# ENERGY CONSERVATION MANAGEMENT FOR PLASTIC RESIN MANUFACTURERS

Miss Phatcharaporn Chaivisad



A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Engineering Management
Regional Centre for Manufacturing Systems Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2013

การจัดการพลังงานในกลุ่มโรงงานอุตสาหกรรมเม็ดพลาสติก

นางสาวพัชราพร ไชยวิเศษ



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาการจัดการทางวิศวกรรม ภาควิชาศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2556

| | |
|---|---|
| Thesis Title | ENERGY CONSERVATION MANAGEMENT FOR PLASTIC RESIN MANUFACTURERS |
| By | Miss Phatcharaporn Chaivisad |
| Field of Study | Engineering Management |
| Thesis Advisor | Associate Professor Parames Chutima, Ph.D. |

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

..............................................................Dean of the Faculty of Engineering

(Professor Bundhit Eua-arporn, Ph.D.)

THESIS COMMITTEE

..............................................................Chairman

(Assistant Professor Manop Reodecha, Ph.D.)

..............................................................Thesis Advisor

(Associate Professor Parames Chutima, Ph.D.)

..............................................................Examiner

(Associate Professor Jeerapat Ngaoprasertwong)

..............................................................External Examiner

(Assistant Professor Boonwa Thampitakkul, Ph.D.)

พัชราพร ไชยวิเศษ : การจัดการพลังงานในกลุ่มโรงงานอุตสาหกรรมเม็ดพลาสติก. (ENERGY CONSERVATION MANAGEMENT FOR PLASTIC RESIN MANUFACTURERS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดรปารเมศ ชุติมา, 164 หน้า.

งานวิจัยนี้เป็นการศึกษามาตรการการอนุรักษ์พลังงานในโรงงานอุตสาหกรรมเม็ดพลาสติก เพื่อวิเคราะห์และลำดับความสำคัญของแต่ละมาตรการโดยการใช้ระยะเวลาคืนทุนเป็นเกณฑ์กำหนด งานวิจัยนี้มุ่งประโยชน์ให้กับกลุ่มอุตสาหกรรมเม็ดพลาสติกในการนำมาตรการการอนุรักษ์พลังงานไปใช้ มาตรการอนุรักษ์พลังงานที่ใช้งานวิจัยนี้ได้ทำการรวมรวมจากรายงานการจัดการพลังงาน โดยมาตรการที่รวบรวมได้มีทั้งหมด 47 มาตรการ จากโรงงานเม็ดพลาสติกทั้งหมด 17 โรงงาน มาตรการที่รวบรวมนี้จะถูกนำมาวิเคราะห์ โดยแบ่งเป็น 5 ระบบ คือ ระบบแสงสว่าง ระบบปรับอากาศ ระบบอัดอากาศ กระบวนการผลิต และ ระบบไอน้ำ เพื่อหาสาเหตุของการสูญเสียพลังงาน โดยใช้ แผนภูมิก้างปลา และ วิเคราะห์การลดลงของการใช้พลังงานด้วยเทคนิค วิศวกรรมคุณค่า

จากการทำวิจัยพบว่า สาเหตุหลักในการสูญเสียพลังงานมาจาก พนักงานในโรงงาน และ ตัวของเครื่องจักร ผลของการจัดลำดับความสำคัญของการอนุรักษ์พลังงานสามารถแบ่งบอกเป็น 3 ระยะ ตามระยะเวลาคืนทุน คือ ระยะสั้น ระยะกลาง และระยะยาว โดยมีมาตรการระยะสั้นทั้งหมด 28 มาตรการ มาตรการระยะกลาง 7 มาตรการ และ มาตรการระยะยาว 9 มาตรการ สำหรับมาตรการระยะสั้น มีการใช้เงินลงทุนรวม 90,000,000 บาท ทำให้มีผลประหยัดเกิดขึ้น 236,000,000 บาทต่อปี หรือ มีการคืนทุนภายใน 0.9 ปี มาตรการในระยะกลาง มีการใช้เงินลงทุนรวม 20,000,000 บาท ทำให้มีผลประหยัด 11,000,000 บาทต่อปี หรือมีการคืนทุนภายใน 3 ปี และในส่วนของมาตรการระยะยาว มีการลงทุนรวม 30,000,000 บาท ส่งผลให้มีผลประหยัด 3,080,000 บาทต่อปี หรือสามารถคืนทุนภายใน 49 ปี





ภาควิชา ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต

สาขาวิชา การจัดการทางวิศวกรรม

ปีการศึกษา 2556

ลายมือชื่อนิสิต ..........

ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ..........

# # 5471242021 : MAJOR ENGINEERING MANAGEMENT
KEYWORDS: ENERGY CONSERVATION MEASURE PAYBACK PERIOD ENERGY SAVING

PHATCHARAPORN CHAIVISAD: ENERGY CONSERVATION MANAGEMENT FOR PLASTIC RESIN MANUFACTURERS. ADVISOR: ASSOC. PROF. PARAMES CHUTIMA, Ph.D., 164 pp.

This research studies energy conservation measures in plastic resin manufacturing to analyze and prioritize the energy conservation measures by using the payback period as a criterion. The energy conservation measures used in this research were collected from energy management reports which have 47 energy conservation measures from 17 plastic resin manufacturers. The energy conservation measures were classified into 5 systems namely lighting, air conditioning, air compressor, production process and steam. Root Cause Analysis was applied to identify energy wastes and Value Engineering was used to analyze reduction of energy consumption.

The main causes of energy wastes were from employees and machines. The results of the prioritization of energy conservation can be divided into 3 phases according to payback period namely short, medium and long term which have 28, 7 and 9 energy conservation measures, respectively. The energy conservation measures were implemented at 17 manufacturers. For short-term, the total energy investment was 90,000,000 baht, resulting in total energy saving of 236,000,000 baht per year or 0.9 year payback period. For medium-term, the total energy investment was 20,000,000 baht, resulting in total energy saving of 11,000,000 baht per year or 3 year payback period. For long-term, the total energy investment was 30,000,000 baht, resulting in total energy saving of 3,080,000 baht per year or 49 year payback period.

| | | | |
|---|---|---|---|
| Department: | Regional Centre for Manufacturing Systems Engineering | Student's Signature | ..................................... |
| | | Advisor's Signature | ..................................... |
| Field of Study: | Engineering Management | | |
| Academic Year: | 2013 | | |

# ACKNOWLEDGEMENTS

I would like to express my gratitude to all people who have helped and supported me during the writing of this research. Firstly, my deepest gratitude goes to my advisor, Professor Parames Chutima, Ph.D., for his advice and guidance throughout all the stages of writing this research from the beginning to the end. In addition, I also thank Mr. Jirayut Jantraphasakun for allowing me visit factory and providing necessary data. Moreover, I would like to thank Dr. Urith Archakositt and Mr. Chatree Wattanasil for suggestions and their kindness. Finally, I would like to thank my parents and all my friends, who has always supported and encouraged me during the whole time of writing this research.

# CONTENTS

Page

Page

Page

# List of Tables

## List of Figures

# Chapter I : INTRODUCTION

## 1.1 Introduction

Plastic resin is one of many products in downstream petrochemical industry. Plastic resin industry is an important industry in Thailand because the plastic resin is base-material used in many plastic applications such as food and beverage bottles, plastic bags, plastic pipe, and so on. In general, the plastic resin industry uses raw material from upstream or intermediate petrochemical products and converges the products to the plastic resin. However, its production process of plastic resin industry consumes a lot of energy and tends to use higher energy in the future. Due to economic growth, it is necessary to provide some energy management guidelines to the industry to reduce the energy consumption and enhance the energy efficiency. The energy management will increase competitive advantages for plastic resin manufacturers not only saving their energy cost but also maximizing the industry benefits, increasing the country competitiveness and conserving the world environment.



An energy conservation measure is the main focus in this research to reduce energy consumption in the buildings and factories for plastic resin industry by focusing in Rayong area. The eight steps of energy management system as ministerial regulation are conducted to collect energy conservation measures for plastic resin manufacturers by focusing on step four, evaluation of energy conservation potential and step 5, energy conservation measures. In this research, collected energy conservation measures will be evaluated by using Value Engineering concept. And then, all practical energy conservation measures will be listed to prioritize by the using payback period as criterion.

### 1.2 Background

There are 17 plastic resin manufacturers located in Rayong Province for being the case study to create guidelines on energy conservation for this industry. The products of this industry are Polyethylene (PE), Polypropylene (PP), High density polyethylene (HDPE), Low density polyethylene (LDPE), Acrylonitrile butadiene styrene (ABS), Styrene-Acrylonitrile (SAN), Expandable Polystyrene (EPS), Polystyrene (PS), Polyvinyl Chloride (PVC), Poly(methyl methacrylate) (PMMA), Polyoxymethylene or Polyacetal (POM), Polyethylene terephthalate (PET), Nylon, Polyacetal, Ethylene-vinyl acetate (EVA).

#### 1.2.1 General information on the studied factories

General information about types of product, working hours and types of energy consumption is attached in Appendix C.

Plant A: It has produced 6 product types namely HDPE, PP, ABS, SAN, EPS and PS.

Plant B: There is only one product of plastic resin, that is to say polyacetal (POM).

Plant C: There are two production lines for producing plastic resin that are LDPE and EVA.

Plant D: It produces PP.

Plant E: It produces PP.

Plant F: There is one production line for Nylon.

Plant G: One production line is available for PE.

Plant H: It produces PVC.

Plant I: It produces PVC.

Plant J: Its product is PET.

Plant K: Its product is PMMA.

Plant L: Its product is PP.

Plant M: It produces Nylon, ABS, and Polyacetal.

Plant N: Its product is PP.

Plant O: Its products are ABS and SAN.

Plant P: It produces PE.

Plant Q: Its product is PE.

### 1.2.2 Plastic resin production process

**1. Layout of studied plastic resin manufacturers**

According to the layout of studied factory (LDPE manufacturer), there are four main areas for a plastic resin plant as shown in Figure 1. The first area is monomer preparation. A monomer is a raw material of plastic resin. So, the first area is raw material preparation area. And then, monomer will be converted to polymer at area 2 called polymerization zone. After polymerization reaction, there are 2 types of polymers, namely inactive polymer and active polymer. At zone 3, these two polymers will be separated. The inactive polymer will be recycled by returning it to zone1while active polymer will be sent to zone 4. An extruder and a pelletizer at zone 4 transform active polymer into plastic pellet. Finally, plastic pellet or plastic resin will be packed into packaging.

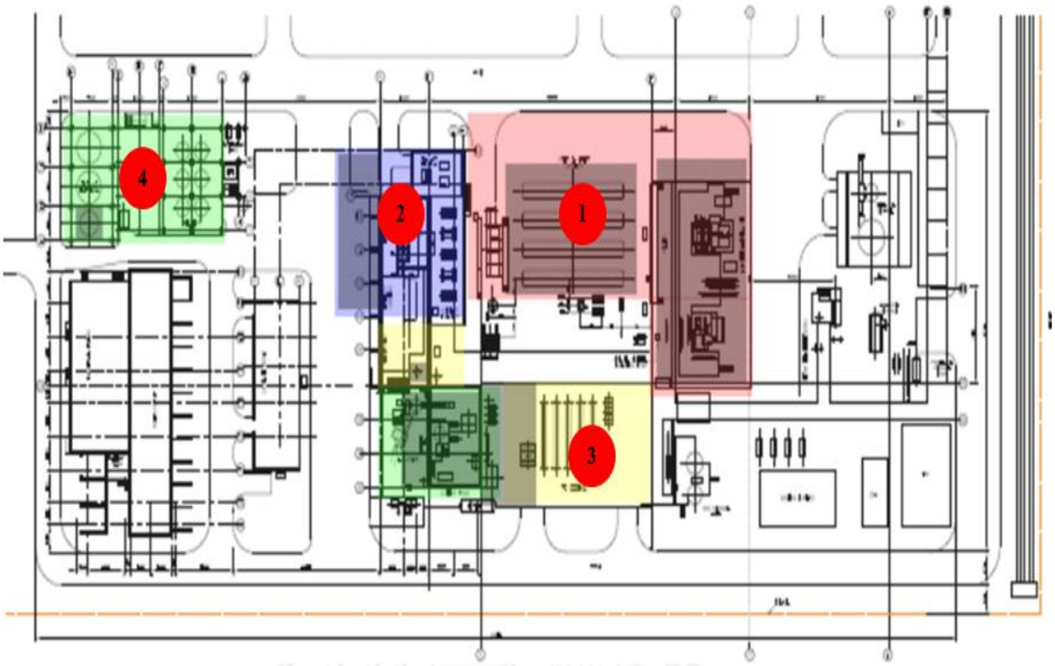



Figure 1 Layout of studied plastic resin manufacturers

Note: (1) Monomer preparation (2) Polymerization

(3) Separation (4) Pelletization

2. Plastic resin process

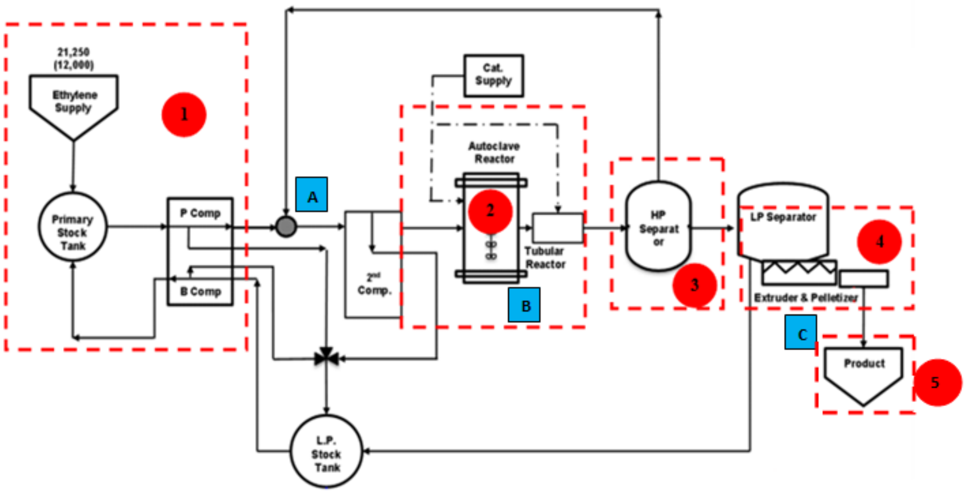



Figure 2 Plastic resin process and equipment

| | | | |
|---|---|---|---|
| Area: | (1) Monomer Preparation | (2) Polymerization | (3) Separation |
| | (4) Pelletization | (5) Blending and Bagging | |

| | | | |
|---|---|---|---|
| Equipment: | (A) Heat exchanger | (B) Reactor | (C) Extruder and Pelletizer |

As shown in Figure 2 is plastic resin process and equipment in plastic resin process that the detail of the process is described as following sections.

1. Increase of monomer pressure (Monomer Preparation)

Ethylene and additive got from the outside must be compressed to increase the pressure with the result that ethylene has higher temperature. So, it is necessary to adjust temperature appropriately before with the help of heat exchanger.  Then, they are fed into the reactor.

**2. Occurrence of polymerization (Polymerization)**

Ethylene and the additive that flow into the reactor will be mixed with catalyst, thereby causing polymerization reaction. As a result, some ethylene becomes liquid polymer. Non-reactive ethylene and liquid polymer will be decreased in pressure and temperature, and then flow into the high pressure separator.

**3. Separation of ethylene and liquid polymer (Separation)**

A mixture of non-reactive ethylene and liquid polymer will be split by high pressure separator. Ethylene will be recycled for re –use by passing through the heat exchanger to reduce the temperature. In addition, there is the system of separating liquid polymer mixed with ethylene before being compressed to increase the pressure for use in production again.

**4. Extrusion and Pelletization**

Liquid polymer will be fed into the extruder, and then pelletized by the machine, resulting in plastic pellet. Later, the plastic pellet will be conveyed for blending to be plastic resin.

**5. Blending of plastic resin and product packaging (Blending and Bagging)**

Plastic pellet sent from the pelletizer will be stored in silos to drive the residual ethylene out. These silos are specially designed for use in mixing evenly. Then, plastic resin will be transferred by the air to the packaging unit further.

1.2.3 Evaluation of energy management in plastic resin manufacturing

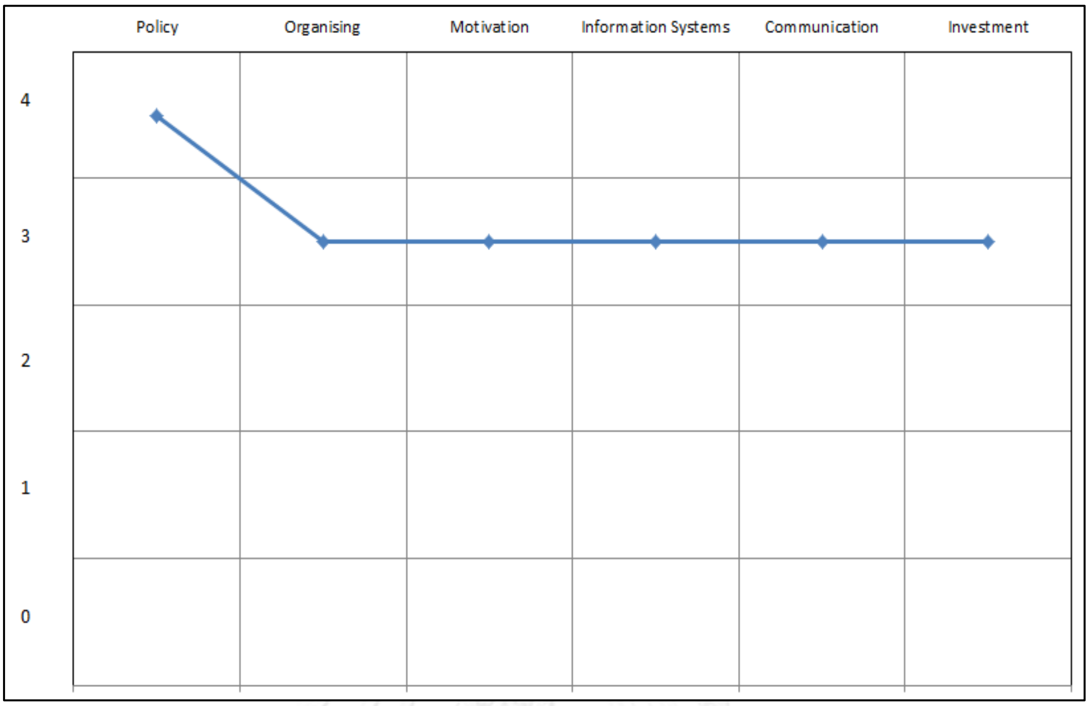



Figure 3 Evaluation of energy management in plastic resin manufacturing

Overall, the situation related to energy management of plastic resin industry is considered as good to very good in all aspects as shown in Figure 3. This means that the energy management has already become a highest priority of the organizations. The next goal is to maintain the system to be sustainable. The assessment of each aspect is detailed as follows:

**1 . Policy**

Regarding the policy on energy conservation in the plastic resin industry, it is considered that there has been the management policy of the administrative section. Besides, this policy is regarded as a part of the company policies.

**2. Organizational management (Organization)**

As regards the organizational management, heads of various sections have been appointed as the group of energy management and persons in charge of energy matters. The management group reports directly to the Committee of Energy Management. There is a clear chain of command. Moreover, the persons in charge of energy have clear roles and responsibilities.

**3. Stimulation and creation of incentives (Motivation)**

The Energy Conservation Committee is the main channel of stimulating and creating incentives for staff and individuals in the plants.

**4. Information system**

In terms of information system, the results of energy consumption have been reported to each section for information. However, the results of saving have not been communicated after introduction of energy conservation measures for use.

**5. Publicity**

In terms of publicity, there has been the publicity for energy conservation regularly. Besides, all staff members are allowed to be informed of energy conservation projects within the plants.

6. Investment

As for investment in energy conservation, the payback period is primarily used in considering the investment. Some energy conservation measures require the high investment funds, but give returns back in a short time. Thus, such measures are taken for use.

### 1.2.4 Evaluation of energy consumption

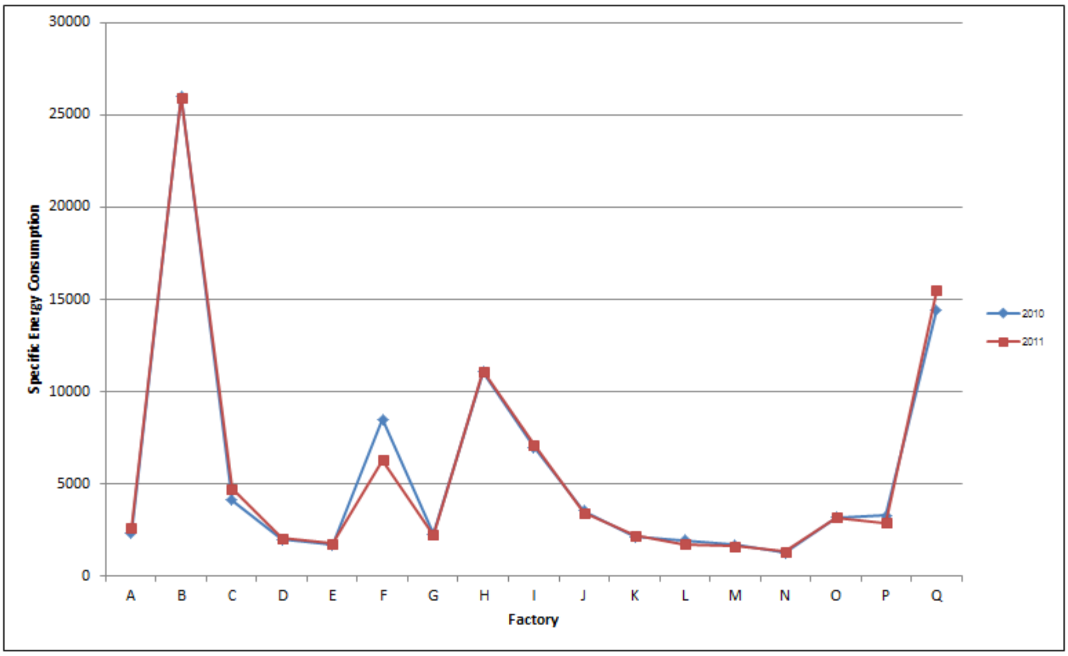



Figure 4 Specific Energy Consumption in plastic resin manufacturing, 2010-2011

The assessment of energy consumption in industrial factories was performed through the energy consumption indices (Specific energy consumption) by doing comparison in the years 2010 and 2011 as shown in Figure 4. It has been found that the energy consumption of both years were not much different. This shows that the factories have controlled the energy consumption well. Additionally, some factories had the reduced energy consumption in 2011. This indicates that there had been the better energy management and the reduced energy consumption. When comparing each plant, it has been found that the SEC is not the same due to the difference of products. In other words, there are both Commodity plastics and Special plastics. Usually, special plastics such as POM involve higher energy consumption than that of commodity plastics because of rather complex production process and need for much energy. Moreover, even the commodity plastics themselves are different in terms of energy consumption.

**1.2.5 Energy use in plastic resin manufacturing**

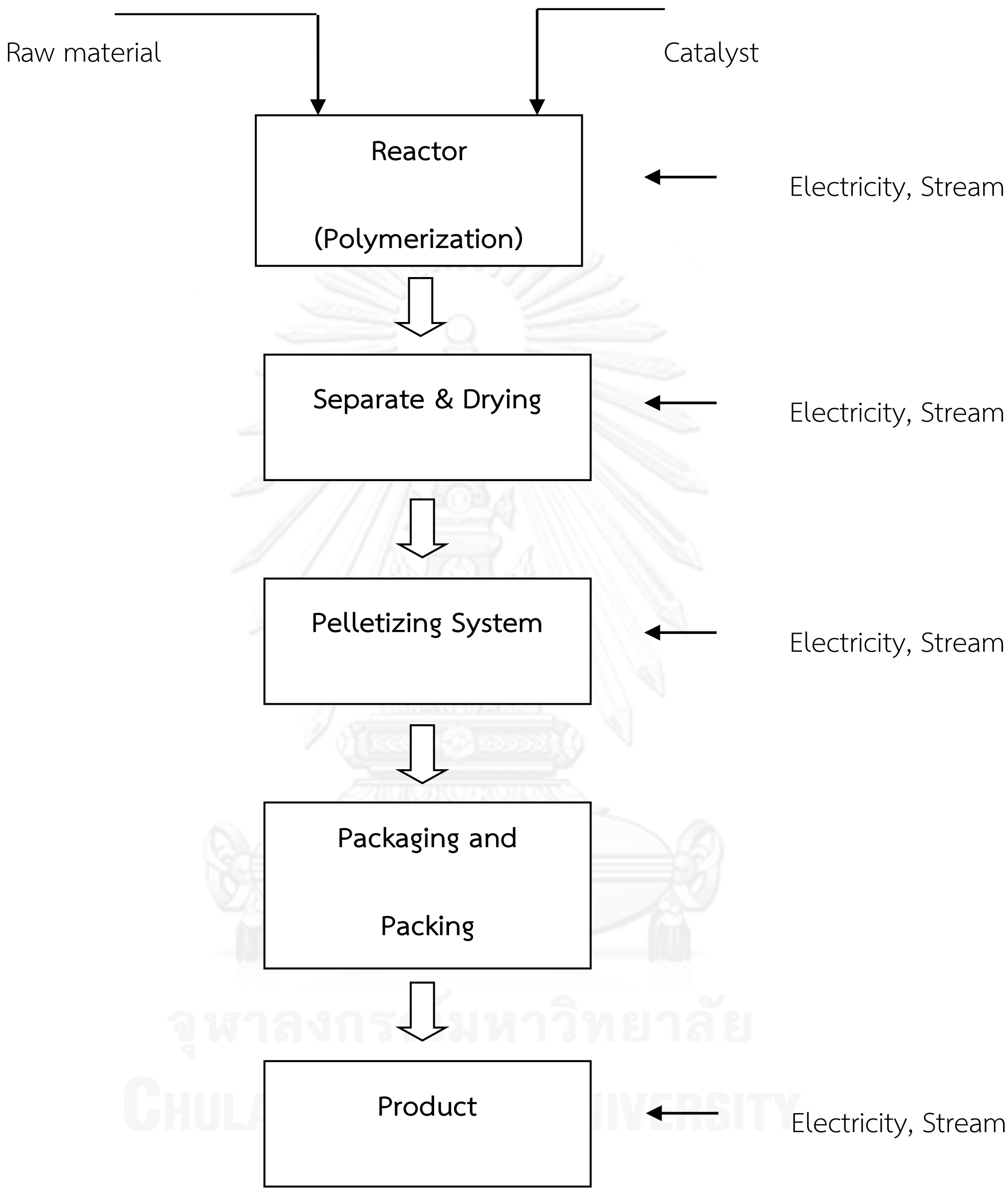



Figure 5 Energy usages in plastic resin process

There are two types of energy use in plastic resin manufacturing such as electric energy and thermal energy as shown in Figure 5. The primary energy is electric energy while thermal energy is mostly used in production process due to require heat to create reaction. Thermal energy is used in term of steam generated by steam generator.

