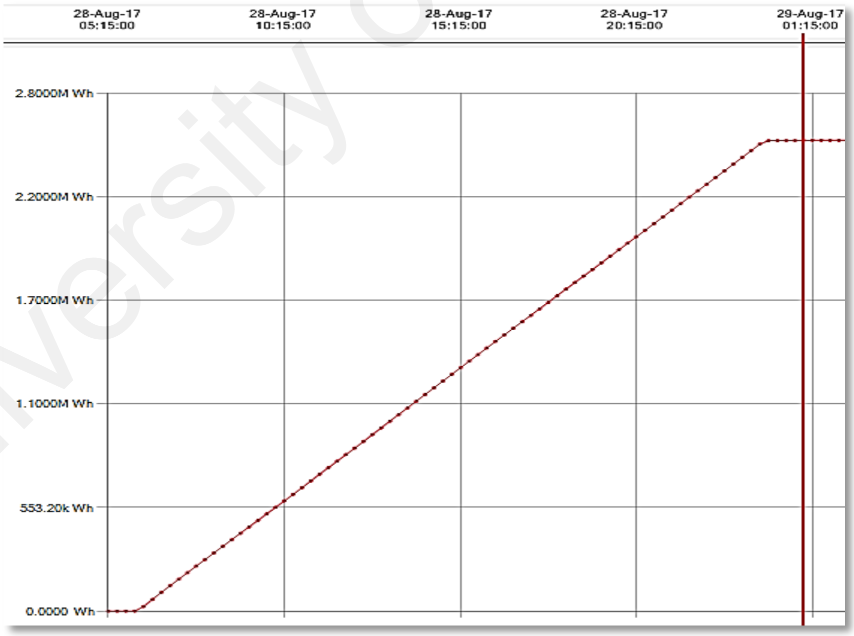

Figure 4.7: Energy consumption of air compressor in a day of production

The average power consumed by the air compressor estimated at 136.0kW with a load factor of 90% which will be used to calculate the savings based on formulas described in previous chapter.

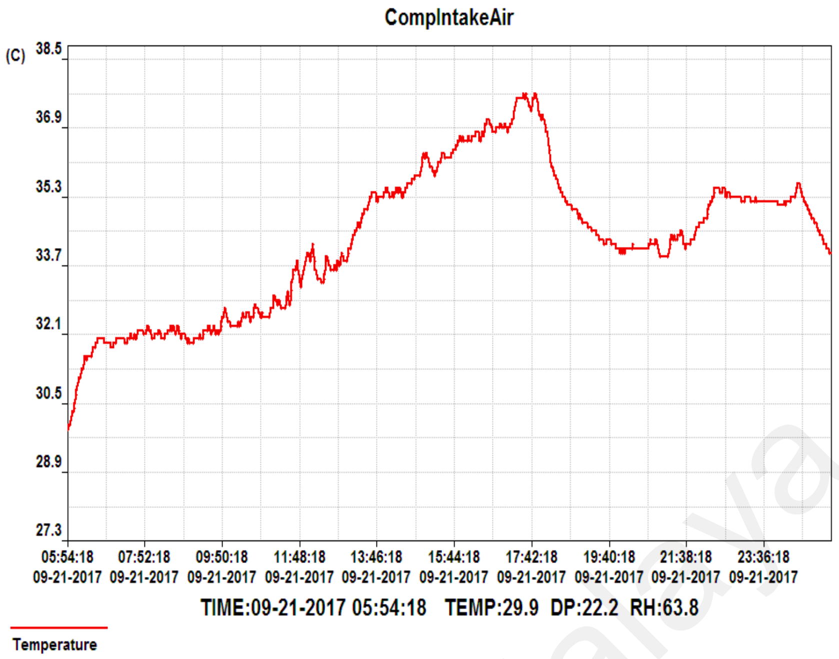

Figure 4.8: Air compressor intake air temperature data

The temperature inside compressor room is estimated to average of 34.0°C for the calculation of savings using outside air temperature of 31.0°C. Table A.10 (Appendices) shows the data extracted on hourly basis using data logger software for average calculation. The result in Table 4.1 is obtained by using formula from previous chapter and data from Appendices.

Table 4.1 Annual energy saving, bill saving and emission reduction analysis for CAS

Saving method	Energy Savings (kWh)	Bill Savings (RM/year)	Emission Reduction (kgCO2/kWh)
Leak prevention	64284.48	22820.90	44613.43
Intake air temp.	3140.94	1115.00	2179.81

From the result, although both methods result in smaller amount of savings and emission reduction, leakage rectification works in this industry saves RM22,820 annually. A consistent leak management programme would ensure the compressor operating performance enhanced in the long run.

4.6 Savings and Emission Reduction on Lighting System

The lighting system focused in this study is high bay lights, flood lights and street lights. Due to absence of energy meter, it is therefore assumed that the maximum number of lights taken into account for the retrofit analysis. Table A.11(Appendices) summarizes the data needed to analyze the savings.

