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A review on energy saving strategies in industrial sector

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ABSTRACT

An industrial sector uses more energy than any other end-use sectors and currently this sector is consuming about 37% of the world's total delivered energy. Energy is consumed in the industrial sector by a diverse group of industries including manufacturing, agriculture, mining, and construction and for a wide range of activities, such as processing and assembly, space conditioning, and lighting. This paper presents a comprehensive literature review about industrial energy saving by management, technologies and policies. Latest literatures in terms of thesis (MS and PhD), journal articles, conference proceedings, web materials, reports, books, handbooks on industrial energy management, policies and energy savings strategies have been compiled. Energy saving by management including energy audit, training programs and housekeeping beside some energy management practices in the world has been reviewed. Energy saving technologies, such as use of high efficiency motors (HEMs), variable speed drives (VSDs), economizers, leak prevention and reducing pressure drop has been reviewed. Based on energy saving technologies results, it has been found that in the industrial sectors, a sizeable amount of electric energy, emissions and utility bill can be saved using these technologies. Payback periods for different energy savings measures have been identified and found to be economically viable in most cases. Finally, various energy-saving policies for few selected countries were reviewed.

Contents

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Nomenclature

ABS_{HEM}	Annual bill saving when using high efficient motors (kWh/year)
ABS_{VSD}	Annual bill saving of VSD (RM/year)
AC_{KWH}	Annual energy consumption (kWh/year)
ACS_L	Annual cost saving from Leaks
AEC_{BAU}	Annual energy consumption without variable speed drive (kWh/year)
ACE_{NP}	Annual energy consumption with variable speed drive (kWh/year)
AER_{CO_2}	Annual emissions reduction of CO_2 (kg/year)
AER_{SO_2}	Emission factor of SO_2 (kg/kWh)
AES_{HEM}	Annual energy saving when using high efficient motors (kWh/year)
AES_{VSD}	Annual energy saving when using variable speed (kWh/year)
$AES_{CS_{leak}}$	Annual energy savings by preventing leak (MWh/year)
AUE	Annual energy usage
EF_{CO_2}	Emission factor of CO_2 (kg/kWh)
EF_{CO}	Emission factor of CO (kg/kWh)
EF_{NO_x}	Emission factor of NO_x (kg/kWh)
EF_{SO_2}	Emission factor of SO_2 (kg/kWh)
FR_i	Ratio of proposed power consumption to current power consumption
$ES_{\%}$	Energy savings percentage by preventing leak
FEC	Fuel energy content (kJ/kg)
GR	Generation requirement (kW/cfm)
IC_{HEM}	Incremental cost of high efficient motors (RM)
IC_{HR}	Incremental cost of heat recovery system (Economizer) (RM)
IC_{VSD}	Incremental cost of VSD (RM)
K	The ratio of specific heat for air (k = 1.4)
L	Load factor (percentage of full load)
LR	leakage rate (cfm)
N_{Hp}	Motor horsepower (Hp)
N_L	Number of leaks
N_{motors}	Number of motors
OPH	Operating hours in year (h/year)
P	Pressure (kPa)
PBP_{HEM}	Payback period of high efficient motors (years)
PBP_{HR}	Payback period of heat recovery (years)
PBP_{VSD}	Payback period of VSD (years)
P_{dc}	Discharge pressure at current pressure conditions (kPa)
P_{dp}	Discharge pressure at proposed operating pressure conditions (kPa)
P_i	Inlet pressure
SR_{ratio}	Speed reduction ratio
T	off-load time (min)
t	on-load time (min)
$TABS_{HR}$	Total annual bill saving of heat recovery (RM/year)
$TAES_{HR}$	Total annual energy saving of Heat recovery (kWh/year)
UEP	Unit energy price (RM/kWh)
$UFP_{\square}$	Unit fuel price (RM/liter or RM/kg)
V	Volume ($m^{3)}$
ρ_f	Density of a particular fuel (kg/m^3)
η_{motor}	Efficiency of motor
$\eta_{std\ motor}$	Efficiency of standard motor
$\eta_{ef\ motor}$	Efficiency of efficient motor

%F	Percentage of fuel (%)
$\%_{fg}$	Percentage of heat losses in flue gas
$\%_{HR}$	Efficiency of heat recovery system
3600	Conversion factor from kWh to kJ
0.7456	Conversion factor from horsepower to kilowatt

1. Energy consumption

Energy is a basic need for different purposes in industrial facilities around the world. Huge amount of energy needed for countries with faster economic growth. Energy is thus a crucial factor for economic competitiveness and employment. However, global population and energy needs are increased hand-in-hand. This concern must be addressed by the international community to overcome any shortage of energy resources in the future.

World marketed energy consumption is projected to increase by 33% from 2010 to 2030. Total world energy use rose from 82,919 ZW in 1980 to 116,614 ZW in 2000 and then is expected to reach 198,654 ZW in 2030 as shown in Fig. 1 [1].

The most rapid growth in energy demand from 2006 to 2030 is projected for nations outside the Organization for Economic Cooperation and Development (non-OECD nations). This is because, in recent decades, OECD countries have been in transition from manufacturing economies to service economies. Total non-OECD energy consumption was increased by 73% compared to a 15% increase in energy use among the OECD countries [1].

The USA consumes 25% of the world's energy. However, the most significant growth of energy consumption is currently taking place in China, which has been growing at 5.5% per year [1].

The industrial sector uses more energy than any other end-use sectors, currently consuming about 37% of the world's total delivered energy. Energy is consumed in the industrial sector by a diverse group of industries including manufacturing, agriculture, mining, and construction and for a wide range of activities, such as processing and assembly, space conditioning, and lighting. Over the next 25 years, worldwide industrial energy consumption is projected to grow from 51,275 ZW in 2006 to 71,961 ZW in 2030 by an average of 1.4% per year (Fig. 2) [1,2].

1.1. Industrial energy consumption by fuel

Fuel prices shape the mix of fuel consumption in the industrial sector, as industrial enterprises are assumed to choose the cheapest fuels available to them, whenever possible. Because liquid fuels are more expensive than other fuels, world industrial sector liquid fuels use increased at an average annual rate of only 0.68% and the share of liquid fuels in the industrial fuel mix declines. The liquid fuels share is displaced primarily by electricity use, which grows by an average of 3.5% per year from 2006 to 2030 (Figs. 3–5) [1].

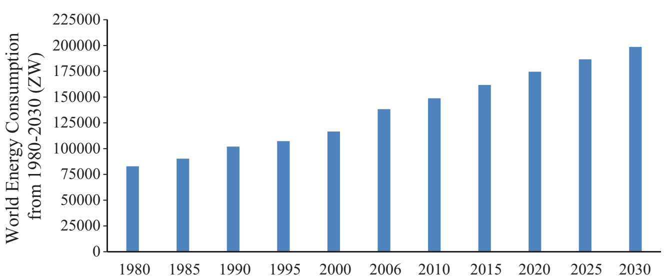

Fig. 1. World marketed energy consumption from 1980 to 2030 (ZW) [1].

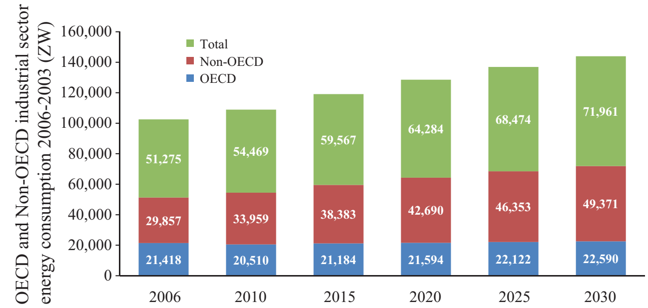

Fig. 2. OECD and non-OECD industrial sector energy consumption from 2006 to 2003 (ZW) [1].

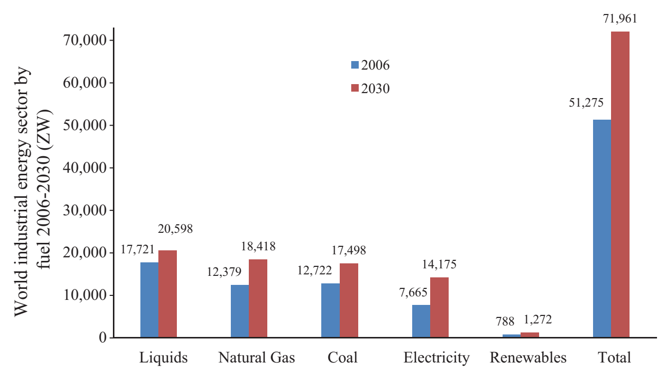

Fig. 3. World industrial energy consumption by fuel in 2006 and 2030 (ZW) [1].

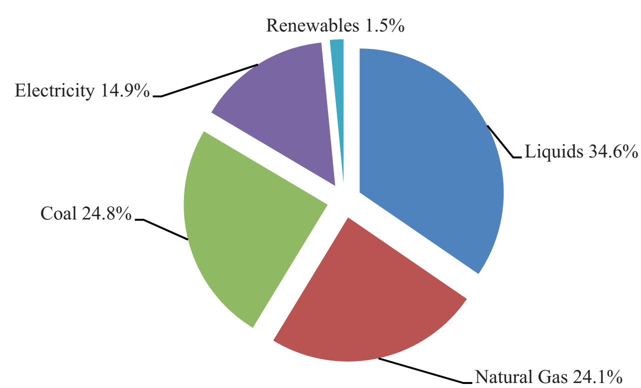

Fig. 4. World industrial energy sector share by fuel in 2006.

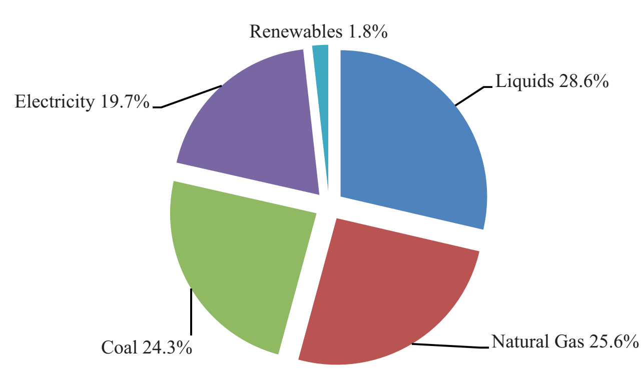

Fig. 5. World industrial energy sector share by fuel in 2030.

