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REVIEW

A review on energy efficiency techniques used in machining for combined generation units

Neslin H. Ocak[1] · **Ali Can**[1]

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Abstract

Energy efficiency is considered an important indicator after the efficiency term is one framework of economic planning. The review results show that the gained energy is completely different in industries due to the production line, raw material, used fuel, system automation, application of thermodynamic rules, and energy recovery applications. The thermal parameters of the machining system are the main indicators to determine the system's efficiency. Dynamic behavior, effectiveness, and thermal capacity limitation are some parameters used for the optimization of machining energy efficiency. The temperature, pressure, flow rate, and other operating conditions as a function of time are the physical quantities to determine the dynamic behavior. The machining tools are intensive energy-consuming types of equipment and mostly consume electricity in manufacturing industries.

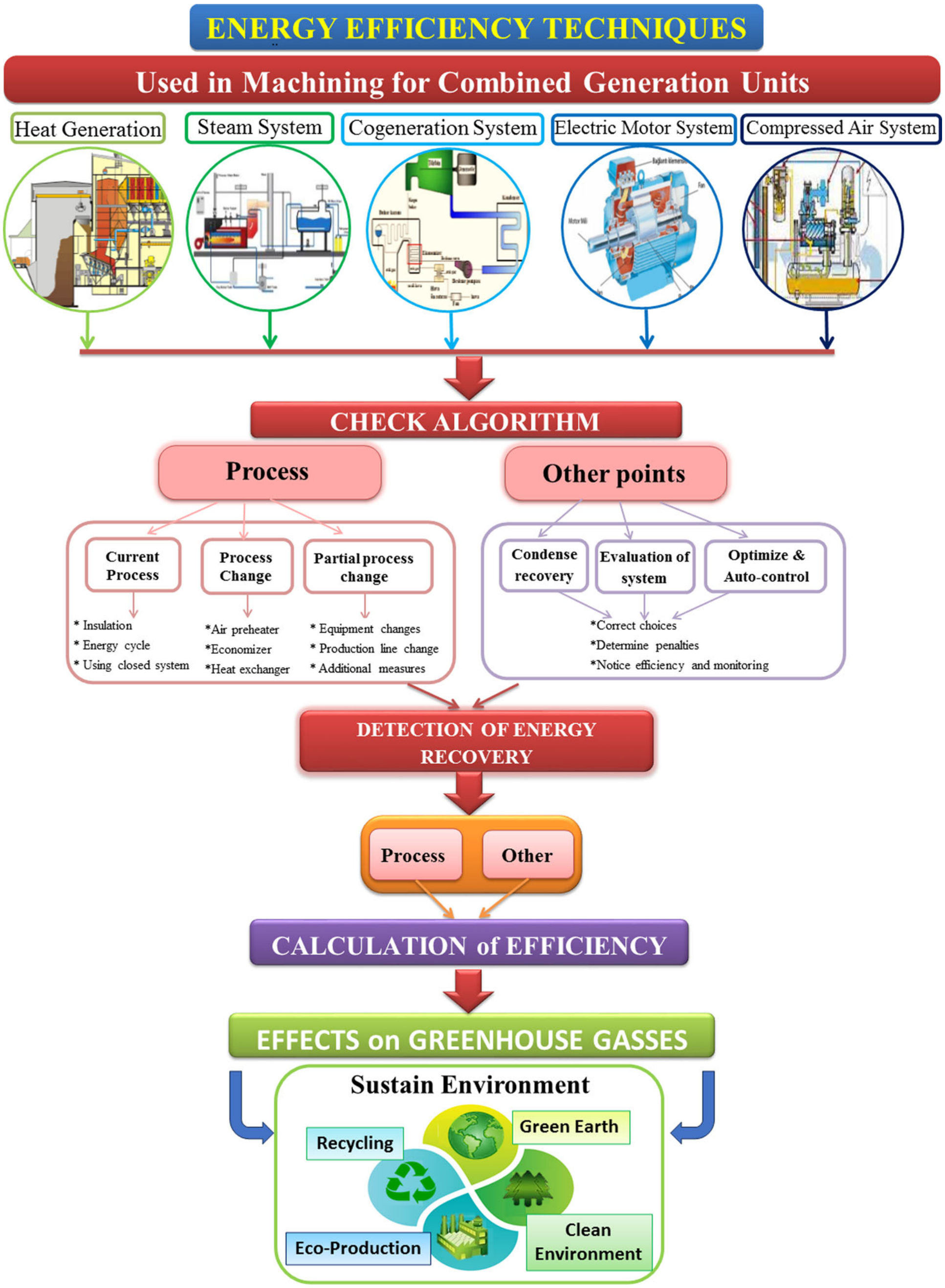
The general approach for cost-effective planning is to set a complete energy-efficient system. Mass, energy, and exergy analyses are the general bases for the efficiency consideration of heat generation. But the easiest and most expeditious energy recovery is observed in effective machining like micromechanical systems and hybrid systems, up to 20% of overall losses can be recovered. If the general usage of steam to produce electricity is considered, controlling the existing configuration will improve energy efficiency by applying quantitative optimization of the electricity usage. This quantity can be increased by an extra 20%. To optimize the entire cogeneration or trigeneration machining system, a holistic approach is needed that improves the system's energy efficiency by up to 65%. The energy efficiency is increased in the range from 3 to 35% by innovative EMS. Air leaks are causing the highest energy losses in CA systems. More than 90% energy efficiency can be achieved with an appropriate CAES system mostly in isothermal and high-pressure conditions for machining purposes. Moreover, the recovered energy will mitigate GHGs. And it is strict that, any developing plan of countries which contains an energy efficiency strategy, is necessary to sustain a habitable earth.

✉ Ali Can
drac0312@hotmail.com; alican@karabuk.edu.tr

Neslin H. Ocak
1838129007@ogrenci.karabuk.edu.tr

[1] Energy Division, Mechanical Engineering Department, Engineering Faculty, Karabuk University, Balıklar Kayası Mevkii, Karabük 78100, Turkey

Graphical abstract



Keywords Industrial energy efficiency · Energy balance · Exergy balance · Machining system

Abbreviations

$c_{p\text{-}g}$	Exhaust gas average specific heat
$E_{biomass}$	Biomass input
E_{coal}	Coal input
$E_{cooling}$	Cooling output
$E_{heating}$	Heating output
E_i	Total electricity demand (annual) (GJ/yr)
$E_{in,i}$	Exergy input to a component (kW)
$E_{out,k}$	Exergy output to a component (kW)
ES_y	Electricity savings (measure y for x) (GJ/yr)
E_X	Exergy (J)
$E_{xbiomass}$	Exergies of biomass (kW)
E_{XC}	Exergy values for cooling

E_{xcoal}	Exergies of coal (kW)
$E_{xcompair}$	Exergy values for compressed air
EX_{gt}	Exergy (the net power output of gas turbine)
E_{XH}	Exergy values for heating (kW)
$EX_{hot\ water}$	Output exergy of the hot water (kW)
EX_{in}	Input exergy of the system (kW)
$E_{xsewage}$	Exergies of sewage (kW)
EX_{st}	Exergy of power output of steam turbine (kW)
F_y	Fuel thermal content (kWh)
H	Hot
h	Enthalpy (specific) (kJ/kg)
h_1	Enthalpy of compressed air (kJ/kg)
h_{2s}	Isentropic enthalpy of compressed air (kJ/kg)
h_f	Enthalpy of fuel (kJ/kg)
in	Inlet
$\dot{I}$	Irreversibility or exergy loss (kW)
k	Heat transfer coefficient (W/mK)
L	Thickness (m)
m_c	Coal consumption rate (kg/s)
m_{coal}	Mass flow rates of coal (kg/s)
m_{sevage}	Mass flow rates of sevage (kg/s)
m_w	Waste consumption rate (kg/s)
$\dot{m}$	Mass flow rate (kg/s)
$\dot{m}_f$	Flow rate of the fuel (kg/s)
$\dot{m}_g$	Exhaust gas mass flow rate (kg/s)
n	Number of modules
out	Outlet
P	Air pressure (Pa)
P_C	Power consumption of compressor (kW)
P_E	Available extra power for the CAES (MW)
P_{gt}	Gas turbine power (MW)
P_{in}	Input power (W)
P_{net}	Net power output (W)
P_{out}	Power output (W)
P_P	Power output of pneumatic energy (W)
P_{st}	Steam turbine power (MW)
$P_{tot,net}$	Net total power output (kW)
$P_{w,net}$	Net power output of the waste (kW)
Q	Heat load
Q_C	Cooling air output (W)
Q_c	Energy input of the coal (kW)
$Q_{compair}$	Compressed air output (W)
Q_{exh}	Exhaust heat from gas turbine (MW)
Q_{gain}	Energy gain (W)
Q_H	Heating air output (W)
Q_p	Primary energy (kW)
Q_{sf}	Steam flow energy (kW)
Q_w	Energy input of the waste (kW)
$\dot{Q}$	Heat transfer (kW)
$\dot{Q}_1$	Heat addition (the steam per cycle) (kW)
$\dot{Q}_2$	Heat rejection (the steam per cycle) (kW)
$\dot{Q}_b$	Recovered thermal power (kW)
$\dot{Q}_L$	Heat recovered by LPE
$\dot{Q}_{loss}$	Sum of heat Losses (W)
$\dot{Q}_{out}$	Sum of useful heat outputs (W)
$\dot{Q}_{s\&w}$	Transferred heat to the steam and water (kW)
$\dot{Q}_{tot}$	Heat losses sum & useful heat outputs (W)
q	Heat flux (W/m^2)
$q_{c,net}$	The coal net caloric values (kJ/kg)
q_{coal}	Lower caloric values of coal (kJ/kg)
q_{sevage}	Lower caloric values of sevage (kJ/kg)
$q_{w,net}$	The waste net caloric values (kJ/kg)
S_i	Total value of the boiler losses (%)
T	Temperature in unit °C
$\dot{U}$	Heat loss increment due to the saved steam (kW)
V	Volume of air (m^3)
W	Power production by the cogeneration (kW)
$\dot{W}_c$	Compressor set total work (kW)
W_e	The expander produced output work (kW)
$W_{in,j}$	Supplied work (kW)
W_{net}	Net power output (kW)
$W_{out,l}$	Work output (kW)
W_p	Pump set total work (kW)
X	Faulty samples
X*	Normal samples