**1.2.6 Energy consumption in the plastic resin manufacturing classified by systems**

Electricity consumption

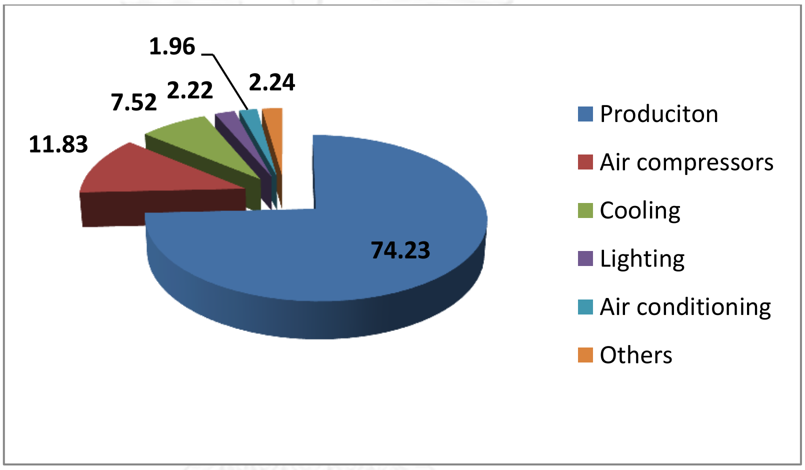



Figure 6 Proportion of electricity used in manufacturing

Thermal Energy consumption

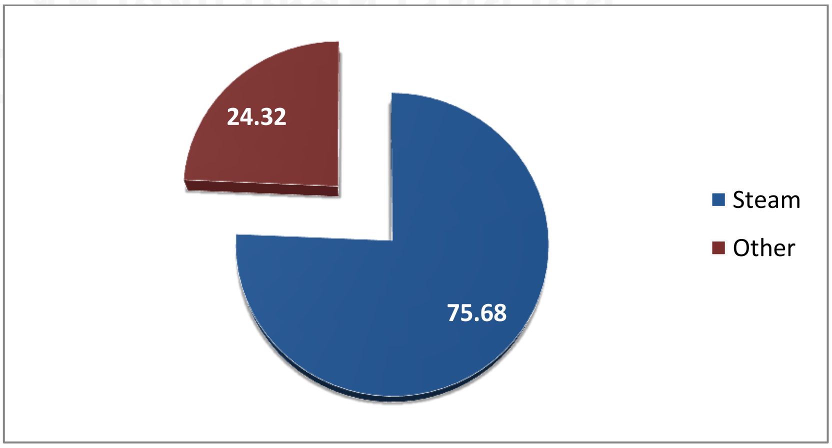



Figure 7 Proportion of thermal energy used in manufacturing

Energy used in manufacturing was classified by systems which were production, air compressors, cooling, lighting, air conditioning, and other. As shown in Figures 6 and 7, Production sector was the largest electricity consumption, with 74.23 % of total. The air compressors accounted for 11.83 % of electricity consumption, cooling consumed 7.52 %, lighting 2.2 %, air conditioning 1.96 % and the other 2.24 %.While the greatest thermal consumption was steam, representing around 75.68 % of thermal energy used. So this research will be developed energy conservation measure as the systems. For the thermal energy, the other can refer to natural that in some plants used the natural gas to be fuel for thermal systems.

**1.3 Statement of problem**

From the study of the energy management reports that plastic resin manufacturers submitted to the Department of Alternative Energy Development and Efficiency, it has been found that they had different energy conservation measure even though they had similar production process. The study has revealed that a total of 47 energy conservation measures have been applied in the plastic resin manufacturers but most of them didn’t use the same energy conservation measures. For example, there were only two factories implemented air leak detection measure and six factories implemented change efficiency light bulbs. Additionally, the number of energy conservation measures in each factory was not equal. For example, the plant A has deployed 7 energy conservation measures while the plant E has applied one energy conservation measure only. The unequal energy management and adoption of energy conservation measures for use are due to the following causes:

1. Unequal ability to find energy waste in the plants. This means that some plants can identify for the causes of energy waste greatly whereas some plants are less able to find the causes.

2. Unequal ability to manage energy due to the differences in terms of resources, technology and humans.

On the basis of these causes, the researcher has, therefore, energy conservation measures in plastic resin manufacturing requires list of energy conservation measures to identify gap of energy conservation measures for each plastic resin manufacturer.

**1.4 Objective**

To identify the energy conservation measures suitable for plastic resin manufacturers and prioritize the energy conservation measures by using the payback period as a criterion.

**1.5 Scope of thesis**

This thesis focuses on the plastic resin manufacturers located in Rayong province, Thailand and energy conservation measures will be prioritized by using the payback period as a criterion.

## 1.6 Expected Benefits

1. Suggestion of suitable energy conservation measures for plastic resin manufacturers.

2. Gaining of competitive advantages by reducing expenditure and energy consumption.

## 1.7 Methodology

1. Collect data from

1.1 Energy Research Institute, Faculty of Engineering, Chulalongkorn University

1.2 Ministry of Energy

1.3 Department of Alternative Energy Development and Efficiency (DEDE)

2. Pull information from energy management report

3. Identify energy waste in plastic resin manufacturing by classifying in systems

4. Analyze energy conservation measures as Value Engineering concept

5. Prioritize energy conservation measure by using payback period as criteria

6. Give an example of case study factory by comparing the case study factory and collected energy conservation measures.

# Chapter II : LITERATURE REVIEW

This chapter contains the reviews of literature related to the research that will be adapted to this research. The reviews include past researches and case studies about an energy management report which is the resource of energy conservation in this research and energy conservation in plastic industry. The review also includes concept of Value Engineering which is a management tool applied to energy conservation. The reviews of this research are as following section.

## 2.1 Energy management report

The energy management report by industrial factory that must be delivered to Department of Alternative Energy Development and Efficiency has 8 steps as shown in Figure 8.

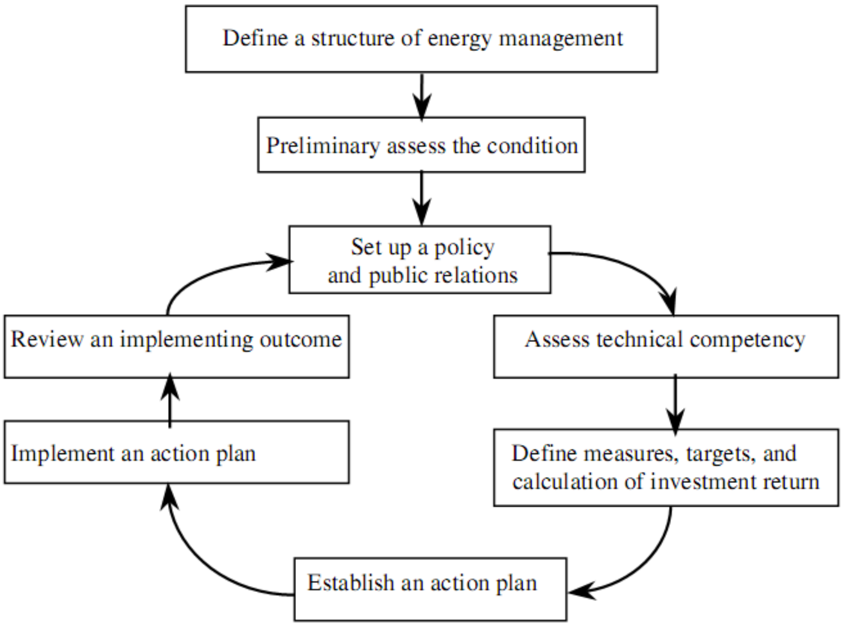



Figure 8 Proportion of thermal energy used in manufacturing

From: Department of Alternative Energy Development and Efficiency, 2009

In this research, the step for assessing technical competency and defining measures will be focused so these two topics will be described how to apply following sections.

**1. Assessment of technical competency**

This stage gathers a list of devices in the plant that consumes higher proportion of energy, including an assessment of technical and manufacturing processes for research of energy conservation measures. The advantage of this stage is to know the extent of energy consumption in each stage, the condition of machines and equipment within the factory condition, and how long it has been used. For example, a factory has been using an air conditioner for 7 years. After evaluating, results show that it has high energy consumption. The evaluation of the compressor found that the compressor is located in an area with high dust concentration, hence it increases the compressor's workload. Therefore, a change is required to allow for a better air flow whereby the air compressor to be moved, cleaned more frequently, or by utilizing various other methods.

**2. Defining measure, target and calculation of investment return**

In this process, the implementation of energy conservation by following energy conservation measures along with comparisons of energy use data with the history data for identifying the saving results. It also engages with the purposes of energy conservation measures, responsible man, time, budget, and expected results. In this process, the part to be retrieved are name of energy conservation measures, objectives, and to calculate the payback.

### 2.2 Energy conservation

Energy conservation by the definition of Department of Alternative Energy Development and Efficiency is to reduce energy consumption by managing energy properly for the maximum benefit without causing a decrease in the production line and changes in quality of the product (Department of Alternative Energy Development and Efficiency, 2009). By which energy conservation should go step by step. Energy conservation starts with simple technology and minimal investment to a more advanced technology with higher investment, as follows:

1. Primary care and maintenance (House Keeping) is to tune up equipment and its functions such as determining a proper process of maintenance. Mostly these methods will not increase any expense or is a measure with low cost, but with a short payback period of less than 4 months.

2. Improving the existing processes to achieve higher efficiency or to decrease losses which required detail analysis. In general, these measures will require medium investment with payback period of 1-2 years.

3. Changes in equipment or systems (Major Change Equipment) when the initial analysis suggests that the performance can be increased significantly by changing or adding equipment. However, it is imperative to assess the financial gained from the implementation of such measures. This measure would require a high investment with a payback period of 2-5 years.

The energy conservation in regulated factory is classified into two type that is energy conservation in utility and production process which is detailed as following sections.



**2.2.1 Energy conservation in utility systems**

The utility systems are the system that support the production process including lighting system, air conditioning system, air compressor, steam generator, and pump and so on (Department of industrial works, 2004). The utility system should be checked and surveyed to see to see what happens on the ground and to initiate energy management (Intelligent Energy Europe, 2006). There are many problems in the utility systems that cause energy waste. For the air conditioning system, there are 3 problems areas for air conditioners which are oversize of air conditioners, duct leakage and air-conditioning system (Rhodes et al., 2011). For the steam system, the steam system includes the steam generation and steam distribution (Bhatt, 1999). Mostly energy losses occur in steam line and recovery unit. Moreover, the energy waste can occur in the another equipment such as a motor left running without loads, the equipment in utility system left running even though lines are shut down, the size of motor is unsuitable, the chiller left running when no required. The energy conservation in utility systems is revealed in many researches (Wang and Chen, 2012). The technologies were applied widely in energy efficiency such as energy efficiency electric motors that have high efficiency and costly, variable speed drives (Maheswaran et al., 2012). The variable speed drives was applied in air conditioning unit which was installed blower fan to reduce energy consumption by adjusting load to match actual demand (Bandara et al., 2008). Besides these devices, there are more energy efficiency devices such as soft starter, energy efficiency transformers, electronic ballast, efficiency light control and energy efficiency lamps.

**2.2.2 Energy efficiency in production process**

In this research, production process is the plastic resin process. Plastic resin is from polymerization reaction by synthesizing with different raw materials (National Metal and Materials Technology Center, 2007). The raw material of polymerization called monomer and the synthetic polymer will be transformed to plastic resins. The equipment that uses to transform synthetic polymer to plastic resin is extruder as shown in Figure 6. The main components in an extruder are screws, heaters, motors and barrels. The screws are rotated by motors that use electricity to drive the motors. The heaters are used to generate heat in extruder by passing a current through a conductor and barrel is the place for melting polymer being until the polymer will be pushed out from the die (Levinjobet, 2010).

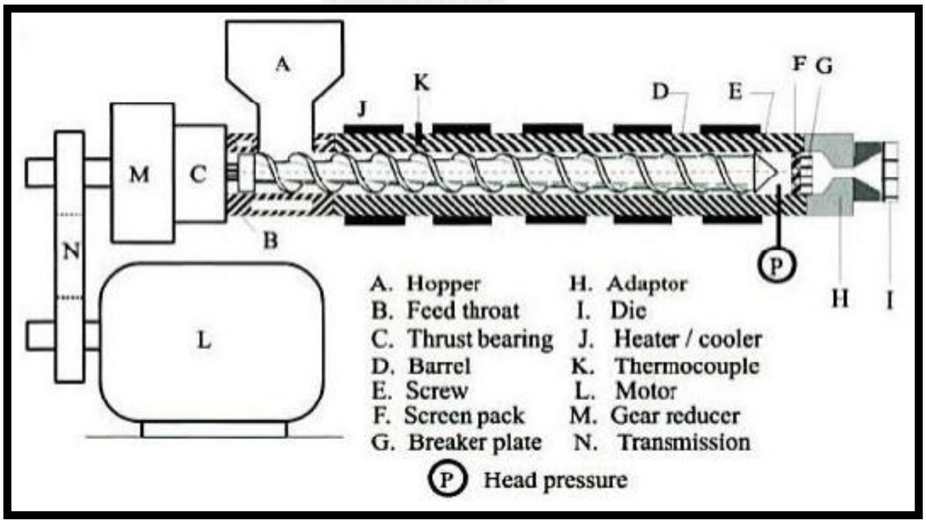



Figure 9 Element of extruder machine (Levinjobet, 2010)

The energy efficiency in plastic resin process will focus in the machine which is an extruder. There are many researches about extruder machine. Energy efficiency extruder can be done by selecting high efficiency motor and variable speed drives. The right extruder should be used to the right job. The screw diameter and design should be checked to make sure they fit the polymer and product. The extruder size should be matched to the product profile to minimize waste. The extruder should be set to sun at its most efficient speed (usually maximum design speed) and the screw speed should be controlled to give an extrusion rate as close to the maximum as possible while maintaining good product quality (Schepp et al., 2006). Moreover, the extruder motor should run most efficiently close to their design output. The motor should be right for the extruder. A large motor at part load is less efficient than a small one at full load. Optimize extruder speed maximizes heat transfer from mechanical work and minimize the amount of electricity needed. Doubling the rotational speed of the extruder, as long as the downstream equipment does not limit output, can cut energy consumption by nearly 50% (Kent, 2005). Preventive maintenance has conducted at the polymers filling department to optimize the production and reduce unnecessary production costs, such as repair parts or labor costs, and can reduce energy consumption and produce higher quality products. The study has found that the level of standby thermal performance, fast production rate performance, quality performance, and overall efficacy of the machine is increased to 93.83 %, 91.55 %, 99.9 % and 85.88 % respectively (Klongklew and Jongprasittiporn, 2009).

**2.3 Concept of Value Engineering**

Value Engineering or VE is a theory in Engineering. In the field of Initiatives Strategic Management and DEDE had adopt this theory that can be applied in energy conservation project in VE plant. (Department of Industrial Promotion, 2003) Value Engineering has occurred in the period after World War 2 because of shortage of materials in production. During the 1940 crisis, it has affected the General Electric Company in the United States, which has tried to develop the purchasing system, shortages of asbestos. In 1947, engineer of the company named Lawrence D. Miles, who worked in the purchasing department, has been trying to figure out materials to replace the asbestos. The material has to have similar useful applications, such as fire protection and is relatively cheaper. He had discovered the relationship between the cost of products and functions as listed in the “values " and have developed it further, although the war had come to an end. Miles was ordered to develop a concept called the emphasis on functions or the beneficial use in functionality and it has pushed the mentioned idea in the purchasing system until the approach of the development a new system, which was called the Value Analysis (VA). The U.S. government has had changed its name to Value Engineering, (VE). With the vision that engineering has more practical meaning, the users are often engineers, not analysts and it is easier to understand. Therefore, its name has been changed to VE. In the first century, VA / VE has been used to design new products that provided the same benefits but lower costs, which refers to the reduction in the unnecessary expenses.

Moreover, VA / VE have been used to design and improve the production processes as well. It could be said that the introduction of VA or VE to various organizations has been successful. Which has been an interesting and currently there has been an indication of the VA / VE technique in the plan of conservation of energy that it is one of the techniques used to conserve energy and has been used as one of the foundation to identify and rectify problems to save energy, which was essentially a concept of value engineering. This concept is to realize the relationship between functionality and cost, in which this relationship could be exemplified through the formula as Equation 1.

$$V = F/C \tag{1}$$

When V refers to Value

F refers to Function

C refers to Cost

After evaluating cost that has evoked in the manufacturing or the services, we should understand that the actual cost in the processes includes ideal cost and wasted cost. The wasted cost is what we aim to reduce to the minimum. The reason of the cause of wasted cost is from the inefficient processes of production, administration, control, or incapabilities of management, and the inability to design, etc. If put effort in reducing the wasted cost, it will lower the cost of production significantly, in which it could be called as "Standardized costs". In the United States, also including both Japan and Thailand, have been using the VE principle in cost reduction of various manufacturing processes, including transportation, inventory, documentations, and manufacturing in various industries. Although the mentioned cost reduction has objectives to reduce costs, the indirect results also helps with reducing the cost of energy as well. When factories emphasize on increasing the efficiency in energy usage to the appropriate amount, it will result in cost reductions within factories. The management of energy has been an important tool in the energy usage of factories, which has been efficient, and is able to reduce manufacturing costs inindustry. Nowadays, there has been techniques in management of engineering in order to reduce costs, which is known as Industrial Engineering (IE), Quality Control (QC) and Value Engineering (VE). This research aims to study VE as VE aims to conserve energy which is the exploration of the usage of energy in order to gain insights into wasted costs that are overlooked and important usages.

Value engineering has been used in factories in order to boost the human resources in the industry to consider the wasted costs of energy that was initially overlooked (The Institute of Industrial Energy, 2002). This requires relying on observation and looking at the wasted energy that latent in industrial manufacturing processes. This will give access to the root cause of the problem and can properly fix it that ultimately leads to improved factory performance to achieve energy savings with respect to avoiding high investments in equipment. When specifically addressing of energy saving, an example could be to reduce repetitions in the positioning of light bulbs. Moreover, a switch in the use of the equipment to control the usage of fluorescent that is energy efficiency and reducing energy consumption in the production process. This includes the shutdown of machines that are not being used, reducing the on-off time of the boiler in order for the boiler work less without disrupting the production process. The improvements are made on the basis of our understanding about the benefits of the equipment and machinery in factories. Value engineering is applied in order to ensure the efficient usage of energy and to increase the efficiency of machinery (Thailand Industry, 2010). For example, housekeeping policies, by taking into account the power consumption in normal conditions with minimal leakage or waste, as this is a simple investment and has short payback period. There are various energy conservation measures conducted by Value Engineering. Measures to reduce lighting energy use in the daytime is by using natural light, measures to remove light bulb with light output that is higher than the standard level, grouping of on / off switch, proper lighting, and direct to the area of use, measures to repair leakage in compressed air systems, measures to reduce heat loss through insulation, measures to reduce the loss of steam by replacing steam traps that was damaged, measures to reduce idle time, measures to reduce waste from the manufacturing process, and much more. The mentioned measures can reduce the energy cost of the designated factory by approximately 30% of the capabilities in energy saving.

The energy conservation behavior should be introduced in the factory to build employee awareness. The barrier to implement energy conservation was lack of knowledge. So providing knowledge of energy issue to worker can conduct energy conservation behavior. Beginning change with WH question that are what, why, how. There have been two factors that affect conservation manners to individual behaviors that are cultures, and attitudes. Furthermore, monetary inducements and rewards account for motivation in energy conservation behavior (Kaplowitz et al., 2012).

# Chapter III : DATA COLLECTION AND ANALYSIS

In this chapter presents the collection and analysis of data on energy conservation in plastic resin manufacturing. This information will be analyzed to determine the cause of the energy waste in plastic resin manufacturing in order to contribute to energy conservation measures for the plastic resin manufacturers

## 3.1 Data collection

The resource of energy conservation data was the energy management report that collected from the Department of Alternative Energy Development and Efficiency. The data was collected to gather energy waste and energy conservation in plastic resin manufacturing. In the energy management report includes eight topics as following sections (Department of Alternative Energy Development and Efficiency, 2009):

1. Energy management committee
2. Evaluation of energy management
3. Energy conservation policy
4. Evaluation of energy conservation potential
5. Goal of energy conservation, energy conservation measures, training plans and energy conservation promotion activities
6. Compliance with energy conservation measures, auditing, and analysis of compliance with energy conservation goals and plans

7. Energy management monitoring, auditing and evaluation
8. Review, analysis, and correction of defects on energy management

Energy audit is the means to achieve energy conservation so the topic 4 and 5 were focused in order to pull energy conservation information. The topic 4 shows the current condition of equipment for example, size, numbers, operating condition, operating hours. The topic 5 was indicated energy conservation measures from each plastic resin manufacturing. The energy conservation details are presented by Appendix F. The topic 5 indicates detail of an implementation plan for each measure for instance, equipment, energy consumption level, investment and cost saving. Energy wastes of plastic resin manufacturing can conclude as shown in Appendix B.

### 3.2 Root Cause Analysis

Root Cause Analysis is a technique to identify the root cause in order to solve the problems and reduce incident recurring (Fagerhaug, 2006). Root Cause Analysis was applied in this chapter to find the root cause of energy waste classified by systems including lighting system, air conditioning system, air compressor, production process and steam system that lead to figure out the action to eliminate and reduce energy waste.

### 3.2.1 Lighting system

Lighting system is the necessary system for all buildings to provide lights to workers as shown in Figure 10. In the factory, lights are used in two parts. One is in the office and the other is in the production process. The lights mostly are turned on during working hours. The impact of energy waste in lighting system is increasing of electricity bills. The Root Cause Analysis can be summarized as shown in Figure 11 to find cause of waste in lighting system.


Figure 10 Lighting system in manufacturing

From: http://www.lumin-lighting.com/link/Factory-Tour.htm

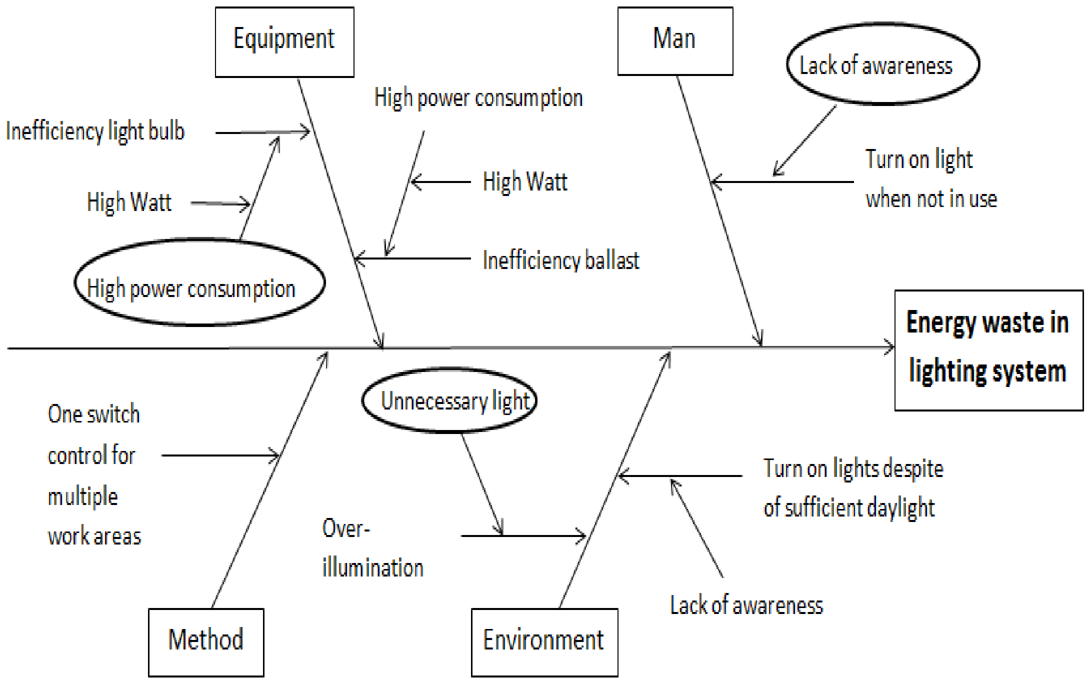



Figure 11 Root Cause Analysis for energy waste in lighting system

1. Equipment

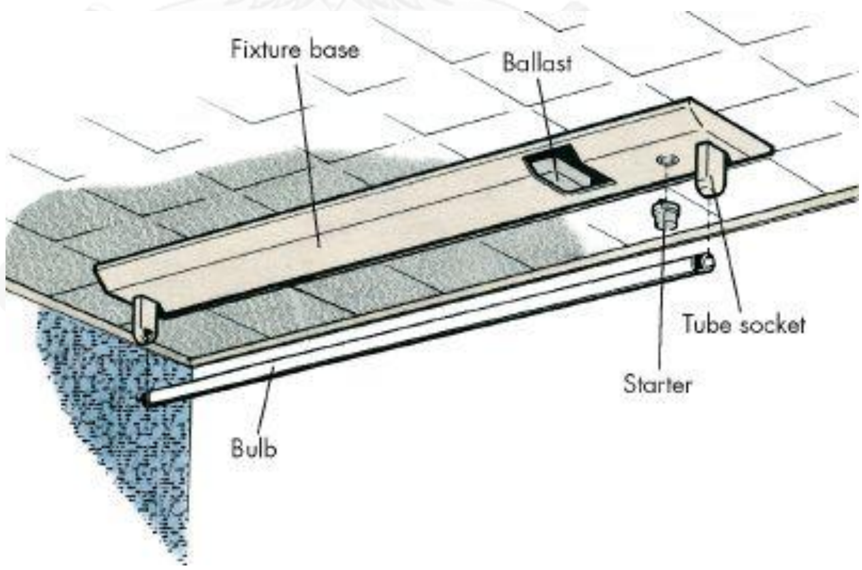



Figure 12 Main parts of lighting equipment

From: http://home.howstuffworks.com/home-improvement/repair/how-to-install-a-fluorescent-lamp.htm

The main equipment of lights as shown in Figure12 includes a light bulb, ballast and starter so if these three devices are inefficient, they cause energy waste in lighting system. The property of an inefficient light bulb is high wattage. The number of watt is calculated in the electricity bill so the more high watt, the more cost of energy bill. In case of plastic resin manufacturers, type of inefficient light bulb used were T8, High pressure sodium light bulb. T8 is one type of light bulb that T stand for tubular and number 8 refers to diameter of light bulb. The diameter of T8 is 1 inch and its life time is 8000 – 20,000 hours. The significant property is the power consumption that is 38 watts. For the high pressure sodium light bulb, power consumption in watts are various; 100 – 500 watts. Its life span is 15,000 hours. Each type of ballast is different power consumption. As the light bulb, the more high watts, the more electricity bills. The power consumption of magnetic ballast is 10 watts. These characteristic of light bulb and magnetic ballast will be compared to efficiency equipment in the next chapter.

**2. Man**

The root cause of energy waste from human is lack of awareness. They don't turn off light when they leave the room as shown in Figure 13 for example, after finishing meeting or when they go outside for lunch.

Figure 13 Lights are turned on when no one in a room

From: http://www.yellowatwork.com/TH/content/Pages/FengShui_09302013_s.aspx

**3. Method**

Method in this case means method to install light switch to control all lights in a building. In case of plastic resin manufacturers found that they used one switch to control lights for multiple work areas. When pressing the switch, lights were on in all areas even though no one was in that area that accounts for energy waste. An example of one light switch is shown in Figure 14. This picture shows one light switch used to control 3 light bulbs. If switch control is turned on, these three light bulbs are also switched on.