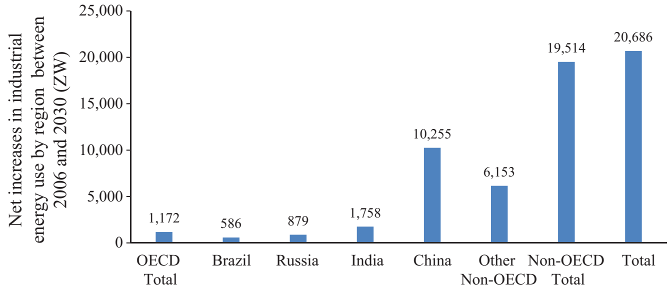

Fig. 6. Net increases in industrial energy use by region between 2006 and2030 (ZW) [1].

1.2. Industrial energy consumption by regions

Currently, non-OECD economies consume 62% of global delivered energy in the industrial sector. By the year 2030, industrial energy use in the non-OECD is expected to grow at an average annual rate of 2.7%. The so-called "BRIC" countries (Brazil, Russia, India, and China) account for more than two-thirds of the growth in non-OECD industrial energy use (Fig. 6). Because the OECD nations have been undergoing a transition from manufacturing economies to service economies in recent decades and have relatively slow projected growth in economic output, industrial energy use in the OECD region as a whole grows by an average of only 0.2% per year from 2006 to 2030 [1].

Fig. 7 provides historical energy consumption in the industrial sector for ten regions around the world from 1971 to 2004. Primary energy consumption in the industrial sector grew from 89 EJ to 160 EJ during this period [2].

1.2.1. Industrial energy consumption in USA

The United States is the largest energy consumer in terms of total use. In 2004, industrial used about 33% of the total energy use (Fig. 8).

Most of the energy consumed in the industrial sector in USA is used for manufacturing. The remainder goes to mining, construction, agriculture, fisheries, and forestry. Within manufacturing, large consumers of energy are the petroleum and coal products, chemicals and allied products, paper and allied products, and primary metal industries as shown in Fig. 9 [1,3].

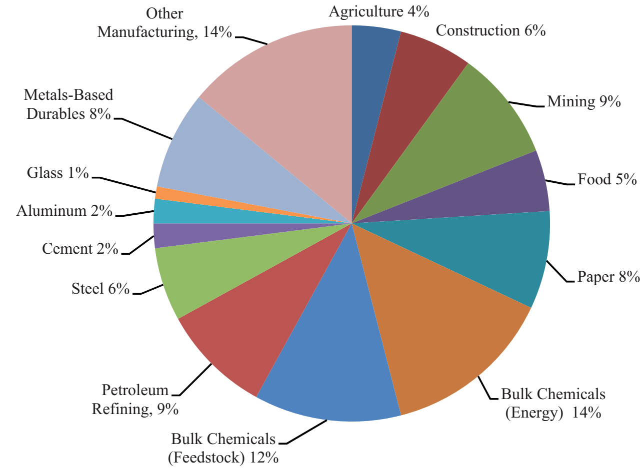

Fig. 9. Primary energy use in industry by industrial sub-sector in 1997 [3].

1.2.2. Industrial energy consumption in China

China's GDP has been growing steadily by about 10% every year since 2003. This surpasses the country's aim to grow at 7.5% per year, set out in its 11th Five-Year Plan, covering 2006–2010. China alone accounts for about 23% of world industrial energy use. China's industrial sector is extremely energy-intensive and accounted for 60% of the country's total energy use in 2000 and 70% in 2003 respectively. Industrial energy use in China grew at an average rate of 5% per year [2,4–6]. This growth is five times faster than the average growth that took place in the industrial sector worldwide during the same time period. Energy end use consumptions by sector in China from 1985 to 1997 and 2003 are shown in Figs. 10 and 11 respectively. In 2003, manufacturing used 85.2% of the final industrial energy use as shown in Fig. 12 [4–7].

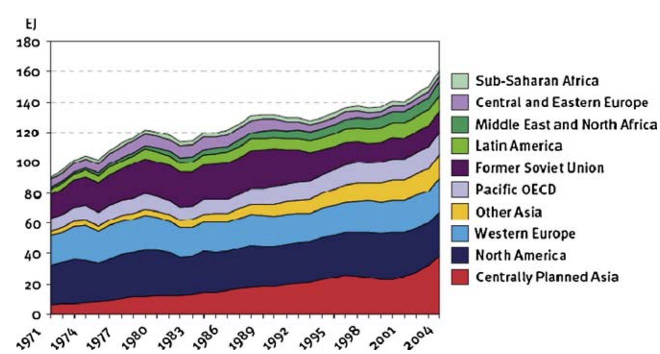

Fig. 7. Historical industrial energy consumption by major world region [2].

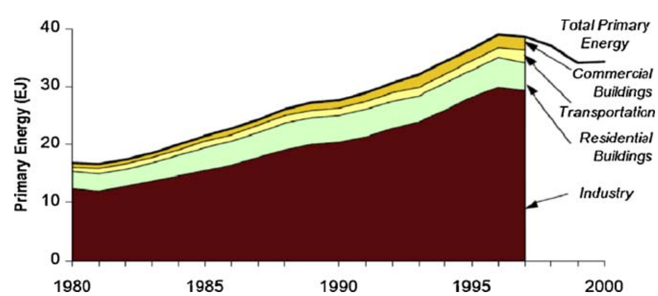

Fig. 10. Total energy consumption by sector in China from 1985 and 199 [4,5,7].

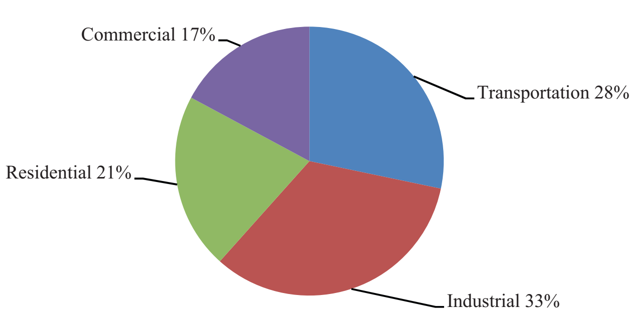

Fig. 8. Percentage of energy consumption by sector in USA in 2004 [1].

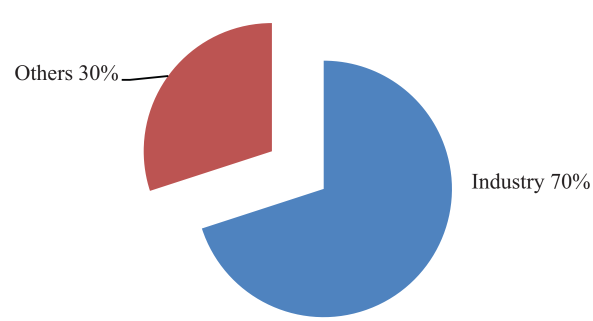

Fig. 11. Share of industry in 2003.

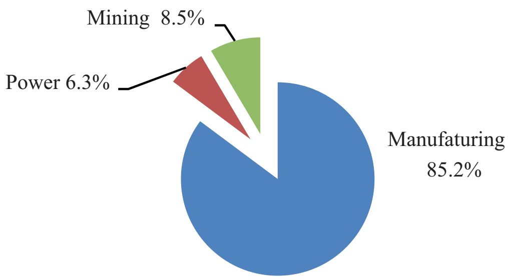

Fig. 12. Final energy consumption mix of industry in 2003.

1.2.3. Industrial energy consumption in India

India is projected to sustain the world's second-highest rate of GDP growth, averaging 5.6% per year from 2006 to 2030. This translates into a 2.3% average annual increase in delivered energy to the industrial sector. India's economic growth over the next 25 years is expected to derive more from light manufacturing and services than from heavy industry, so that the industrial share of total energy consumption falls from 72% in 2006 to 64% in 2030. The changes are accompanied by shifts in India's industrial fuel mix, with electricity use growing more rapidly than coal use in the industrial sector [1].

1.3. Industrial energy consumption by major energy-intensive industry shares

In 2006, five industries account for 68% of all energy used in the industrial sector (Fig. 13): chemicals (29%), iron and steel (20%), nonmetallic minerals (10%), pulp and paper (6%), and nonferrous metals (3%). The quantity and fuel mix of future industrial energy consumption will be determined largely by energy use in those five industries. In addition, the same industries emit large quantities of carbon dioxide, related to both their energy use and their production processes [1].

1.4. Importance of energy efficiency in industry

Industrial development across the world will result in more energy use and will lead to more concentration of greenhouse gases such as carbon dioxide (CO_2) and other emissions such as sulfur dioxide (SO_2), nitrogen oxide (NO_x) and carbon monoxide (CO) which all have disastrous consequences for the earth's climate like rising temperature, drought, floods, famine and economic chaos [8]. The Intergovernmental Panel on Climate Change (IPCC) reported that continued emissions will lead to a temperature increase of between 1.4 and 5.8 °C over the period from 1990 to 2100. Furthermore, The Department of Energy (The United States of America) highlighted that, global carbon emissions are rising more than 2% per year and by 2015 may be more than 50% above 1997 level, all of which because of increasing energy demand and inefficient way of energy use [9].

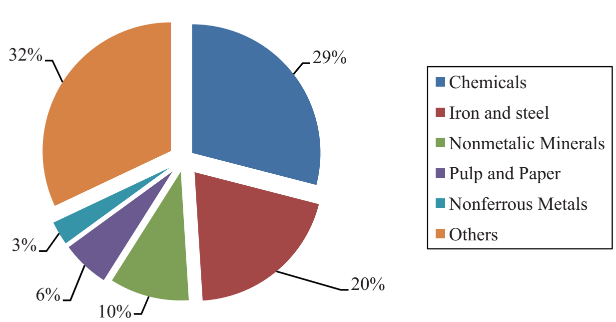

Fig. 13. World industrial sector energy consumption by major energy-intensive industry shares in 2006 [1].

Energy efficiency in the industrial sector began to be considered one of the main functions in the 1970s. Since then, the world has trimmed its energy budget by utilizing higher efficiencies, while still growing economically, and has realized the importance of protecting the environment.

In industry, large plants with high energy consumption tackled the problem by retrofitting process plants and facilities. Other industrial sectors resorted to investments with the shortest possible payback such as heat recovery and reduction of losses [10,11]. In industry, energy efficiency can be improved by three different approaches as follow:

1. Energy savings by management.
2. Energy saving by technologies.
3. Energy saving by policies/regulations.

In this study each part of these approaches are discussed in details.

2. Energy management

Energy management is the strategy of meeting energy demand when and where it is needed. This can be achieved by adjusting and optimizing energy using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total costs of producing the output from these systems [11,12]. Energy management began to be considered one of the main functions of industrial management in the 1970s as the result of the rising price of energy and reports about the approaching exhaustion of world energy resources [11].