Greek Symbols

α	Portion of electricity demand by industrial motors
β_i	Portion of system x in total electricity
γ_x	Portion of total electricity demand by system x
ΔT_{lift}	Temperature lift (°C)
ε_c	Compression ratio
η_{comp}	Compressor efficiency
η_{con}	Conversion efficiency
η_{el}	Electrical efficiency
η_{en}	Energy efficiency
$\eta_{en,\ tot}$	Total energy efficiency
$\eta_{en,\ w}$	Waste-to-electricity efficiency
η_{ex}	Exergy efficiency
η_{gt}	Gas turbine efficiency
η_i	Standard efficiency
η_j	Increased efficiency
η_L	Low efficiency motor
η_Q	Thermal efficiency
η_{RT}	Round trip efficiency
η_s	Isentropic efficiency of the PM
η_{st}	Steam turbine efficiency
τ_y	Share of total electricity demand by measure y
ψ	Specific exergy (kW/kg)

Acronyms

A	Area (m.^{2})
B	The replaced equipment age (years)
C	Cold
D	Lifetime of the equipment (years)
d	Adiabatic index
CA	Compressed air systems
CAES	Compressed air energy storage system
CAP	Chilled ammonia process
CART	Classification and regression tree
CCHP	Combined cooling, heating and power
CFL	Compact fluorescent light
CFPP	Coal-fired power plant
CHP	Combined heat and power
CO_2	Carbon dioxide
COP	Coefficient of performance
CWSP	Coal-water slurries containing petrochemicals
DLFLN	Double linear fast learning network
EEM	Energy efficiency measures
EI	Energy-relevant investment
EMDS	Electric motor driven systems
EMR	Energetic macroscopic representation
EMS	Electric motor systems
EEM	Energy efficiency measures:
ERG	Exhaust gas recirculation
EUF	Energy utilization factor
FWH	Feedwater heater
GHGs	Greenhouse gases
GSHP	Ground source heat pump
HHV	Higher heating value
HTI	Heat transfer intensification
I-CAES	Energy storage of isothermal compressed air
IEE	Improvement in energy efficiency
LAES	Liquid air energy storage
LHV	Lower heating value
LPE	Low-pressure economizer:
MCHP	Combined heat and power in micro sacle:
MEA	Monoethanolamine:
NGCC	Natural gas combined cycle
NO_x	Nitrogen oxides
NPV	Net present value
PM	Pneumatic motor
SO_2	Sulfur dioxide
TCO_2ER	Trigeneration CO_2 emission reduction
TDV	Temperature driving force
TI	Total investment
TRNSYS	Transient System Simulation Tool

1 Introductıon

Increasing the level of economic, environmental, and social welfare is commonly expressed by performance, quality, strategy, and efficiency [1, 2]. The efficiency term is related to the production stages in the industries. The general explanation considering these terms is "sustainability". The balance of sustainability with prosperity life has become the goal of countries with the inclusion of the concept of development in strategic planning. Industrial sectors are projected to use clean and eco-environmental production lines with improvements in energy consumption, production, and machining lines [3]. The reduction of environmental pollution positively affects the consumption behavior of human beings [4]. In this context, performance, modification, optimization, and quality are realized effectively at low cost by using the best equipment, best technology, and energy-efficient systems in the sectors. The optimization in the production stages usually requires many parameter considerations in a prioritizing sequence. The best technology, however, can only be achieved by energy-efficient devices [5, 6]. Industry, which is the foundation stone of development, is meeting national and international demands and has high economic value in processing raw materials into products [7]. Sectoral differences increase the differentiation of industrial production and product diversity. Theoretical review, empirical modeling, and policy applications in the industries are common solutions and directions for future research despite their differences. The achievement of these goals can only be realized through economic optimization and energy efficiency [8]. The efficient operation of the industry raises the need for technical knowledge. It brings the differences in the application of sectors towards productivity including operating processes [9–11]. Energy efficiency has become essential for the sustainability of the industry. Saving fuel by adjusting air–fuel ratios can increase efficiency. [12]. The correct and conscious use of energy is only possible by strengthening the technical infrastructure and evaluating the energy management in the facilities. Energy management is the implementation of energy efficiency and energy conservation by maintaining the level of production [13]. Energy efficiency in industry results generally in reducing the losses of energy as heat, gas, and steam in the systems [14]. Machining is the one count to recover energy through the spindle motors and axial machine movements. In every stage of the production lines, which means energy-efficient machining will support highly in the reduction of energy usage in terms of electricity [15, 16].

Efficiency phenomena are grouped structurally, and it is increased by technical devices and equipment, which is defined as machining, apart from the purposes of energy use [17]. The assembly of the components of machining is a metric that needs to be cautious. The design of a machine tool has technically achievable efficiency limits. The interaction of components can be restricted on a small percentage scale due to these limitations. There aren't any standard methods to evaluate the machining tools. However, percentage recovery may be the best indicator of whether a processing system is being established [18]. If the switching of machining does not cause any loss of production quality, it will be the best technology for efficiency. The switching recovery results in considerable utilization and improvement in production [19]. The consistency check is another new parameter to apply to the components of machining. The sufficiency and consistency terms are two new focuses near the energy efficiency term [20].

The entire industry facility system has to be evaluated to integrate the machining tools [21]. The flow of energy balance is the best-interrelated approach to focus on existing measurements in the process cycle. The machining inefficiencies and the identified shortcomings can be remedied within this content [22]. The energy characteristics of the machining process tend to be very complex and vary substantially concerning different configurations of machine tools, workpieces and process parameters [23]. A multi-dimensional coupling model can be established for energy-efficient systematic configurations. The effectiveness of each parameter in machining tools is developed gradually [24].

In this context, structural changes are implemented in the form of partial or entire changes in production stages [25, 26]. Efficiency is also a part of steam distribution networks, cooling systems, boilers, furnaces, heating systems, power generation units, transport systems, and energy usage. Energy gains in industries are also affecting the quality of products [27].

The energy needed at every stage is commonly provided by the combustion unit apart from heat and electrical energy in the production processes. Heat treatments, hot water, and steam production are the areas where these facilities are commonly used. The hierarchical framework of the system proposes to address the wasted energy consumption on specific mechanisms to enhance the optimum machining tools [28, 29]. However, a high workload is usually concluded with low efficiency. Working at high capacity does not mean efficient production. Ageing, wear, and efficiency loss sometimes reach 50%. The resistance of each parameter in the operating system could be a part of the efficiency considerations in the process. Independent optimization of the parameters dynamically promotes energy usage. The relationship of each production parameter is correlated with energy usage [30–32]. Effective fuel consumption is highly achieved by the maintenance, repair, and cleaning of combustion units. The recovery provided by fuel saving is increased up to 5.6% [33]. Technically, the recycling of heat is the general method for energy gaining in boilers, furnaces, or heat treatment units. The recovery amount is an essential EE variable, but some input parameters as moisture, are preventing the recovery quantity from around 15% [34]. Complex energy usage and flow in the industry can be dropped to a single-dimension optimization to characterize the system consumption and recovery possibility. However, in this system, individual evaluation of the manufacturing processes and consideration of each machining is necessary. In other meaning, manufacturing energy efficiency is divided into equipment optimization and process optimization. Process optimization is to be followed by equipment optimization. [35, 36].

Energy recovery points in steam production start at combustion plants which are categorized as adding preheater, gaining waste heat, changing fuel, saving from air–fuel ratios, balancing boiler capacity loading rates, and providing necessary pressure and temperature for atomizing fuel [37–41]. The energy recovered from the system is commonly made by using a preheater. The recovery from waste heat is achieved with a heat exchanger. When the fuel is changed, efficiency is also achieved by decreasing the consumption of high-calorie fuel in the system. Environmental emissions are controlled by lessening fuel [42, 43]. Saving from air–fuel ratios is one technique to increase the efficiency to the desired level. It is also decreasing fuel consumption with a balanced supply of oxygen and fuel. In this way, solid fuels are burned at 95% by reducing the proportion of waste and ashes. Burning for liquid and gas fuels is almost around 99% [44]. The balancing of boiler capacity and controlling of loading rates are also increasing efficiency. The system working with full loading reduces the loss rates [45, 46]. The relationship between pressure and temperature is another factor affecting efficiency according to thermodynamics law. The atomized combustion of liquid and gaseous fuels affects the efficiency values considerably within the system, sometimes up to 10% [47].