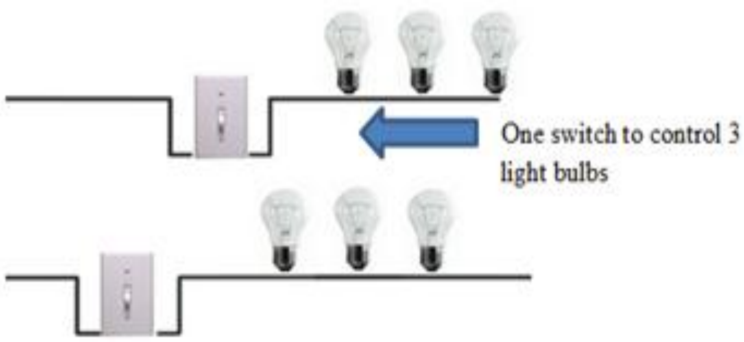



Figure 14 An example of one light switch is used to control multiple light bulbs

From: http://www.avdomotics.com/compare.shtml

**4. Environment**

Due to sufficient natural light in daytime, the artificial light from light bulbs is not necessary. The same as an area that have light bulbs over demand which causes over-illumination is accounted for waste to over light production.

**3.2.2 Air conditioning system**

An air conditioner is the important device for workers because it helps workers feel comfortable in workplace, especially in Thailand because weather in Thailand is very hot. The core function of the air conditioner is to provide cool air within the rooms. The picture of air conditioning system is shown in Figure 15.

(a) Outside air conditioning system (b) Inside air conditioning system

Figure 15 Air conditioning systems

From: http://www2.dede.go.th/bhrd/old/Download/file_handbook/Pre_Build/Build_14.pdf

The main components of air conditioning system consist of a water chiller, a water pump, a cooling tower and an air handling unit. The water chiller as shown in Figure16 (a) is equipment to produce cooling water to air handling unit. The water pump is used to propel water in the system. The picture of water pump is shown in Figure 16 (b). The cooling tower is the device to reduce water temperature as shown in Figure 16 (c). The air handling unit as shown in Figure 16 (d) is the equipment to provide cool air.

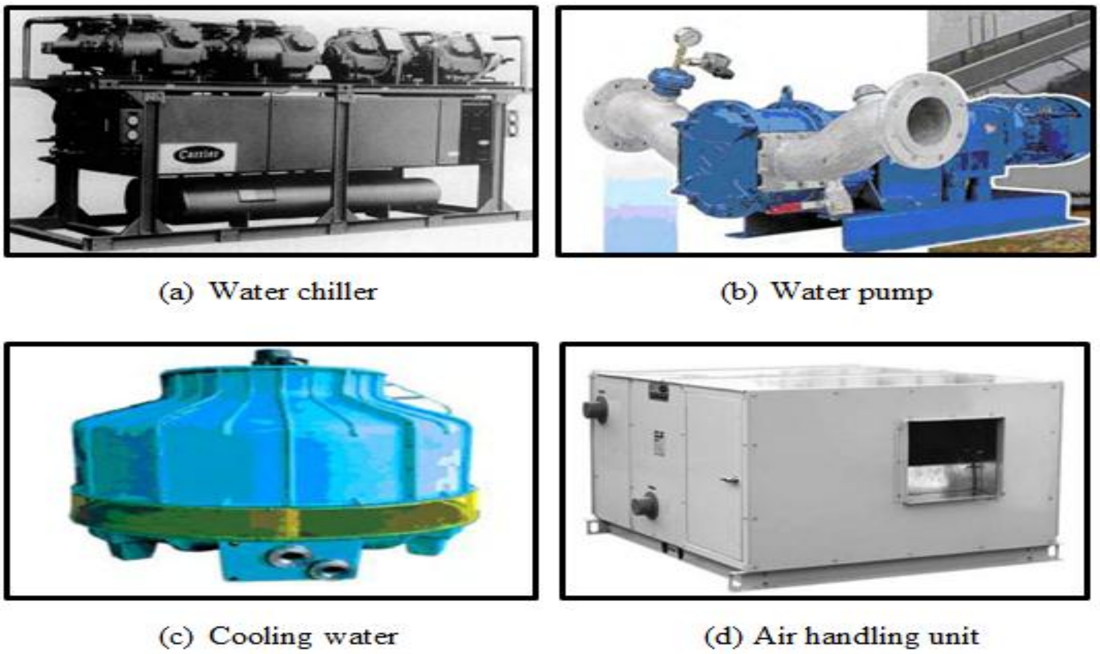



Figure 16 Components of air conditioning system

From: http://www2.dede.go.th/bhrd/old/Download/file_handbook/Pre_Build/Build_14.pdf

There are many reasons to cause of waste in air conditioning system. According to energy management reports, there are four energy wastes that can be summarized in Figure 17 by Root Cause Analysis to find the root cause of energy waste in air conditioning system. Moreover, air conditioner equipment was addressed to be cause of energy waste to cover all energy waste in air conditioning system.

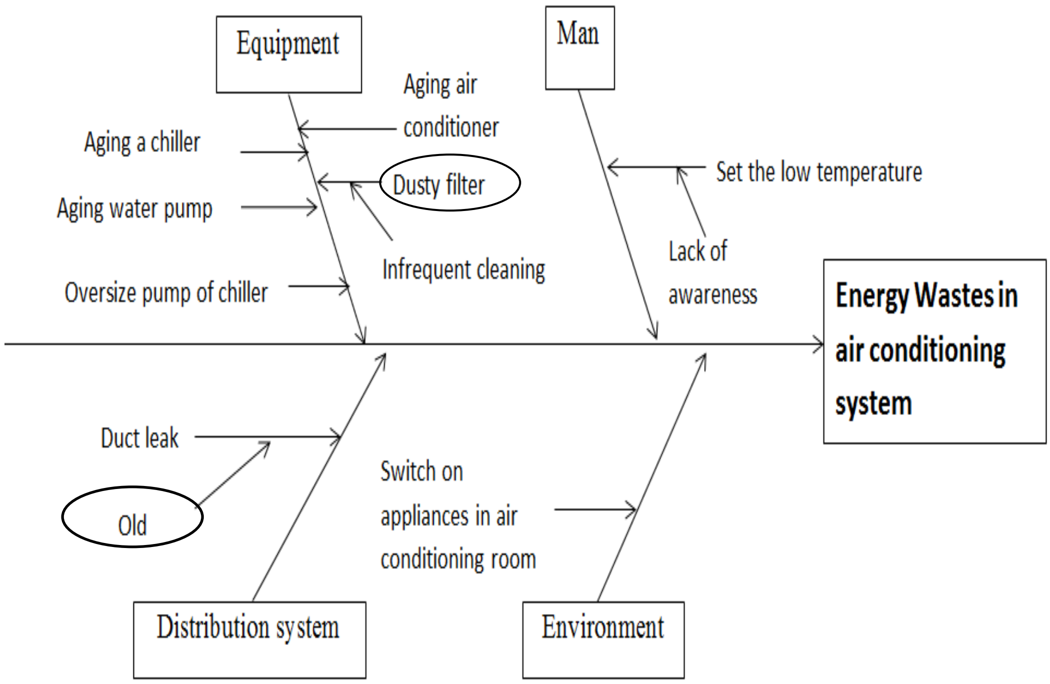



Figure 17 Components of air conditioning system

1. Equipment

Mostly the problem that faced with equipment was aging equipment such as chiller, water pump and air conditioner. From observation found that, the aging equipment consumed high power than normal so it caused increasing of electricity bill. Moreover, the filter that was not cleaned regularly as shown in Figure 18 is cause of high power consumption because dust was block the air flow and reducing ability to absorb heat. For the pump chiller that had oversizing, it consumed high power than necessary.

Figure 18 Components of air conditioning system

**2. Man**

The cause of energy from human always is lack of awareness. Because the Thailand weather is hot, workers set the air temperature at lower temperature than suggested temperature from Department of Alternative Energy Development and Efficiency that is 25-26 degree Celsius (Ministry of Industry, 2013) When set the temperature at low, the air conditioner will work hard to provide cooler air.

**3. Environment**

Environment in this case means environment in air conditioning room. The function of air conditioner is to provide cool air by removing hot air. Hence if a room has source of heat, air conditioner has to work harder to remove that heat before providing cool air.

**4. Distribution system**

An air conditioner contains 2 parts which are an air conditioner and a compressor. These parts were separated from each other. The air conditioner is in the building whereas the compressor is outside. These two parts work together by connecting with duct. If there are leaks on duct, air can escape to the environment as shown in Figure 19. So the air conditioning system will be work hard to produce more cool air to replace leak air.

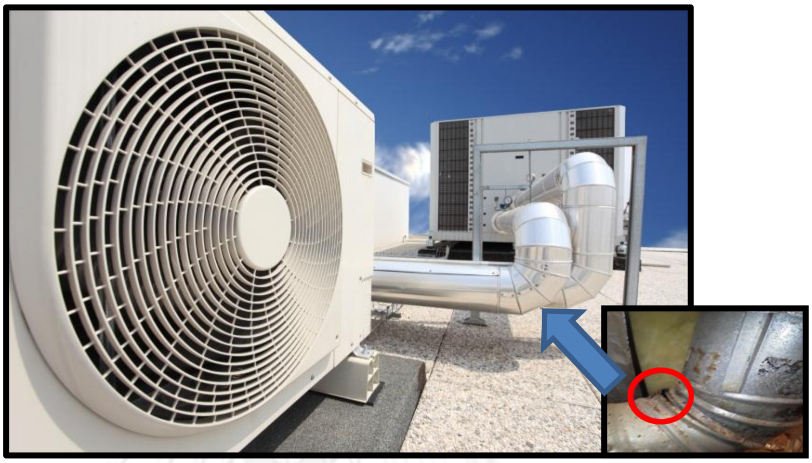


Figure 19 Duct leak in air distribution system

From: http://adminpilot.s3.amazonaws.com/unitedservicesair/files/2013/08/commercial-air-conditioning.jpg

### 3.2.3 Air compressor

There are two sections to investigate abnormality of air compressor that are air compressor and air distribution system as shown in Figure 20. The energy waste in air compressor can occur when the end-use equipment requires compressed air because the compressed air will be produced and transfer to the end-use equipment. During transportation wastes can occur. The root cause of energy wastes in air compressor will be analyzed as shown in Figure 21. The impact of energy waste in air compressor is the factory has to pay unnecessary electricity bill.

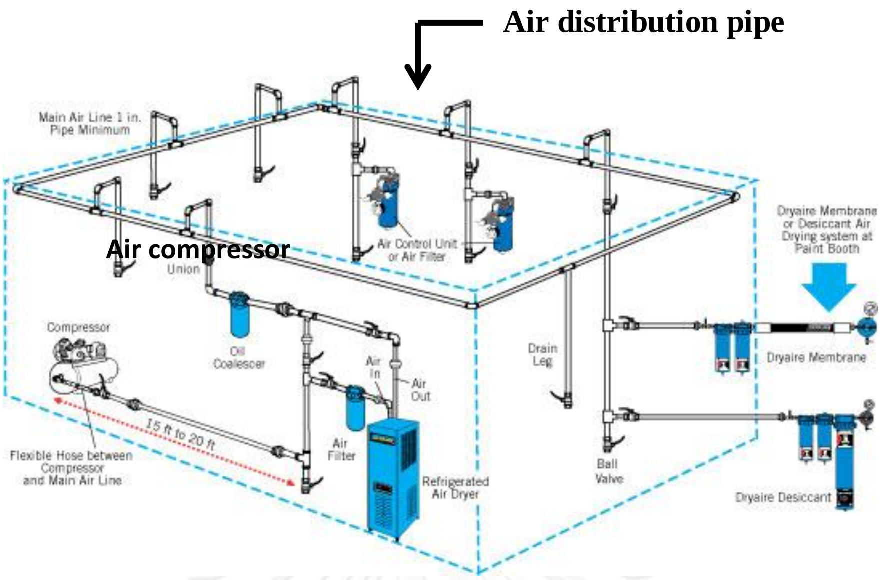



Figure 20 Air compressor system

From: http://www.sharpe1.com/sharpe/sharpe.nsf/Page/Refrigerated+Air+Dryers

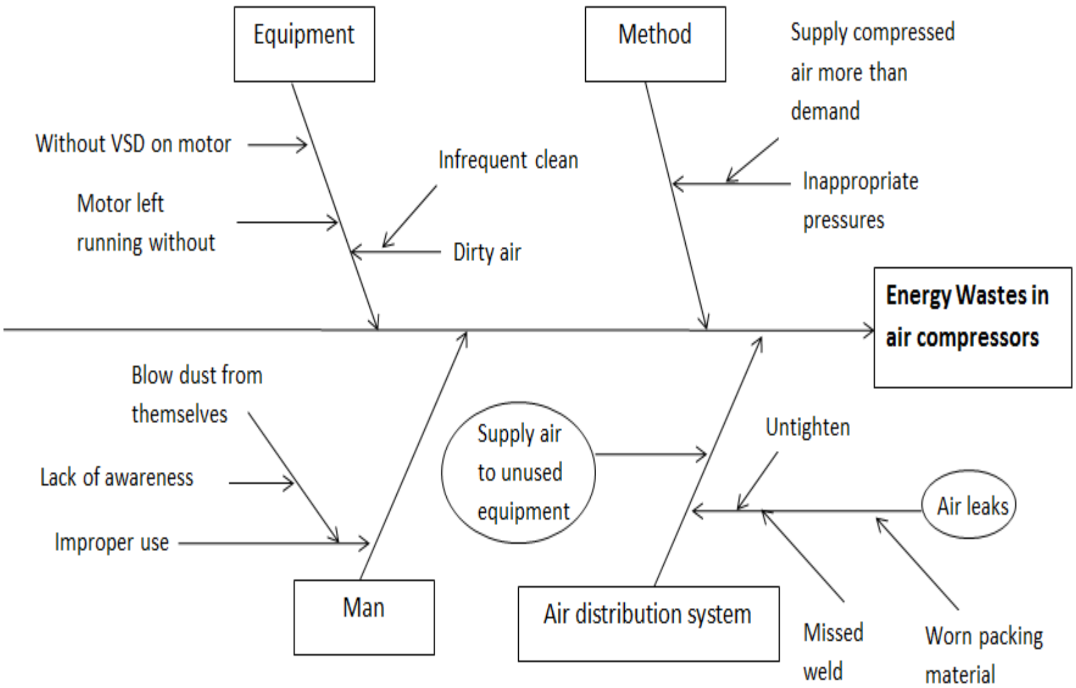



Figure 21 Root Cause Analysis of energy waste in air compressors

**1. Equipment**

A motor is the main component to drive air compressor as shown in Figure 22. The motor was left running without load account for waste due to more energy consumed unnecessary. Because Variable speed drives is the equipment that is able to adjust speed of motor, it can reduce motor speed when unload. From case study, the motor of air compressor ran unloaded at 25% of full load that was the unnecessary energy cost. An air filter is an important component of air compressor to protect dust when intake air to the air compressors. If the air filter is dusty, the dust will contaminate in the air and the compressor has to work hard to intake air in the air compressor.

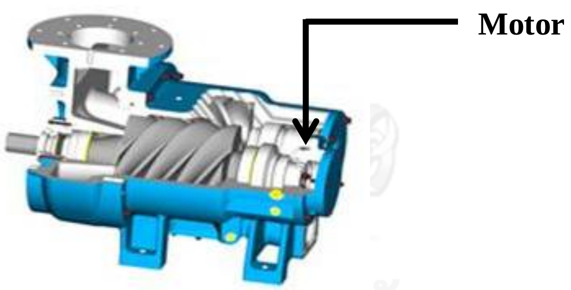



Figure 22 Air compressor motor

From: http://www.diytrade.com/china/pd/7271490/Motor_Special_for_Air_Compressor_AC.html

**2. Method**

The air compressor was set at pressure that higher than demand of end-used equipment. The compressed air was produced at high pressure than necessary for example, the end-used equipment required 4 Psi but the air compressor delivered compressed air at 7 Psi.

**3. Air distribution system**

The air distribution system is connected from air compressor to distribute compressed air to the end-used equipment. The compressed air is distributed through distribution pipes. Leak can occur during transportation. The common areas as shown in Figure 23 are joints, connections, couplings, hoses, tubes and fittings (Office of industrial technology, 1988). The direct impacts of compressed air leakage are high cost of energy, pressure drop and shorter equipment life. The indirect impacts are waste the time, decrease the production, (Na-Narong, 2013) increase the waste and drop the quality.

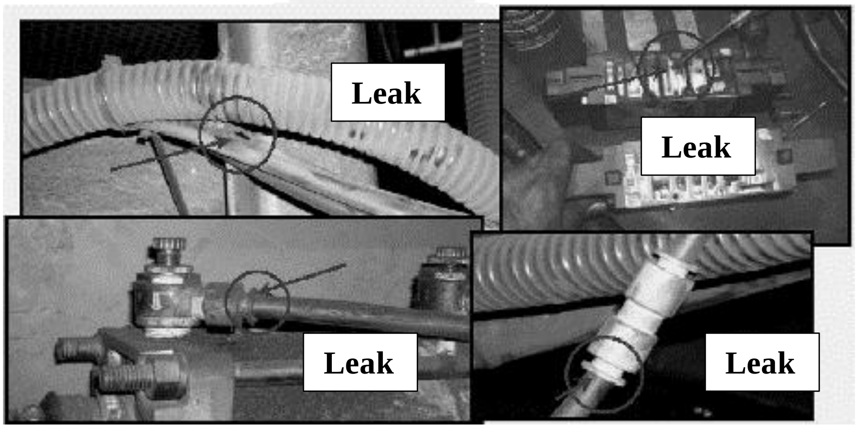



Figure 23 The common areas for air leakage

From: http://www.thailandindustry.com/guru/view.php?id=19431&section=9

**4. Man**

The staffs ignore to investigate and check the air compressor to find the problems. The problem cannot fix and prevent as a consequence of energy waste. The staffs use the compressed air improperly by using compressed air blows dust from their body.

**3.2.4 Production process**

Energy waste in production process can occur from the extruder and the pelletizer because these are main devices. Due to plastic resin process is a continuous process, the machine is running most the time. So there have a chance to occur waste in the machine all the time. Because to run extruder and pelletizer consume electricity, the electricity will be increase if the machine left run as inefficiently. As shown in Figure 24 is root cause of energy waste in production process that the main causes are running without load and heat loss.

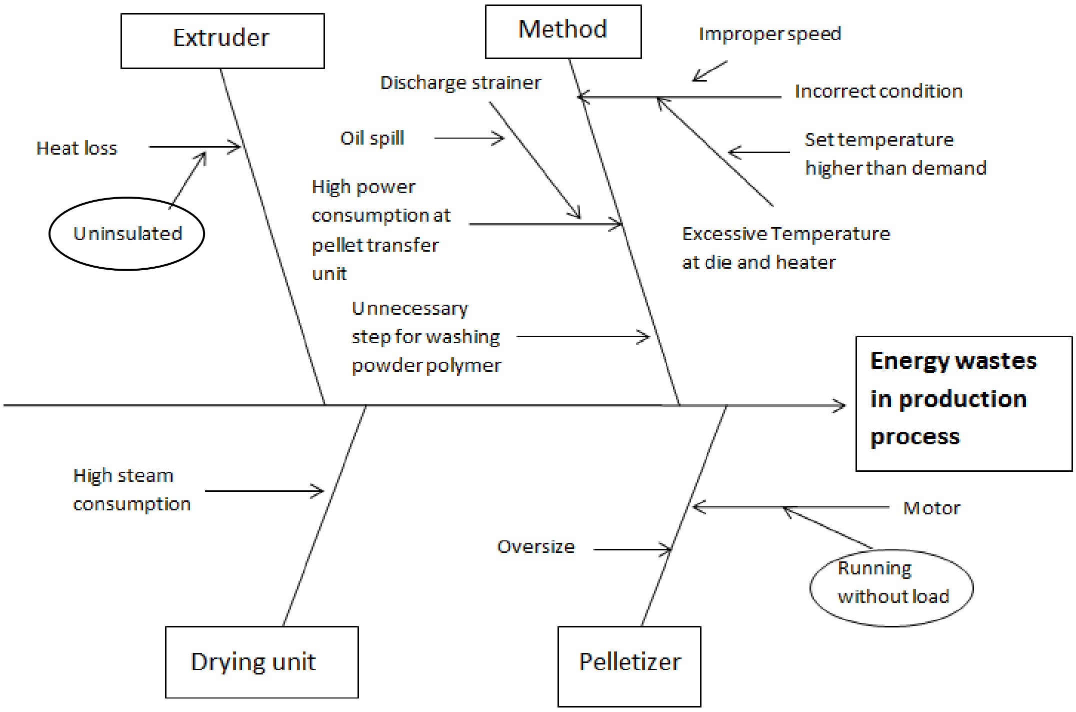



Figure 24 Root Cause Analysis of energy waste in production process

1. Extruder

An extruder is the machine to heat the polymer before transforming to plastic pellet as shown in Figure 25. There are two components of an extruder that generate heat that are a heater and a screw. There is other machine that involves heat is die. Because the extruder machine involves heat, heat loss can occur. There have a chance to loss thermal energy when the machine was uninsulated.

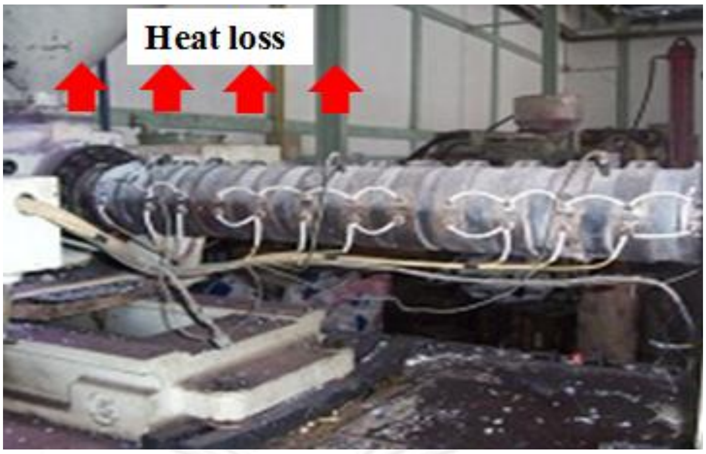



Figure 25 Heat losses in an extruder machine

From: http://energysavingtechnology.blogspot.com/2012/07/electrical-heater.html

**2. Method**

There are three wastes can be found from collected data. The first was an employee set the temperature at extruder higher than necessary. The polymer is melted at specific temperature so the highest temperature is not necessary to melt polymer. Because the screw extruder is driven by motor, the wrong speed of motor is energy waste.

**3. Pelletizer**

There are two factors that cause energy waste in the pelletizer which are motor and size of pelletizer. The pelletizer consumes more power in which it has a large size. Moreover, it allows the pelletizer to wait for the polymer to enter to machine in order to be cut. Idling time causes energy loss during transit due to constant run of the motor.

Figure 26 Pelletizer

From: http://www.indianyellowpages.com/specificengineering/

**4. Drying unit**

Due to dying unit used steam, the energy waste can occur when used steam over demand in dying unit. Using steam more than demand also means high cost of purchasing energy.

**3.2.5 Steam system**

The energy wastes in steam system can occur during operation hours because the production is operating most the time. The energy wastes in steam system can occur two parts that is steam generator and steam distribution pipe. The impact of energy waste in steam system is to waste in fuel. To generate steam, fuel is used that means how much steam leaks from the system, the more fuel will be consumed. The root cause of energy waste in steam system is identified as shown in Figure 27.

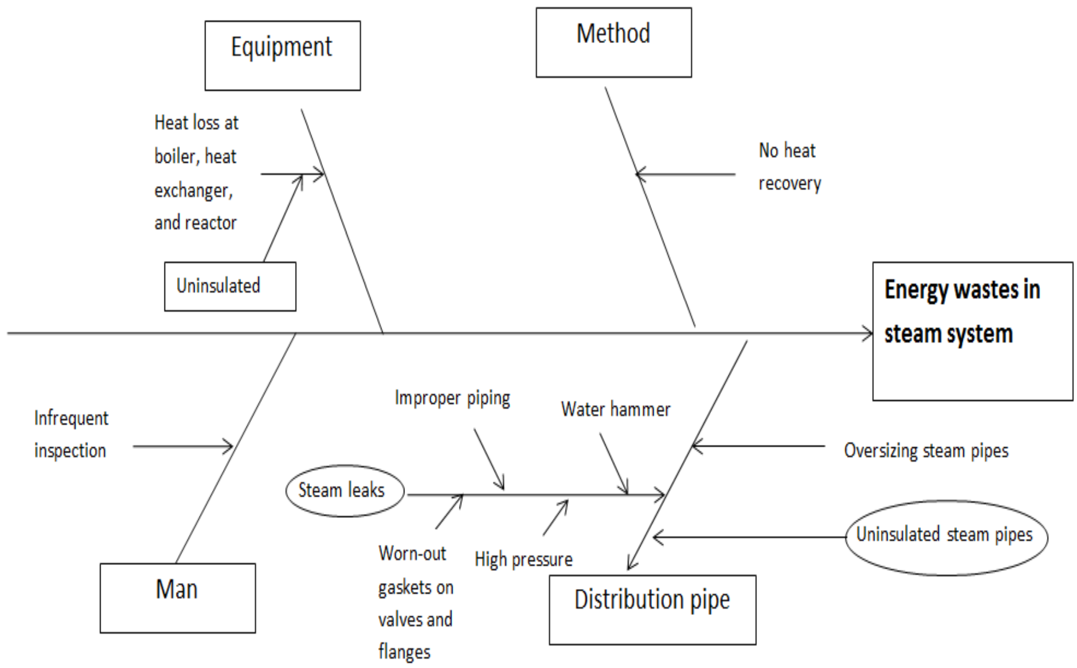



Figure 27 Root Cause Analysis of energy waste in production steam system

1. Equipment

The devices that involve steam are a boiler, a reactor and a heat exchanger. Due to heat involvement, heats can loss from the surface of machine if the machine didn't cover by insulation. As shown in Figure 28 is an example of heat loss from boiler surface.


Figure 28 Heat losses from a boiler

From: http://mte.kmutt.ac.th/elearning/Energy_Conservation_in_Industrial_Plant/5_1_1.html

2. Man

Due to the reason that the factory appoints workers to check for leakage in pipes in which, if workers do not regularly check for leaks, it often results in involuntarily huge loss of steam.

3. Method

The waste heat is the heat of combustion fuel or chemical reaction which is discarded into the environment without being used again. However, there was heat residue in steam that can be recovered to provide heat. If there were no heat recovery unit as shown in Figure 29, the heat lost from the system or production process.