Nowadays, the role of energy management has greatly expanded in industries. Top management of the company participates in planning various energy management projects on a regular basis. The annual reports of the many companies should mention the details of energy conservation activities and various achievements by the company regarding energy conservation projects. To be effective, energy management programs should include four main sections [11,13]: (1) Analysis of historical data; (2) Energy audit and accounting; (3) Engineering analysis and investments proposals based on feasibility studies; (4) Personnel training and information.

2.1. Objectives of energy management

The objectives of energy management are: To minimize energy costs/waste without affecting production and quality and to minimize environmental effects [12].

2.2. Organizational structure and energy management program

The components of comprehensive energy management program are: the organizational structure, a policy and plan for audit, education, reporting and strategy. All these components are depicted in Fig. 14.

2.3. Types of energy savings by management

There are many types of energy saving by management. In this review three types will be discussed as follow:

1. Energy audit.
2. Energy efficiency courses and training program.
3. Housekeeping.

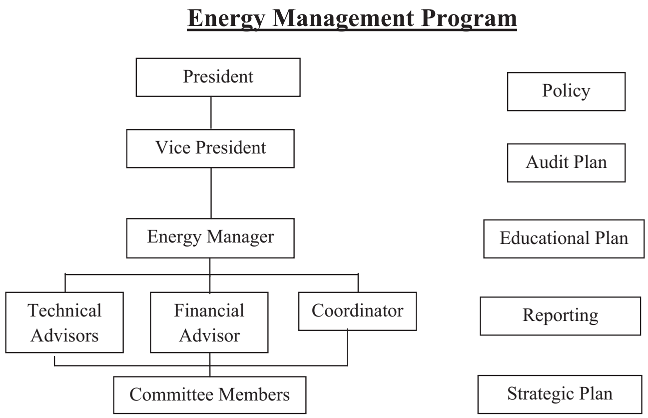

Fig. 14. Organizational structure and energy management program [14].

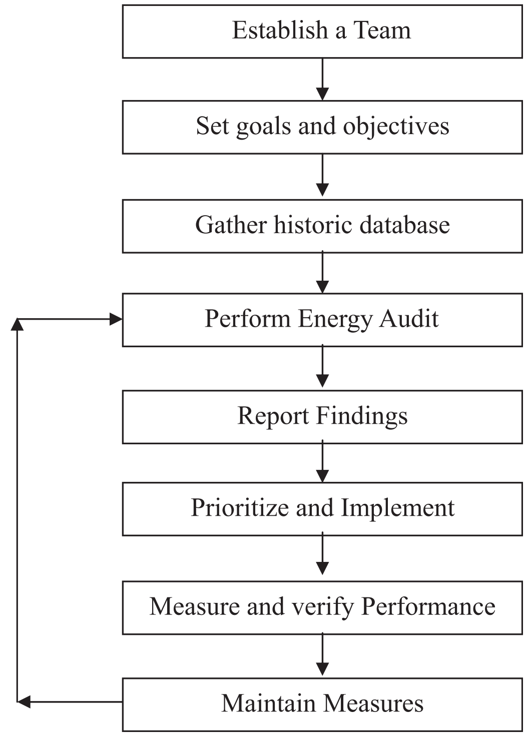

Fig. 15. Typical energy audit program [15].

2.3.1. Energy audit

Energy audit is an inspection, survey and analysis of energy flows for energy conservation to reduce the amount of energy input into the system without negatively affecting the output. The energy audit is the key for decision-making in the area of energy management. Energy audit is thus a reliable and systematic approach in the industrial sector. It helps any organization to analyze its energy use and discover areas where energy use can be reduced and waste can occur, plan and practice feasible energy conservation methods that will enhance their energy efficiency, serve to identify all the energy streams in a facility, quantify energy usage, in an attempt to balance the total energy input with its use [15].

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labor and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction [12].

2.3.1.1. Energy audit process and resources. Energy audit requires a systematic approach-from the formation of a suitable team, to achieving and maintaining energy savings. A typical process is outlined in Fig. 15. Resources required for an energy audit are shown in Fig. 16.

2.3.1.2. Benefits of energy audit. Many benefits can be achieved through energy audit. Some of these benefits are [15]:

Reduction in specific energy consumption and environmental pollution.
Reduction in operating costs (approximately 20–30%) by systematic analysis.
Improves the overall performance of the total system and the profitability and productivity.
Slower depletion of natural resources and narrowing demand supply gap.
Averts equipment failure.

2.3.1.3. Types of energy audit. There can be three types of energy audits:

1. Preliminary audit
2. General audit
3. Detailed audit

2.3.1.3.1. Preliminary audit. Preliminary audit (alternatively called a simple audit, screening audit or walk-through audit) is the simplest and quickest type of audit and conducted in a limited span of time. It involves minimal interviews with site-operating personnel, a brief review of facility utility bills and other operating data, and a walk-through of the facility to become familiar with the building operation and to identify any glaring areas of energy waste or inefficiency. It focuses on major energy supplies and demands of the industry. The scope of this audit is to highlight energy costs and to identify wastages in major equipment processes it sets priorities for optimizing energy consumption. This type of energy audit checks energy use and energy management in factories [15].

Preliminary energy audit is conducted to [12]:

- Ensure top management commitment.
- Establish energy consumption in the organization.
- Estimate the scope for saving.
- Identify the most likely (and the easiest areas for attention).
- Identify immediate (especially no-/low-cost) improvements/savings.
- Identify areas for more detailed study/measurement.
- Preliminary energy audit uses existing, or easily obtained data.

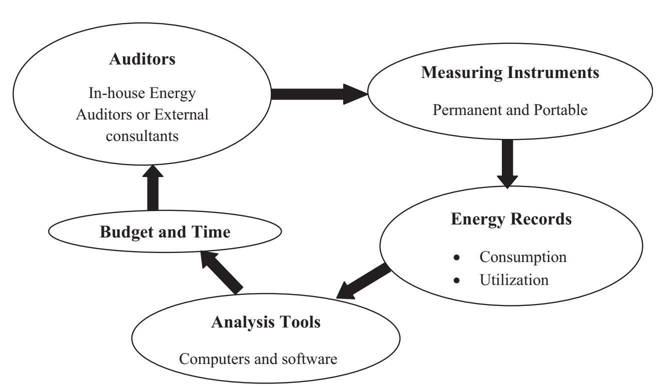

Fig. 16. Resources required for an energy audit [16].

2.3.1.3.2. General audit. The general audit alternatively called a mini-audit, site energy audit or complete site energy audit expands on the preliminary audit described above by collecting more detailed information about facility operation and performing a more detailed evaluation of energy conservation measures identified. Utility bills are collected for a 12–36 months period to allow the auditor to evaluate the facility's energy/demand rate structures, and energy usage profiles. Additional metering of specific energy-consuming systems is often performed to supplement utility data. In-depth interviews with facility operating personnel are conducted to provide a better understanding of major energy-consuming systems as well as insight into variations in daily and annual energy consumption and demand [15].

2.3.1.3.3. Detailed audit. The detailed audit (alternatively called a comprehensive audit, Investment-grade audit, maxi audit, or technical analysis audit) expands on the general audit described above by providing a dynamic model of energy-use characteristics of both the existing facility and all energy conservation measures identified. The building model is calibrated against actual utility data to provide a realistic baseline against which to compute operating savings for proposed measures. Extensive attention is given to understanding not only the operating characteristics of all energy-consuming systems, but also situations that cause load profile variations on short and longer term bases (e.g. daily, weekly, monthly, annual). Existing utility data is supplemented with submetering of major energy-consuming systems and monitoring of system operating characteristics [15]. Generally, detailed energy auditing is carried out in three phases: Phases I, II and III as follow [12]:

Phase I – pre-audit phase, **Phase II** – audit phase, and **Phase III** – post-audit phase (Table 1).

2.3.1.4. Tools for energy audit. To conduct a detailed energy audit in industry, there are many tools needed to get the pertinent data for motor energy use some of these tools are [12,15]:

1. Fuel efficiency monitor: This measures oxygen and temperature of the flue gas. Calorific values of common fuels are fed into the microprocessor which calculates the combustion efficiency.
2. Clamp-on power meter: This type of meter helps measure power consumption, current drawn, load factor and power factor. The meter should have a clamp-on feature to measure current and probes to gauge voltage so that measurements can be recorded without any disruption to normal operation.
3. Leak detectors: Ultrasonic instruments are available which can be used to detect leaks of compressed air and other gases which are normally not possible to detect with human abilities.
4. Portable tachometer: This meter is useful for measuring the speed of the motor. Optical type tachometer is preferable due to the ease of measurement.
5. Thermocouple sensor: Thermometer/thermocouple sensors are useful to measure the temperature of the motor so that level of temperature can be checked whether motor is overheated or not. This will prevent motor failure or damage. Moreover, temperature gain will cause a motor to consume more energy. Knowing temperature allows the auditor to determine motor efficiency. Most commonly used sensors in industry are RTDs and thermistors.
6. Data logger: Data loggers are used to monitor and log data such as temperatures, motor current, and power. Data loggers are normally portable and can accept different inputs from sensors.

Table 1
Ten steps methodology for detailed energy audit [12].

Step no.	Plan of action
Phase I – pre-audit phase	
Step 1	Plan and organize Walk-through audit Informal interview with energy manager, production manager
Step 2	Conduct of brief meeting/awareness program with all divisional heads
Phase II – audit phase	
Step 3	Primary data gathering, process flow diagram and energy utility diagram
Step 4	Conduct survey and monitoring
Step 5	Conduct of detailed trials/experiment for the highest energy consumption equipments
Step 6	Analysis of energy use
Step 7	Identification and development of energy conservation (ENCON) opportunities
Step 8	Cost–benefits analysis
Step 9	Reporting and presentation to the top management
Phase III – post-audit phase	
Step 10	Implementation and follow up

2.3.2. Energy efficiency courses and training program

Energy efficiency courses and training programs are very important to increase the awareness of people who are involved in the industrial sector. Generally, there are two ways to get an industrial energy management course. The first one is relevant to engineers working in industry, while the second is based on the energy management course at the university level. In both of these, an energy management certificate is given to the participants who complete the course successfully and submit an energy conservation report. This report covers a case study, which is an actual on site study or analysis performed for an industry. These courses, in general, focus on legal, technological, environmental, social and economical dimensions of energy efficiency as shown in Fig. 17 [10,17].