The purpose of energy efficiency studies has generally concentrated on reducing the amount of energy consumption. It is indicated by reducing the paid-for energy [48]. Energy efficiency is considered in the same context as exergy efficiency. Because, in exergy studies, the ideal definition of energy is captured mechanically and the maximum benefit from the energy is obtained by balancing energy in a way by multidimensional component [49]. The multi-component of energy features is increasing the uncertainty of energy losses. Multi-dimensional coupling optimization, however, increases energy reduction by up to 22% and decreases time-consuming by 16% [24]. The component analysis is used to evaluate energy analysis by considering all input and output parameters of the system including machining. The results are generally consistent with statistical calculations and assessments [50]. Energy is recovered and valorized by exergy efficiency in intensive processes in the industries. Differences among the industries can be eliminated by highlighting system analysis and underlying the complete exergy losses [51]. The relationship between the exergy balance equation and the energy balance equation is established through the entropy balance equation. [52]. The second law of thermodynamics deals with the conservation of entropy and the quality of energy. This law reduces exergy losses to ensure sustainability and to ensure systemic equivalence that connects the exergy with the environment [53]. Inefficiency studies, every unit of energy used and produced in industries is considered. Therefore, reducing energy losses will not be different from minimizing exergy losses and returning the losses to production [54].

In industry, good design, proper process, maintenance, and accurate analysis are the result of efficient production, efficient use of energy resources, and suitable equipment maybe it seems outside but also specialized technical manpower. Any parameter that limits the system production directly or indirectly is a topic of efficiency [55–57]. Utilization is applied to all basic units of manufacturing, such as temperature stabilization, pressure maintenance, heat exchangers, mixers, conveyors, valves, and power generation units. Evaluation of each machine process under general headings will reveal a different definition for production [58–61]. Optimizing the efficiency of complex energy systems is achieved by exergy analysis assessment. The thermodynamic rules are powerful techniques to identify the components of the system and their gaps [62, 63]. The energy consumption of machining tools is generally attributed to electrical energy. Assigning the quantity of used electrical energy, whether directly or indirectly, determines machining operational efficiency. The electric power profile of machining indicates the different power levels and operating times. The state times, standby, and processing efficiencies are some techniques to identify the components of the system and their gaps. The utilization of machining with the other components is the limit of machining [36, 64–66]. As can be seen from Fig. 1, the starting point of energy saving is the identification of facility components.

In this review study, the energy efficiency of machining is grouped and considered as heat generation, steam system, cogeneration system, electric motor system, and compressed air system. All these categories are the parts of combined energy generation units. Therefore, multilevel energy analyses and the optimization of all these processes allow an integrated querying of the entire system to set up a fully energy-efficient mechanism in the industries.

The main aim of this study is to determine energy efficiency techniques, especially in the machining of combined energy units in industrial facilities. The studies consider models, experiments, and facility detection measurements by reviewing energy balance. Results, used methodologies, application points of machining, and the benefits of methods are tabulated and figured according to the reviewed articles. The efficiency terms are described by mathematical formulas depending on scientific bases. Efficiency application points in the machining are researched and analyzed in detail. The 20% to 30% energy recovery is crucial for environmental sustainability since energy use in industry is a key cause of climate change. The recovered energy will mitigate GHGs. And it is strict that, any developing plan of countries contains an energy efficiency strategy to sustain a habitable earth. This review article also presents many techniques in terms of empirical, statistical, and model evaluation. The classification is mainly on the quantification of components of the entire system with the integration of machining. Optimization, consistency, and efficiency are the main frames for machining. The improvement of energy recovery can be maintained by decreasing and canceling energy losses.

2 Methodology

2.1 Heat generation

The heat generation is the facilities that operate by burning fuel for a particular process. The review of the scientific studies has shown that different methods are applied to the generation unit machining to increase efficiency. The process starts with the fuel input to the boiler. Solid, liquid, or gas fuels have different characteristics in the process [67–69]. In heat generation, two methods are commonly used for machining processes. The first one is the empirical calculations. The second one is temperature measurements through the heat flux in the processes [70]. The temperature influence in machining is considered a very important parameter [71]. Influence tool wear and process quality are some examples related to troubles in machining [72]. Moreover, the total energy entering the boiler is not completely used for the processes [73]. The temperature measurement is one type of technique to determine the temperature distribution over the entire system [74]. The main approach is to set up an algorithm to determine the losses of energy in the machining system [69]. Losses such as heat, flue gases, exit temperature, steam, etc. are all important variables for the total efficiencies of heat generation processes [69, 75]. To enhance the overall performance of the plants, each section such as a chimney, machining, distribution systems, boilers, and pipes must be considered separately. Although the main section is the machining, the entire system must be considered to lessen the energy losses [76]. The heat content of unburned residues as wasted energy in the fuel is regarded as a heat drop. Energy transferred to the process is optimized based on energy balance rules. Experimental studies are generally combined with models such as neural models, simulators,

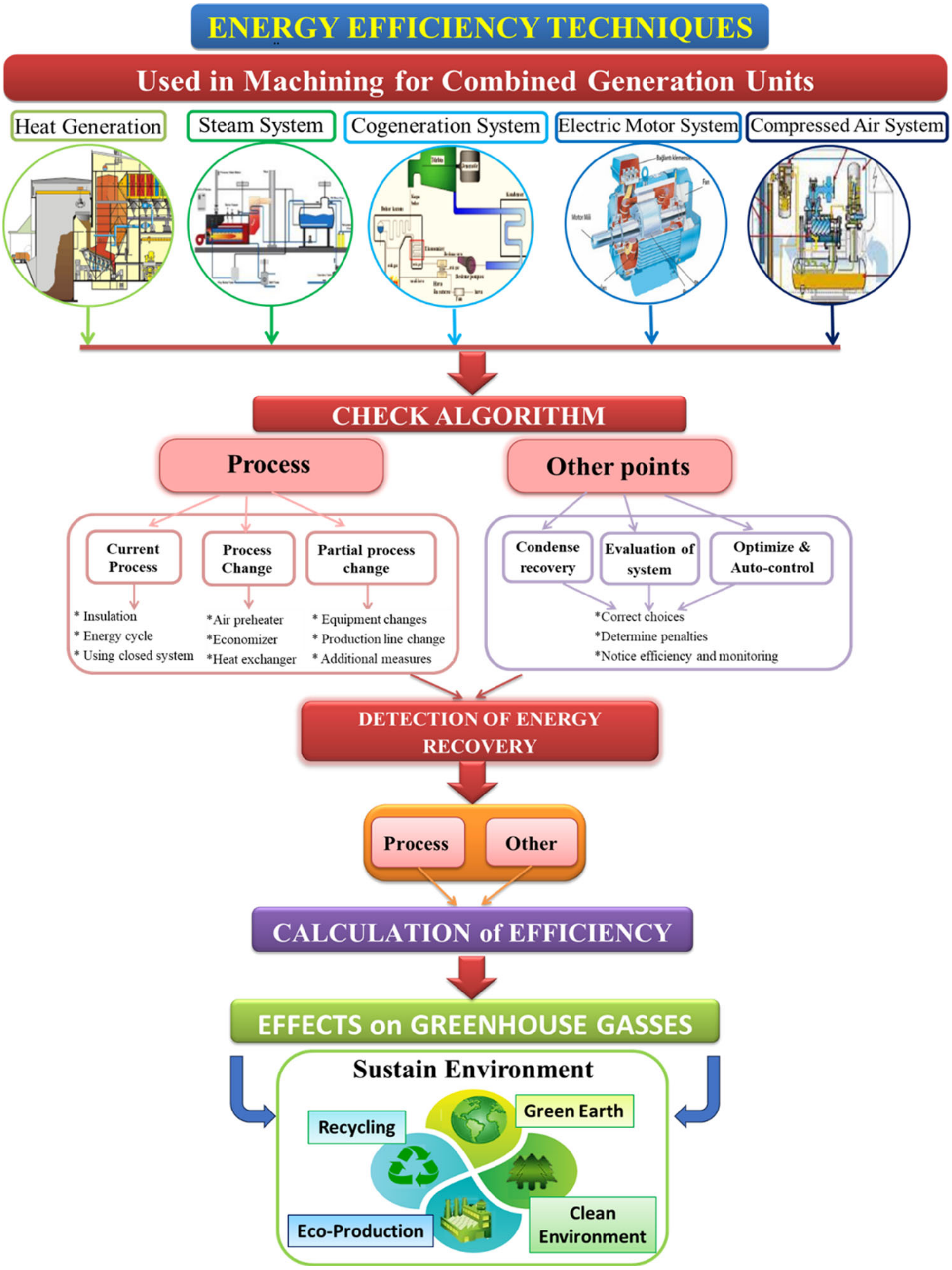


Fig. 1 Machining energy efficiency

and ESS software [69, 75, 77]. Table 1 presents many methods applied in heat generation and concludes the efficiency outputs.