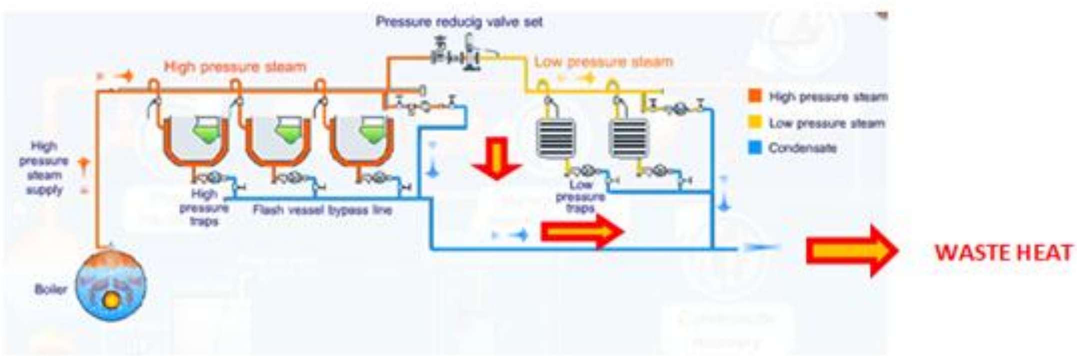



Figure 29 The production process without waste heat recovery unit

From:http://www2.dede.go.th/bhrd/old/web_display/websemple/swf_ind45/45_thai.swf

**4. Distribution pipe**

In steam pipeline system, it consists of the steam pipe to distribute steam to endpoints that requires using heat from steam. The cause of waste is from steam leakage as shown in Figure 30 that is very common in the joints. Besides, waste is also caused from the steam pipe that is not insulated because steam within the pipe is hot so there is heat loss during the transportation of steam causing a portion of steam to condense into droplets of water. This causes a portion of steam to be lost and requires more fuel to produce steam, thus resulting in unnecessary power consumption.

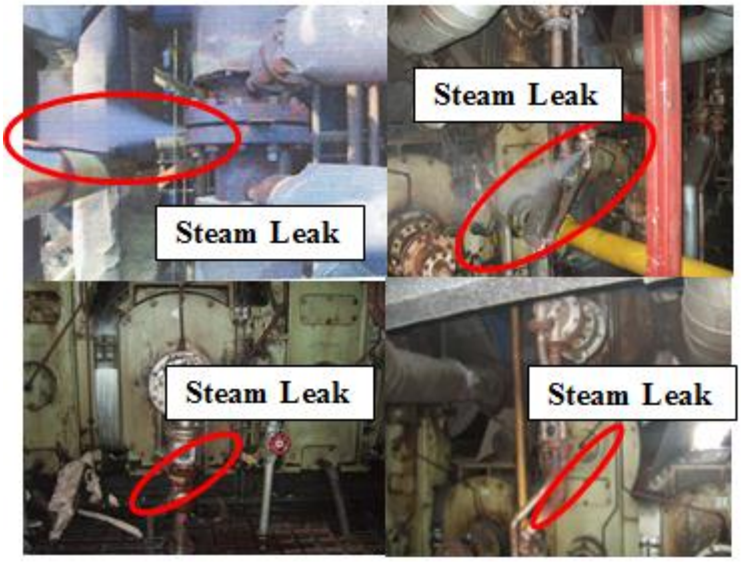



Figure 30 Common areas for steam leakage

**3.3 Waste Elimination**

In this topic, energy conservation will be created to eliminate and reduce energy wastes that are identified in the previous topic to increase machines and equipment efficiency in plastic resin manufacturing.

**3.3.1 Energy conservation in lighting system**

There are many causes of energy wastes in lighting system. As shown in Table 1 is the solution to eliminate waste in lighting system. The main causes are using inefficiency light bulbs and improper use. To reduce energy consumption and increase energy efficiency, inefficiency lights should be replaced by efficiency light bulb such as T5 and LED and educate people about energy saving in lighting system to reduce light usage by turning off lights when not in use

Table 1 Energy conservation in lighting system

| No | Cause | Action | Energy Conservation measure |
|---|---|---|---|
| 1. | Use a high watt light bulb | Change to a lower watt light bulb | Change the high watts to lower watts light bulbs (T5, LED) |
| 2. | Lack of awareness of workers | Increasing awareness<br>Applying technology | Training energy conservation program<br>Using timer |
| 3. | Unnecessary light bulbs | Remove unnecessary light bulbs | Delamping |
| 4. | Using one switch to control light system | Separate switch | Using pull switch |

From the collection of the total energy loss in lighting system, it has measures in energy conservation that will reduce the loss that has occurred which could be resolved as follows:

**Measure 1**: Change the high watts to lower watts light bulbs

The problem of energy loss is from the use of light bulbs with high energy consumption so there should be a change to the light bulbs which consumes less power. From gathering information, found out that a new technology of light bulb consumes lesser power, such as the T5, LED. Therefore, the researcher proposes measures to change the light bulb from high watts bulbs to lower watts which have equal performance or better quality. As shown in Figure 31is improvement of light efficiency by replacing with the new efficiency light bulb. In Figure 31 (a) is before improvement and 31 (b) is after improvement.

(a) Before improvement (b) After improvement

Figure 31 Comparison of inefficiency and efficiency light bulbs

**Measure 2**: Using timer to control time to turn on/off light

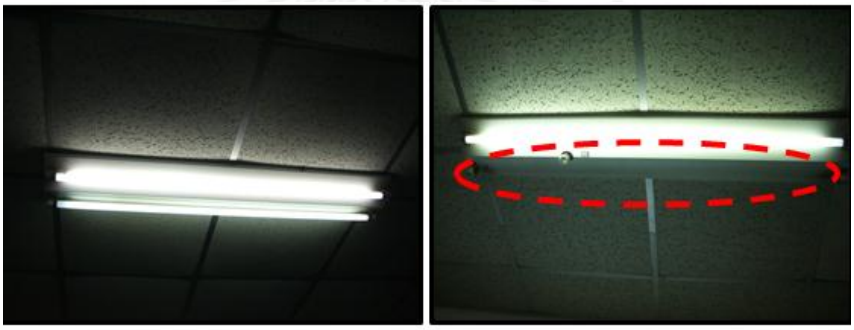
People are the key factor in the implementation of various activities in the factory. In terms of energy conservation, it would require the cooperation of all workers. Therefore, the problem of lack in staff awareness could be solved by training workers in order for workers to gain further knowledge on energy conservation and hence, create awareness on energy conservation. However, the factor of people is hard to control. The researcher has offered a device that aid in energy conservation by controlling the turning on and off instead of using people, which is the timer as shown in Figure 32.


Figure 32 Timer

From:http://www.coolestgadgets.com/20100720/light-switch-timer-shuts-set-times/

**Measure 3**: Delamping

Delamping is an energy conservation measure as shown in Figure 33 to remove unnecessary light bulbs to reduce the amount of electricity that is not necessary in some areas in which lighting is already sufficient.



(a) Before removing light bulbs (b) After removing light bulbs

Figure 33 Energy conservation in lighting system by delamping

**Measure 4**: Using pull switch

This measure is created to separate the light switch in order to solve the problem of turning on lights in unnecessary areas by installing pull switch as shown in Figure 34.

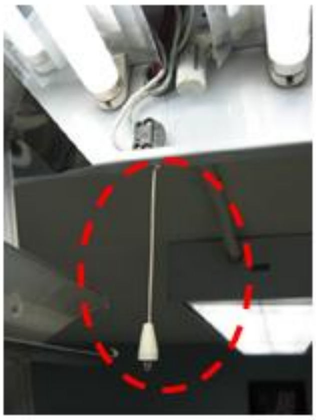


Figure 34 Pull switch

From: http://bbznet.pukpik.com/scripts2/view.php?user=clubsdmax&board=1&id=27606&c=1&order=numtopic

**3.3.2 Energy conservation measure in air conditioning system**

The waste elimination of air conditioners is shown in Table 2. The main cause of energy waste in air conditioner is a lack of maintenance such as left filters dirty. So to eliminate this, component of air conditioner should maintenance regularly. Cleaned filters enhance ability to absorb heat and save electric energy 4 percent. Moreover, there are causes from aging air conditioner that can solve by replacing by the new efficiency one.

Table 2 Energy conservation in air conditioning system

| No | Cause | Action | Energy Conservation measure |
|---|---|---|---|
| 1. | Aging a chiller | Change the aging chiller | Replacing the old chiller by new chiller |
| 2. | Aging air conditioner | Change the aging air conditioner | Replacing aging air conditioner by the high efficiency air conditioner |
| 3. | Dusty filter | Clean filter | Cleaning filter regularly |
| 4. | Oversize pump of chiller | Reduce water supply to match actual demand | Adjust load of water supply |
| 5. | Lack of awareness | Building awareness | Providing energy conservation program |
| 6. | Duct leak | Seal duct | Repair a duct leak |
| 7. | Switch on appliances in the air conditioning room | Switch off appliances | Switch off appliances in air conditioning room |

From exploring energy waste in the air conditioning system, it has been founded that the main cause is due to old machines, which maybe from devices that were installed since the building of the factory. Therefore, measures 1 to 3 for the air conditioning system is purchasing of new machines because new machines tend to be more efficient and power consumption would be lower as well.

**Measure 1**: Replacing the old chiller by new chiller

Recently, Chillers are designed and developed with lower power consumption than older chillers and it enables to save energy 20-30 % of energy consumption.

**Measure 2**: Replacing aging air conditioner by the high efficiency air conditioner

The new air conditioners have better performance and lower power consumption so it can save energy approximately 20-30% of energy consumption in air conditioner.

**Measure 3**: Cleaning filter regularly

From the analysis of the causes of power loss, it has been found that there is dust on filters, causing the loss of power. The researcher proposes simple measure by cleaning filters regularly. The study has found that most factories have two types of cleaning filters which are major cleaning and minor cleaning. The major cleaning is done once every 6 months. The cleaning of filters will allow the conditioning system to better exchange heat in order to enhance the effectiveness in cooling.

**Measure 4**: Adjust load for large machines

A Large machine consume large amount of electrical power during its operation because it runs as full capacity. For example, water pump of chiller is too large. The cooling water that supplied from the pump didn't match with the actual cooling water demand. So flow rate of cooling water should be adjusted to meet requirement and to reduce energy consumption.

**Measure 5**: Providing energy conservation program

This is a measure that relates to building awareness on energy conservation as well as regarding the energy savings in lighting system. This measure is a campaign in order to raise the awareness of workers which is to reduce the use of air conditioners when not in use.

**Measure 6**: Repair a duct leak

Repairing a duct leak is a measure to solve the problem of leakages in ductwork by repairing leak as shown in Figure 35 in order to keep the cool air to be sent to the rooms. This measure, other than the fact that it could help keep cool air in the system, it could also allow the cooling machine work efficiently because it does not have to create more cool air to replace the cool air that is lost.

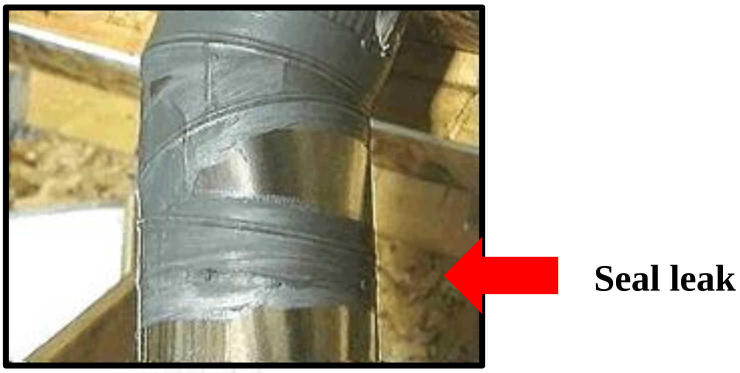



Figure 35 Repair duct leak

From: http://saveonutilities.com/General%20Pages/Prepare%20in%20Fall,%20save%20$$%20in%20Winter.htm

**Measure 7**: Switch off appliances in air conditioning room

This measure was applied to turn off of electrical appliances in the office when not in use as shown in Figure 36 because the appliances are a source of heat in an air conditioned room. Therefore, to reduce the usage of air conditioners, electrical appliances that are not in use should be turned off.


Figure 36 Switch off appliances in air conditioning room

From: http://www.sterling-studios.com/officeadmin.html

### 3.3.3 Energy conservation measures in air compressor

Air compressor consist of the air compressor and air distribution system. So cause of waste can happen in these two parts. To eliminate wastes in air compressor is classified into two parts as shown in Table 3. The main cause is air leak along distribution pipe. Therefore the way to eliminate this waste is to check and repair leaks. Because air compressors involve with high pressure, pressure should be carefully used to reduce energy consumption.

Table 3 Energy conservation measure in air compressor

| No | Cause | Action | Energy Conservation measure |
|---|---|---|---|
| 1. | Motor left running without load | Reduce speed of motor when unloading | Install VSD on air compressor motor |
| 2. | Motor didn't install VSD | Install VSD | |
| 3. | Dusty air filter | Clean air filter | Clean air filter regularly |
| 4. | Pressure compress air was set more than demand | Set pressure to match demand | Set pressure to match requirement from end-use equipment |
| 5. | Unused equipment still connected to air distribution system | Stop providing compressed air to unused equipment | Disconnect unused equipment from air distribution system |
| 6. | Air leak | Seal leak | Check and repair steam leak |

From exploration of the waste in air compressor, it has been found that the waste is from 5 factors that are the air compressor left running without load, dusty filter, unmatched pressure requirement, air distribution pipe connected with unused equipment and finally, compressed air leak. Therefore, the measure of energy conservation is to reduce or eliminate energy waste in the air compressor that shown as follows:

**Measure 1**: Install VSD on air compressor motor

The motor left running without load is energy waste. If there is no reduction in the speed of the motor, the motor will continue rotating at full speed. Moreover, the motor without variable speed drive (VSD) causes the over usage of the motor and speed of motor doesn't match with actual demand. Therefore, this cause can be controlled with installation of the VSD as shown in Figure 37, which is a tool used to adjust the motor speed according to actual demand. During unload, the motor will rotate only slightly so it does not consume much energy (Anglani and Benzi, 2010).

Figure 37 Variable Speed Drive (VSD)

From: http://en.wikipedia.org/wiki/Variable-frequency_drive

**Measure 2**: Clean filter regularly

Cleaning of filters will help the air compressor perform better as the air compressor needs to pull ambient air from the outside. If the filter is not clogged with dust, it will be able to draw air from the outside easier and will not require a lot of energy to draw air into the compressor.

**Measure 3**: Set pressure to match requirement from end-use equipment

This measure is to reduce the pressure in transporting compressed air to match the actual use of endpoint machine by measuring the actual use of each machine. Transporting compressed air that matches the actual needs allow the compressor to not consume as much energy for the production of compressed air at high pressure. For example, the endpoint machine that requires 4 Psi will go for 4 Psi or a little higher than that level because the air pressure will drop during transportation of compressed air.

**Measure 4**: Disconnect unused equipment from air distribution system

To disconnect unused equipment from air distribution system, unused equipment will be removed from the area or valve which is a gate to unused equipment will be turned off. This measure will reduce the production of compressed air for delivery to these devices, thus not wasting as much energy.

**Measure 5**: Check and repair compressed air leak

Leaks can be fixed by sealing the leak areas with seal tapes or tightening connections. Minimizing and reducing leaks increase efficiency of air compressor because the air compressor won't work hard to reproduce compressed air that can save cost of electricity .That means the life time of air compressor will be longer. Fixing leaks can reduce leak around 10 % of compressed air(Yang, 2009). The leaks can reduce by cooperating from workers who involve air compressors. The worker should check leaks regularly and fix when leaks occur. Moreover, workers should be trained to use compressed air properly.



### 3.3.4 Energy conservation measures in production process

The devices that involve in production process are extruder and pelletizer. The energy conservation measures for production process are as shown in Table 4. Because extruder occur heat during operation, energy waste mostly is heat loss. Insulation is the material to prevent heat loss and help the machines maintain heat in the system. Hence insulation is used to eliminate energy waste form heat loss.

Furthermore, motor that is component of extruder left running without load so VSD is used to resolve this problem.

Table 4 Energy conservation in production process

| No | Cause | Action | Energy Conservation measure |
|---|---|---|---|
| 1. | Heat loss at heater | Heater insulation | Heater insulation |
| 2. | Temperature was set higher than demand | Reduce extruder temperature | Set the right temperature as the instruction |
| 3. | Improper speed of screw and motor | Adjust motor speed | Install VSD on extruder motor |
| 4 | Oil spill at pellet transfer unit | Reduce oil spill | Install filter oil collector |
| 5 | Oversize pelletizer | Reduce operation of pelletizer | Reduce amount of repellet resin |
| 6. | Pelletizer left running without load | Reduce motor speed when unloading | Install VSD on pelletizer |
| 7. | High usage of steam in dryer unit | Reduce steam usage | Reduce steam at dryer unit |



**Measure 1**: Heater insulation

Heater is a source of power for extruder machine in the process of melting polymer powder. In order to prevent the loss of heat from the heater, there has to be heat insulator as shown in Figure 38 so as to keep heat within the system. The benefit of insulation is to reduce the cost of energy loss due to the fact that heat is not lost so it does not require the use of energy to replace the energy lost.

Moreover, it also improves the working environment of the factory because the area is not insulated will radiate heat. Therefore, when there is insulation, there will not be heat accumulation in the work area. Workers in that area or the supervisor of the extruder machine will not be affected from the heat generated.


Figure 38 Heater insulation

From: http://energysavingtechnology.blogspot.com/2012/07/electrical-heater.html

**Measure 2**: Set the right temperature as the instruction

Because the temperature of extruder was set at higher temperature than specific value, energy waste in heating the extruder machine occurred. Therefore the temperature should be set as instruction or slightly high temperature to ensure that the powder polymer will melt completely.

**Measure 3**: Install VSD on extruder motor (Schepp et al., 2006)

Typically, when the extruder machine is in the waiting process, the workers should adjust speed of extruder motor at lower speed. However, with factors that are hard for the supervisor to control the machine, there should be a device that helps controlling of speed for the extruder machine, which is the installation of the VSD within the extruder machine in order to adjust the speed of the motor in the extruder to match actual demand as shown in Figure 39.

Figure 39 Install VSD to main motor extruder

**Measure 4**: Install oil mist collector

Installing the oil filter is to prevent the leakage of oil that is on the compressor which causes the compressor to be overused.

**Measure 5**: Reduce amount of repellet resin (Duplicate cutting)

The reduction duplicated cutting of pellets is due to the large size of the pelletizer that cause the energy wastage of power in repellet. Therefore, using the APC program will help to control the manufacturing process to become more efficient in order to reduce the number of plastic pellets that are duplicated in the cutting process.

**Measure 6**: Install VSD on pelletizer

Measure 6 is similar to Measure 3, the pelletizer is left turned on while other processes are going on this causes wastage of energy. Furthermore, workers are not aware with reducing its speed. Therefore the installation of VSD device could help save energy when there is no load.

**Measure 7**: Reduce steam at dryer unit

There is high usage of steam in dryer unit so the temperature of dryer and separation unit should be set at lower in order to reduce energy consumption. The temperature should be decreased step by step without affecting the production process.

**3.3.5 Energy conservation measures in steam system**

There are two main causes of energy wastes in steam systems that are leakage, lack of insulation as shown in Table 5.  For heat recovery unit, it is not energy waste but it is used to return waste to use in the system again. Because waste in steam system is still hot that means still have thermal energy, returning waste to system can reduce thermal energy requirement. In other word, boiling warmer water is consumed less fuel and time.

Table 5 Energy conservation in steam system

| No | Cause | Action | Energy Conservation measure |
|---|---|---|---|
| 1. | Heat loss at boiler, heat exchanger, reactor | Boiler insulation<br>Heat exchanger insulation<br>Reactor insulation | Boiler insulation<br>Heat exchanger insulation<br>Reactor insulation |
| 2. | No heat recovery | Recover waste heat | Install heat recover unit |
| 3. | Uninsulated steam pipe | Steam distribution insulation | Steam distribution insulation |
| 4. | Steam leak | Seal leak | Repair and check leak |
| 5. | Infrequent inspection | Using technology | Using wireless steam trap monitor |

The Main reasons that cause a loss in steam system is losing heat due to the steam generator, steam distribution system, and the leakage of steam. Therefore, energy conservation measures in the steam system are as follows:

**Measure 1**: Boiler, reactor and heat exchanger insulation

Boiler, reactor and heat exchanger should be insulated in order to prevent heat loss from thesurface of these devices. As shown in Figure 40 is an example of boiler uninsulation.


Figure 40 Boiler insulation

From: http://www.wdm.ca/mj/shortline/updates_page2.html

**Measure 2**: Install heat recovery unit

In the processes which require heat and leftover heat, the waste heat should be recovered as shown in Figure 41 because the waste heat still has accumulated heat which could be reused for the benefits of production.

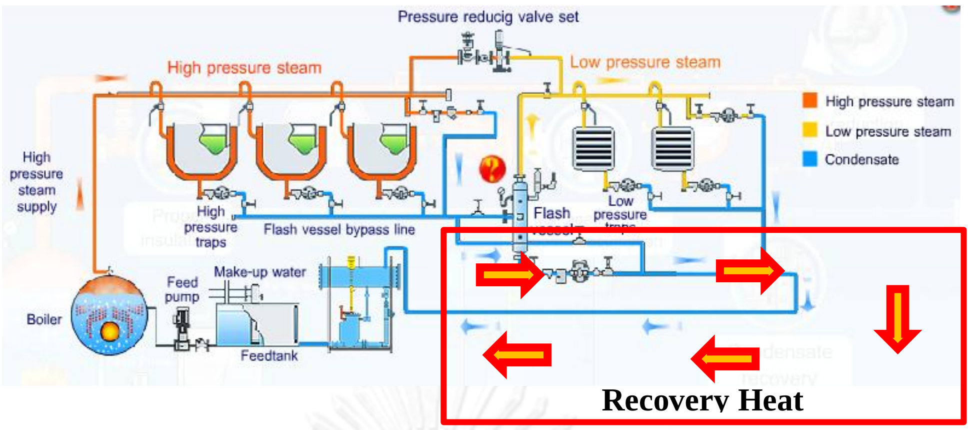



Figure 41 Steam systems with heat recovery unit

From:http://www2.dede.go.th/bhrd/old/web_display/websemple/swf_ind45/45_thai.swf

**Measure 3**: Steam distribution pipe insulation

To prevent the heat loss of steam within the steam pipes, there should be insulation of steam pipes as shown in Figure 42 in order to prevent heat loss at the surface of the pipes.

Figure 42 Insulation of steam distribution pipe

**Measure 4**: Check and repair steam leak

Due to the leakage of steam which implies high energy waste, there should be measures to check and repair the leakages immediately. This reduces the loss of steam from the system in order to save the fuel used in the production of steam. Steam leak can be repaired by sealing pipe as shown in Figure 43. There are two type seal material as shown in Figure 43 (a) is reinforcing tapes and Figure 43 (b) is pipe tourniquet.

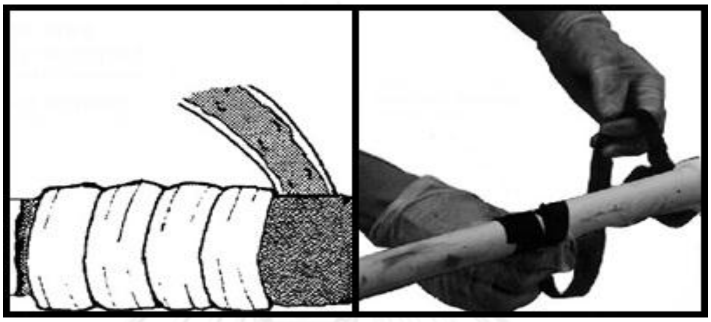


Figure 43 Seal materials for steam leakage

From: http://appliedmaintenance.com/pipe-and-leak-repair.html

**Measure 5**: Using wireless steam trap monitor

Currently, there has been usage of people to check for location of leakages. The steam pipe system is long in length, which makes the checking not as thorough and may miss the leakages. Therefore, there should be an introduction of technology to help with the checking process, which is the wireless steam trap monitor to reduce human error. There is a new technology that called wireless steam trap monitor as Figure 44. It helps to automatically monitor steam traps for failures, and to notify staff in a timely manner to avoid wasting energy. This device also helps staffs know the leak and repairing immediately. A small steam trap can lose thousands of dollars per year through leaks so it can help to save money. Hence the new measure can increase value of existing measure.

Figure 44 Wireless steam trap monitor

From: http://www.cypressenvirosystems.com/products/wireless-steam-trap-monitor-2/

### 3.4 Energy conservation measures

From the collection of information on the energy waste in 17 plastic resin plants, twenty seven energy conservation measures are created following systems as shown in Table 6.

Table 6 Energy conservation in plastic resin manufacturing

| System | Energy Conservation Measures |
|---|---|
| Lighting system (4) | 1. Change light bulb from T8 to T5<br>2. Using timer<br>3. Delamping<br>4. Using pull switch |
| Air conditioning (6) | 1. Replace the new chiller<br>2. Replace the new air conditioner<br>3. Clean filter regularly<br>4. Adjust load of water supply<br>5. Repair duct leak<br>6. Switch appliances in air conditioning room |
| Air compressor (5) | 1. Install VSD on air compressor motor<br>2. Clean filter regularly<br>3. Reduce pressure to match actual demand<br>4. Disconnect unused equipment and distribution system<br>5. Check and repair air leak |

Table 6 Energy conservation in plastic resin manufacturing (Cont.)

| System | Energy Conservation Measures |
|---|---|
| Production process (7) | 1. Heater insulation<br>2. Set the right temperature at heater<br>3. Install VSD on pelletizer<br>4. Install VSD on Extruder<br>5. Prevent oil spill by installing filter oil collector<br>6. Reduce amount of repellet resin<br>7. Reduce steam at dryer and separation unit |
| Steam (5) | 1. Boiler, heat exchanger and reactor insulation<br>2. Install waste gas recovery boiler<br>3. Steam distribution insulation<br>4. Repair and check leak<br>5. Using wireless steam trap monitor |

Besides energy conservation measures that created from collection energy waste in plastic resin manufacturing, there were energy conservation measures created from process improvement to increase energy efficiency. In the next chapter, Value Engineering technique will be used to analyze the energy conservation measures that have been implementing in plastic resin manufacturing to reduce energy consumption by eliminating waste which is mentioned in this chapter.

# Chapter IV : VALUE ENGINEERING IN ENERGY CONSERVATION

In this chapter, Value Engineering will be used to describe how concept of Value Engineering was applied to energy conservation measures that collected from energy management reports and the previous chapter to reduce energy consumption. Firstly, the concept of Value Engineering in energy conservation will be introduced. And then, the energy conservation measures will be analyzed with the Value Engineering concept by classifying as the system including lighting system, air conditioning system, air compressor, production process and steam system as following sections.

## 4.1 Concept of Value Engineering

Value Engineering is a technique to provide necessary function or improve function at the lower cost to increase value of products or services. The relationship between function and cost to increase value of products or services is shown in Figure 45.