2.3.3. Energy saving by housekeeping

In industry, efficient production and a good working environment are complementary. The elimination of inefficiencies and accident hazards caused by unfavorable conditions in the workplace is essential in getting the job done efficiently and safely. The attention to these important details is widely referred to as "good housekeeping".

Housekeeping involves every phase of industrial operations. It is more than mere cleanliness. It requires orderly conditions, the avoidance of congestion, and attention to such details as an orderly layout of the whole workplace, the marking of aisles, adequate

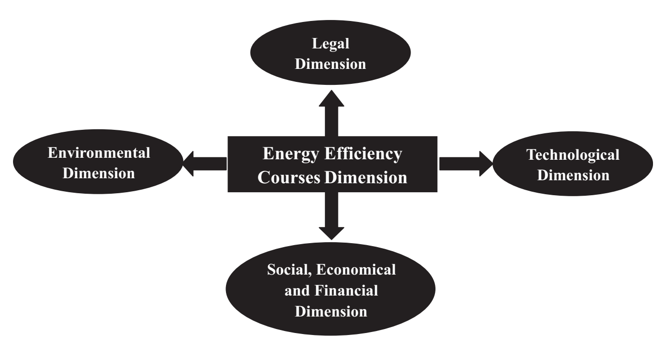

Fig. 17. Energy efficiency courses and its dimensions [17].

storage arrangements, and suitable provision for cleaning and maintenance [78].

2.3.3.1. Elements of a good housekeeping campaign. The following are some of the basic elements of a good housekeeping that save energy in any industrial company [78].

- **Lighting**: Well-distributed artificial light and effective use of available daylight could save energy significantly.
- **Waste removal**: Adequate facilities to prevent congestion and disorder. Some of these elements are:
  (1) **Paint the walls**: Light-colored walls reflect light. Dirty or dark-colored walls absorb light.
  (2) **Maintain the light fittings**: Attention to light fittings should be an integral part of any good housekeeping program. Dirty lamps and shades, and lamps whose output has deteriorated with use, deprive employees of essential light. It's been found that lighting efficiency may be improved by 20–30% simply by cleaning the lamps and reflectors.
  (3) Dispose of scrap and prevent spillage:
  It's a common practice to let the floor catch all the waste and then spend time and energy cleaning it up. It is obviously better to provide convenient containers for scrap and waste and educate employees to use them. Safety will benefit, expense will be saved, and the factory will be a better place in which to work.
  (4) **Look after your first aid gear**: First aid facilities and equipment should be kept under spotlessly clean conditions and fully stocked so that they are always ready in the event of accidents or illness.
  (5) **Inspect fire-control equipment**: It is essential to ensure that all fire-fighting equipment such as extinguishers and fire hoses is regularly inspected and kept in good working order. Fire protection should be in good working order. Doors and exits should always be kept clear of obstructions.
  (6) **Regular maintenance**: Maintenance is the most important element of good housekeeping. Regular maintenance allows management team to repair machinery, broken windows, damaged doors, defective plumbing, and leaking, broken floor surfaces. A good maintenance program will make provision for the inspection, lubrication, upkeep and repair of tools, equipment, machines and processes.
  (7) **Prepare a check**: A sound method to ensure that housekeeping is done is for management to prepare a check list to suit the requirements of the workplace.

2.4. Examples of energy management studies around the world

2.4.1. China

The China Standard Certification Center (CSC) has been authorized by the Chinese government to develop a series of national energy management standards. Three standards are planned for release by March 2008: Management system for energy – requirements, management system for energy – guidelines for performance, and management system for energy – Guidelines for auditing. The Chinese government has selected the top-1000 energy-consuming enterprises as a major source of potential energy savings to meet national energy reduction goals [18].

2.4.2. Netherlands

In The Netherlands, guidance for establishing an energy management system based on the ISO standard for environmental management systems has been developed in support of the Long-Term Agreements. This energy management system specification was developed in 1998 in cooperation with Bureau Veritas, an ISO 14001 certification institute, and introduced into the Long-Term Agreements (LTAs) program activity in 2000. Companies that signed or joined LTAs have the obligation to implement an energy management system within 2 years [18].

2.4.3. Sweden

Sweden has had a voluntary agreement program since 1994, but only added an energy management standard as a program requirement in 2003. The Program for Improving Energy Efficiency in Energy-Intensive Industries (PFE) which is managed by the Swedish energy agency has offered certification for a standardized energy management system and undertakes electrical energy efficiency improvements in those industries. The program requires a 5-year initial commitment, with specific milestones to report by the end of 2 years, as follows [18]:

- implement the energy management standard that is certified by an accredited certification body;
- complete an in-depth energy audit and analysis to baseline use and identify improvement opportunities. A list of measures identified in the energy audit with a payback of 3 years or less must be submitted to the Swedish Energy Agency;
- establish procurement procedures that favor energy-efficient equipment, and
- establish procedures for project planning and implementation.

3. Energy saving technologies

Applications of technologies have tremendous potential to reduce industrial energy sue. Industrial energy use can also be reduce using variable speed drive in motor operated system, high efficient motors, efficient nozzles in compressed-air system, waste heat recovery system in boilers etc. Some of them are discussed as below.

3.1. Variable speed drive

A variable speed drive is an electronic power converter that generates a multi-phase, variable frequency output that can be used to drive a standard ac induction motor, and to modulate and control the motor's speed, torque and mechanical power output. This application offers a significant energy saving if applied in many industrial applications [19]. AC drive can be described by different terms. AFD, variable speed drives (VSD), VFD and inverters all are employed, but have the same meaning. VSD's have been used to provide significant savings in a number of applications around the world [20,21].

The affinity Laws (also called the cubic Laws) states that pump output or flow are directly proportional to the speed of the pump. Therefore, to produce 50% flow, the pump would be run at 50% speed. At this operating point, the pump would require only 12.5% of rated horsepower ($0.5 \times 0.5 \times 0.5 = 0.125$ or 12.5%) [22]. VSD also offers a significant annual bill saving and emissions reduction; for example, the food manufacturer Northern Foods in the UK achieved an annual energy saving of 769 MWh/year, over £30,000 saving a year in electricity costs, payback period of just 10 months and annual CO_2 reduction of 338 ton [23].

From a mechanical benefit standpoint, bearings run at reduced speeds typically last much longer than their full speed counterparts. Also, drives inherently "soft start" the driven mechanical equipment. This soft start extends not only the life of the motor and bearings, but also drastically reduces belt wear and tear [23].

3.1.1. Variable speed control system

One of the many possible circuits to control the speed of an induction motor is schematically represented in Fig. 18 [24].

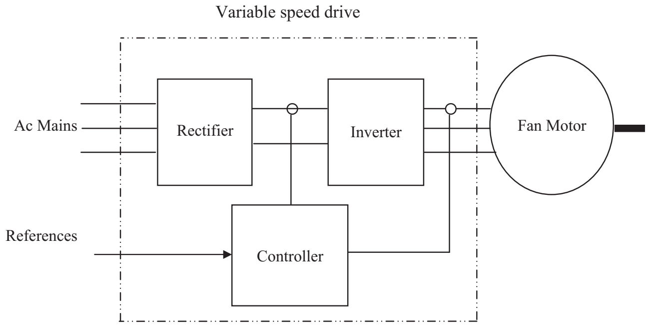

Fig. 18. The block diagram of the variable speed drive system [24].

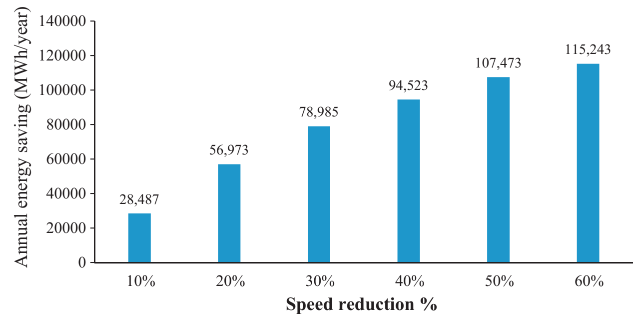

Fig. 19. Total annual energy saving (MWh/year) at different speed reduction [20].

3.1.2. Energy saving through VSD

Ozdemir [37] shows in his study that, a fan motor speed is decreased from 1450 to 255 rpm using (VSD) to reduce the amount of excess air that is not needed in low loads. After implementation of the VSD, the results obtained were: increasing of the boiler efficiency by 2.5%, 8000 kWh electrical energy saving in a month and a payback period of 1.8 months as shown in Table 2.

Another example of VSD, is when a fan motor speed is slowed by 50%, an 80% electrical energy savings is achieved [24]. Table 3 shows the potential energy savings associated with the speed reduction using VSD for industrial motors [20].

3.1.2.1. Mathematical formulations to estimate energy savings using VSD. Annual energy consumption of electrical motors without using variable speed drive can be expressed mathematically from the following equation:

$$AEC_{BAU} = \frac{M_{Hp} \times 0.7456 \times N_{motors} \times OPH}{\eta_{motor}} \quad (1)$$

Annual energy consumption when using variable speed drive depends on annual energy consumption without using VSD and speed reduction ratio. This can be calculated from the following equation:

$$AEC_{NP} = AEC_{BAU} \times (1 - SR_{ratio})^2 \quad (2)$$

Annual energy saving when using VSD is therefore the difference between annual energy consumption without using VSD and annual energy consumption when using VSD. The annual energy saving equals:

$$AEC_{VSD} = AEC_{BAU} - AEC_{NP} \quad (3)$$

Table 2
Measured electrical values after and before variable speed drive application [24].

Value	Without variable frequency control application	With variable frequency control application
Speed (rpm)	1460	255
Voltage (V)	380	31
Frequency	50	8.5
Current (A)	25	8
Power (W)	13,500	365

Table 3
Potential saving of VSD when reducing the speed [20].

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

3.1.2.2. Energy saving results when using variable speed drives. - When installing variable speed drives in industry and based on Eqs. (1)–(3), the results of total annual energy saving in industrial boilers MWh 28,487 and MWh 115,243 of energy could be saved annually in 10% and 60% speed reduction respectively as shown in Fig. 19.

3.1.3. Emission reduction by variable speed drive

3.1.3.1. Mathematical formulations to estimate emission reduction when using VSD. The environmental impact of the VSD is a potential reduction of greenhouse gases or other element that have a negative impact on the environment. These gases include carbon dioxide CO_2, sulfur dioxide SO_2, nitrogen oxide NO_x and carbon monoxide CO.