2.2 Steam system

Producing steam in the industry is the most efficient way to transfer energy with the desired quality, pressure, and quantity. [92]. However, the steam distribution systems and distribution networks are considerably losing energy [92–94]. The temperature, pressure, flow rate, and other operating conditions as a function of time are the physical quantities to determine the dynamic behavior of the steam on the machining. The effects of the aforementioned parameters on machining operations must be determined through experimental, mathematical, or modeling analyses. [95]. The control of temperature and pressure reduces the losses and maximizes energy efficiency with the optimization of systems [94, 96]. The application of cautions to the steam systems is listed as boiler, fuel, pipe network layout, insulation, machining, and devices. The machine tools process in high steam power and temperature to manufacture in large quantities. The lessening of the energy can

Table 1 The review of heat generation

Result	Method	Equation	Description	Application Points	Country
High efficiency (~ 10–20% overall improvement)	Application of micro mechanical system	$\eta_{con} = \sum_{m}^{n} \frac{P_{out,m}}{P_{in,m}}$	Thermal and power characteristics [67, 78]	Experimental modelling of heat transfer rate controlling	India, China
High efficiency, reducing heat loss through the chimney, low fuel consumption, low emissions (15–20% efficiency increase)	Modernization of the boiler device and optimization of coal combustion	$\eta_{\mathrm{con}} =$ constant with low fuel	Water and steam thermal energy [68, 79]	Industrial process boiler and combustion	Poland
High efficiency and economic benefits besides traditional approaches (Energy efficiency increased 25%)	Improvement on energy and exergy efficiencies	$\eta_{en} = \frac{W_{net}+Q_C+Q_H+Q_{compair}}{m_{coal}*q_{coal}+m_{sevage}*q_{sevage}} \times 100$ $\eta_{ex} = \frac{W_{net}+E_{XC}+E_{XH}+E_{Xcompair}}{E_{Xcoal}+E_{Xsevage}} \times 100$	Flexibility in fuel sources, energy products and power system. Quantitative thermodynamics evaluations [80, 81]	Input and output of all power producing sections	China
Decrease in waste and increase the energy and exergy efficiency by CO_2 cycle integration (0.42% increase in energy efficiency and 8.34% increase in net waste-to-electricity efficiency)	Using hybrid system to increase the efficiency	$\eta_{en,tot} = \frac{P_{tot,net}}{Q_C+Q_W} = \frac{P_{tot,net}}{m_c \times q_{c,net}+m_v \times q_{w,net}}$ $\eta_{en,tot} = \frac{P_{tot,net}}{Q_C+Q_W} = \frac{P_{tot,net}}{m_c \times q_{c,net}+m_v \times q_{w,net}}$	Integrated system to sustain a stable the coal and waste consumption rate [82, 83]	Coal fired power plant combustion	China
Increased boiler and combustion efficiency by coal size and coal durability (26% lowering the maintenance)	Statistical investigation of the relationships of pulverized fuel types according to grain size	$\eta_B = 100 - \sum S_i$	Coal grain size and combustion determination of optimization [73, 84]	Power output and combustion	Poland, China
Recovering the maximum amount of waste heat and energy saving (1.34% max energy saving)	Test hot and cold heat exchanger target; using preheater; test the boiler feeding water temperature; using flash tank; retrofitted design	Increase η_B efficiency	Energy saving and increase energy efficiency [85–87]	Heat exchanger, flue gas, exit temperature	India, China, Taiwan

Table 1 (continued)

Result	Method	Equation	Description	Application Points	Country
High combustion efficiency in boiler (0.27% increase in final average efficiency)	Modelling for combustion	$\eta_B = 1 - \frac{\dot{Q}_{loss}}{\dot{Q}_{tot}} = 1 - \frac{\dot{Q}_{loss}}{(\dot{Q}_{out} + \dot{Q}_{loss})}$	Optimization in coal fired boilers [88, 89]	Boiler and combustion	Poland, Korea
Save energy consumption, heat drop, exergy loss for each equipment (ESS programme) (Energy efficiency 32%; exergy efficiency 35.2%)	Calculation of mass, energy, and exergy balance (ESS software)	$\eta_B = \frac{\dot{m}(h_{in} - h_{out})}{\dot{m}_f h_f}$ $E_x = \dot{m}.\psi$	Mass, energy and exergy analysis of steam power plant [75]	Every point at power plant	Iran
Energy efficiency by CO_2 Capturing (30.6% max energy efficiency)	Modelling and analysis of a supercritical coal-fired power plant in the Aspen Plus Software	$\eta_c = \frac{P_{net}}{HHV_{coal}.(Coal feed quantity)}$	Optimization of configurations, modifications for overall energy saving [77, 90]	Modelling	Korea
Optimized thermal efficiency on combustion process by neural modelling (91.57% max thermal efficiency)	Optimization with a neural model of combustion properties	Increase η_B efficiency	In a coal-fired boiler, an algorithm has been created to optimize the operating parameters and combustion of the boiler [69]	Combustion	China
Fuel savings ranging from 2 to 8%	The data utilized to conduct the system optimization	Increase energy efficiency	Enhancing the combustion efficiency in power boilers [91]	Coal combustion in boiler plants	Poland

Table 2 The review of steam system

Result	Method	Equation	Description	Application Points	Country
Increase at the performance and the energy efficiency of the integrated plant (Net efficiency of 39.1%)	Using MEA (monoethanolamine) solvent, scaled-up to meet the CFPP capacity, and heat Recovery used for boiler feedwater	$\sum_i \dot{E}_{in,\ i} + \sum_j \dot{W}_{in,\ j} = \sum_k \dot{E}_{out,\ k} + \sum_l \dot{W}_{out,\ l} + \dot{I}$	Energy loss reduction in steam systems and CO_2 optimization [92, 102]	Heat recovery from leaving flue gas and used for heating up boiler in power plant	UK, China
Economic saving and decreasing pollution (SOx by 40% and NOx by 20% decreasing)	Using coal-water slurries containing petrochemicals (CWSP) instead of coals	$m_{Fuel}{*}Cost_{fuel}$ decrease depending on operation cost	Emission and operational cost reduction [93, 103]	Experimental for thermal power plant steam cycle point	Russia, China
Comparison of various carbon liquefaction methods in steam power (coal-fired) plant (11% decrease in energy consumption)	Investigating different parameters for carbon capture, carbon liquefaction process	$\eta_B = \frac{\dot{Q}_{s\&w}}{\dot{m}_f LHV}$	Carbon capture and liquefaction for efficiency increases [104, 105]	Power Plant	Iran, Russia
Heat recovery improvement, energy efficiency increases and pollution decrease (4.3% decrease in heat demand, more than 22% increase in general profit)	Developing heat transfer intensification and exhaust gas recirculation (HTI & ERG) techniques with CO_2 Capturing	$T_{DV} = \frac{(T_{IH}-T_{OC})-(T_{OH}-T_{IO})}{ln[(T_{IH}-T_{OC})/(T_{OH}-T_{IO})]}$	Retrofitting in NGCC power plants (natural gas combined cycle) [98, 106]	Modelling	UK, China
Energy efficiency improvement (> 35% increase in power generation)	Using IPSE pro simulation to see the effects of different heat recovery configurations at the recovery boiler	$COP = 40.789.(\Delta T_{lift} + 2 \times 1.0305)^{-1.0489} \times (T_{h,out} + 274.18)^{0.29998}$	Heat recovery in boilers (latent heat recovery), different heat sink options including heat pumps [94, 107]	Modelling	Finland, China

Table 2 (continued)

Result	Method	Equation	Description	Application Points	Country
Energy efficiency improvement and support for sustainable designs (6.5–8.1% fuel Savings)	Investigating waste heat recovery steam systems due to techno-economic applicability by thermodynamic modelling	$\eta_B = \frac{\dot{Q}_b}{\dot{m}_g c_{p-g}(T_{og} - T_{ng})}$	Waste heat recovery steam systems (high pressure optimizations) [96, 108]	Ship Power Plant	UK, Germany
Time and cost saving (up to 89% decrease in heat losses)	Developing an empirical method to determine the optimum thickness of hot water pipes by constructing mathematical models	$q = \frac{Q}{L}$	Heat transfer pipes' thicknesses [99, 109]	Pipe Insulation	Turkey, Russia
Thermal equilibrium efficiencies (0.48% increase in second law efficiency & 0.36% decrease in first law efficiency)	Investigation of LPE (low-pressure economizer) for a CFPP (coal-fired power plant)	$ForCFPP;$ $\eta = \frac{W_{net}}{\dot{Q}_1} = 1 - \frac{\dot{Q}_2}{\dot{Q}_1}$ $ForLPE;$ $\eta = \frac{W_{net} + \dot{W}_{p,T,0}}{\dot{Q}_1 + \dot{Q}_L} = 1 - \frac{\dot{Q}_2 - \dot{U}}{\dot{Q}_1 + \dot{Q}_L}$	Exhaust flue gas waste heat recovery application [100, 110]	Industry	China, Greece
Fault isolation improvement (Theoretical studies of fault gaining)	Construction of binary classification trees by using CART algorithms	$X = X^* + \varepsilon$ $(gainingoferror\varepsilon)$	Fault detection and isolation [101]	Theoretical	South Korea

cause some essential problems. Therefore, energy efficiency can only be achieved by recycling or recovery techniques [97]. The main methodologies in the reviews of articles are appointed on energy efficiency increment by CO_2 optimization, post-combustion capture, heat recovery from flue gas and latent heat, decreasing the formation of sulphur and nitrogen, retrofitting the energy cycle, using different heat sinks such as heat pumps, pressure optimization and determination of faulty variables of steam systems. All these methods are increasing energy efficiency [93, 98–101]. Table 2 describes the best energy-gaining methods and their effects on the system.