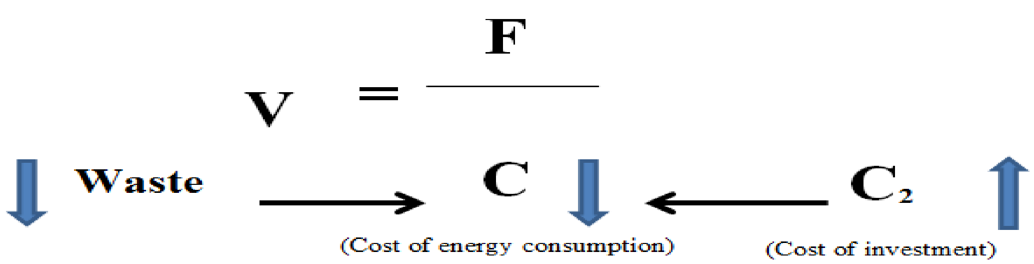



Figure 45 Relationship between value and cost as Value Engineering concept

Where: F refers to function of equipment

C refers to cost of energy consumption

Value Engineering is applied to reduce energy cost by eliminating energy waste to increase value. However, there is the other cost that has to be considered besides, cost of energy consumption which is cost of an investment in energy conservation for example, cost for purchasing the new efficiency light bulbs. Hence, the researcher defines $C_2$ for cost of investment. After implementing energy conservation measures, the energy consumption of equipment or process is reduced; it can be defined as $C''$. The parameter for equipment without energy efficiency is defined as $C'$. So the difference between before and after implementing energy conservation measure is energy saving, $C_1$ as shown in Equation 2.

$$\text{Energy saving } (C_1) = (C' - C'') \qquad (2)$$

Where $C'$ refers to energy consumption before improving

$C''$ refers to energy consumption after improving

As Equation 2, it means the more energy can be saved, the less energy consumption is consumed. Therefore, we can say that there are 2 methods to increase value by reducing energy cost such as

1. Perform the same function at lower cost $\dfrac{F \rightarrow}{C \downarrow} \Rightarrow V \uparrow$

For example:

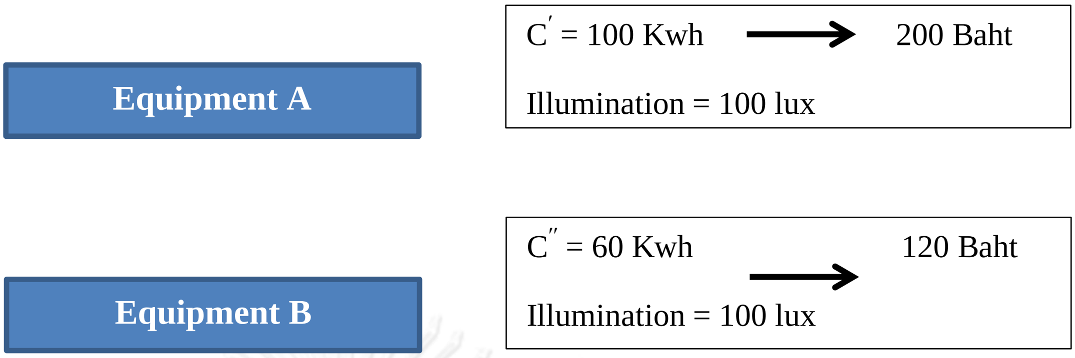



Figure 46 An example of value engineering to reduce cost and perform the same function

$$\text{Energy consumption (C)} = W \times H/1000 \qquad (3)$$

Where: W refers to power consumption (watts)

H refers to time (hours)

Assume function of equipment A and B was illumination that was100 lux

Electricity charge = 2 Baht/Kwh

Price of equipment B = 160 Baht

As shown in Figure 46, the cost of energy consumption reduced after using equipment B instead of equipment A while the illumination function is the same so value increased. That meant the cost of energy saving was (200 – 120) = 80 Baht. Cost of investment when using equipment B was 160 Baht so return on investment was

$$\text{Payback period} = 160/80 = 2 \text{ year}$$

2. Improve function at the lower cost $\frac{F\uparrow}{C\downarrow} \Rightarrow V\uparrow$

For example:

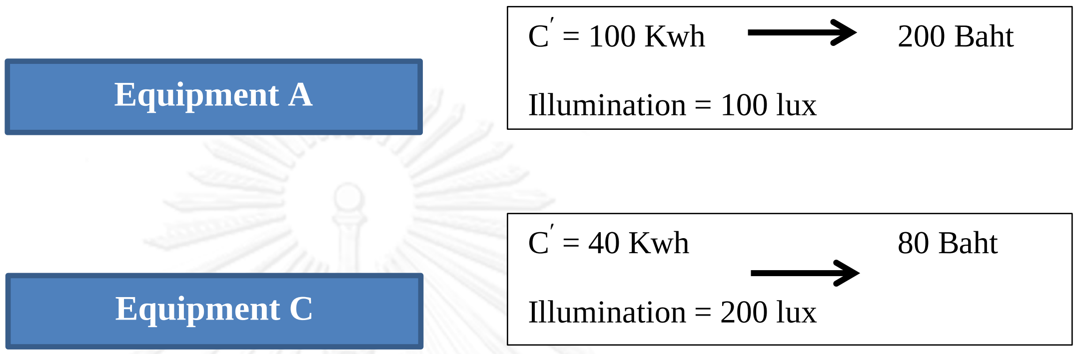



Figure 47 An example of value engineering to reduce cost and improve function

Where: W refers to power consumption (watts)

H refers to time (hours)

Assume function of equipment A and B was illumination that was100 and 200 lux respectively.

Electricity charge = 2 Baht/Kwh

Price of equipment C = 360 Baht

As shown in Figure 47, when changing from equipment B to C, equipment C provided the lowest watts amount three types of equipment and also provided more illumination that meant function was improved. So when equipment was brought to use the energy consumption was lowest whereas the cost of investment was highest. The parameter that has to be considered is payback period.

Payback period = (240)/ (200-80) = 3 years

The payback period shows the equipment C was higher than equipment B so it depends on the executive management which factor is significant between energy cost reduction and payback period. According to above Equation, the guideline to increase value in an industrial are as follows:

1. Analyze function of equipment to replace the new equipment that has lower energy consumption by considering payback period as well.

2. Analyze the necessary function of equipment to reduce energy consumption

3. Utilize the energy and resource to reduce energy cost by focusing on necessary function of equipment.

**4.2 Payback Period**

$$\text{Payback period} = \frac{C_2}{C_1} \qquad (4)$$

Where $C_1$ refers to cost of saving

$C_2$ refers to investment

To calculate payback period as shown in Equation 4, the parameters that have to consider are working hours, working days. The working hours and working days of plastic resin manufactures are shown in table 7.

Table 7 Working hours from case study factories

| Factory | Area | Working hour/day | Working day/year | Total working hours/year |
|---|---|---|---|---|
| A | Office | 8 | 246 | 1986 |
| | Production | 24 | 365 | 8760 |
| B | Office | 8 | 246 | 1986 |
| | Production | 24 | 335 | 8040 |
| C | Office | 8 | 245 | 1960 |
| | Production | 24 | 334 | 7992 |
| D | Office | 8 | 240 | 1920 |
| | Production | 24 | 365 | 8760 |
| E | Office | 8 | 250 | 2000 |
| | Production | 24 | 365 | 8760 |
| F | Office | 8 | 244 | 1952 |
| | Production | 24 | 355 | 8520 |
| G | Office | 8 | 246 | 1968 |
| | Production | 24 | 365 | 8760 |
| H | Office | 8 | 248 | 1964 |
| | Production | 24 | 365 | 8760 |
| I | Office | 8 | 246 | 1976 |
| | Production | 24 | 365 | 8760 |
| J | Office | 8 | 264 | 2212 |
| | Production | 24 | 365 | 8760 |
| K | Office | 8 | 251 | 2008 |
| | Production | 24 | 342 | 8208 |
| L | Office | 8.5 | 247 | 2050 |
| | Production | 24 | 360 | 8640 |

Table 8 Working hours from case study factories (Cont.)

| Factory | Area | Working hour/day | Working day/year | Total working hours/year |
|---|---|---|---|---|
| M | Office | 8.5 | 245 | 2083 |
| | Production | 24 | 358 | 8592 |
| N | Office | 8 | 260 | 2080 |
| | Production | 24 | 365 | 8760 |
| O | Office | 8.5 | 248 | 1984 |
| | Production | 24 | 365 | 8760 |
| P | Office | 8 | 250 | 2000 |
| | Production | 24 | 365 | 8760 |
| Q | Office | 8 | 250 | 2000 |
| | Production | 24 | 365 | 8760 |

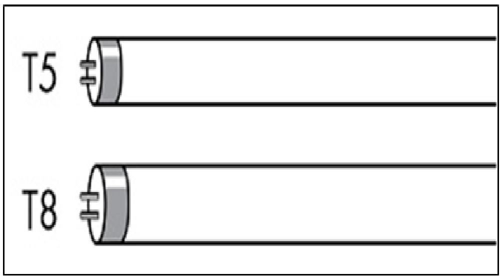
### 4.3 Applying Value engineering to energy conservation in plastic resin manufacturers

The latest chapter that energy waste was collected from energy management reports will be explained in this topic that how waste elimination reduces energy consumption and increase value. In this topic, concept of value engineering used to analyze collection of energy conservation measures. In addition, investment cost and payback period will also be considered for resulting in the decision to implement energy conservation measures.

#### 4.3.1 Energy conservation measures in lighting system

**1. Using energy saving lighting bulbs**

The energy saving light bulbs refer to low watt light watt light bulb. The popular energy saving light bulbs are T5 and the new coming technology that is LED. After using T5 instead of T8, the energy waste from using high watt light bulb was eliminated. Because power consumption of T5 is less than T8, the energy consumption reduced. According to concept of value engineering applied to energy conservation in lighting system, value increasing by reducing energy consumption of light bulbs. The reduction of energy consumption after changing T8 lamps to T5 is shown as Figure 48. The power consumption of each type of light bulb is shown in Table 8 that will be used to calculate energy consumption.




$C' = (46 \text{ x } 8 \text{ x } 246)/1000 = 90.528 \text{ Kwh}$

$C'' = (31 \text{ x } 8 \text{ x } 246)/1000 = 61.008 \text{ Kwh}$



Figure 48 Comparison of energy consumption between T8 and T5 lamp

Table 9 Properties of T8, T5 and LED

| Equipment | Power consumption | | | Saving (T8-T5) | % saving (T8-T5) |
|---|---|---|---|---|---|
| | T8 | T5 | LED | | |
| Light bulb | 36 | 28 | 20 | 8 | 22% |
| Ballast | 10 | 3 | 0 | 7 | 70% |
| Total | 46 | 31 | 20 | 15 | 33% |

From: http://www2.dede.go.th/share/T5.pdf

Assumption: Working hours = 8 hours/ day

Working days = 246 day/ year

Working hours = 1968 hours/ year

Electricity charge = 3.5 Baht/ kWh

Price of T5 = 250 Baht/ light bulb

Cost saving = (15 x 8 x 246/1000) x 3.5 = 213 Baht/light bulb/year

Payback period = 250/213 = 1.2 years

Using the T5 light bulb can save money 235.53 Baht per light bulb and return on investment within 1.2 years when light was turned on 1986 hours per year. The life time of T5 light bulbs is around 10 years so after 1.2 years is the benefit.

2. Delamping

Delamping is the energy conservation measure to remove unnecessary light bulbs that account for waste in working area. The light bulbs were removed, the power consumption also reduced. This measure can reduce cost of energy consumption as shown in Figure 49 without investment so the delamping can increase value. The energy saving of this measure depends on the amount of removal of light bulb.

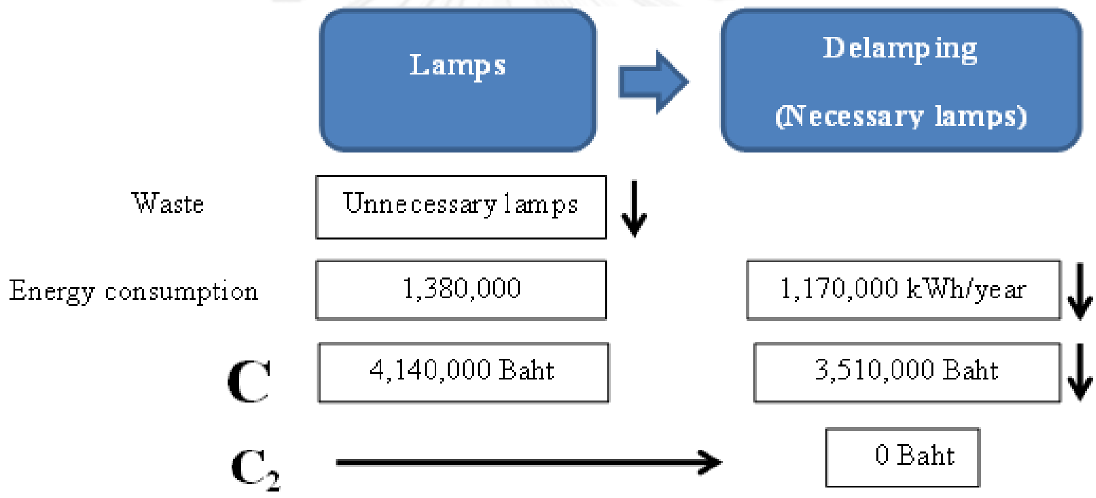



Figure 49 Reduction of energy consumption when removing unnecessary lamp

3. Using pull switch

A pulling switch is used to reduce energy consumption by switching on lights only needed areas as shown in Figure 50.

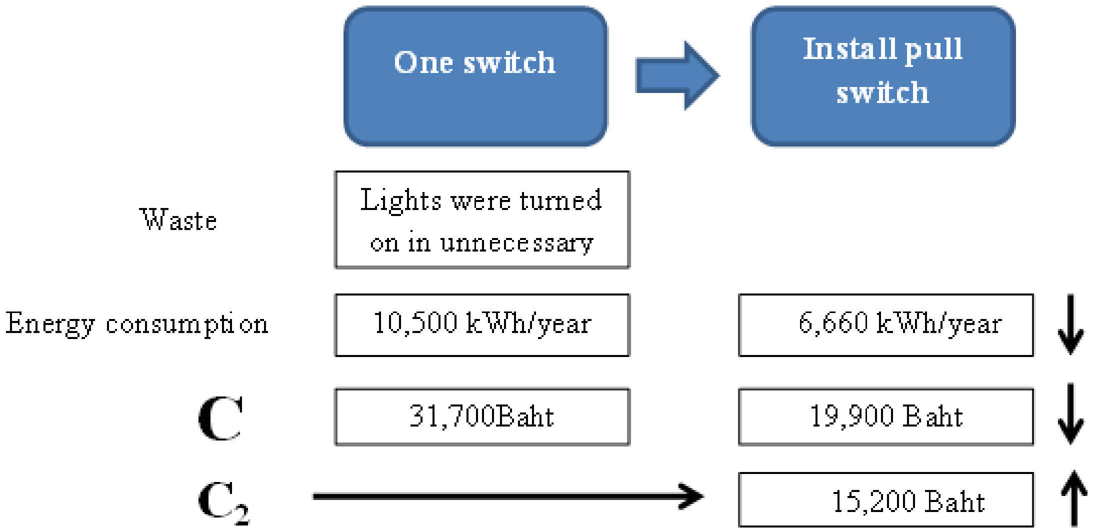



Figure 50 Reduction of energy consumption when using pull switch

The pull switch is used to save electricity bill, however, cost of pull switch should be added to calculate payback period. This measure increased value of the lighting system by reducing cost of energy consumption.

Assumption: Working hours = 8 hours/ day

Working days = 261 day/ year

Working hours = 2088 hours/ year

Electricity charge = 3.00 Baht/ kWh

Payback period = (15,200)/ (11,800) = 1.29 years



#### 4.3.2 Energy conservation measures in air conditioning system

From gathering information, the cause of problem in air conditioning system was aging. The old equipment has power consumption and thus changed the new device was more efficiency. Due to purchase the new equipment, investment cost and payback period should be considered.

**1. Chiller replacement**

The energy waste in aging chiller was high energy consumption so replacing new efficient chiller can reduce energy consumption as shown in Figure 51.

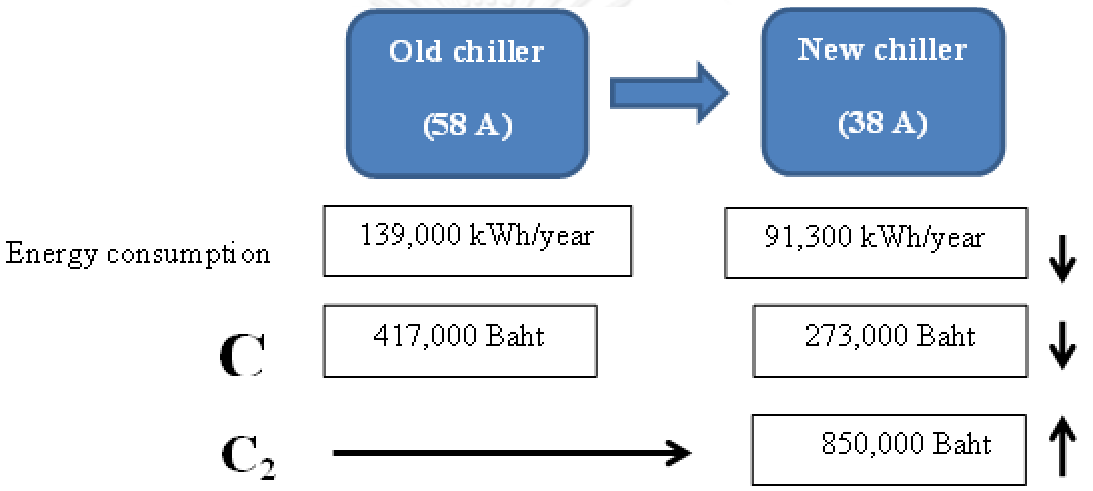



Figure 51 Reduction of energy consumption when installing new chiller

Assumption: chiller has been operated 10 hours per day, 365 days per year and the electricity charge per unit was 2.99 Baht/ kWh

Energy saving = 47,700 kWh/year

Energy cost saving = 47,700 x 2.99 = 144,000 Baht/year

The cost of energy consumption reduced due to replace by new chiller. Because power consumption of new chiller was lower than the old one, the cost of energy consumption is reduced. Hence the value of chiller increased. To consider whether the chiller should be replaced or not, payback period is used to making decision.

Payback period = (850,000)/ (144,000) = 5.92 years

2. Air conditioner replacement

This measure is similar to the chiller replacement by changing to the new efficient air conditioner.

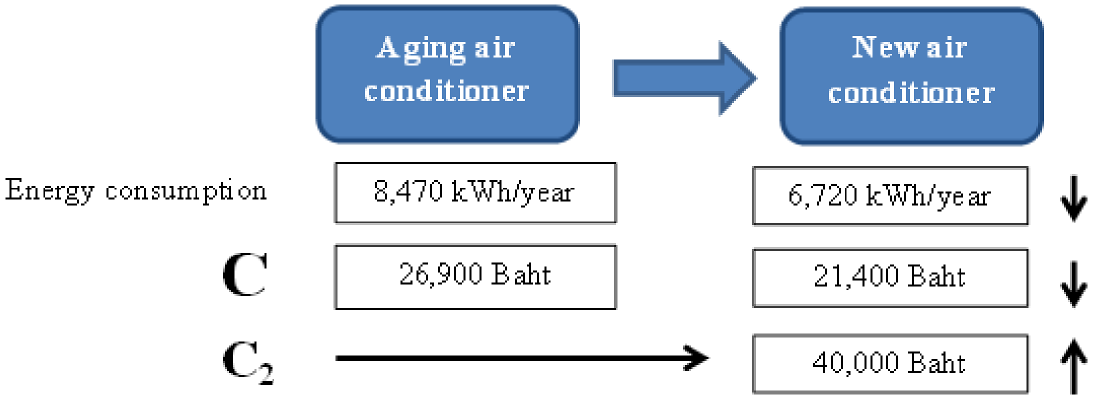



Figure 52 Reduction of energy consumption when installing new air conditioner

Assumption: the air conditioner has been operated 10 hours per day, 260 days per year and electricity charge was 3.18 Baht/kWh

Energy saving = 1750 kWh/year

Energy cost saving = 5580 Baht/year

As shown in Figure 52, replacing the new air conditioner can reduce energy consumption comparing to the old one so changing new air conditioner can increase value as Value Engineering concept. Nevertheless, there is cost for new air conditioner that was 40,000 Baht in the studied factory. So the return on investment was 7.16 years for replacing air conditioner that had been used for 7 years.

Payback period = (40,000)/ (5580) = 7.16 years

3. Adjust load for water supply

This is the energy conservation measure to improve efficient cooling tower unit. Due to large size of pump, the operation of pump didn’t match the requirement. So the flow rate of pump has been reduced as shown in Figure 53 to match the requirement.

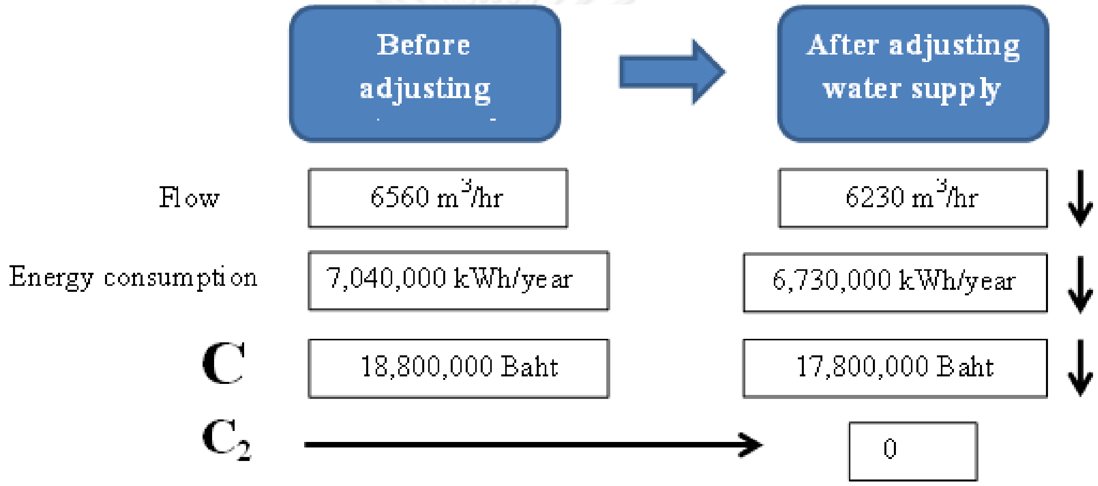



Figure 53 Reduction of energy consumption when adjusting load for water supply

Assumption: the working hours of pump was 8760 hours and electricity charge was 2.67 Baht/kWh

Energy saving = 310,000 kWh/year

Cost of energy saving = 828,000 Baht/year

According to result of calculation, the reduction of pump flow rate can significantly reduce energy consumption so cost of energy also reduces. This measure implemented without cost investment. Due to reduction of energy consumption, value increased as the value engineering concept. When implementing this measure, cost of energy consumption can reduce immediately.

**4. Install VSD at fan of cooling tower**

The large of cooling fan of cooling tower caused a large amount of energy consumption. The cooling fan is driven by motor. The fan motor rotated at a constant speed most of the time to decrease the water temperature as desired. When the water reached desired temperature, the motor was still running as highest speed. So Variable Speed drive (VSD) was installed to adjust speed of motor to match requirement and to consume energy as necessary.

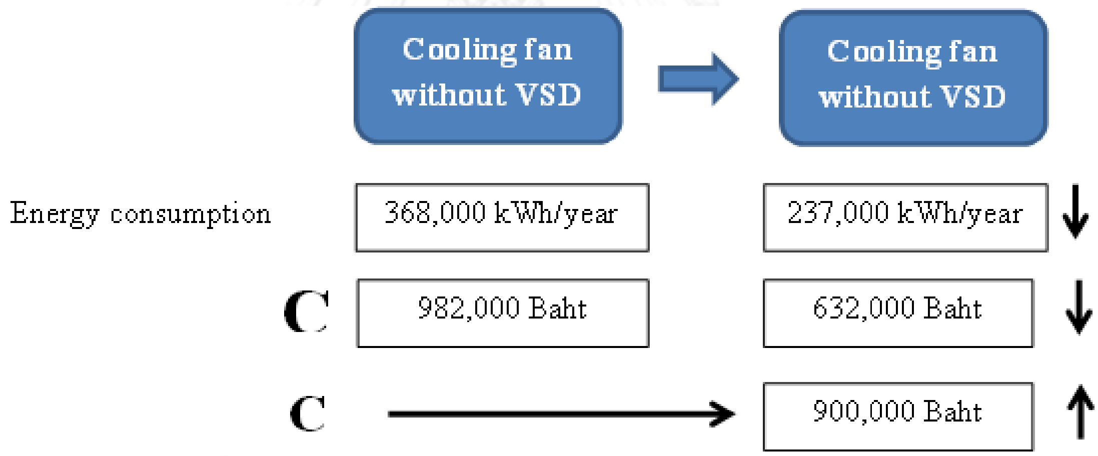





Figure 54 Reduction of energy consumption when installing VSD at fan of cooling tower

Assumption: the operation hours for cooling tower was 8760 hours per year and electricity charge was 2.66 Baht/kWh

Energy saving = 131,000 kWh/year

Energy cost saving = 131,000 x 2.66 = 351,000 Baht

Installing VSD in cooling fan motor could reduce energy consumption around 35.71% of cooling tower energy. There was investment cost for purchasing VSD that around 900,000 Baht so the payback period was 2.56 years. The VSD installation could increase value of cooling fan by reducing energy consumption of cooling tower as shown in Figure 54.

**5. Installing cooling PAD**

Installing a cooling pad is not to eliminate waste in the system, however, it improves the performance of the air conditioning to reduce energy cost of air conditioning system. It can be installed to provide cooling for the air compressor which can save electricity. Moreover, cooling PAD is installed in condensing unit chiller and thus prolongs the lifetime of the compressor and the power bills as well.

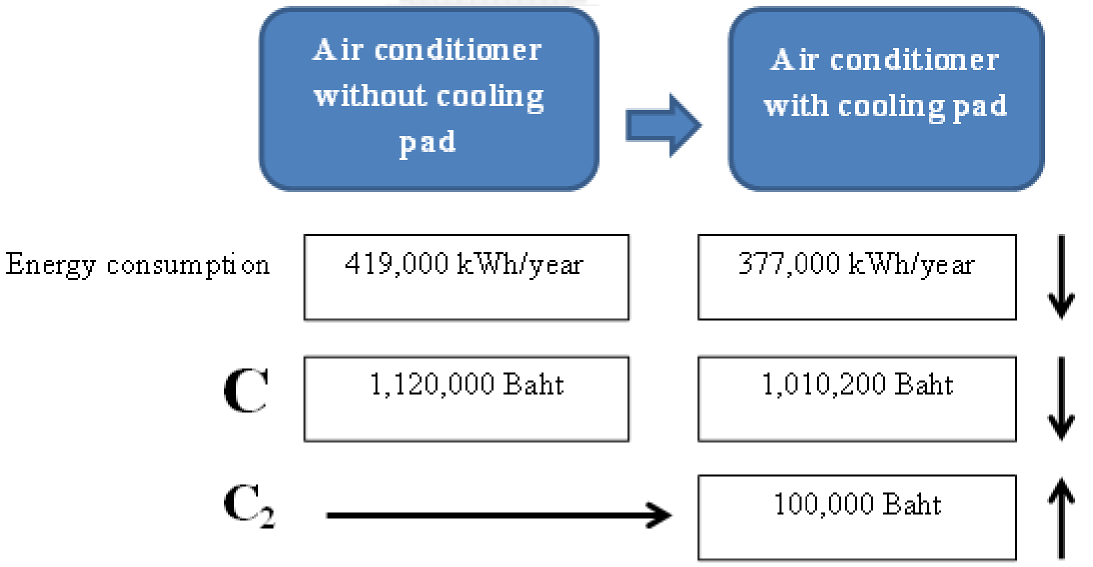



Figure 55 Reduction of energy consumption when installing cooling PAD

Assumption: air conditioning system has been operated 8760 hours per year and electricity charge was 2.67 Baht/kWh

Energy saving = 41,200 kWh/year

Energy cost saving = 42,000 x 2.67 = 112,000 Baht

Installing cooling PAD can increase value in air conditioning system by reducing energy consumption of air conditioner as shown in Figure 55. For this measure, there is investment cost for buying cooling PAD that was around 100,000 Baht so the return on investment was within 0.9 years.