When using VSD, emissions reduction is a function of energy saving of VSD, percentage of fuel used and emission factor of the particular fuel. Thus emissions reduction can be calculated using the following equations:

$$AER_{CO_2} = AEC_{VSD} \times \sum(\%F \times EF_{CO_2}) \quad (4)$$

$$AER_{CO_2} = AEC_{VSD} \times \sum(\%F \times EF_{SO_2}) \quad (5)$$

$$AER_{NO_x} = AEC_{VSD} \times \sum(\%F \times EF_{NO_x}) \quad (6)$$

$$AER_{CO} = AEC_{VSD} \times \Sigma(\%F \times EF_{CO}) \quad (7)$$

3.1.3.2. Emission reduction results when using variable speed drives. When installing variable speed drives in industry and based on Eqs. (4)–(7), the results of total annual CO_2, SO_2, CO and NO_x emissions reduction when using VSD in industrial boilers and motors have been quantified and tabulated in Table 4.

The results from Table 12 show that increasing speed reduction in industrial motors will result in more emissions reduction. These results represent a huge amount of emissions reduction that can be achieved when applying VSD in industrial boilers.

3.1.4. Economic analysis by variable speed drive

3.1.4.1. Mathematical formulations to estimate cost saving when using VSD. When using VSD, annual bill saving can be calculated based on annual energy saving and the unit price of energy. The formula that associated with the above cost savings are as follow:

$$ABS_{VSD} = AES_{VSD} \times UEP \quad (8)$$

Payback period is the function of the incremental cost of VSD divided by the annual bill saving of VSD in a particular year.

Table 4
Total annual emissions reduction (ton) at different speeds reduction [20].

20% speed reduction				40% speed reduction				60% speed reduction			
CO_2	SO_2	NO_x	CO	CO_2	SO_2	NO_x	CO	CO_2	SO_2	NO_x	CO
284,593	1703	803	173	472,165	2826	1332	287	575,653	3446	1623	350

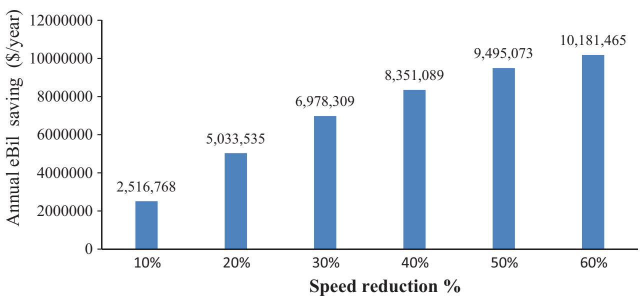

Fig. 20. Total annual bill saving ($/year) at different speed reduction [20].

Payback period can be expressed mathematically from the following equation:

$$PBP_{VSD} = \frac{IC_{VSD}}{ABS_{VSD}} \tag{9}$$

3.1.4.2. Cost–benefit results when using VSD. When installing variable speed drives in industry and based on Eqs. (8) and (9), the results of total annual bill saving and average payback period have been quantified and illustrated in Figs. 20 and 21 [33].

These results indicate that VSD is an economically viable application as it has payback period less than one third of the motor life which is estimated to be 20 years as an average.

3.2. Waste heat recovery from flue gas by economizer

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reused for some useful and economic purpose. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Economizer is a device used to recover the waste heat from the flue gas and consists of a series of horizontal tubular elements and can be characterized as bare tube and extended surface types [25].

Benefits of waste heat recovery can be broadly classified in two categories; Direct and indirect benefits; direct benefits include recovery of waste heat that has an effect on the efficiency of the process and reduction in the utility consumption & costs. Indirect benefits include: Reduction in pollution, Reduction in equipment sizes such as fans, stacks, ducts, burners, etc and fuel consumption [25].

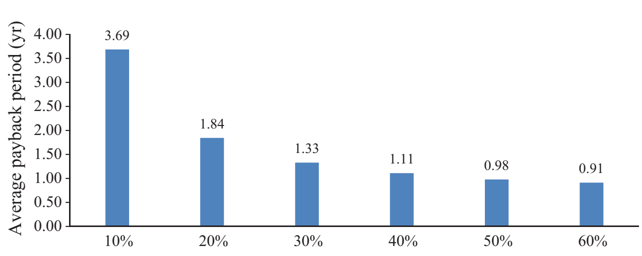

Fig. 21. Average payback periods at different speed reduction [20].

It is necessary to assess the benefits of using economizer on the basis of financial analysis such as investment, depreciation, payback period, rate of return etc. In addition to, how much the stack temperature can be reduced the inlet temperature of the fluid to be heated, and the operating hours of the boiler. Generally, the possible reduction in flue gas temperature should be at least 25–30 °C to make it economically viable to install a heat recovery system. Also the advice of experienced consultants and suppliers must be obtained for rational decision [25].

3.2.1. Energy saving by economizer

3.2.1.1. Mathematical formulations to estimate energy savings by economizer. Total annual energy saving when using economizer can be calculated from the following equation:

$$TAES_{HR} = AC_{KWH} \times \%_{fg} \times \%_{HR} \tag{10}$$

3.2.1.2. Energy saving results by economizer. According to Abdelaziz [26], when installing economizers in industrial boilers and based on the equation (10), the result of total annual energy saving has been found to be 2,529 MWh. Moreover, according to Willims [27], economizers can increase boiler efficiency by 2.5-4%, dependent on the number of tubes, addition of tube fins, and allowable pressure drop, but it is most dependent on the boiler feed water temperature. For every 40 °F reduction in boiler gas outlet temperature, the efficiency gain is 1%.

3.2.2. Emission reduction by economizer

3.2.2.1. Mathematical formulations to estimate emission reduction. The environmental impact of the heat recovery systems is a potential reduction of greenhouse gases or other element that give negative impact to the environment. The common potential reductions in this study include carbon dioxide CO_2, sulfur dioxide SO_2, nitrogen oxide NO_x and carbon monoxide CO. Emissions reduction when using heat recovery systems can be calculated as follow:

$$AER_{CO_2} = TAES_{HR} \times EF_{CO_2} \tag{11}$$

$$AER_{NO_x} = TAES_{HR} \times EF_{NO_x} \tag{12}$$

$$AER_{CO} = TAES_{HR} \times EF_{CO} \tag{13}$$

$$AER_{SO_2} = TAES_{HR} \times EF_{SO_2} \tag{14}$$

3.2.2.2. Emission reduction results when using economizer. According to Abdelaziz [26], when installing economizer in industrial boilers and based on Eqs. (11)–(14), the results of total annual CO_2, SO_2, CO and NO_x emissions reduction when using economizer have been quantified and tabulated in Table 5.

Table 5
Emissions reduction (ton) at different factories when installing economizer [26].

CO_2 reduction	SO_2 reduction	CO reduction	NO_x reduction
2150	6.324	0.506	41.888

These results show that a huge amount of emissions reduction can be achieved when installing economizer in the industrial applications.

3.2.3. Cost–benefit results when using economizer

3.2.3.1. Mathematical formulations to estimate cost saving when using economizer. Total annual bill savings associated with the above energy savings equals to total annual energy saving multiplied by fuel price. It can be calculated from the following equation:

$$TABS_{HR} = \frac{TAES_{HR} \times 3600 \times UFP}{FEC \times \rho_F} \quad (15)$$

Payback period equals to the installation cost of heat recovery divided by total annual bill saving when using heat recovery systems. Payback period of this application can be calculated from the following equation:

$$PBP_{HR} = \frac{IC_{HR}}{TABS_{HR}} \quad (16)$$

3.2.3.2. Cost–benefit results when using economizers. According to Abdelaziz [26], when installing economizers in industrial boilers and based on Eqs. (15) and (16), the results of total annual bill saving and average payback period are RM 238,573 and 2.2 years respectively. Also according to Willims [27], addition of an economizer with a 2.5–4% efficiency gain will result in a savings of $20,000–$32,000 per year in fuel costs. These results represent a huge amount of bill saving can be achieved when installing economizers in the industrial sector.

3.3. High efficiency motors

The bulk of electricity consumption in the industrial sector is by electric motors. Activities and processes in the industry depend heavily on electric motors including for compacting, cutting, grinding, mixing, fans, pumps, materials conveying, air compressors and refrigeration.

There are four basic types of losses in a squirrel-cage induction motor:

Stator and Rotor losses (I^2R losses in stator and rotor windings).
Core (Magnetic) losses; this is the sum of the hysteresis and eddy current losses of the laminated stator and rotor core.
Friction and windage; this is the loss due to fans and the bearing friction.
Stray losses; this is the lump sum of all losses in the motor which cannot be attributed to one of the other four components. It is principally due to electrical harmonics and stray currents in the motor.

It must be emphasized that a standard motor is already an efficient device with efficiency above 80% over most of the working range, rising over to above 90% at full load. However, motor manufacturers have been able to increase the efficiency further with the following additional improvements:

improved steel properties,
thinner laminations,
increase conductor volume,
modified slot design,
narrowing air gap,
improved rotor insulation,
more efficient fan design.

In 2005, CEMEP (the European Committee of manufacturers of Electrical Machines and Power Electronics) and the European Commission have devised motor efficiency classification labels – EFF_1, EFF_2 and EFF_3 – to make it much easier for purchasers to identify energy-efficient motors in the market with EFF_1 level as threshold. The motor manufacturers will label their standard motors with efficiency logos [15,16,28,29].

High efficient motors offer many benefits, some of these benefits include [16,28]:

1. Less maintenance and longer life time due to lower temperature in windings and bearings.
2. Higher reliability due to lower losses, including:
   Better tolerance to thermal stresses resulting from stalls or frequent starting.
   Increased ability to handle overload conditions.
   Better resistance to abnormal operating conditions, such as under and over voltage or phaseunbalance.
   Higher tolerance to poorer voltage and current wave shapes.

Higher power factor to improve the load handling of internal electrical system or prevent low factor utility penalty.

In Europe, Switching to energy-efficient motor-driven systems can save up to 202 billion kWh in electricity use, equivalent to a reduction of €10 billion per year in operating costs for industry. It was reported that a reduction of 79 million tons of CO_2 emissions (EU-15), or approximately a quarter of the EU's Kyoto target, is achievable using energy-efficient motors. This is the annual amount of CO_2 that a forest the size of Finland transforms into oxygen. If industries are allowed to trade these emission reductions based on energy saved, this would generate a revenue stream of € billion per year. For EU-25, the reduction potential is 100 million tons [20].