2.3 Cogeneration system

The cogeneration system provides concurrent energy production as heat, electrical, and mechanical in industries. The trigeneration system is performing additional cooling operations [111, 112]. The performance parameters of machining utilize many manufacturing benefits. The goods production involves various aspects such as integrated machine functionalities, improved thermal considerations, and mechanical assemblies. [113]. The cogeneration and trigeneration units in the industries are commonly used to produce electricity [114]. These units are very economical due to less consumption of fuel. The systems are generally applied in higher energy-demand industries such as iron and steel, cement, glass, ceramics, and textile industries [115–118]. Various types of methodologies are listed in Table 3. Aspen-Plus software, black-box model, and TRNSYS software are some good examples of modeling to increase energy gain [119–121]. The machining tools are intensive energy-consuming types of equipment and mostly consume electricity in manufacturing industries. The optimization concentrates on specific energy production and consumption in this system. Therefore, cogenerations and trigeneration productions are not only cheap, but they are energy efficient due to their process stability [122].

2.4 Electric Motor System

Electrical motor system (EMS) forms an important part of industries as energy end-use devices. Electric motors are characterized by standards. The standardization is dependent on their efficiency from IE1 (standard efficiency) to IE5 (ultra-premium efficiency) [136, 137]. The electric machining efficiency can be improved by using more advanced and innovative EMS. Sometimes, simply cooling the motor can result in significant energy savings during machining. [138].

The trading electrical motors are changing from manual control motor systems to advanced technological devices. The conservation of energy and efficient uses of energy are the main concerns for the technological improvement of electrical motors. [139–141]. Therefore, the efficiency studies considering the electrical motor are giving great advantage to its users due to saving money. Replacement of low-efficient motors is part of strategic planning and the most important policy for industrial efficiency considerations [142–144]. Considering nominal conditions and constant operating times rather than thermal conditions and energy consumption to assess the replacement of EMs leads to significant errors in estimating energy savings. The parametric analyses are necessary to set more efficient machining by using high-performance and less energy-consuming EM [145]. The methods and purposes of the electrical motor system in industries are listed in Table 4.

2.5 Compressed air system

Machines used to increase the pressure of a compressible fluid are called compressors. Compressors are not among the most energy-consuming equipment in the industry. The compressed air is used with auxiliary elements on the demand side [149–151]. In machining, the CA system is highly preferred for decreasing the friction and the temperature in the processes [152]. It has also some advantages in increasing the tool life, reducing the force used, and improving the surface finish. All these reduce the production cost in machining and supply a very efficient energy usage. A compressor comprises filters, dryers, coolers, pressure regulators, compressed air tanks, distribution systems, and machining. [153–156] (Table 5). In air compressor systems, the combined optimization process in the machining section can be carried out including exergy efficiency. The thermodynamic properties are applied due to many process parameters under different environmental conditions. The exergy analysis gives some opportunities to control machining quality within this system due to energy consumption and thermal properties [63, 157].

3 Result and dıscussıon

Energy efficiency in industries is considered in many aspects. However, optimization of the processes is the most common method to save energy in the systems. The review of the article has shown that the optimization of the heat generation processes, insulations, steam production and transfer, cogeneration units, and motorized systems are saving a considerable quantity of energy. Although the average energy-saving value changes between 10 and 50% [67, 157], this quantity sometimes reaches 90% with the applied methodology in thermal efficiencies in combustion processes [88]. The results are categorized as heat generation, steam systems, cogeneration systems, electric motor systems, and

Table 3 The review of the cogeneration system

Result	Method	Equation	Description	Application Points	Country
Chemical looping co-fuelled (biomass and coal) combustion for CCHP generation system (Energy efficiency 60.16% and exergy efficiency 22.16%)	Modelling of gasification process with Aspen Plus software	$Energy efficiency;$ $\eta_{en} = \frac{W_{net}+E_{cooling}+E_{heating}}{E_{coal}+E_{biomass}}$ $Exergy efficiency;$ $\eta_{ex} = \frac{W_{net}+E_{XC}+E_{XH}}{E_{Xcoal}+E_{Xbiomass}}$	Thermodynamic analysis for trigeneration system [119, 123]	Modelling	China, Brazil
Generates electricity with a higher thermal efficiency, decrease air pollution and fuel consumption (up to 48–54% increase in system efficiency)	Combined analysis of integrated gasification for electricity generation with fuel preparation unit and lignite drying system	$Agasturbinecombinedcycle:$ $\eta_{en} = \frac{P_{gt}+P_{st}}{\dot{m}_w LHV}$ $Agasturbine:$ $\eta_{gt} = \frac{P_{gt}}{\dot{m}_w LHV}$ $Asteamturbine:$ $\eta_{st} = \frac{P_{st}}{Q_{sf}+Q_{exh}}$ $where,$ $Q_{exp} = \dot{m}_w LHV(1-\eta_{gt})$	Integrated hard coal—lignite gasification (combined cycle) [115, 124]	Experimental	Poland, Egypt
Decrease in exergy destruction values and matched energy level conditioning (43% energy efficiency)	Exergy analysis of the supplementary steam circle	$q = \frac{3600\dot{m}_{coal}\times LHV}{W_{net}}$	Configuration of lignite pre-drying unit [116, 125]	Heaters redirected through a regenerative turbine	China
Electricity and domestic hot water production decrease in exergy destruction, increase COP of GSHP (up to 13.65% exergy efficiency)	Biomass partial gasification	$\eta_{ex} = \frac{EX_{hotwater}+EX_{gt}+EX_{st}}{EX_{in}} \times 100\%$	Combined heating and power system and exergy analysis [111, 126]	CHP System	China
CO_2 capture with chilled ammonia process (CAP) (Penalty reduction from 13.23% to 9.82%)	Evaluation of CAP in coal fired power plant (CFPP)	$COP_{max} = \frac{T_c\times(T_h-T_0)}{T_g\times(T_0-T_c)}$	Optimization of temperature, NH_3 concentration, chilling temperature, internal irreversible factor [127]	Coal-Fired Power Plant	China
High efficiency with evaporative and fogging method in cogeneration plant (up to 0.99% decrease in global warming potential)	Evaporative and fogging method	$m_{naturalgas}$ gaining	Neutralizing steam turbine amine and phosphate to decrease environmental impact [117]	Air input temperature	Thailand
Efficiency of the co- and tri-generation unit, reducing CO_2 emissions of electricity (up to 40% CO_2 emission saving)	Use non-fossil fuels, using heat pump and sorption of energy	$\eta_{el} = \frac{W}{Q_p}$ $\eta = \frac{W+Q}{Q_p}$	Gaining energy and useful heat, reduce CO_2 emission [118, 128]	Power Plant	France, Canada

Table 3 (continued)

Result	Method	Equation	Description	Application Points	Country
A black-box model for the reduction of greenhouse gases from cogeneration and trigeneration system	Modelling trigeneration CO_2 emission reduction (TCO_2ER)	$\eta_{el} = \frac{W}{F_y}$ $\eta_Q = \frac{Q}{F_y}$ $EUF = \eta_{el} + \eta_Q$	Improving of Cogeneration and Trigeneration systems [120]	Modelling	Italy
High efficiency and better heat utilization (> 60% overall efficiency)	Exergy analysis to investigate fluctuations in heat recovery	$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum \dot{m}_i (h_i + \frac{V_i^2}{2} + gz_1) - \sum \dot{m}_e (h_e + \frac{V_e^2}{2} + gz_1)$	Combined efficiency for heat, power, energy [112, 129]	CHP System	China, USA
Analysis of thermo-economic performance of micro MCHP system with dynamic simulations (up to 8.8% energy saving)	Dynamic simulation with software TRNSYS	$\dot{Q} = \frac{\Delta T}{kA/L}$	Well-insulated buildings with lower heating [121]	Modelling MCHP systems in buildings	Italy
High energy efficiency by using biomass	Two examples of biomass-fired micro-cogeneration systems: 1. A wood-fired stove with thermoelectric generators 2. A straw-fired batch boiler with a steam-condensate circuit to the modified Rankine cycle	$\eta = \frac{W}{Q}$	Energy and Ecological Analysis [130, 131]	Experimental	Poland, Greece
Significant increase of the gas yield (29.5%) and energy production (42%)	The utilization of recovered landfill gas in the CHP generation system	Increase energy efficiency	Utilization of recovered landfill gas in a cogeneration system [132]	Biogas Cogeneration Systems	Poland
Increase in energy efficiency and second law efficiency (respectively from 53.6% to 54.31% and from 50.9% to 51.27%)	Employment of thermodynamic to assess the system's performance	Increase energy efficiency	The Kalina cycle for waste heat recovery from a gas turbine [133]	Gas Turbines	Iran
Net thermal efficiency (22.6%), Net exergy efficiency (64.76%)	Optimization of steam ranking systems (SRC) and organic rankine cycle (ORC), testing different fluids (R113, R141b, R152a, R245fa and R365mfc)	Increase energy efficiency	Performance İmprovement of SRC and ORC [134]	The inlet turbine system	Türkiye
A decrease in the minimum adjustable power load and coal consumption (respectively 12% and 10.27 tons)	Development of optimization methods	Increase energy efficiency	Operation optimization by utilizing combined heat and power (CHP) model [135]	Heat storage from wasted energy	China