**4.3.3 Energy conservation measures air compressor**

There are 2 systems for air compressor that are air compressor and air distribution system. There is an opportunity for improve efficiency of air compressor in these 2 systems. The collected energy conservation measures are as following

**1. Install VSD on air compressor motor**

VSD was applied to air compressor to reduce energy consumption when it left running without loads which was regarded as energy waste in air compressor. VSD installations need to be invested. Therefore, these measures are thought to engage the payback period for this measure, for example, in case of studied factory, before installing VSD power consumption of air compressor at 1,310,000 kWh / year. After installing VSD, energy waste caused by idling time was reduced at lower power consumption that was 963,000 kWh/year.

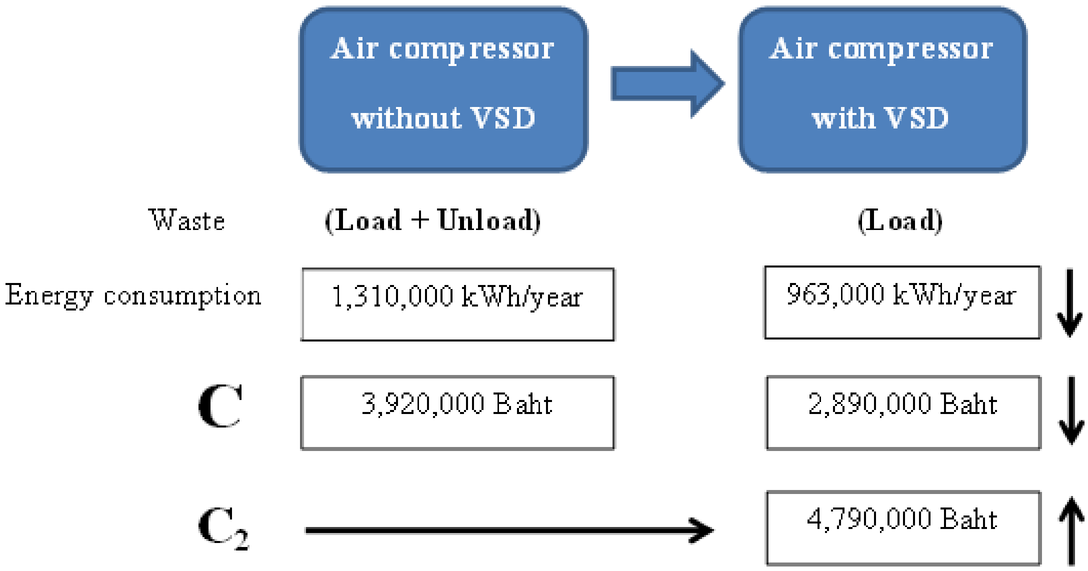



Figure 56 Reduction of energy consumption when installing VSD on air compressor motor

Assumption: the working hour of air compressor was 8 hours per day, 355 days per year and electricity charge 3 Baht

Energy saving = 347,000 kWh/year

Energy cost saving = 347,000 x 3.00 = 1,040,000 Baht/year

As shown in Figure 56, installing VSD in compressor could reduce energy consumption and could save money about 26 % or around 1,040,000 Baht/year. There was cost of purchasing and installing VSD, the payback period should be considered. The payback period was 4.65 years. This measure is consistent the concept of Value Engineering by reducing cost of energy consumption.

Payback period = 4,790,000/ (1,040,000) = 4.65 years

2. Reduce air compressor pressure

After eliminating waste from providing excessive pressure to end-use equipment, the cost of energy will be reduced. The power consumption of air compressor relies on pressure of air compressor, therefore, the high pressure the more energy consumption. This measure is to reduce air compressor pressure to match requirement from end use equipment.

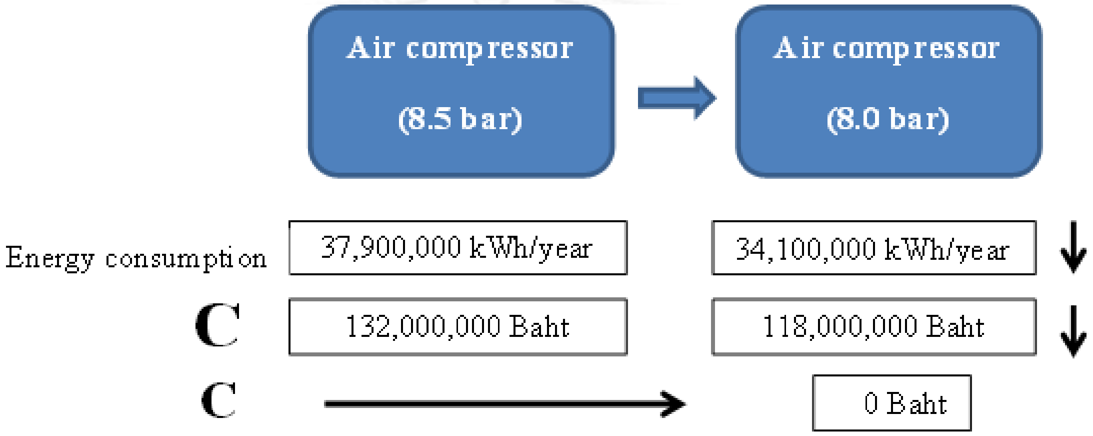



Figure 57 Reduction of energy consumption when reducing air compressor pressure

Assumption: the air compressors have been running 8756 hours per year and the average electricity cost was about 3.47 Baht/kW



Energy saving = 3,800,000 kWh/year

Energy cost saving =3,800,000 x 3.47 = 13,200,000 Baht/year

This measure could implement by adjusting pressure of air compressor it didn’t have investment cost. Implementing this measure can reduce energy consumption over 10 % of energy air compressor consumption as shown in Figure 57. Moreover, the Value Engineering was applied in sir compressor to identify energy waste and eliminate to reduce energy cost. Hence this measure can increase value in accordance with Value Engineering concept.

**3. Check and repair air leak**

Energy waste that occurred from leak can be eliminated by investigating and fixing the leak. There is no investment cost for implanting this measure. If leak occurs in the air distribution pipe, the pressure will drop. That means the end use equipment cannot have the sufficient air to use. On the other hand, the compressed air transfers to the end use equipment without escape, the compressor air won't be necessary to work hard to make up air leakage. Due to reduction of energy consumption, the value of air compressor increased as shown in Figure 58. This measure can help the studied factory saved 170,000 Baht without any investment.

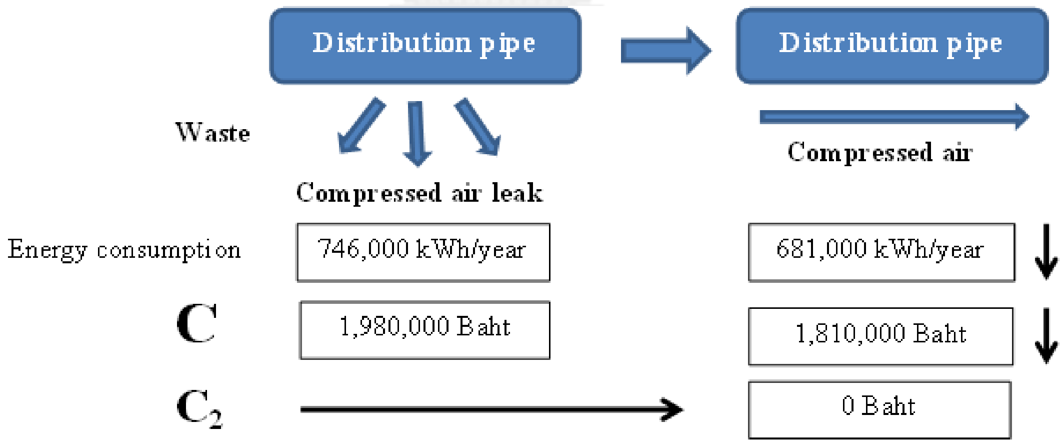



Figure 58 Reduction of energy consumption when checking and repairing air leak

Assumption: The working hour of air compressor was 8520 hours and electricity cost was 2.66 Baht/kWh.

Energy saving = 65,000 kWh/year

Energy cost saving = 65,000 x 2.66 = 170,000 Baht/year

4. Overhaul air compressor

The air compressor that has been used for a while should be maintenance or changed the new one because the old machine consumes a lot of energy. This measure was to overhaul air compressor to reduce electricity consumption as shown in Figure 59. Overhauling air compressor could reduce energy consumption by 3.4% energy consumption in air compressor.

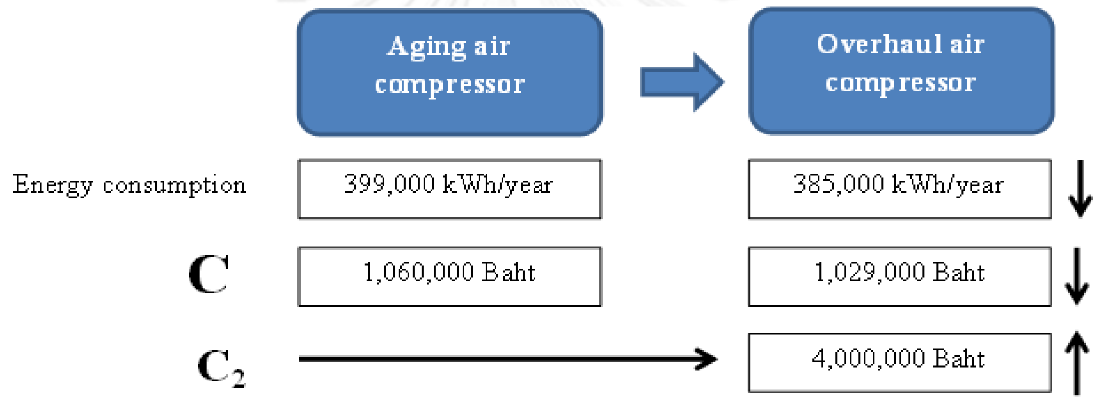



Figure 59 Reduction of energy consumption by overhaul air compressor

Assumption: working hours was 8760 hours/year and electricity price was 2.67 Baht/kW



Energy saving = 31,000 kWh/year

Energy cost saving = 82,800 Baht/year

Comparing the energy cost saving to investment cost, the payback period was quite long around 49 years.

4.4.4 Energy conservation measures production process

1. Heater, Die, Barrel insulation

Due to heat loss by convection and radiation, the heater, die and barrel should be insulated to prevent heat loss from the surface of heater, die and barrel.

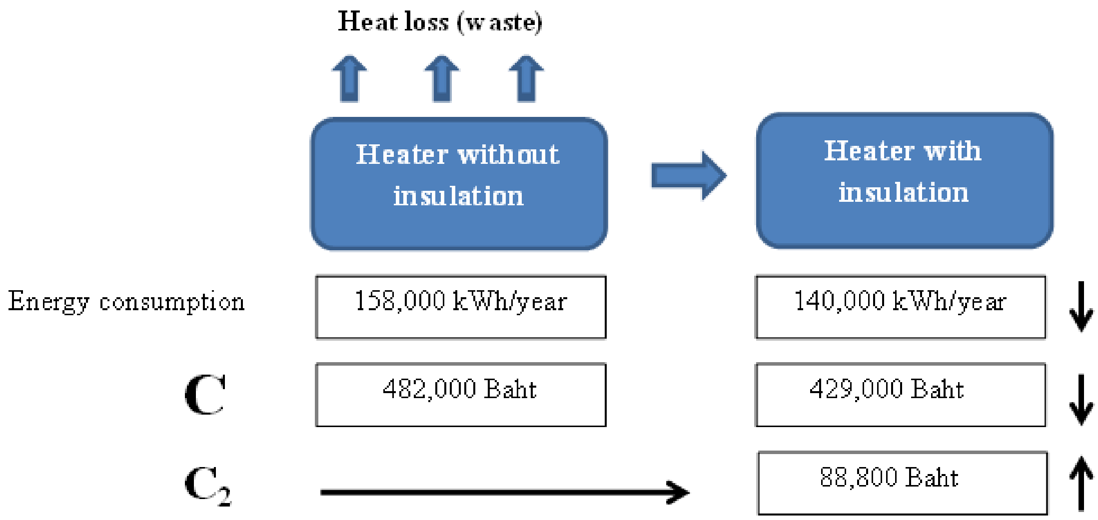



Figure 60 Reduction of energy consumption when checking and repairing air leak

Assumption: operation hour for heater was 8760 hours and electricity power cost was around 3.06 Baht

The energy loss was reduced as a result of insulation as shown in Figure 60. The energy saving was 53,000 Baht/year so the return on investment would be 1.7 years. Because energy consumption was reduced by installing insulation, the value of production process increased as Value Engineering concept.

Energy saving = 18,000 kWh/year

Energy cost saving = 53,000 Baht years

2. Change screw element for an extruder

A screw in extruder is the significant component for an extruder because it uses to melt the polymer powder before transforming into the plastic pellets. The design of screw has an impact on energy consumption so improvement of screw design can reduce energy consumption in extruder. Cost of an investment in new screw design was extremely high expenditure, however, energy consumption was reduced greatly. The reduction of energy consumption is shown in Figure 61.

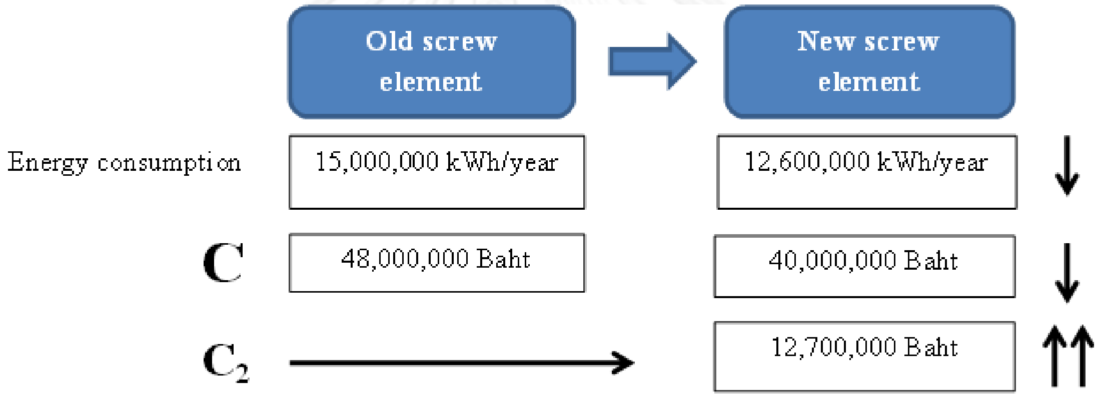



Figure 61 Reduction of energy consumption when changing screw element for an extruder



The energy consumption in extruder can be reduced by adding cost for new screw design so the value of extruder will increase as Value Engineering concept. This measure was not implemented to eliminate waste in extruder but it was applied to enhance performance of extruder to reduce energy consumption.

Assumption: the operation hour of extruder was 8,760 hours and electricity price was 3.18 Baht.

Energy saving = 2,400,000 kWh/year

Energy cost saving = 2,400,000 x 3.18 = 7,630,000 Baht/year

Hence:

Payback period = (12,700,000)/ (7,630,000) = 1.66 years

Even though the investment cost for new screw design was very high, replacement screw increases quality and the output of extruder (screw). Life time of screw machine is longer than payback period so investment on screw is worth. However, it depends on the executive managements that they prefer to consider payback period, investment cost or cost of energy saving.

**4.3.5 Energy conservation measures steam System**

**1. Install waste gas recovery boiler**

The waste gas recovery boiler is a unit to recover waste heat to increase performance of steam generator at lower fuel demand. Fuel is energy on term of thermal energy. The reduction of fuel demand means reduction of energy usage. Most factories have not installed heat recovery at first so the investment cost was very high to invest with the new equipment or redesign the steam generator. The figure 62 shows the result of energy conservation before and after applying this method to factory. The result found that energy could save 30,000,000 Baht/year.

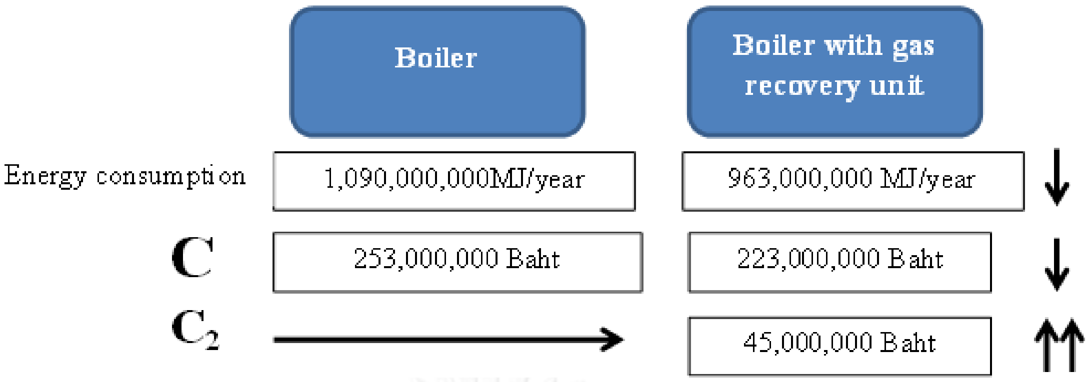



Figure 62 Reduction of energy consumption when installing waste gas recovery boiler

Assumption: the operation hours of boiler was 24 hours per day, 335 days per year and steam price was 650 Baht/Ton

Installing the new boiler can reduce purchasing steam to 11.87 % of steam cost and performance of the boiler has been improved. The waste gas recovery boiler has been installed in order to reduce steam usage to reduce fuel demand so thermal energy was reduced. Value of steam system increased as a result of reduction of energy consumption by installing waste gas recovery boiler.

Energy saving = 127,000,000 MJ/year

Energy cost saving = 30,000,000 Baht/year

Payback period = 1.5 years

2. Steam trap survey and repair

Steam trap is equipment to prevent steam leak from the distribution pipe. Therefore, if the steam trap leaks, hot steam that is used to heat other devices will be lost. The steam generator has to produce steam more steam to supply steam to meet requirement from end use equipment. That means fuel has to consume more. Because leak cause the significant energy waste in steam pipe distribution, leak should be check and repair immediately.

Assumption: steam system operates 24 hours per day, 365 days per year, leak diameter 1.6 mm.

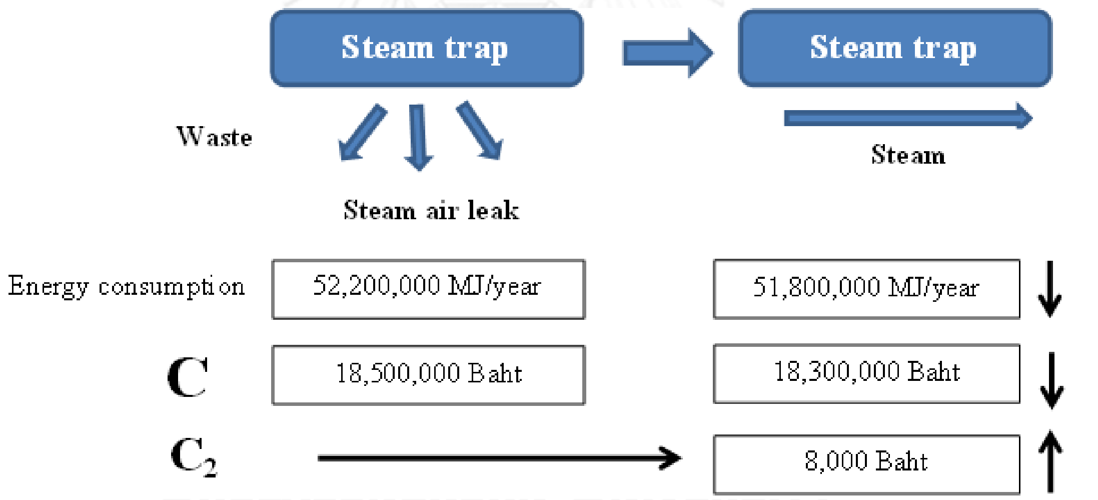



Figure 63 Reduction of energy consumption when surveying and repairing steam trap

Investment cost for this measure is to purchase the new steam trap to replace leaking steam trap. Comparing cost of investment to energy saving is worth the investment because the money can be saved 164,859.00 Baht/year while return on investment was 0.05 years

Energy saving = 400,000 MJ/year

Energy cost saving = 200,000 Baht/year

Payback period = 0.05 years

This measure was applied to reduce steam loss in steam distribution pipe to achieve cost saving from repairing leak and to increase value as shown in Figure 63.

**3. Install new heat exchanger**

A heat exchanger is equipment used to transfer heat from one medium to another medium. In this case, heat exchanger was used to preheat solvent (hexane) to reduce steam that used to heat solvent. The preheating solvent use less steam that normal temperature so preheat the solvent before using save more thermal energy as shown in Figure 64.

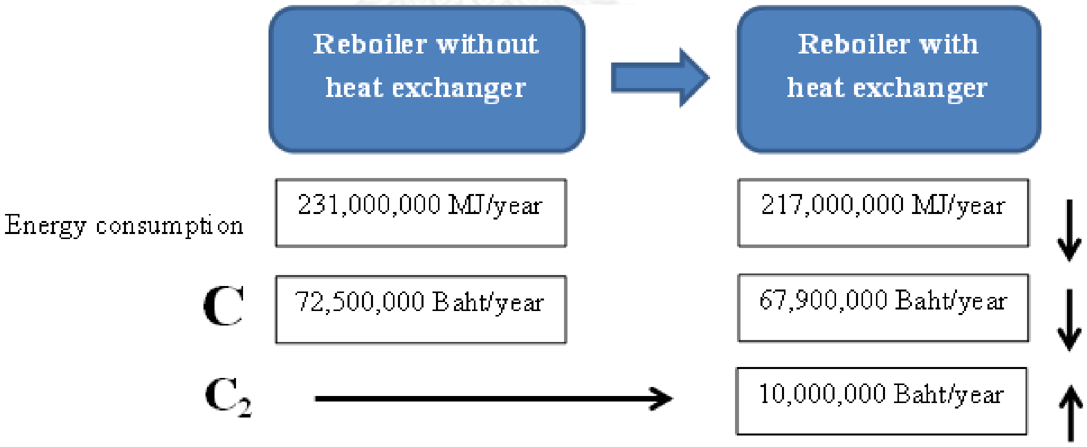



Figure 64 Reduction of energy consumption by installing new heat exchanger

Assumption: working hour for the new heat exchanger was 8760 hours per year and fuel price was 940 Baht/Ton

In term of Value Engineering, the new heat exchanger has been used to reduce steam at reboiler that means the use of fuel also decreased. This measure could increase value by reducing purchasing cost for fuel as shown in Figure 64. However, there was additional cost to buy the new heat exchanger. So the return on investment should be calculated as shown in following Equation.

Energy saving = 14,000,000 MJ/year

Energy cost saving = 4,600,000 Baht/year

Payback period = 2.2 years

**4. Reduce steam pressure**

This measure reduced energy consumption of steam by reducing amount of steam in a production process as shown in Figure 65. However, the steam should be reduced to save fuel without effect on the production process. This measure can decrease cost of energy in term of purchasing fuel as a result of steam reduction so value of steam system increased as Value Engineering concept. This measure implemented without investment cost so payback period didn't need to be calculated.

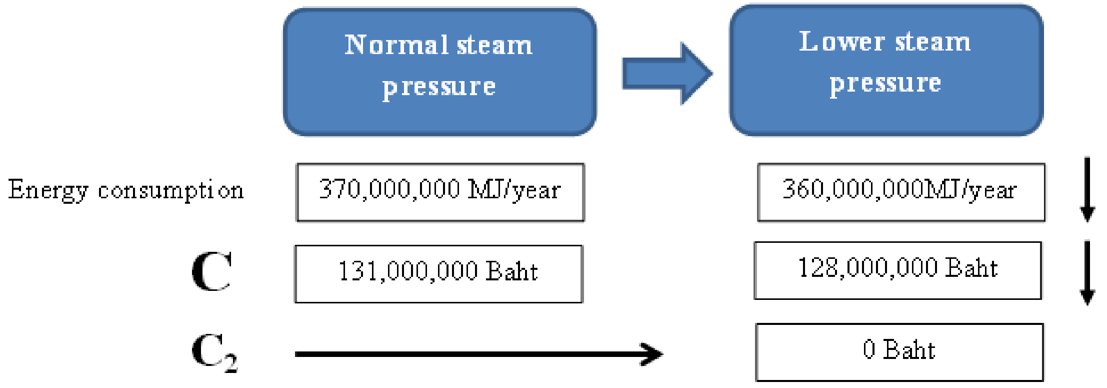



Figure 65 Reduction of energy consumption by reducing steam pressure

Assumption: working hour for steam was 8760 hours and fuel gas price was 278 Baht/MJ

Energy saving = 10,000,000 MJ/year

Cost of energy saving = 3,000,000 Baht/year

# Chapter V CONCLUSION AND RECOMMENDATION

This research studied energy conservation measures in plastic resin manufacturing which have 17 plants located in Rayong province. In this research, there were various problems and different energy conservation measures in plastic resin manufacturers. The total of energy conservation measures were 47 measures for 17 factories. There were a few plastic resin manufacturers implemented the same energy conservation measures. For example, there were merely 2 and 3 factories implemented the same measure which were pressure reduction and leak detection measure respectively. The rest of energy conservation measures were not duplicated even though these manufacturers are in the same industry. Therefore, these energy conservation measures were collected from Department of Alternative Energy Development and Efficiency to analyze the importance of energy conservation measures. First of all, energy wastes in plastic resin manufacturing were identified as Value Engineering concept that waste should be eliminated to reduce energy consumption. Next, the practical energy conservation measures were rearranged by payback period. Finally, the energy conservation measures in plastic industrial were listed as shown in Tables 9, 10 and 11 by classifying in short-term, mid-term and long-term payback period. This thesis will be benefited for plastic resin manufacturers to consider these energy conservation measures to apply to their factories that will be given an example in the next section. For short-term, the total energy investment was 90,000,000 baht, resulting in total energy saving of 236,000,000 baht per year or 0.9 year payback period. For medium-term, the total energy investment was 20,000,000 baht, resulting in total energy saving of 11,000,000 baht per year or 3 year payback period. For long-term, the total energy investment was 30,000,000 baht, resulting in total energy saving of 3,080,000 baht per year or 49 year payback period.

## 5.1 The practical energy conservation measures in plastic resin manufacturing

According to Energy Management Matrix, the plastic resin manufacturers use the payback period as the criteria to consider investment on energy conservation. Therefore, the practical energy conservation measures were classified in short-term, mid-term and long term payback period. The payback period is calculated when investing in new equipment or improving a process. Recovering the investment cost, it takes 1 year as a short-term payback period, 1-3 years as a mid-term and up to 3 years as a long-term payback period.

**1. The short-term energy conservation measures (0-1 year)**

The short-term energy conservation measures are focused on driving immediate cost saving. These conservation measures require the lowest capital investment, but they may not be able to generate the best results. The minimum investment cost of energy conservation measures was around 10,000 Baht whereas the maximum investment was approximately 32,600,000 Baht. Even though there was a high investment, the payback period was very short.