3.3.1. Energy saving by high efficient motors

3.3.1.1. Mathematical formulations to estimate energy savings by high efficient motors. Annual energy savings (AES) by replacing a standard efficient motor with a high energy-efficient motor can be estimated using the following equations:

$$AEC_{BAU} = \frac{M_{Hp} \times 0.7456 \times N_{motors} \times OPH}{\eta_{std\,motor}} \quad (17)$$

$$AEC_{BAU} = \frac{PM_{Hp} \times 0.7456 \times N_{motors} \times OPH}{\eta_{ef\,mtoro}} \quad (18)$$

$$AES_{HEM} = AEC_{BAU} - AEC_{NP} \quad (19)$$

3.3.1.2. Energy saving results when by high efficient motors. According to Saidur et al. [30], when installing high efficient motors and based on Eqs. (17)–(19), the results of total annual energy saving in MWh are illustrated in Fig. 22.

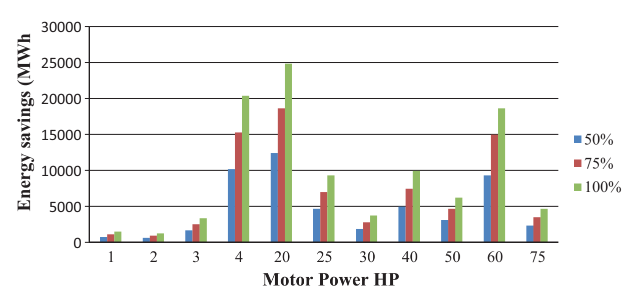

Fig. 22. Energy savings (MWh) for high efficient motor [30].

Table 6
Emission reduction (ton) associated with energy savings for energy-efficient motor [30].

CO_2	SO_2	NO_x	CO
27,140	162	77	17
40.707	244	115	25
39,562	311	128	19

3.3.2. Emission reduction using high efficient motors

3.3.2.1. Mathematical formulations to estimate emission reduction using HEM. The emissions reduction is a function of energy saving, percentage of fuel used and emission factor of the particular fuel. Thus emissions reduction can be calculated as follow:

$$AER_{CO_2} = AES_{HEM} \times \sum(\%F \times EF_{CO_2}) \quad (20)$$

$$AER_{SO_2} = AES_{HEM} \times \sum(\%F \times EF_{SO_2}) \quad (21)$$

$$AER_{NO_x} = AES_{HEM} \times \sum(\%F \times EF_{NO_x}) \quad (22)$$

$$AER_{CO} = AES_{HEM} \times \sum(\%F \times EF_{CO}) \quad (23)$$

3.3.2.2. Emission reduction results when using HEM. According to Saidur et al. [30], when installing high efficient motors in the industrial motors and based on Eqs. (20)–(23), the results of total annual emissions reduction in ton are shown in Table 6.

These results show that a huge amount of emissions reduction can be achieved when installing HEM in boilers.

3.3.3. Cost–benefit results when using high efficient motors

3.3.3.1. Mathematical formulations to estimate cost–benefit analysis when using HEM. When using HEM, annual bill saving is related to annual energy saving and the unit price of energy. The formula that associated with the above cost savings method can be calculated as:

$$ABS_{HEM} = AES_{HEM} \times UEP \quad (24)$$

Payback period is the function of the incremental cost of HEM divided by the annual bill saving of HEM in a particular year.

Table 8
Leakage rates (cfm) for different supply pressures and approximately equivalent orifice size [33].

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

Payback period can be expressed mathematically from the following equation:

$$PBP_{HEM} = \frac{IC_{HEM}}{ABS_{HEM}} \quad (25)$$

3.3.3.2. Cost–benefit results when using HEM. According to Saidur et al. [30], when installing high efficient motors in the industrial motors and based on Eqs. (24) and (25), the results of total annual bill saving and payback period are shown in Table 7.

3.4. Energy savings through leak prevention in air compressors

Leaks represent a significant source of wasted energy in the industrial compressed-air systems. Air leaks are the single greatest source of energy loss in manufacturing facilities with compressed-air systems. Leaks can waste 20–50% of a compressor's output. Stopping leaks can be as simple as tightening a connection or as complex as replacing faulty equipment such as couplings, fittings, pipe sections, hoses, joints, drains, and traps.

Leaks occur most often at the joints, connections, elbows, reducing bushes, sudden expansions, valve systems, hoses, tubes, filters, hoses, check valves, relief valves, extensions, and the equipment connected to the compressed-air lines. This leak can causes a drop in system pressure affecting production. In addition to the increased energy consumption, leaks can make air tools less efficient and adversely affect production, shorten the life of equipment, lead to additional maintenance requirements and increased unscheduled downtime. Leaks cause an increase in compressor energy and maintenance costs. Power losses increased exponentially as the diameter of hole increase as shown in Fig. 23 [31,32].

Table 7
Bill savings and payback period for high efficient motor [30].

Hp	Load (50%)		Load (75%)		Load (100%)	
	Bill savings (RM/year)	Payback (year)	Bill savings (RM/year)	Payback (year)	Bill savings (RM/year)	Payback (year)
0.25	43,469	7.89	65,203	5.26	86,937	3.95
0.5	21,734	5.1	32,601	3,4	43,469	2.55
0.75	37,259	3.48	55,888	2.32	74,518	1.74
1	149,035	2.9	223,553	1.94	298,070	1.45
1.5	18,629	1.94	27,944	1.29	37,259	0.97
2	124,196	1.71	186,294	1.14	248,392	0.86
3	335,329	1.06	502,994	0.7	670,658	0.53
4	2,036,814	1.67	3,055,222	1.12	4,073,629	0.84
5.5	68,308	2.08	102,462	1.39	136,616	1.04
7.5	186,294	1.98	279,441	1.32	372,588	0.99
15	93,147	1.77	139,721	1.18	186,294	0.88
20	2,483,920	1.45	3,725,880	0.97	4,967,840	0.73
25	931,470	1.62	1,397,205	1.08	1,862,940	0.81
30	372,588	1.47	558,882	0.98	745,176	0.74
40	993,568	1.32	1,490,352	0.88	1,987,136	0.66
50	620,980	1.11	931,470	0.74	1,241,960	0.56
60	1,862,940	1.17	2,794,410	0.78	3,725,880	0.59
75	465,735	1.18	698,603	0.78	931,470	0.59

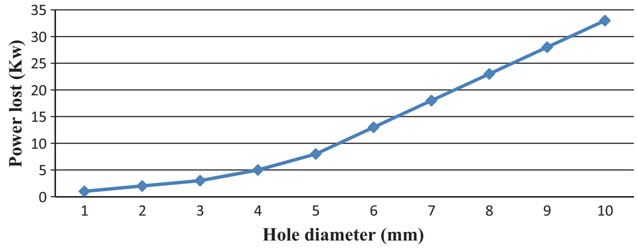

Fig. 23. Dependence of power loss on hole diameter at 600 kPa [31].

Fig. 24. Ultrasonic leak detection probe [35].

Leakage rates are a function of the supply pressure in an uncontrolled system and increase with higher system pressures. Leakage rates are also proportional to the square of the orifice diameter as shown in Table 8 [33].

The cost of compressed-air leaks is the cost of the energy required to compress the volume of lost air, from atmospheric pressure to the compressor's operating pressure. The cost of compressed-air leaks increases as the diameter of the leak increases. Table 9 shows the cost of energy lost for different diameters of leak [34].

Leaks may easily be located through their hissing when other plant operations are idle. In some situations, it may be necessary to wait for a scheduled plant shutdown. Temporary repairs can often be made by placing a clamp over the leak [35].

The best way to detect leaks is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks. Ultrasonic leak detection equipment is an essential component to successful leak abatement programs. This equipment facilitates identification of even the smallest leak regardless of the baseline ambient noise level in an industrial plant. This device is shown in Fig. 24 [35,36].

One of the ways to reduce leaks is to lower the demand air pressure of the system. The lower the pressure differential across an orifice or leak, the lower the rate of flow, so reduced system pressure will result in reduced leakage rates.

Stabilizing the system header pressure at its lowest practical range will minimize the leakage rate for the system. another way to reduce leak is by establishing A good leak prevention program will include the following components: identification (including tagging), tracking, repair, verification, and employee involvement. All facilities with compressed-air systems should establish an aggressive leak program. A cross-cutting team involving decision-making representatives from production should be formed. A leak prevention program should be part of an overall program aimed at improving the performance of compressed-air systems. Once the leaks are found and repaired, the system should be re-evaluated [35].

Table 9
Cost of waste energy due to leak prevention [34].

Diameter of leak (in.)	Cost per year
1/64	$48.00
3/64	$424.00
1/16	$744.00
1/8	$2981.00
1/4	$11,904.00
5/16	$18,721.00
3/8	$27,036.00

3.4.1. Energy saving by leak prevention.

3.4.1.1. Mathematical formulations to estimate energy savings by leak prevention. Leak prevention in compressed-air system can save about 20% of energy. Energy savings through leak prevention can be expressed as

$$AES_{CS_{leak}} = AEU \times ES_{\%} \quad (26)$$

Percentage leak can be estimated as follow:

$$Leakage\% = \left[\frac{T \times 100}{T + t}\right] \quad (27)$$

$$Leakage\ \text{(cfm free air)} = \left[\frac{V \times (P1 - P2)}{T \times 14.7}\right] \times 1.25 \quad (28)$$

3.4.2. Cost saving by leak prevention.

3.4.2.1. Mathematical formulations to estimate energy savings by leak prevention.

$$ACS_L = N_L \times LR \times GR \times OPH \times UEP \quad (29)$$

3.4.2.2. Cost–benefit results by leak prevention. According to U.S. DOE [33], a chemical plant undertook a leak prevention program following a compressed-air audit at their facility. The results of this audit show that $57,069 per year can be saved annually as shown in Table 10.

From this result, it can be observed that the elimination of just 10 leaks of 1/4 in. account for almost 70% of the overall savings. Thus, it is important to fix the largest leaks first [33].

3.5. Energy savings due to pressure drop

In many cases, system pressure can be lowered, thereby saving energy. Most systems have one or more critical applications that determine the minimum acceptable pressure in the system. The hissing of the air leaks can sometimes be heard even in high-noise manufacturing facilities. Pressure drops at end-use points in the order of 40% of the compressor-discharged pressure are not uncommon. Yet a common response to such a problem is the installation of a larger compressor instead of checking the system and finding out what the problem is. The latter corrective action is usually taken only after the larger compressor also fails to eliminate the problem. The energy wasted in compressed-air systems because of poor installation and maintenance can account for up to 50% of the energy consumed by the compressor, and it is

Table 10
Cost saving when preventing leak in a chemical plant [33].

Diameter of leak (in.)	Number of leaks	Cost saving ($)
1/32	100	$5,765
1/16	50	$11,337
1/4	10	$39,967
Total		$57,069

Table 11
regulations and standards in some countries around the world [38–43].