Table 4 The review of electric motor system

Result	Method	Equation	Description	Application Points	Country
Multi-criteria analysis performs better in terms of energy saving (between 1500–4500 kW h/year)	Energy efficiency analysis according to multi-criteria analysis in industrial motor systems (Promethee II Method)	$IEE = \left(1 - \frac{\eta_L}{\eta_m}\right) \times 100\%$	Replacement of low efficiency motors [136]	Industry	Brazil
Energy efficiency measures in electric motor systems	Proposing a framework by considering the factors related to clustered factors	Efficiency η_{factor} improvement	Energy efficiency measures and non-energy factors [139, 146, 147]	Electrical Motor Systems	Italy, Switzerland, Cuba
An innovative framework aiming to improve energy efficiency	Factors affecting the energy improvement	$Q_{gain} = (\eta_j - \eta_i) \times P_{net}$	Non-energy benefits and losses [140]	Industry	Italy
An overview of Energy Efficiency Measures (EEM) was proposed for Electric Motor Systems (EMS) to support industrial decision makers	Categorizing and comparison of various EEMs	$Q_{gain} = (\eta_j - \eta_i) \times P_{net}$	Management of motor, power quality [141, 148]	Electric Motor Systems (Experimental)	Australia, Brazil
An overview of Energy Efficiency Measures (EEM) in industrial applications (up to 14% energy saving)	Dvelopment of a new framework for the main factors, that affect the adoption of EEMs	$Q_{gain} = (\eta_j - \eta_i) \times P_{net}$	Using efficient electrical motors, installation of control hardware [142]	Industry (Experimental)	Australia
Cost curves are developed for higher energy efficiency in industry (~ 17% potential energy saving)	Process optimization of electric motor by gathering data from EMDS	$EI = TI \times \left(1 - \frac{B}{D}\right)$ $ES_y = E_i \times \alpha \times \beta_i \times \gamma_x \times \tau_y$	Energy Savings in EMDSs and determine the penalties [143]	Electric motor driven systems	Switzerland
Higher energy efficiency in motor system (3% to 35% energy saving)	Various energy efficiency measures (EEM)	$Q_{gain} = (\eta_j - \eta_i) \times P_{net}$	Industrial energy efficiency for various innovative EMS [144]	Industry	Sweden

compressed air systems. Energy-efficient machining is a crucial aspect of manufacturing industries as it helps to conserve energy. The general approach for cost-effective planning is to set a complete energy-efficient system. Since the complex characteristics of the machining process are present in different types of industries, the adaptation of energy consumption characteristics depends on process parameters, which determine how energy efficiency applications, modifications, and optimization are taking place in industries [24].

3.1 Heat generation

In heat generation, the highest energy losses are observed at the fuel combustion unit. The heat transfer rate is very high compared to the other sections. The wasted energy depends on the air mixture, the temperature, the deposit level in the boiler, and its components. The chemical burning processes are the second important section in a significant rate of energy saved by system optimization. The formation of carbon monoxide, hydrocarbons, and volatile gases during the incomplete combustion process has resulted in chemical energy losses. Unburned fuel losses are also considered as

Table 5 Compressed air system

Result	Method	Equation	Description	Application Points	Country
The compressed air system energy efficiency measures and non-energy benefits	Heat recovery, upgrade performance and adjust temperature, controller and ancillary equipment	System efficiency improvement s_{system}	Optimize pressure, reduce leaks, change driven equipment [149, 158]	CAES system	Sweden, Czech Republic
Analyses of Compressed Air (CA) systems (Least specific energy consumptions values received at the 70% supply rate)	Fixed and different speed drive compressors modeling by simulation	System efficiency improvement s_{system}	Energy consumption and energy efficiency [150, 159]	Modelling on CA	Australia, Poland
The modelling of compressed air energy storage system (System efficiency improvement—13% to 60%)	Different configurations model development (single-stage designs to multi-stage designs)	$\eta_{comp} = \frac{W_e}{W_c}$	Efficiency analysis in CAES [151, 160]	Experimental	China, Canada
Increased amount of power with CAES systems sizing (System efficiency improved from 13 to 60%)	NPV method uncertainties in the system—Renewable Energy source	$\dot{W}_c = P_E \times \eta_{comp}$	Thermo-economic analysis in CAES system [161, 162]	Photovoltaic (PV) Farm	Brazil, Canada
The increase in exergy efficiency (55.1%), finned piston efficiency (78.4%)	Design and modelling a new finned piston compressor with I-CAES systems	$\dot{W}_{in} = \dot{Q}_{out} \times \Delta\dot{E}$	Energy conversion, its storage and exergy efficiency [153]	Experimental	Switzerland
Investigation of electromechanical, fluid mechanics and heat transfer phenomena in an air compressor (27.3% net effective energy and 47.8% exergy efficiency)	Energetic macroscopic representation (EMR) modelling depending on electromechanical, fluid mechanics and heat transfer	$\eta_{comp} = \frac{E_x}{W} \times 100\%$	The thermal resistor and capacitor effect on heat transfer [154]	Modelling	Switzerland
Investigation of Advanced Adiabatic CAES at different pressure and output power (max. 55.06% energy efficiency)	Creating a adiabatic CAES system model with Aspen Plus software and its simulation	$P_c = P \times V \times \frac{d}{d-1} \times \left(\varepsilon_c^{\frac{d-1}{d}} \text{-}1 \right)$	Recovery and use of waste heat in CAES system [155, 163]	Modelling	China

Table 5 (continued)

Result	Method	Equation	Description	Application Points	Country
Maximum power output and efficiency, compressed air consumption rate of pneumatic motor (max. 94.35% efficiency of the generator)	Economical and performance analysis in pneumatic compressors	$\eta_p = \eta_s \times \eta_m = \frac{P_p}{m \times (h_1 - h_2)}$	Investigation of power performance and energy efficiency of pneumatic motor and generator [156]	Experimental	China
Optimal physical and operational configuration of LAES systems for high performance (up to 76.6% exergy efficiency)	A review of LAES systems, optimization studies	$\eta_{RT} = \frac{W_{out}}{W_{in}}$	Energy efficiency with LAES systems [164, 165]	Experimental Optimization	Ireland, USA
The adiabatic efficiency of main components of the liquid air energy storage system is increased (Increasing adiabatic efficiency from 74 to 95% and decreasing exergy loss from 84.37% to 80.12%)	Thermodynamic analysis of LAES systems	$\eta = \frac{W_e}{W_c + W_p}$	Exergy analysis on four stage compressor and expansion [157, 166]	Experimental	China, UK
Increase in power production and exergy efficiency (Respectively 3.38%, 3.1%)	A comprehensive thermodynamic analysis	Increase energy efficiency	Analyzing energy efficiencies of CA energy storage systems [167]	Experimental	Iran
Higher efficiency rates were achieved (Up to 51.64%)	Thermodynamic model of a liquified air energy storage system	Increase energy efficiency	Modelling of a coal-fired power unit [168]	Modelling	China

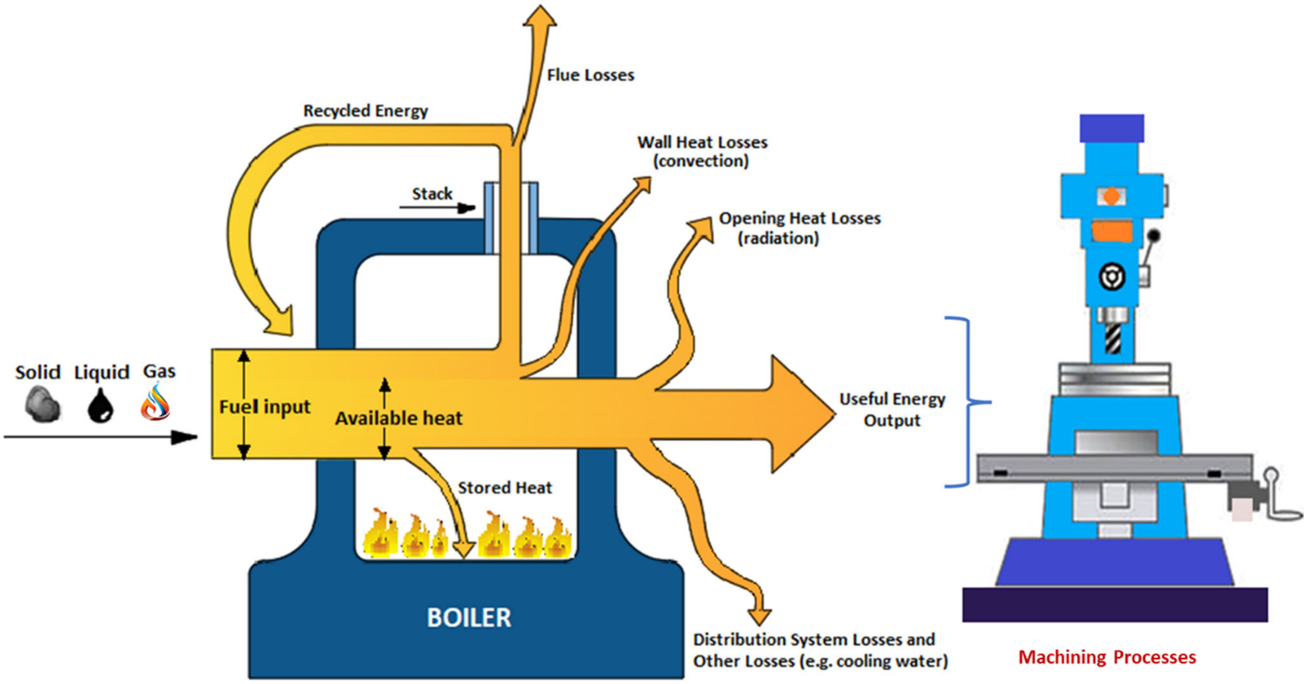


Fig. 2 The energy input and output of the heat generation

an economical parameter in industries. The system's energy efficiency increased by more than 20% due to good insulation [99]. The general energy efficiency points are given in Fig. 2. When the figure is observed, approximately 50% of the energy is utilized as useful energy and the remaining is wasted. The thermal parameters, specifically temperature distribution over the system, are considered a very important parameter for the machining. Many articles related to energy efficiency problems concentrate on thermal problems in the machining processes. As it is the one important section of heat generation, the machining process is considered the most affected section for quality. Therefore, the influences through the temperature must be minimized by efficient thermal applications. This creates highly efficient processes for machining [24].