Table 10 Energy conservation measures in short-term payback period (0-1 year)

| Energy conservation measures | No | Investment cost (Baht) | Electricity saving (kWh/year) | Fuel Saving (MJ/year) | Cost saving (Baht) | Payback Period (Year) |
|---|---|---|---|---|---|---|
| Lighting system | | | | | | |
| 1. Control time to turn on/off lights | 1 | 0 | 28,100 | | 79,000 | 0 |
| 2. Reduced lighting in unoccupied areas | 1 | 0 | 37,100 | | 115,000 | 0 |
| 3. Using pull switch to control lights on/off | 2 | 13,400 | 11,400 | | 36,900 | 0.74 |
| 4. Used electronic ballasts instead of magnetic ballasts | 2 | 22,300 | 9,490 | | 23,900 | 0.93 |
| Air conditioning system | | | | | | |
| 1. Control time to turn on/off air conditioner | 1 | 0 | 35,900 | | 101,000 | 0 |
| 2. Optimum of cooling water supply | 1 | 0 | 352,000 | | 941,000 | 0 |
| 3. Cleaned condenser chiller | 1 | 0 | 24,700 | | 65,820 | 0 |
| 4. Installed cooling PAD | 1 | 100,000 | 41,900 | | 111,800 | 0.89 |

Table 9 Energy conservation measures in short-term payback period (0-1 year) (Cont.)

| Energy conservation measures | No | Investment cost (Baht) | Electricity saving (kWh/year) | Fuel Saving (MJ/year) | Cost saving (Baht) | Payback Period (Year) |
|---|---|---|---|---|---|---|
| **Air compressor** | | | | | | |
| 1. Reduced air compressor pressure | 2 | 0 | 1,900,000 | | 6,590,000 | 0 |
| 2. Install VSD on air compressor | 1 | 100,000 | 119,000 | | 318,000 | 0.26 |
| 3. Checked and repaired compressed air leak | 3 | 0 | 189,000 | | 496,000 | 0 |
| **Production process** | | | | | | |
| 1. Reduced power consumption of ethylene compressor PP | 1 | 0 | 57,000 | | 149,000 | 0 |
| 2. Reduce electric consumption at pellet transfer blower and rotary valve | 1 | 0 | 689,000 | | 2,070,000 | 0 |
| 3. Improved washing process | 1 | 0 | 66,800 | | 180,000 | 0 |
| 4. Reduced downtime at bagging unit (PP) | 1 | 0 | 5,000 | | 15,900 | 0 |

Table 9 Energy conservation measures in short-term payback period (0-1 year) (Cont.)

| Energy conservation measures | No | Investment cost (Baht) | Electricity saving (kWh/year) | Fuel Saving (MJ/year) | Cost saving (Baht) | Payback Period (Year) |
|---|---|---|---|---|---|---|
| Steam system | | | | | | |
| 1. Reduce steam pressure | 1 | 0 | | 17,600,000 | 6,440,000 | 0 |
| 2. Check and survey stream trap | 2 | 254,000 | | 2,870,000 | 907,000 | 0.2 |
| 3. Install waste gas recovery boiler | 1 | 51,000,000 | | 240,000,000 | 68,500,000 | 0.7 |
| 4. Install heat exchanger to reduce steam | 1 | 6,50,000 | | 24,300,000 | 7,190,000 | 0.9 |
| 5. Using heat exchanger to recovery waste heat | 1 | 3,000,000 | | 26,200,000 | 7,25,000 | 0.4 |
| Others | | | | | | |
| 1. Control to turn on/off computer | 1 | 0 | 1,970 | | 5,340 | 0 |
| 2. Install VSD on blower | 1 | 200,000 | 80,900 | | 223,000 | 0.9 |
| Total | 34 | 90,000,000 | 30,000,000 | 310,000,000 | 236,000,000 | 0.9 |
| | | | | | | |

**1. Medium term energy conservation measures (1-3 years)**

Medium term energy conservation measures are focused on driving high-impact cost saving with longer-term result desired. The mid-term energy conservation measures require some investment cost and enable to generate good results. The time for mid-term payback period is 1-3 years. The lowest investment cost was about 12,000 Baht while the highest investment cost was 12,977,990 Baht.

Table 11 Energy conservation measures in mid-term payback period (1-3 year)

| Energy conservation measures | No | Investment cost (Baht) | Electricity saving (kWh/year)) | Cost saving (Baht) | Payback Period (year) |
|---|---|---|---|---|---|
| **Lighting system** | | | | | |
| 1. Change hi-bey in warehouse | 1 | 1,000,000 | 218,000 | 582,000 | 1.7 |
| 2. Change 40-watts bulbs to 36-watts bulbs | 1 | 12,000 | 2,100 | 6,300 | 1.9 |
| 3. Changed T8 light bulbs to T5 | 6 | 206,500 | 23,600 | 67,900 | 3 |
| 4. Change from hi-bey 400 to fluorescent 5x54 watts | 1 | 82,800 | 19,500 | 61,300 | 1.4 |
| **Air conditioning system** | | | | | |
| 1. Install VSD at fan of cooling tower | 2 | 900,000 | 225,000 | 590,000 | 1.5 |
| **Production process** | | | | | |
| 1. Changed screw element for extruders | 1 | 12,978,000 | 3,200,000 | 9,600,000 | 1.4 |
| 2. Heater insulation | 2 | 88,810 | 17,500 | 53,000 | 1.7 |
| Total | 14 | 20,000,000 | 3,710,000 | 11,000,000 | 3 |

**3. Long-term energy conservation measures (up to 3 years)**

The long-term energy conservation measures focus on the payback period after 3 years. To achieve long-term energy efficiency, the new efficiency machine and high capital are required.

Table 12 Energy conservation measures in long-term payback period (up to 3 years)

| Energy conservation measures | No | Investment cost (Baht) | Electricity saving (kWh/year) | Fuel Saving (MJ/year) | Cost saving (Baht) | Payback Period (Year) |
|---|---|---|---|---|---|---|
| Lighting system | | | | | | |
| 1. Change from HPS 250 watts to LED 30 watts | 1 | 90,000 | 8,430 | | 26,500 | 3.4 |
| Air conditioning system | | | | | | |
| 1. Replace new air conditioner | 1 | 40,000 | 3,350 | | 10,700 | 3.7 |
| 2. Chiller replacement | 1 | 1,120,000 | 155,000 | | 492,000 | 3.8 |
| 3. Tie load of cooling tower | 1 | 4,600,000 | 239,000 | | 671,000 | 6.9 |
| Air compressor | | | | | | |
| 1. Installed air compressor inverter | 1 | 4,793,300 | 344,000 | | 1,030,000 | 4.7 |
| 2. Overhaul air compressor | 1 | 4,090,000 | 31,168 | | 83,100 | 49 |
| Steam system | | | | | | |
| 1. Increasing efficiency of steam | 1 | 4,000,000 | | 495,667 | 134,000 | 30 |
| Others | | | | | | |
| 1. Changed to high efficiency motor | 1 | 540,000 | 51,500 | | 132,000 | 4.1 |
| 2. Maintenance machine appropriately (H) | 1 | 6,050,000 | 198,000 | | 498,000 | 12.1 |
| Total | 9 | 30,000,000 | 1,030,000 | 495,667 | 3,080,000 | 49 |

## 5.2 Energy conservation in plastic resin process

The energy conservation measures in plastic resin process are applied in the plastic resin chart as shown in Figure 66 to a clear vision about implementing energy efficiency in the production process. The pelletizing system has number of energy conservation measures higher than other systems by focusing on extruder machine. The equipment that involves thermal energy such as reactor and extruder always conserves energy by covering insulation to prevent heat loss. Because plastic pellet is transferred to pack before distribution, improving efficiency of pellet transfer can also conserve energy in plastic resin process.

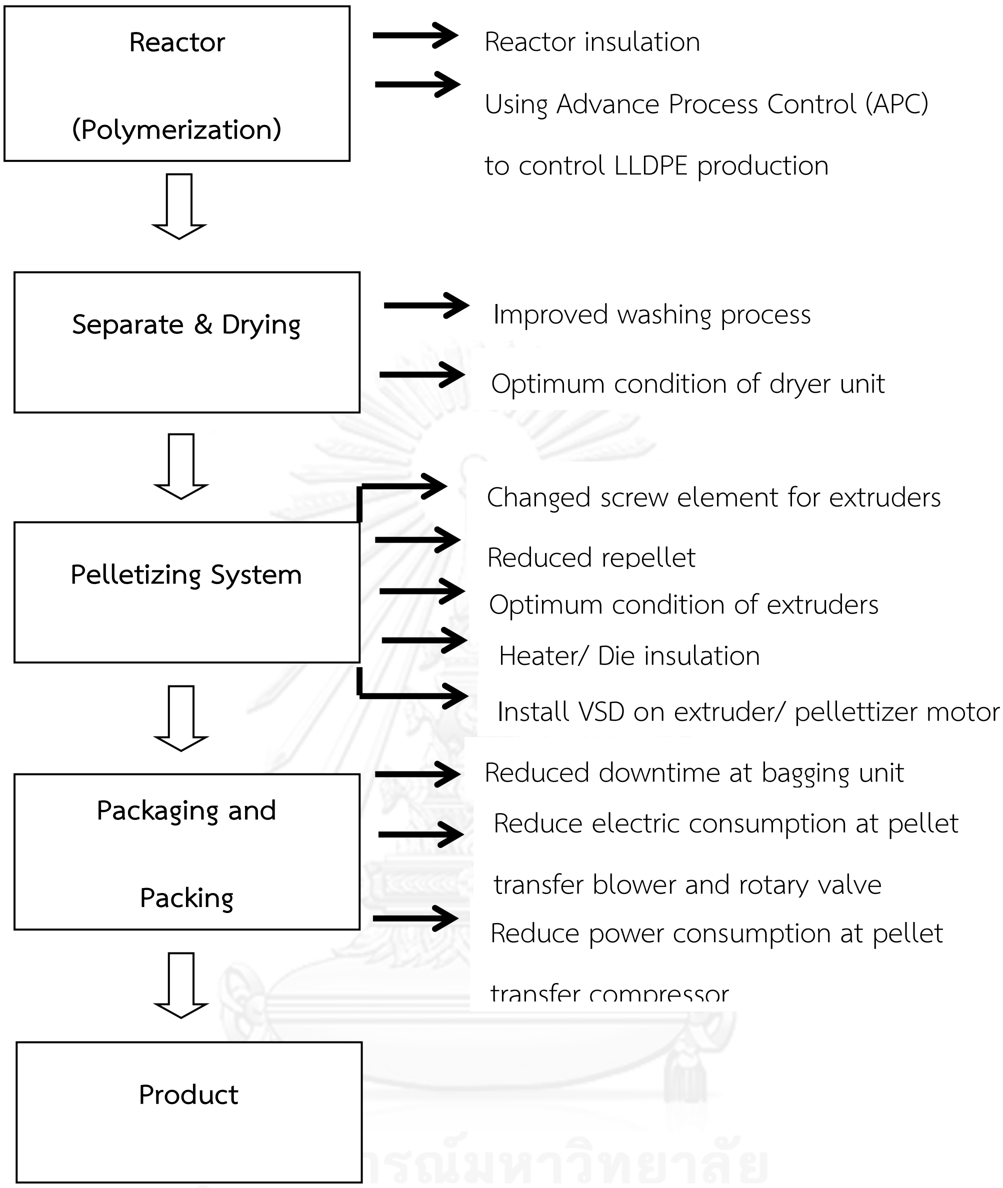



Figure 66 Energy conservation measure in plastic resin process

**5.3 An example of case study factory in selecting energy conservation**

Factory G is the example of plastic resin manufacture in this research to find the opportunity to increase energy efficiency from practical energy conservation measures. The energy conservation measure of factory G and all collected energy conservation measures are shown in Table 12 to consider the energy conservation measure that they won't implement. Factory G has been implementing energy conservation measures in 5 systems including lighting system, air conditioning system, air compressor and steam system. There were 12 energy conservation measures that Factory G has been implemented 12 energy conservation measures

Table 13 Energy conservation measures of factory G

| System | All energy conservation measures | Fact. G |
|---|---|---|
| Lighting system | Change Hi-Bey light in warehouse | ✓ |
| | Changed T8 light bulbs to T5 | ✓ |
| | Used electronic ballasts instead of magnetic ballasts | X |
| | Change 40-watts bulbs to 36-watts bulbs | X |
| | Control time to turn on/off lights | X |
| | Change Hi-Bey from 250 W to 100W | X |
| | Reduced lighting in unoccupied areas | X |
| | Using pull switch to control lights on/off | X |
| | Change from HPS 250 watts to LED 30 watts | X |
| | Change from hi-bey 400 to fluorescent 5x54 watts | X |
| | Separated switch control | X |
| | Delamping | X |
| Air conditioning system | Optimum of cooling water supply | ✓ |
| | Install inverter at fan of cooling tower | ✓ |
| | Installed cooling PAD | ✓ |
| | Replace new chiller at chiller unit | X |
| | Control time to turn on/off air conditioner | X |
| | Cleaned condenser chiller | X |
| | Replace new air conditioner | X |
| Air compressor | Overhaul air compressor | ✓ |
| | Reduce air compressor pressure | X |
| | Install air compressor inverter | X |
| | Check and repair compressed air leak | X |
| | Install VSD on air compressor | X |

Table 12 Energy conservation measures of factory G (Cont.)

| System | All energy conservation measures | Fact. G |
|---|---|---|
| Production process | Reduced repellet | ✓ |
| | Optimum condition of extruder | ✓ |
| | Optimum condition of dryer unit | ✓ |
| | Decrease ethylene temperature to reduce steam | ✓ |
| | Changed screw element for extruders | X |
| | Reduced downtime at bagging unit | X |
| | Reduced power consumption of ethylene compressor PP | X |
| Steam | Repaired and surveyed steam traps | ✓ |
| | Install new heat exchanger | ✓ |
| | Installed waste gas recovery boiler | X |
| | Increasing efficiency of steam | X |
| | Reduced steam pressure | X |
| | Using heat exchanger to recover waste heat | X |

Note: ✓ refers to the energy conservation measures that the factory F already implemented

X refers to the energy conservation measure won't implement



For the lighting system, factory G already implemented in changing the light from inefficiency light bulbs to efficiency light bulbs such as T5 and lower watt light bulbs. The energy consumption in lighting system was reduced by replacing the high efficiency equipment that must have investment cost. They have not implemented in the house keeping energy conservation such as delamping or reducing lighting in the unoccupied area. So the factory G should do energy audit in the lighting system to find opportunity to reduce energy conservation without investment cost. The factory G should check control switch that it controls all light in the division or in the multiple work areas. If yes, the factory should consider installing pull switch to reduce energy consumption because the payback period of this energy conservation measure is very short as the factory L and N already implement.

For the air conditioning system, the factory G reduced energy consumption by installing the equipment that improved performance of air conditioning components such as VSD and cooling PAD. The factory has not implemented in changing new efficiency equipment maybe because the investment cost. However, they should check the life time of air conditioning system whether it should be changed or not. Moreover, the simplest way to conserve energy as cleaning condensing unit won't be applied so this measure should be considered to implement as well. To clean condensing unit, the factory G should check the place of condensing unit located to explore dusts in the area. And then, identify the time to clean condensing unit per year.

For the air compressor, the factory G designed to overhaul the air compressor that had long payback period. So they should consider the other measures that don't have investment cost such as reduce air compressor pressure and Check and repair compressed air leak. Furthermore, they can install VSD in compressor motor to reduce energy conservation because the payback period of this measure was very short which was within 3 months. Even though the investment cost of buying air compressor inverter was near with overhaul air compressor, the payback period was extremely shorter.

For production process, the factory G focused on adjusting condition of machine to reduce energy consumption and increase energy efficiency without investment cost such as Reduced repellet, Optimum condition of extruder, Optimum condition of dryer unit and Decrease ethylene temperature to reduce steam. There are left 3 energy conservation measures in production process that have been implemented. They should consider reducing energy conservation in screw element of extruder and bagging unit. Changing screw element in extruder has high investment but payback period is very short. If consider by using payback period as criteria, this is very interesting energy conservation measure. The factory G can apply energy conservation measure that is reduce energy consumption of ethylene compressor by reducing energy consumption in propylene compressor as their product which is Polypropylene (PP).

For steam system, the factory G has been implemented 2 energy conservation measures from 6 energy conservation measures so they still have 4 energy conservation measures that they could apply to their factory. The factory G should consider installing heat recovery equipment such as waste gas recovery boiler or heat exchanger to recovery heat. However, these two measures have high investment cost but short payback period. There is left one energy conservation measure that doesn't have investment cost is steam pressure reduction.

### 5.4 Energy audit checklist

The energy audit checklists are created from identified energy wastes as described in Chapter 3. The checklist shows the possible energy waste areas in each system including lighting system, air conditioning system, air compressor, production process and steam system.

**1. Lighting system**

As shown in Table 13 is the checklist for energy wastes in lighting system. The staff can use this checklist to find waste in the lighting system

Table 14 Energy audit checklist for lighting system

| Activities | Yes | No | Comments |
|---|---|---|---|
| **Lighting** | | | |
| 1.Turn off the lights when leaving the room | | | |
| 2. Turn on lights despite of sufficient daylight | | | |
| 3. Have the high watt light bulbs been used? | | | |
| 4. Have magnetic ballasts been used? | | | |
| 5. Have efficiency lights been used? | | | |
| 6. Are there unnecessary light bulbs? | | | |
| 7. Have lights on in unoccupied areas? | | | |
| 8. Have the employee been trained energy conservation programs? | | | |

**2. Air conditioning system**

Energy wastes for air conditioning system are listed in Table 14. The checklist is designed by questions that collected from energy wastes in plastic resin manufacturing.

Table 15 Energy audit checklist for air conditioning system

| Activities | Yes | No | Comments |
|---|---|---|---|
| **Air conditioner** | | | |
| 1. Are the filters cleaned regularly? | | | |
| 2. Are the air conditioner more than 7 years? | | | |
| 3. Have the ducts leaked? | | | |
| 4. Have the temperature been set at 26-28 $^{\circ}$C ? | | | |
| 5. Have the appliances been turned on during turn on air conditioners? | | | |
| 6. Are the size of pump in chiller unit suitable? | | | |
| 7. Are the water pump old? | | | |
| 8. Are the chiller unit old? | | | |

**3. Air compressor**

Energy wastes in steam system are analyzed to be criteria for energy audit checklist for steam system as shown in Table 15.

**Table 16 Energy audit checklist for air compressor**

| Activities | Yes | No | Comments |
|---|---|---|---|
| Air compressor | | | |
| 1. Does component of steam system leak? | | | |
| -Condensate traps | | | |
| -Shut-off valves | | | |
| -Fittings and pipe joints | | | |
| -Disconnections | | | |
| -Hose | | | |
| 2. Are the filters cleaned regularly? | | | |
| 3. Are the air compressors and motors running without load? | | | |
| 4. Has the VSD been installed a motors? | | | |
| 5. Does the compressor pressure match requirement from end-use equipment? | | | |
| 6. Have the unused equipment been removed or disconnected from compressed air distribution? | | | |

**4. Production process**

The energy audit checklist for production process focuses on an extruder machine and a pelletizer which are the main machines as shown in Table 16.

**Table 17 Energy audit checklist for production process**

| Activities | Yes | No | Comments |
|---|---|---|---|
| Extruder | | | |
| 1. Is an extruder insulated? | | | |
| 2. Is an extruder running without load? | | | |
| 3. Is the heater insulated? | | | |
| 4. Is the barrel insulated? | | | |
| 5. Does the temperature set right? | | | |
| 6. Are the motors proper sizes? | | | |
| 7. Is a screw design right to the extruders? | | | |
| Pelletizer | | | |
| 1. Is a pelletizer running without load | | | |
| 2. Is size of pelletizer suitable? | | | |

**5. Steam system**

Energy wastes in steam system are analyzed to identify criteria for energy audit checklist for steam system as shown in Table 17.

**Table 18 Energy audit checklist for steam system**

| Activities | Yes | No | Comments |
|---|---|---|---|
| **Steam System** | | | |
| 1.Check for leak areas<br>1.1 Connection | | | |
| 1.2 Union | | | |
| 1.3 Pipe Joints | | | |
| 1.4 Steam Traps | | | |
| 1.5 Valves | | | |
| 2.Insultion<br>Boiler | | | |
| Heat Exchanger | | | |
| Pipe distribution | | | |
| Reactor | | | |
| 3. Have the recovery units been installed? | | | |
| 4. Are the pipe distribution oversize? | | | |

**5.5 Recommendation for further studies**

The further studies can be separated into many topics because energy management is broad topic. These are some areas that can be pointed for further study

1. Management of Change

People is important to implement and conduct energy conservation in the factories. They can accept or reject energy conservation. Management of change can help to handle these problems.

2. Continuous improvement

To get the result in long-term, continuous improvement such as Kai-Zen should conduct to get more energy efficiency in the plastic resin process.

# REFERENCES

ANGLANI, N. & BENZI, F. In the proceeding of ICEM (International Conference on Electrical Machines), September 6th - 8th 2010 Rome (Italy)

BANDARA, K., KARANARATHNE, W., ARLAMPLAM, A. & ABEYRATNE, S. 2008. Energy saving by controlling the inlet air flow of oil fired boiler using a VSD driven blower fan.

BHATT, M. 1999. Energy audit case study I steam system. *Applied thermal energy* 20**,** 285-296.

DEPARTMENT OF ALTERNATIVE ENERGY DEVELOPMENT AND EFFICIENCY. 2009. *Development of an energy management system for factory and building* [Online]. Available: http://www.ecc.rmutk.ac.th/file/qa3.pdf [Accessed January 4 2014].

DEPARTMENT OF INDUSTRIAL PROMOTION 2003. *New energy management guideline in the industrial sector,* Bangkok, Nana Printing House.

DEPARTMENT OF INDUSTRIAL WORKS 2004. *Handbook for energy conservation in textile industrial,* Bangkok, The emperor p group.

FAGERHAUG, T., AND ANDERSEN, B. 2006. *Root causes analysis: simplified tools and techniques,* Milwaukee, USA, ASQ Quality Press.

INTELLIGENT ENERGY EUROPE. 2006. *Low Energy Plastics Processing* [Online]. Available: http://www.carbontrust.com/resources/guides/energy-efficiency/energy-management [Accessed January 2 2014].

KAPLOWITZ, M., THROP, L., COLEMAN, K. & YEBOAH, F. 2012. *Energy conservation attitudes, knowledge, and behaviors in science laboratories* [Online]. Available: doi:10.1016/j.enpol.2012.07.060 [Accessed February 3 2014].

KENT, R. 2005. *Energy efficiency in plastic processing* [Online]. Available: www.tangram.co.uk [Accessed March 10 2014].

KLONGKLEW, S. & JONGPRASITTIPORN, S. 2009. *Productivity improvement by preventive maintenance, A case study of bagging and packing section Bangkok Polyethylene Public Company Limited* [Online]. Available: http://www.journal.kmutnb.ac.th/journal/182910255015121.pdf [Accessed March 10 2014].

LEVINJOBET, N. 2010. *Energy analysis in the extrusion of plastics* [Online]. Available: http://www.theseus.fi/bitstream/handle/10024/53774/NANA_LEVI.pdf?sequence=1 [Accessed January 9 2014].

MAHESWARAN, D., JENBU, K., RANGARAJ, V. & ADITHYA, W. 2012. *Energy Efficiency in Electrical Systems* [Online]. Available: 10.1109/PEDES.2012.6484460 [Accessed December 15 2013].

MINISTRY OF INDUSTRY. 2013. *Practical approach to energy saving for medium and small industry* [Online]. Available: http://www.diw.go.th [Accessed December 27 2013].

NA-NARONG, A. 2013. *Energy loss in air compressor* [Online]. Available: http://www.thailandindustry.com/guru/view.php?id=19431&section=9 [Accessed December 15 2013].

NATIONAL METAL AND MATERIALS TECHNOLOGY CENTER. 2007. *Plastic resin process* [Online]. Available: http://www2.mtec.or.th/th/special/biodegradable_plastic/process_plas.html [Accessed March 8 2014].

OFFICE OF INDUSTRIAL TECHNOLOGY. 1988. *Compressed air system leaks* [Online]. Available: http://www.compressedairchallenge.org/library/factsheets/factsheet07.pdf [Accessed March 9 2014].

RHODES, J., STEPHENS, B. & WEBBER, M. 2011. Using energy audits to investigate the impacts of common air-conditioning design and installation issues on peak power demand and energy consumption in Austin, Texas. *Energy and Buildings,* 43**,** 3271-3278.

SCHEPP, C., NICOL, J., TOM, T., NICOL, J. & TABRIZI, M. 2006. *Plastics industry energy best practice guidebook* [Online]. Available: https://focusonenergy.com/sites/default/files/plastics_guidebook.pdf [Accessed January 20 2014].

THAILAND INDUSTRY. 2010. *Value engineering and energy conservation in factory* [Online]. Available: http://www.thailandindustry.com/guru/view.php?id=12094&section=9&rcount=Y [Accessed February 22 2014].

THE INSTITUTE OF INDUSTRIAL ENERGY. 2002. *Energy conservation with value engineering technique* [Online]. Available: http://www.iie.or.th/iie2003/knowledge/casestudy/detail.aspx?id=4 [Accessed February 22 2014].

WANG, F. & CHEN, A. 2012. *Energy Management Handbook* [Online]. Available: http://www.bsr.org/reports/bsr-energy-management-handbook.pdf [Accessed December 2 2013].

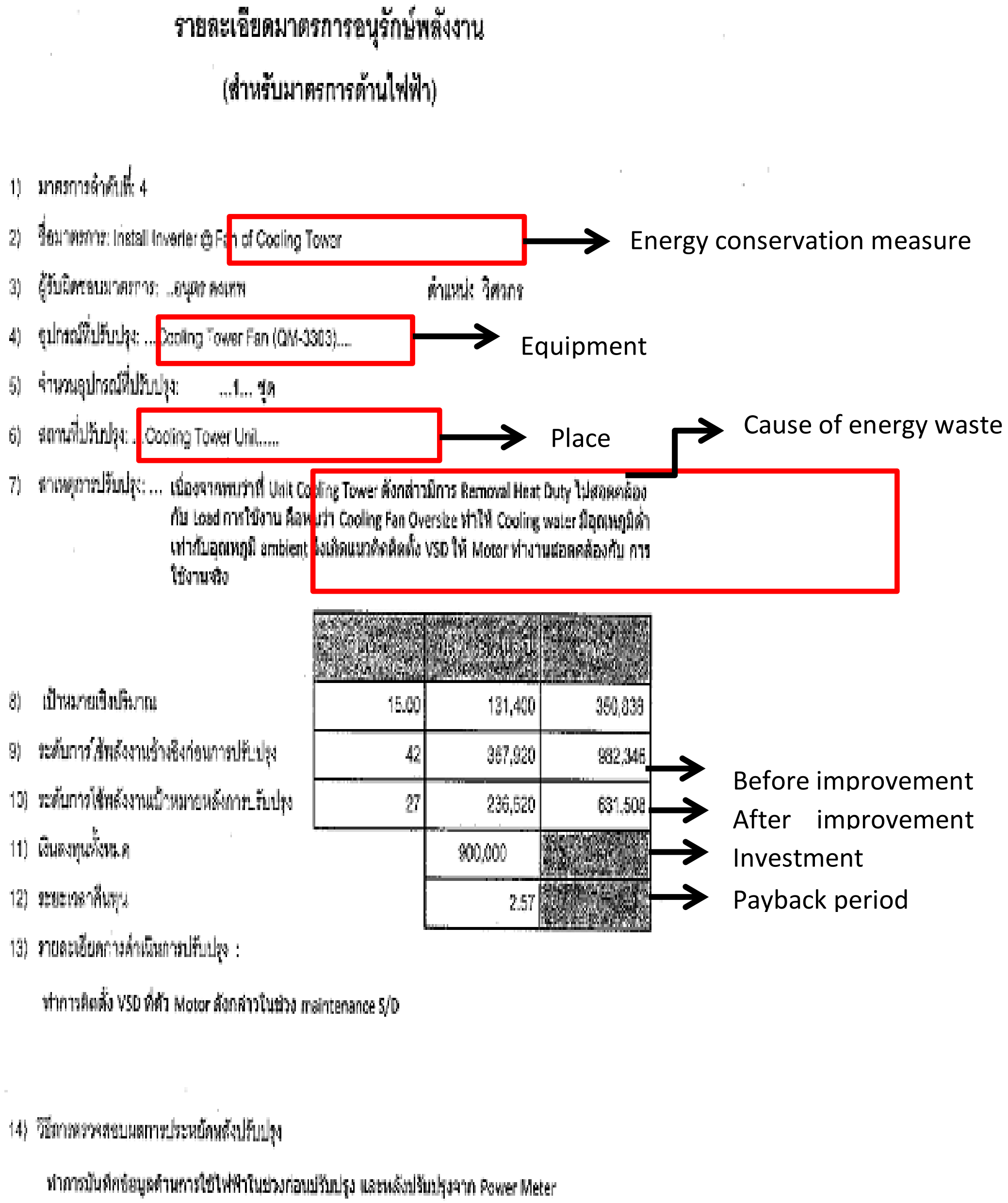
YANG, M. 2009. Air compressor efficiency in a Vietnamese enterprise. *Energy Policy* 37**,** 2327–2337.