Country	Industrial Policy
Brazil	Minimum efficiency levels for high-efficiency motors
Canada	Canada's Energy Efficiency Regulations
USA	U.S. Energy Policy Act Motor Efficiency Standards
Italy and Japan	the Mandatory Energy Manager Programs

believed that about half of this amount can be saved by practicing energy conservation measures [35].

Minimizing pressure drop requires a systems approach in design and maintenance. Air treatment components should be selected with the lowest possible pressure drop at specified maximum operating conditions and best performance. Manufacturers' recommendations for maintenance should be followed, particularly in air filtering and drying equipment, which can have damaging moisture effects like pipe corrosion. Finally, the distance the air travels through the distribution system should be minimized.

Operating compressed-air systems at the lowest functional pressure that meets production requirements will result in energy saving. For example, reducing pressure settings by 13 kPa will reduce energy consumption by 1%. Another example is when reducing the pressure for about (70–84 kPa), 5–6% savings of compressed-air electrical demand could be saved [32,36].

3.5.1. Energy-saving formulations

Energy savings due to pressure drop can be estimated as:

$$AES_{pd} = M_{Hp} \times L \times 0.746 \times OPH \times (1 - FR_i) \quad (30)$$

FR can be estimated using the following equation:

$$[(FR)] \downarrow i = \frac{[((P_1 dp + P_1 i)/(P \downarrow i))]^T ((k-1)/k) - 1}{[((P \downarrow dc + P \downarrow i)/P_\downarrow i)/(P \downarrow i))] \uparrow ((k-1)/k) - 1} \quad (31)$$

4. Industrial energy saving by policies

Energy Policy is the manner by which a given entity (often governmental) has decided to address issues of energy development including energy production, distribution and consumption. The attributes of energy policy may include legislation, international treaties, incentives to investment, agreements, guidelines for energy conservation, taxation, energy efficiency standards, energy guide labels [37]. Energy policies are used widely in the industrial sector to meet specific energy use or energy efficiency targets. Industrial energy policy can be viewed as a tool for developing a long-term strategic plan, covering a period of 5–10 years, for increasing industrial energy efficiency and reducing greenhouse gas emissions. This policy engages not only the engineers and management at industrial facilities, but also includes government, industry associations, financial institutions, and others. There are many types of policies and programs that have been used in countries worldwide to improve energy efficiency in the industrial sector. Some of these policies and programs as include [38–43]:

Regulations/standards,
Fiscal policies,
Agreements/targets,
Reporting/benchmarking.

4.1. Regulations/standards

Regulations and standards are mandatory policies for improving energy efficiency. Regulations and standards are typically applied to particular pieces of equipment such as motors, boilers, etc. In addition, regulations can require that industrial facilities conduct energy audits, employ an energy manager, or adopt an energy management system. Examples of regulations and standards in some countries are shown in Table 11.

4.2. Fiscal policies

Fiscal policies include imposition of taxes, tax rebates, investment tax credits, and establishing investment bank lending criteria for promotion of energy efficiency. Taxation policies are a mandatory means for influencing the introduction of energy efficiency. Taxation policies can also influence energy efficiency through the use of tax rebates or investment tax credits. Investment bank lending criteria can be established to give higher priority for funding projects that improve energy efficiency [38].

4.3. Agreements/targets

Agreements are used widely in the industrial sector to meet specific energy use or energy efficiency targets. Such agreements, which are typically but not always voluntary, are defined as "agreements between government and industry to facilitate voluntary actions with desirable social outcomes, which are encouraged by the government, to be undertaken by the participants, based on the participants' self-interest". An agreement can be formulated in various ways: two common methods are those based on specified energy efficiency improvement targets and those based on specific energy use or carbon emissions reduction commitments. Either an individual company or an industrial subsector, as represented by a party such as an industry association, can enter into such agreements. Some of these policies are tabulated in Table 12.

Table 12
Industrial sector policies in some countries around the world.

Country	Industrial policy	Author
Canada	Industry Program for Energy Conservation (CIPEC)	[44,45]
Denmark	Agreements on Industrial Energy Efficiency	[46–48]
Germany	Declaration of German Industry on Global Warming Prevention (DGWP)	[48,49]
Finland	Agreements on Industrial Energy Conservation Measures	[50]
U.K	Climate Change Levy, Energy Efficiency Best Practice Program, Make a Corporate Commitment Campaign (MCCC), Energy-Intensive Industry Sector Efficiency Targets, Climate Change Agreements (CCAs)	[51,52]
Australia	Energy Smart Business Program; Greenhouse Challenge	[53]
France	Voluntary Agreements on CO_2 Reductions	[54]
Sweden	ECO-Energy	[48,55]
Norway	Norwegian Industrial Energy Efficiency Network	[56,57]
Netherlands	Long-Term Agreements on Energy Efficiency (LTAs)	[58–60]
China	China's National Climate Change Programme, 11th Five-Year Plan (FYP), Energy Conservation Law	[61]

Table 13
History of some comprehensive energy-saving policy in China [62].

Year	Energy policy
1986	Interim regulation of energy-saving management
1990	Plan of energy saving in the eighty five
1996	Regulation of technological innovation projects of energy saving and utilization
1996	Regulation of supervision of energy saving of the ministry of coal industry
1998	Law of the People's Republic of China on Energy Conservation
2000	Regulation of energy-saving utilization of civil construction
2001	Regulation of electricity saving
2004	Medium and long term specific schema on energy saving
2006	Implementation suggestion of the top ten key energy-saving projects in 'the eleventh five'
2007	Suggestions to energy saving and emission reduction of coal industry
2007	Emergent notification to reinforcement of industrial structure adjustment and preventing blind re-expansion of high energy-consuming industries

Table 14
Proposed 10th five-year plan targets for specific energy consumption for key energy-intensive industries [7].

Energy-intensive industrial sector	Specific energy intensity unit	1995	2000	2005	Annual % decline 1995–2000	Annual % decline 2000–2005
Iron and steel	GJ/ton	33.30	31.70	30.90	−1.0%	−0.5%
Copper	GJ/ton	40.40	37.50	34.60	−1.5%	−1.6%
Aluminum	kWh/t	14,736	14,100	13,800	−0.9%	−0.4%
Synthetic ammonia	GJ/ton	43.30	40.60	37.50	−1.3%	−1.6%
Cement clinker	GJ/ton	6.00	5.50	5.30	−1.8%	−0.6%
Synthetic fabrics	kWh/t	1,955	1,500	1,350	−5.2%	−2.1%
Oil refining	GJ/ton	0.50	0.50	0.40	−0.7%	−0.8%

4.4. Energy policy in China

Energy efficiency policy in China has evolved greatly since the People's Republic was established in 1949, moving through three main phases: "Soviet-Style" energy policy (1949–1980), initial reforms (1981–1992), and the current transition to a Market-Based Economy (1993–present) [7]. Since 1980s, Chinese government has implemented many energy policies which aim at reducing energy consumption across all sectors. Some of these energy policies are as shown in Table 13 [62].

The 10th Five-Year Plan has been issued in March 2001 and a number of energy efficiency policies for different sectors have been included. Energy-intensive industries such as iron and steel, Copper, Aluminum, and Cement etc., are one of these sectors. According to this plan, specific energy consumption levels for these industries have decreased significantly. Summary of this plan are shown in Table 14. Moreover, there are a number of policies and projects focused on improving industrial energy efficiency in China. Currently, there are sets of projects related to Industrial Sector Energy Efficiency in China. Table 15 provides a list of a number of these projects.

In 2005, the Chinese government announced 11th Five-Year Plan and declared a targeted goal of reducing energy consumption per unit of GDP by 20% below 2005 levels by 2010. The government projects that meeting this target would reduce China's greenhouse gas emissions 10% below business as usual; researchers estimate that over 1.5 billion tons of CO_2 reductions would be achieved. One of the key programs for realizing this goal is the top-1000 Energy-Consuming Enterprises program which was launched in 2006 by The National Development and Reform Commission (NRDC). The

Table 15
Current projects related to industrial sector energy efficiency in China.

Area of focus	Title of project	Funding/participating organizations
Technology	Energy-Efficient Motors and Boilers Technology Cooperation	China Clean Air and Clean Energy Technology Cooperation (CACETC, formerly Technology Cooperation Agreement Pilot Project, TCAPP)
	Efficient Industrial Boilers	World Bank, Global Environmental Facility (GEF)
	Motor Test Laboratory and Test Procedure Project	GTZ, China Electric Power Research Institute (EPRI)
Training	China Motor System Energy Conservation Program	State Development Planning Commission, United Nations Industrial Development Organization, United Nations Foundation (UNF), United States Department of Energy, Lawrence Berkeley National Laboratory, American Council for an Energy-Efficient Economy
Standards and labeling	China Energy Efficiency Program: Labeling and Certification Program for High Efficiency Motors	International Institute for Energy Conservation
Information dissemination and demonstration	China Energy Conservation Project: Energy Conservation Information Dissemination Center	State Economic Trade Commission (SETC), World Bank, Global Environmental Facility (GEF), AEA Technology Environment
Policy development	Chinese Energy and Carbon Scenarios Project	Beijing Energy Efficiency Center (BECon), Lawrence Berkeley National Laboratory, Energy Foundation
	Industrial Sector Energy Efficiency Policy Development: Developing Chinese Regulatory Infrastructure Project	China Energy Conservation Association (CECA), Lawrence Berkeley National Laboratory, Energy Foundation

Table 16
UK climate change levy tax rates [67].

Fuel	Tax rate (€)
Natural gas	13 €/ton CO_2
Coal	7 €/ton CO_2
Electricity	14 €/ton CO_2

Table 17
Few selected energy efficiency measures in the UK industrial sector [68].

Title of measure	Year	CO_2 estimated annual saving by end of 2010 (MT/year)
Climate change agreements	2001	1.1
Carbon trust programs	2001	4
Carbon reduction commitment	2009	0.3
UK emissions trading scheme	2009	1.1

energy consumption of these 1000 enterprises accounted for 33% of national and 47% of industrial energy usage in 2004. Activities to be undertaken through this program include benchmarking, energy audits, energy saving action plans, information and training workshops, and annual reporting of energy consumption [2,61,63].

In November 2006, the Ministry of Finance increased export taxes on energy-intensive industries. This includes a 15% export tax on copper, nickel, aluminum and other metals; a 10% tax on steel primary products, and a 5% tax on petroleum, coal and coke. Simultaneously, import tariffs on 26 energy and resource products including coal, petroleum, aluminum and other mineral resources will be cut from their current levels of 3–6% to between 0 and 3%. These tax shifts aim to discourage the export of energy-intensive products as a means of conserving domestic energy resources [61,62].