Optimization processes, waste recovery, surface increment for heat transfer to the system, surface decrease to the outside convection, radiation or conduction, good insulation, CO_2 cycle integration by pressure and temperature adjustment, increased durability of coal, using appropriate coal fineness, input and output variable dependence of combustion system, using affective heat exchanger, collecting flue gases, temperature and pressure controlling are the techniques applied to the heat generation system for increasing efficiency. Mass, energy, and exergy analyses are the general bases for the efficiency consideration of heat generation. But the easiest and most expeditious energy recovery is observed in effective machining like micromechanical systems and hybrid systems, up to 20% of overall losses can be recovered [67].

In the improvement of heat generation, the experimental studies are supported by empirical models. Neural modeling, Aspen Plus Simulator, and ESS Software are very common in testing the system [69, 75, 77]. In modeling, the important thing is the system energy circulation as given in Fig. 1. Detailed analysis of inputs and outputs is crucial for obtaining accurate model results [80, 169]. The energy efficiency is determined as 32% and exergy efficiency is obtained as 35% due to the simple balance of the ESS model [75]. The environmental effect of heat generation is very high compared to the other sections studied in this article.

3.2 Steam system

The review results of the steam system are given in Fig. 3. The six main steps are determined for increasing efficiency. The steam efficiency can be increased by selecting the appropriate boiler; high quality and heating value fuels (especially gaseous fuels); appropriate, adequate, and good insulated pipes; the determination of losses at the boiler, pipes, and system inputs; heat recovery by optimizing flue-gases, pumps, and exchangers and finally well-monitored system by timely and necessary measurements [92, 98–100]. The dynamic behavior of the entire system is a very important parameter for machining. The effectiveness of the steam system is being maintained by a control system. The main reason is

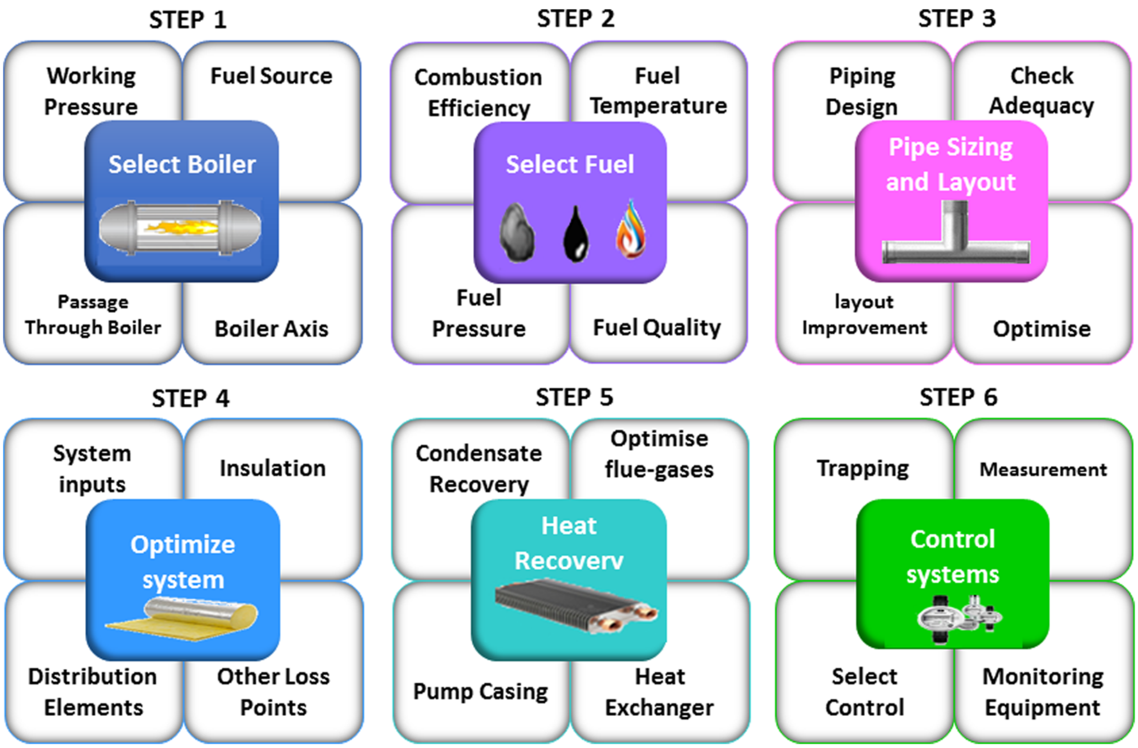


Fig. 3 Factors affecting steam systems

the limited thermal capacities of any steam system. Therefore, machining will be limited by the system's capacities. Each parameter must be considered and evaluated separately to maximize higher energy efficiency for the entire steam system [170]. The exergy and energy balance of steam flows through the systems are the main indicators for energy gain. The latent heat used to convert the liquid to the vapor of the steam system is very sensitive points and depends on temperature, pressure, network length, and pipe materials [101, 104].

At the steam systems, coal-tar, and ash products for solid fuels, fuel sediments for liquid fuels, and fugitive escapes for gaseous fuels are important energy loss problems depending on inefficient burnings. The economic assessments are considered in these stages. The environmental evaluations of the systems are also very important owing to the fugitive emissions of steam production. The water-containing slurries especially for coal-power plants decrease the SO_x and NO_x concentrations with respective values of 40% and 20%. These pollutants decrease in quantity with an increase in fuel efficiency, ranging from 5 to 30%. [93]. Scrubbing is an alternative methodology to clean the gases from an environmental point of view [94]. PSE-pro simulation software and CART algorithm are some modeling tools that are used for steam cycle simulations. The steam system model studies show that the increase in efficiency is possible up to 35% by determining fault points and heat recovery [94, 101]. The numerical results have permitted analyses of a detailed system optimization in machining. The modeling studies point to significant economic savings. If the general usage of steam to produce electricity is considered, controlling the existing configuration will improve energy efficiency by applying quantitative optimization of the electricity usage. This quantity can be increased up to 20% [95, 171].

3.3 Cogeneration system

The inputs of the cogeneration system and the processes are two main categories for energy efficiency applications. The ratio of oxygen to carbon indicates that efficient fuel combustion is one of the primary sources of energy gain. The percentage of energy gaining could be increased up to 60% by heat utilization, co-fuelled gasification, and biomass usage [111]. The CO_2 capture reduces efficiency penalties by an average of 11.5% [127]. The optimal energy-gaining point for the energy supply units is power generation and chilling. The energy used for machining in industries is focused on reducing process time and cost. Numerous scientific papers have delved into the comprehensive analysis of cogeneration or trigeneration. Different approaches for best energy efficiency applications are listed in this review paper. But complete analysis and energy efficiency applications give the best optimization for the entire system. To optimize the entire system including machining, a holistic approach is