# APPENDIX

# APPENDIX A

## AN EXAMPLE OF ENERGY REPORT

## FROM CASE STUDY FACTORY



## รายละเอียดมาตรการอนุรักษ์พลังงาน

## (สำหรับมาตรการด้านไฟฟ้า)

1) มาตรการลำดับที่: 4

2) ชื่อมาตรการ: Install Inverter @ Fan of Cooling Tower

3) ผู้รับผิดชอบมาตรการ: ..อนุชา ผลเทพ ตำแหน่ง: วิศวกร

4) อุปกรณ์ที่ปรับปรุง: ...Cooling Tower Fan (QM-3303)....

5) จำนวนอุปกรณ์ที่ปรับปรุง: ...1... ชุด

6) สถานที่ปรับปรุง: ..Cooling Tower Unit.....

7) สาเหตุการปรับปรุง: ... เนื่องจากพบว่าที่ Unit Cooling Tower ดังกล่าวมีการ Removal Heat Duty ไม่สอดคล้องกับ Load การใช้งาน คือพบว่า Cooling Fan Oversize ทำให้ Cooling water มีอุณหภูมิต่ำเท่ากับอุณหภูมิ ambient จึงเกิดแนวคิดติดตั้ง VSD ให้ Motor ทำงานสอดคล้องกับ การใช้งานจริง

| | [illegible] | [illegible] | [illegible] |
|---|---|---|---|
| 8) เป้าหมายเชิงปริมาณ | 15.00 | 131,400 | 350,838 |
| 9) ระดับการใช้พลังงานอ้างอิงก่อนการปรับปรุง | 42 | 367,920 | 982,346 |
| 10) ระดับการใช้พลังงานเป้าหมายหลังการปรับปรุง | 27 | 236,520 | 631,508 |
| 11) เงินลงทุนทั้งหมด | | 900,000 | |
| 12) ระยะเวลาคืนทุน | | 2.57 | |

13) รายละเอียดการดำเนินการปรับปรุง :

ทำการติดตั้ง VSD ที่ตัว Motor ดังกล่าวในช่วง maintenance S/D

14) วิธีการตรวจสอบผลการประหยัดหลังปรับปรุง

ทำการบันทึกข้อมูลด้านการใช้ไฟฟ้าในช่วงก่อนปรับปรุง และหลังปรับปรุงจาก Power Meter

# APPENDIX B

## ENERGY WASTE IN PLASTIC RESIN MANUFACTURING

Energy waste in plastic resin manufacturing

| No. | Factories | Energy wastes/ Energy audit |
|---|---|---|
| 1. | A | 1. Magnetic ballast<br>2. Using T8<br>3. Using light bulb 40 Watt<br>4. Heat lost at die<br>5. Aging a chiller |
| 2. | B | 1. Decreasing of magnetic ballast efficiency due to in use for a long time<br>2. No have heat recovery unit |
| 3. | C | 1. dusty condensing unit<br>2. Using magnetic ballast<br>3. Over illumination in LDPE office<br>4. Low efficiency motor |
| 4. | D | 1. Air compressor ran unloaded at 25% of full load<br>2. Aging of motor ( motor was used more than 20 years)<br>3. High temperature of motor during operation |
| 5. | E | 1. Compressor operated that necessary |
| 6. | F | 1. Cooling tower operated more than demand |
| 7. | G | 1. Aging cooling water pump<br>2. Low efficiency of recycle gas blower<br>3. Aging air compressor<br>4.Oversize pelletizer<br>5. Oversize cooling fan (motor ran faster than necessary) |

| | | |
|---|---|---|
| | | 7. Oversize pump supply cooling water (supply water that necessary)<br>8. Using inefficiency light bulb ( หลอดนวลจันทร์, T8)<br>9. Steam trap leaked<br>10. Dryer unit มีการใช้ steam ค่อนข้างสูง |
| 8. | H | 1. Air compressor leaked<br>2. Cooling fan ran that necessary |
| 9. | I | 1. Air compressor operated than necessary<br>2. Air compressor leaked<br>3. Steam trap leak |
| 10. | J | 1. Using inefficiency light bulb (T8)<br>2. Improper speed of air blower |
| 11. | K | 1. Aging chiller<br>2. Aging air conditioner |
| 12. | L | 1. Heat loss at extruder<br>2. Illuminating an unoccupied area<br>3. Using inefficiency light bulb (T8) |
| 13. | M | 1. Using inefficiency light bulb (T8)<br>2. Using magnetic ballast<br>3. Heat lose at heater extruder<br>4. Using high pressure sodium light bulb (250 W)<br>5. Using high pressure sodium light bulb (400 Watt) at line process extruder |
| 14. | N | 1. Air compressor system leaked<br>2. Aiging air condition ( life time more than 7 years) |
| 15. | O | 1. Many steps for washing polymerization powder |

| | | |
|---|---|---|
| 16. | P | 1. Pellet transfer compressor consumed electric energy than necessary |
| 17. | Q | 1. Using one switch to control light system<br>2. Using inefficiency light bulb (T8) |

# APPENDIX C

## GENERAL INFORMATION IN PLASTIC RESIN MANUFACTURING

(1) Factory A

The size of factory A is large according to Royal Decree on designated factory B.B. 2540. The factory has been producing various products such as HDPE, PP, ABS, SAN, EPS and PS. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

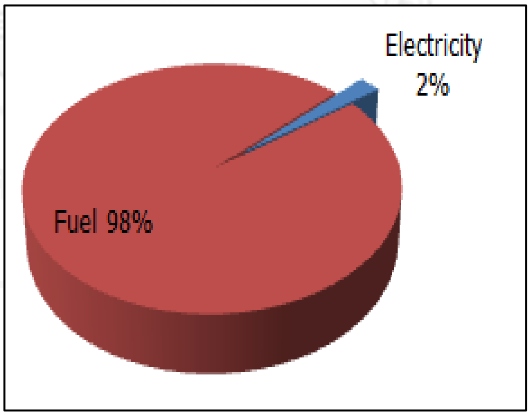
246 days/year

1,968 hours/year

Production: 24 hours/day

365 days/year

8760 hours/year




Proportion of fuel and electricity consumption in factory A

(2) Factory B

Factory B is classified in large manufacturing. Its product is polyacetal (POM). The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

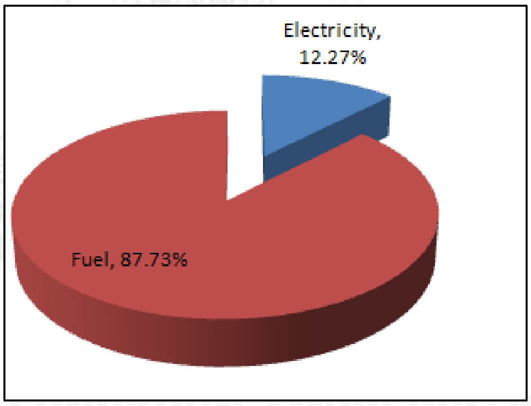
246 days/year

1,968 hours/year

Production: 24 hours/day

335 days/year

8040 hours/year




Proportion of fuel and electricity consumption in factory B

(3) Factory C

Factory C is classified in large manufacturing. Its products are LDPE and EVA. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

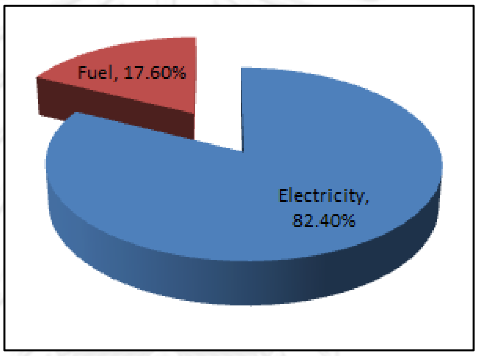
245 days/year

1,960 hours/year

Production: 24 hours/day

334 days/year

7,992 hours/year




Proportion of fuel and electricity consumption in factory C

(4) Factory D

Factory D is classified in large manufacturing. Its product is PP. The factory has both of office and factory area so working hour is indicated into two areas as follows:



Office: 8 hours/day

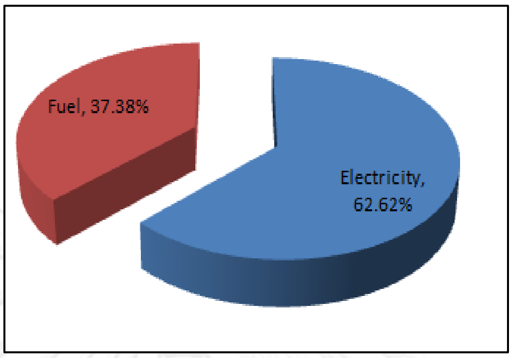
240 days/year

1,920 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory D

(5) Factory E

Factory E is classified in large manufacturing. Its products are PP. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

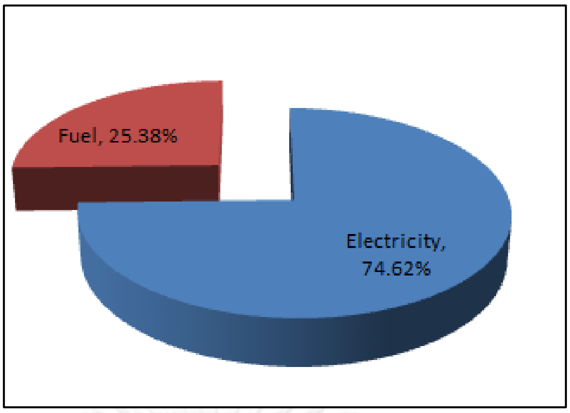
250 days/year

2,000 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory E

(6) Factory F

Factory F is classified in large manufacturing. Its products are Nylon. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

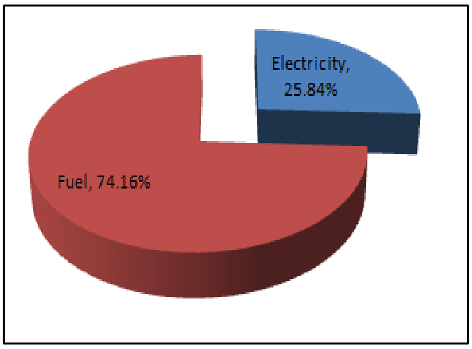
244 days/year

1952 hours/year

Production: 24 hours/day

355 days/year

8,520 hours/year




Proportion of fuel and electricity consumption in factory F

(7) Factory G

Factory G is classified in large manufacturing. Its products are PE. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

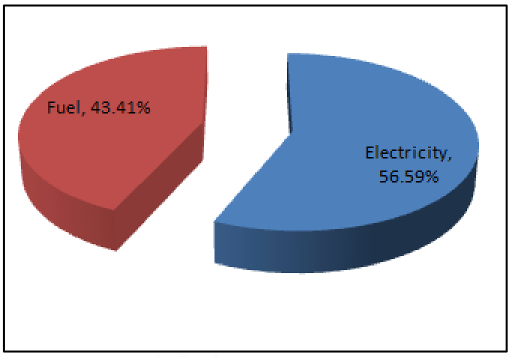
246 days/year

1968 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory G

(8) Factory H

Factory H is classified in large manufacturing. Its products are PVC. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

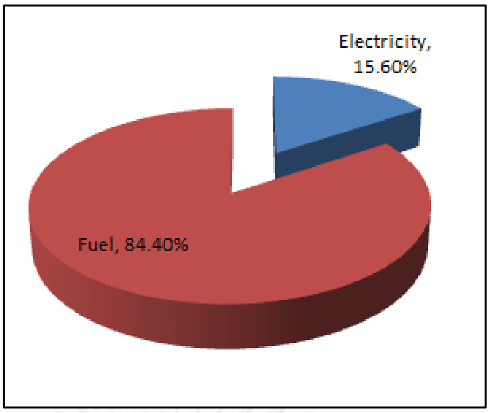
248 days/year

1964 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory H

(9) Factory I

Factory I is classified in large manufacturing. Its products are PVC. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

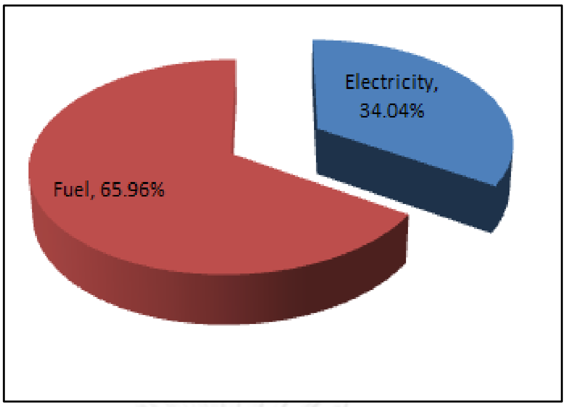
247 days/year

1976 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory I

10. Factory J

Factory J is classified in large manufacturing. Its products are PET. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

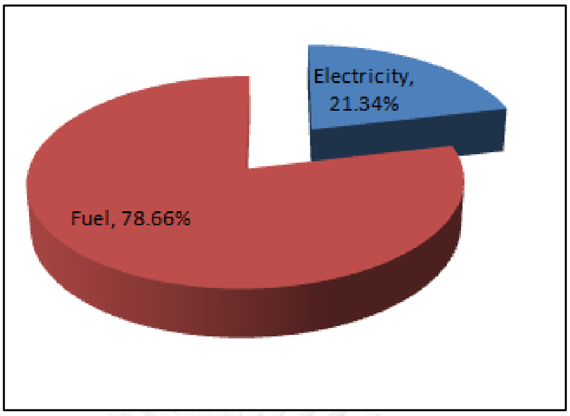
264 days/year

2212 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory J

11. Factory K

Factory J is classified in small manufacturing. Its products are PMMA. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

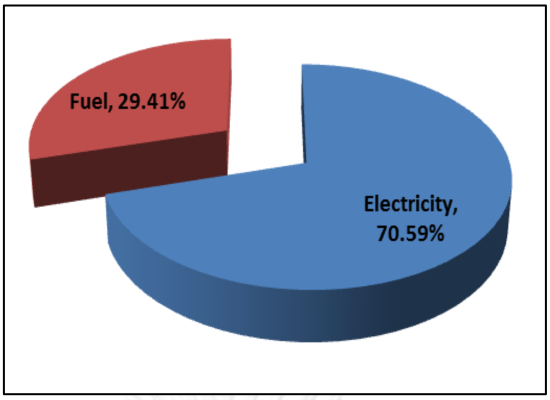
251 days/year

2008 hours/year

Production: 24 hours/day

342 days/year

8,208 hours/year




Proportion of fuel and electricity consumption in factory K

12. Factory L

Factory L is classified in large manufacturing. Its products are PP. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8.30 hours/day

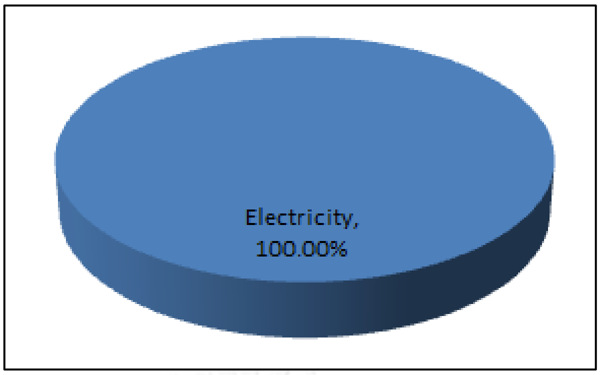
247 days/year

2050 hours/year

Production: 24 hours/day

360 days/year

8,640 hours/year




Proportion of electricity consumption in factory L

13. Factory M

Factory M is classified in large manufacturing. Its products are Nylon, ABS, Polyacetal. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8.50 hours/day

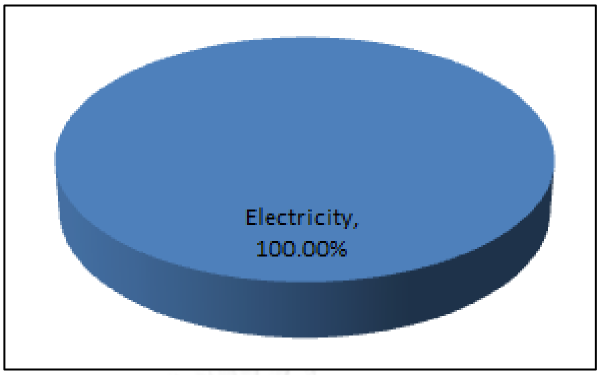
245 days/year

2083 hours/year

Production: 24 hours/day

358 days/year

8,592 hours/year




Proportion of electricity consumption in factory M

14. Factory N

Factory N is classified in large manufacturing. Its product is PP. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

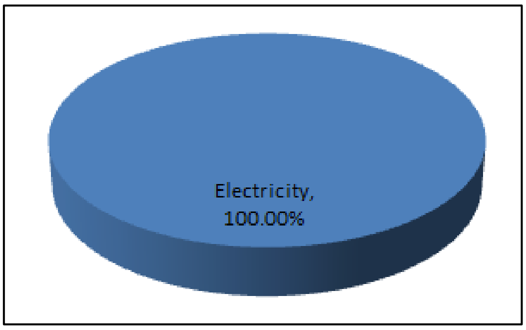
260 days/year

2080 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of electricity consumption in factory N

15. Factory O

Factory O is classified in large manufacturing. Its products are ABS and SAN. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8.50 hours/day

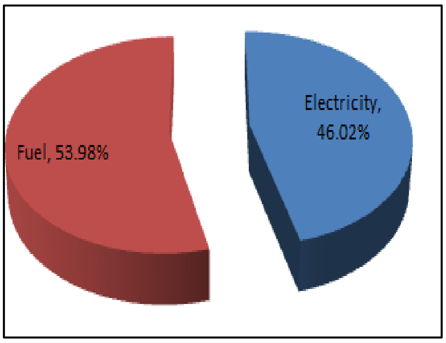
248 days/year

1984 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory O

16. Factory P

Factory O is classified in large manufacturing. Its product is PP. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

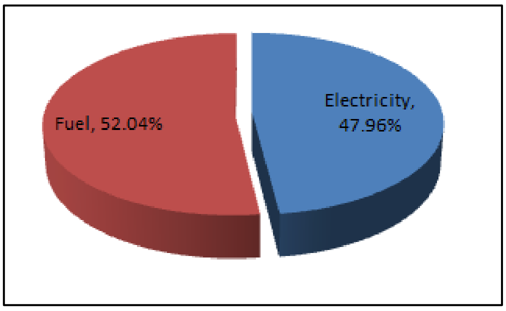
250 days/year

2000 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory P

17. Factory Q

Factory Q is classified in large manufacturing. Its product is PE

. The factory has both of office and factory area so working hour is indicated into two areas as follows:

Office: 8 hours/day

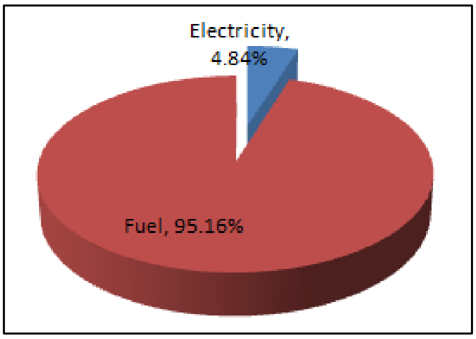
250 days/year

2000 hours/year

Production: 24 hours/day

365 days/year

8,760 hours/year




Proportion of fuel and electricity consumption in factory Q

# APPENDIX D

# THE PROPERTIES OF EFFICIENCY LIHGT COMPARE TO INEFFICIENT LIGHT

| T5 and T8 Fluorescent Lamp Performance Comparison | | | |
|---|---|---|---|
| | T5 | T5HO | T8 |
| Initial rated light output(1) | 2,900 lumens | 5,000 lumens | 2,950 lumens |
| Nominal lamp watts | 28W | 54W | 32W |
| Initial lamp efficacy(1) | 104 lpw | 93 lpw | 92 lpw |
| Initial system efficacy(2) | 89 lpw | 85 lpw | 90 lpw |
| Lumen maintenance(1) | 97% | 95% | 93%(3) |
| Maintained system efficacy | 86 lpw | 81 lpw | 84 lpw |
| Rated life | 16,000 hrs | 16,000 hrs | 20,000 hr |
| Optimum operating temperature | 95°F | 95°F | 77°F |

*(1) Based on 4 ft nominal lamp length, 85 CRI lamps*

*(2) Based on 4 ft nominal lamp length, 85 CRI, 2-lamp rapid-start electronic ballast*

*(3) This value varies, depending on manufacturer and phosphor coating technology used in the manufacturing process*

**Table 1. T5 and T8 fluorescent lamp performance comparison.**

# APPENDIX E

# ENERGY WASTE CLASSIFIED IN SYSTEMS

From these data can conclude energy waste as systems such as lighting system, air conditioning system, air compressor system, cooling system, production process, steam system and other systems.

Energy wastes classified by systems

| System | Energy Wastes |
|---|---|
| 1. Lighting | 1. Magnetic ballast<br>2. Using inefficiency light bulb (T8)<br>3. Using one switch to control light system<br>4. Using high pressure sodium light bulb (250 W)<br>5. Using high pressure sodium light bulb (400 Watt)<br>6. Using light bulb 40 Watt<br>7. Over illumination in LDPE office<br>8. Decreasing of magnetic ballast efficiency due to in use for a long time<br>9. Illuminating an unoccupied area<br>10. Turing on lighting at lunch break |
| 2. Air conditioning | 1. Dusty condensing unit<br>2. Aging air conditioner (more than 7 years)<br>2. Aging a chiller<br>6. Aging cooling water pump<br>9. Oversize pump supply cooling water (supply water that necessary)<br>8. Oversize cooling fan (motor ran faster than necessary)<br>10. Cooling fan ran that necessary |

| System | Energy Wastes |
|---|---|
| 3. Air compressor | 1. Air compressor system leaked<br>2. Air compressor operated than necessary<br>3. Air compressor ran unloaded at 25% of full load |
| 4. Production process | 1. Heat loss at die<br>2. Oversize pelletizer<br>3. Heat loss at extrude<br>4. Heat loss at heater extrude<br>5. Many steps for washing polymerization powder<br>6. Pellet transfer compressor consumed electric energy than necessary<br>7. High steam use at dryer unit |
| 5. Steam | 1. No have heat recovery unit<br>2. Steam trap leaked |
| 6. Other systems | 1. Improper speed of air blower<br>3. Low efficiency motor<br>4. Aging of motor ( motor was used more than 20 years)<br>5. High temperature of motor during operation<br>7. Low efficiency of recycle gas blower<br>11. Improper speed of air blower |

# APPENDIX F

## COLLECTED ENREGY CONSERVATION MEASURES IN PLASTIC RESIN MANUFACTURING

Energy conservation measures in plastic resin manufacturing

| System | Energy Wastes |
|---|---|
| Lighting (11) | -Used electronic ballasts instead of magnetic ballasts (A, B)<br>- Changed T8 light bulbs to T5 (A, B ,G, I, L, M, Q)<br>- Change 40-watts bulbs to 36-watts bulbs (A)<br>- Control time to turn on/off lights (C)<br>- Change hi-bey in warehouse (G)<br>- Change hi-bey from 250 W to 100W (I)<br>- Reduced lighting in unoccupied areas (L)<br>- Using pull switch to control lights on/off (L, N)<br>- Change from HPS 250 watts to LED 30 watts (M)<br>- Change from hi-bey 400 to fluorescent 5x54 watts (M)<br>- Separated switch control (Q) |
| Air conditioner (5) | - Replace new chiller at chiller unit (A, K)<br>- Control time to turn on/off air conditioner (C)<br>- Install inverter at fan of cooling tower (G, H)<br>- Cleaned condenser chiller (I)<br>-Replace new air conditioner (K)<br>- Optimum of cooling water supply (G)<br>- Installed cooling PAD(G) |
| Air compressor (9) | -Reduced air compressor pressure (A, H)<br>- Installed air compressor inverter (D)<br>- Overhaul air compressor (G)<br>- Checked and repaired compressed air leak (H, I, N)<br>- Install VSD on air compressor (I) |

Energy conservation measures in plastic resin manufacturing (Cont.)

| System | Energy Wastes |
|---|---|
| Production (12) | - Changed screw element for extruders (A)<br>- Reduced downtime at bagging unit (PP) (A)<br>- Reduced power consumption of ethylene compressor PP (E)<br>- Reduced repellet (G)<br>- Optimum condition of extruders (G)<br>- Optimum condition of dryer unit (G)<br>- Decrease ethylene temperature to reduce steam (G)<br>- Reduce electric consumption at pellet transfer blower and rotary valve (O)<br>- Improved washing process (O)<br>- Heater insulation (L, M)<br>- Using Advance Process Control (APC) to control LLDPE production (Q)<br>- Reduce power consumption at pellet transfer compressor (P) |
| Steam (6) | - Installed waste gas recovery boiler (B)<br>- Repaired and surveyed steam traps (G, I)<br>- Increasing efficiency of steam (G, H)<br>- Install new heat exchanger (G)<br>- Reduced steam pressure (H)<br>- Using heat exchanger to recover waste heat (H) |

Energy conservation measures in plastic resin manufacturing (Cont.)

| System | Energy Wastes |
|---|---|
| Other (5) | - Control to turn on/off computer (C)<br>- Changed to high efficiency motor (D)<br>- Install VSD on blowers (J)<br>-Tie load of cooling tower (F)<br>- Maintenance machine appropriately (H) |

# VITA

Ms. Phatcharaporn Chaivisad was born on 23 May 1988 in Mukdahan. She completed bachelor’s Degree of Engineering, Petrochemical and Polymeric Materials from Silpakorn University, Thailand in 2010. Then she continues her Master degree at Regional Centre for Manufacturing Systems Engineering and University of Warwick in the major of Engineering Supply Chain and Logistic Management.