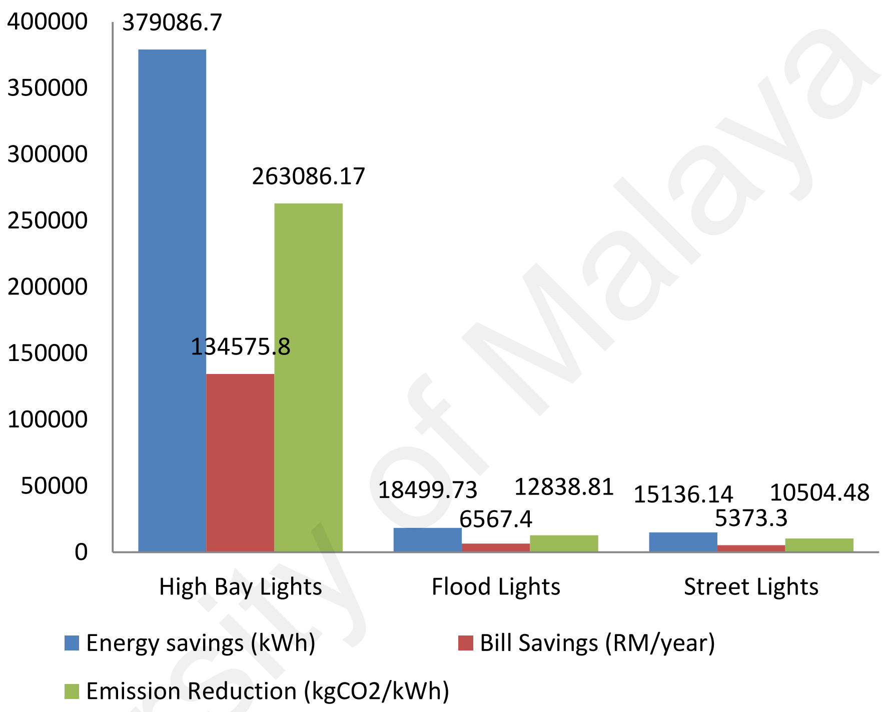

Figure 4.9: Annual energy savings, bill savings and emission reduction for lighting system retrofit

The total amount of energy savings for lighting system is 412.7 MWh annually which is considered a huge price. High bay lights contribute 92% of the share due to significant power reduction. In terms of savings percentage, it is more economical to replace flood lights and street lights because which is the base loads operating throughout the year. LED fixtures are definitely a viable solution to consider although initial purchase price is higher. The technology is greener, less light pollution and long lasting.

4.7 Summary

The outcome of each methodology has been analyzed. All methods are unique with different way of approach. Energy savings and emission reduction by means of speed reduction using VSD is best suited in this factory followed by HEM, lightings and lastly, CAS. The results obtained are of similar trend as found in the literatures.

CHAPTER 5: CONCLUSION AND FUTURE WORK

5.1 Conclusion

The fact that natural resources is slowly diminishing is undeniable. Although strategy to use renewable energy is seen as wise choice, it would not be economically worthy if the energy is utilized inefficiently. There are many ways to reduce energy consumption in the industries and in this study, a few methods has been thoroughly analyzed.

Upgrading to high efficiency motors and estimating the potentials on different loadings could be a viable solution to replace motor running operating towards end of its lifespan, longer operating hours and high percentage of loading. Total annual amount of 20,942 kWh of energy savings, RM10,124 bill savings and 14.534 tons of CO_2 emission reduction could be achieved by this method and at 50% motor load. The greater the loading percentage, the greater the savings is.

It is notably the preferred choice to use VSD for speed reduction in this industry because most of the fans and pumps are running at full speed. Hence, there is opportunity to reduce the speed to best efficiency point. Total annual amount of 266,755 kWh of energy savings, RM94, 698 bill savings and 185.13 tons of CO_2 emission reduction could be achieved by reducing the speed of the motors by 10% alone. This in fact would bring down the energy consumption below the ceiling level set by EC.

Tackling compressed air system for energy savings is another method deployed in this study. The most energy saving method by researches and literatures is to locate and repair the point of leak in the system. Total annual amount of 67,425 kWh of energy savings, RM23, 935 bill savings and 46.79

tons of CO_2 emission reduction could be achieved by repairing air leak and using outside intake air temperature for the compression. The latter contributes 13% in annual bill savings.

Lighting system in industry most often overlooked as small contributor of energy consumer and neglected. However, significant amount of savings is achievable by venturing into latest green technology in this field. Total annual amount of 412,721 kWh of energy savings, RM146, 515 bill savings and 286.43 tons of CO_2 emission reduction could be achieved by retrofitting existing lights with proposed LED type luminaires.

5.2 Future work

This dissertation concentrated on the energy and emission analysis in the spice manufacturing plant. Probably could be a pioneering study in the specified food industry in Malaysia. The viability of the findings has been proven for all the approaches. It is suggested that in the future, further studies can be carried out on the possibility to integrate ice energy storage and heat recovery from process heaters with chillers. The idea is to shed utility load during the peak hours

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