4.5. Energy policy in the Netherlands

In the Dutch Long-Term Agreements (LTAs), voluntary agreements between the Dutch Ministry of economics and industrial sectors consuming more than 1 petajoule (PJ) per year and covering 90% of industrial energy consumption were established and aimed at reducing CO_2 emission from 3 to 5% in 2000 compared to 1989s level and improving industrial energy efficiency by 20% in 2000 compared to 1989. This policy ended in 2000 with an average improvement in energy efficiency of 22.3% over the period 1989–2000 Due to the comprehensive process management by the Dutch energy agency NOVEM (now SenterNovem), these agreements can be regarded as European best practice. The Ministry of Economic Affairs provided a great deal to support the industries that implemented this policy including tax rebates for energy-efficient investments, subsidies, detailed audits of industrial facilities (including an inventory of energy-consuming equipment, assessment of energy use, and identification of cost-effective energy-efficient investments) and coordination of regulatory measures aimed at energy efficiency in industry.

Following the previous policy on energy efficiency in Dutch industry, a new policy has been developed for the energy-intensive industries. In the new policy, industry groups agree to strive to be among the world's most energy-efficient producers by 2012. The policy will use benchmarking of regions (with a similar production capacity as in The Netherlands) to monitor and verify the results of the industry efforts [2,59,60,64,65].

4.6. Energy policy in UK

In 1997, The UK government has committed itself to reduce CO_2 emissions to 20% below 1990 levels by the year 2010 and has promised more action to promote energy efficiency [66]. There are many suggested policies for the industrial sector. Some of these policies are; Climate Change Levy, Energy Efficiency Best Practice Program, Make a Corporate Commitment Campaign (MCCC), Energy-Intensive Industry Sector Efficiency Targets [66]. The government introduced in 2001 the Climate Change Levy, which is a tax on the energy use. The tax rates are provided in Table 16 [67].

As part of the Levy package, UK government signed Climate Change Agreements (CCAs) giving industries an 80% discount provided they meet agreed carbon reduction targets of 9.2 $MtCO_2$ by 2010, which is ten times the estimated savings from the Levy without the agreements. During the first target period (2001–2002) total realized reductions were three times higher than the target for that period. The Government will also implement the Carbon Reduction Commitment (CRC) in 2009 [68]. Table 17 shows some selected energy efficiency measures in the UK industrial sector.

The process for setting the Climate Change Agreement targets begins with information gathering on the part of the government. The government obtained information regarding energy efficiency potential in energy-intensive industries through the Energy Efficiency Best Practices Programs. Then, for the ten largest energy-consuming sectors, individual companies made estimates of what energy efficiency improvements they could make based on an assessment of their potential and provided this information to their trade associations. The sector then offered a target for the whole sector to the government. Negotiation then drew the process forward, with government often requiring the industry sector to improve their offer to a more challenging level, based on information on cost-effective processes and general standards of energy management in the sector [2].

4.7. Energy policy in Canada

The Canadian Industry Program for Energy Conservation (CIPEC) is a completely voluntary program, established in 1973, in which collective targets are set for each industrial sector. Under the program, the sector tasks forces identify energy efficiency opportunities, review and address the barriers associated with these opportunities, and develop and implement strategies for realization of the opportunities. The program includes annual measuring and reporting by industry participants. Benchmarking is conducted in which facilities are compared to the industry mean as well as to a "best practice" which is defined as the top quartile. Between 1973 and 1990, this program achieved cumulated energy savings of 26.1% per unit of production represented an ongoing reduction of 30.4% in Canada's industrial emissions. Since 1990, this program has seen an average annual energy intensity improvement of 0.9%. Also since 1990, GDP from the CIPEC industrial sectors rose 17.2% and energy use rose 10%. Between 2000 and 2010, CIPEC program continues to improve energy saving of Canadian's industrial sector. Some if this plan includes the following [44,45,69]:

- enlist voluntary commitments from individual companies to improve their energy efficiency and reduce their output of emissions;
- coordinate the establishment of consolidated energy efficiency improvement commitments and individual sub-sector-level targets;
- encourage sub-sector-level implementation of action plans;
- use sector task forces to encourage industries to exchange technical information and promote synergy among sectors; and
- encourage, facilitate and provide energy management training.

Table 18
History of energy policies in India [75].

Year	Energy policy
1988	The Companies Act stressed the importance of disclosing the particulars on energy efficiency, such as energy consumption, value added, and the amount of major products for 3 years
1991	India liberalized the regulatory regime in India to promote industrial competitiveness. The objective of this reform was to increase market-based competition
1995	The Government of India adopted a policy to promote energy efficiency in the country by allowing the accelerated depreciation for energy efficiency and pollution control equipment
1997	Capital investment in industrial energy efficiency totaled $12 billion
2001	The government identified certain energy-intensive industries as designated consumers brought under The Energy Conservation Act, and gave a period of 5 years for those energy-intensive industries to comply with a number of mandatory provisions. These include: (1) establishing norms for energy consumption; (2) mandatory energy audits by accredited energy auditors; (3) establishing efficiency standards and labeling; (4) mandatory appointment of energy managers
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4.8. Energy policy in Denmark

In 1990, Denmark has committed to reduce CO_2 emissions from all sectors by 20% in 2005 compared to 1988 emissions. The industrial sector is expected to contribute to this goal by reducing CO_2 emissions by 4.6% in 2005 relative to 1988 emissions. 143 companies entered into agreements with the Danish Energy Agency, representing 45% of total industrial energy consumption in Denmark. Under the agreements, the companies are required to implement all ‘‘profitable'' energy savings projects which are defined as projects with payback periods of up to 4 years as identified in an energy audit. In addition, companies must introduce energy management and motivate staff to ensure investments in new equipment will be energy efficient. Subsidies are provided for up to 30% of the cost of these investments in energy-efficient project. One analysis of this program found that firms with an agreement had electricity savings of 7% while those who did not have agreements (and thus were subject to the full CO_2 tax) had electricity savings of 8%, illustrating that similar savings can be achieved through policies and measures as those achieved using taxation alone. The Danish Energy Authority, as the result of a 2002 evaluation of the voluntary agreement system, found that half of the companies involved had reduced their energy usage by 20% [18,38,46–48,71,77].

In 1993, a general CO_2 tax was introduced in Denmark. The effective tax on trade and industry was 50 DKK (6.71€) per tones CO_2 for most companies. In 1995, the industrial tax corresponded to around 15% of the cost of electricity, 23% of the fuel oil cost and 35% of the cost of coal. During the period 1996–2000 the CO_2 tax was increased gradually and a new SO_2 tax was also introduced [73,74].

Under the Kyoto Protocol, a new target was set to reduce GHG emissions by 21% below 1990 levels by 2008–2012. To reach this goal, Danish Agreements on Industrial Energy Efficiency were introduced in 1996 and based on the imposition of a mandatory carbon dioxide emissions tax where the level of taxation depends on the purpose of the energy use, the type of energy used, and whether an agreement exists between the company and the Danish Energy Agency. The agreements are made for a period of 3 years. Under the agreements, the companies are required to implement profitable energy savings projects with payback periods of up to 4 years. Subsidies are provided for up to 30% of the cost of these investments in energy-efficient projects.

4.9. Energy policy in Japan

Japan ratified the Kyoto Protocol in 2002 to reduce greenhouse gas (GHG) emission. A report of the Ministry of Environment of Japan emphasized a policy mix with a central focus on a ‘‘Climate Change Tax'' propose in August 2003. The proposed tax rate was 3400 yen per ton of carbon (yen/tC) emitted from the combustion of fossil fuels. The tax would be levied on fossil fuel use and the revenue will be distributed to encourage the purchase of energy-efficient equipment. Some recent studies showed that, if the Climate Change Tax policy were to be successful, it would imply that the energy intensity improvement would need to exceed 2% per year from now through the Kyoto commitment period.

However, experience in the US suggests this program may be much less effective than needed for Japan to meet its Kyoto commitment. This suggestion leads to consider domestic and international emission trading as a way to meet the Kyoto commitment [74].

4.10. Energy policy in India

In India, energy efficiency policy and investment in industrial energy efficiency are regarded as important issues. Energy demands in India will increase by 150% in the next 15 years. A number of energy efficiency polices have been developed and implemented in India. These policies include (1) pricing policy; (2) institutional development policy; and (3) energy efficiency technology policy. In 1997, these policies have attracted over $12 billion of capital investment in energy efficiency in the industrial sector. Some policies, for example disclosure of energy efficiency particulars and mandatory appointments of energy efficiency managers and professionals at the industrial enterprises, have greatly facilitated energy efficiency in the industrial enterprises. Some of energy policies in India are shown in Table 18 [75].

4.11. Energy policy in USA

In USA, there are two suggested policy scenarios; a Moderate scenario based on the establishment of voluntary agreements with industry that set modest annual energy efficiency improvement commitments and an advanced scenario setting higher voluntary energy efficiency improvement commitments. The two policy scenarios assume successful implementation of a portfolio of policy measures to improve energy efficiency. These voluntary industrial sector agreements are supported by a comprehensive package of policies and programs designed to encourage implementation of energy-efficient technologies and practices [3].

Between 1995 and 2001, a study of 41 completed industrial system energy efficiency improvement projects was completed in the United States and targeted an average 22% reduction in energy use. In aggregate, these projects cost US$16.8 million and saved

US$7.4 million and 106 million kWh, recovering the cost of implementation in slightly more than 2 years. A more recent series of 3-day steam and process heating assessments conducted in 2006 at 200 industrial facilities by the United States Department of Energy identified a total of US$ 485 million dollars in annual energy savings and 55 petajoules (PJ) of annual natural gas savings, which, if implemented, would reduce the United States annual carbon dioxide emissions by 3.3 million tons. Six months after their assessments, 71 plants had reported almost US$140 million worth of energy savings recommendations either completed, underway or planned [2,76].

5. Conclusion

In this review, various energy savings strategies such as energy savings by management, technologies and policies have been reviewed. The role of energy management is vital and has greatly expanded in industries. Top management of the company participates in planning various energy management projects on a regular basis. It has been found that energy saving technologies for example use of high efficient electric motors, reducing boiler flue gas temperature, use of variable speed drive to match load requirement have been found to be cost-effective energy saving measure to reduce energy consumption of major energy using equipment in the industrial facilities. These savings strategies found to be economically viable in most cases. Along with energy savings, sizeable amount of emission can be reduced using various energy savings strategies. It was also observed that effective public policies are also needed to reduce industrial energy consumption along with emission reduction.

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