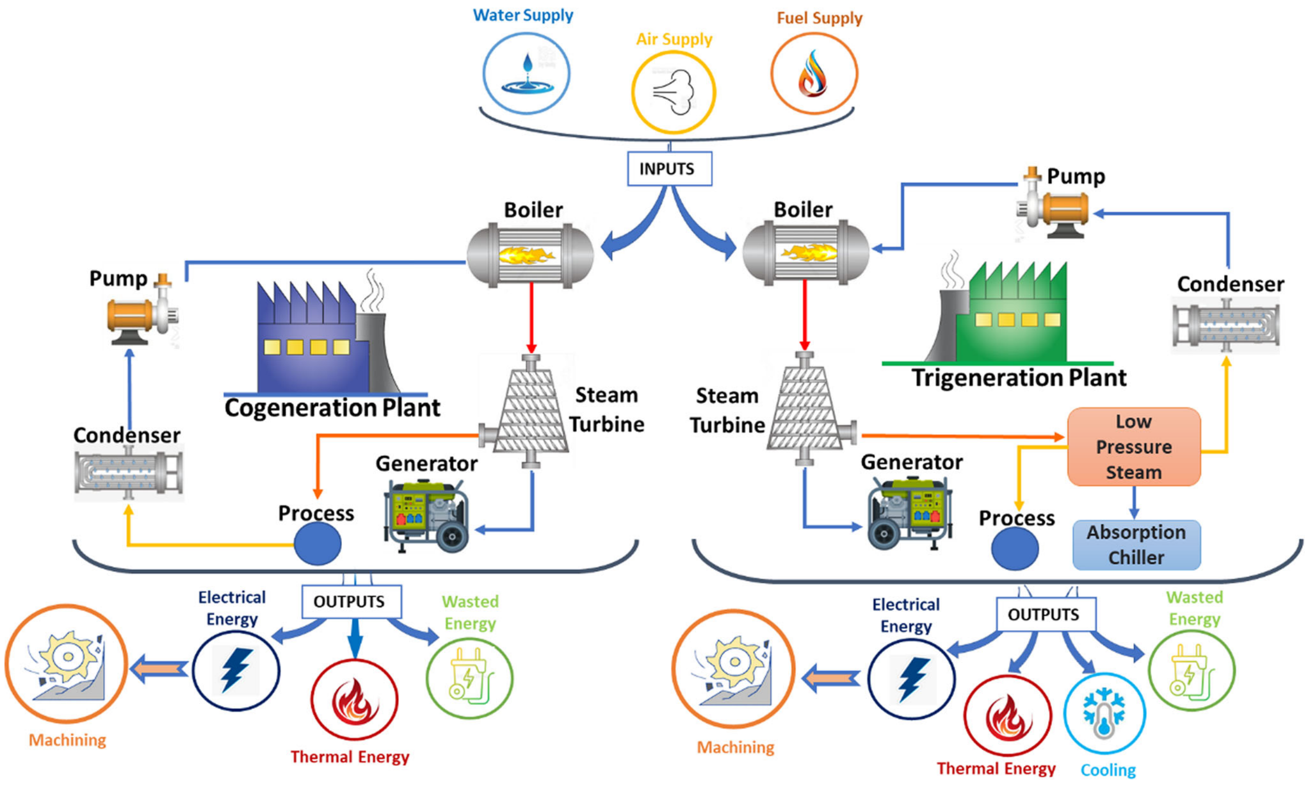


Fig. 4 The cogeneration and trigeneration units

needed that improves the system's energy efficiency by up to 65% [172]. Gasification of hard coal, lignite, and co-fuelled are alternative ways of energy-gaining applications in the industries. Pre-drying of fuels, using a heat pump (in a trigeneration plant), inserting a regeneration system, and wall insulation are some other best techniques for gaining energy in co-generation systems [115, 116]. The co-generation system is defined due to its outputs. If its output is producing electrical energy and thermal energy with energy waste, it is a co-generation system. If a cooling process is added to these three outputs, it is the trigeneration system [120]. Figure 4 shows an integrated energy system that operates using water, fuel, and power as inputs. This system consists of boilers, steam turbines, condensers, and generators. The electricity produced by the system is used for machining. Thermodynamic principles are applied to optimize energy efficiency. The system's performance is evaluated for each cycle, and a sensitivity analysis is conducted to determine how the system parameters affect it.

The exergy and energy analyses are applied to every step of the cogeneration and trigeneration systems. The range of energy efficiency is changing between 8.8 and 60.2% [111, 115, 121]. Therefore, high differences between entrance and exit energies of any sub-section are energy-gaining quantities in the cogeneration system. The extension of heat exchange surface, reduction of length and dimensions, automation of the process, reduction of acidification, eutrophication, and toxicity are some other methods applied in the production processes steps to increase energy efficiency [117, 118, 121, 130]. The cogeneration system yields an insignificant amount of energy, usually less than 1% of the total output. The exergy gaining is generally limited to around 15% [111]. The cogeneration and trigeneration systems are very suitable systems for supplying energy to the last operation units. The optimal load can also be considered according to the needed energy of the machining to assume efficient energy usage [173].

The trigeneration system is usually applied where the cooling demand is high and persistent. In this system, 50% to 60% of energy as heat is used for cooling purposes using a vapor-compression cycle. The increase of COP value measuring the performance of the heat pump shows total energy gaining in the trigeneration system. The required input and desired output of energy ratios optimize the COP value within the system. The energy gaining is usually explained by the energy efficiency ratio (EER) value [112].

3.4 Electric motor system

Electric motor system technically consists of motor-driven units, motor control systems, and power transmission systems as given in Fig. 5. The efficiency studies on electric

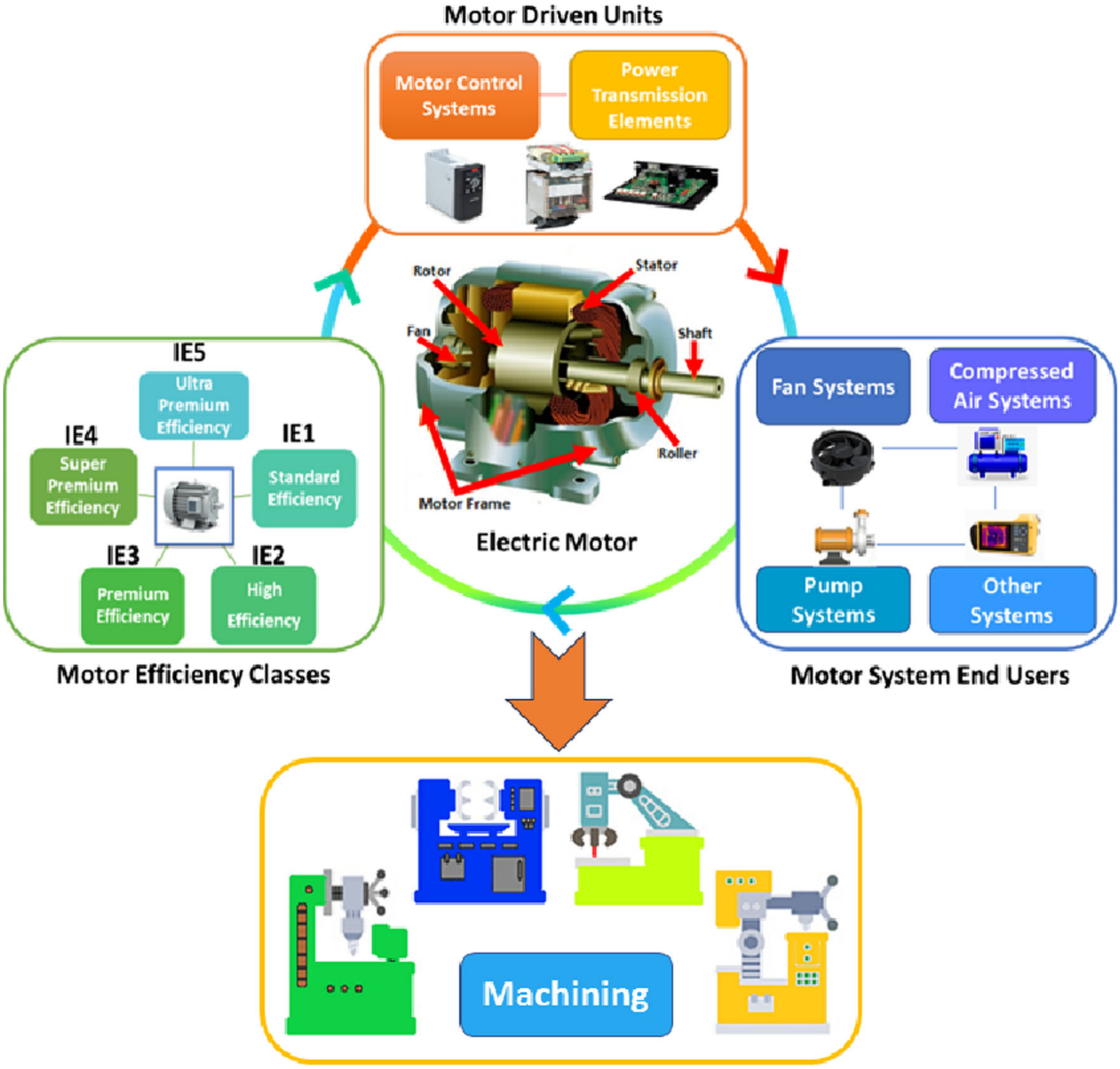


Fig. 5 The efficiency studies on electric motor system

motors are mainly performed with the replacement of low-efficient systems by innovative ones [136, 139]. The technological improvement of motors is providing many advantages to their users due to the consumption of less energy and high productivity capacity. However, the efficiency studies of replacing low-efficient motors are bringing some other technical features [141]. The main aim is to predict the accurate efficiency of the machining. The design process will concentrate on the driving forces of the machining. The parameters testing and the loss description in many aspects depend on the energy circuit. If enough optimizations have been done, then the energy efficiency in the machining system can be increased by more than 8% of the total used energy [174]. As manufacturing increasingly incorporates auto control systems, system monitoring becomes more difficult, necessitating maintenance checks to sustain these complex systems. Electrical motor systems consist of hardware and software components [142].

The usage of innovative motors is also affecting non-energy factors. These factors are lined up as; increasing workers' productivity, reducing operational costs, controlling environmental pollution, and decreasing material (raw material, mid-range product, final product) handling [144]. To optimize your system's efficiency, you must create a comprehensive map of the entire system, taking into account the machining process. This approach will enable to assess the performance of machining under varying conditions, pinpointing opportunities for enhancement and ultimately boosting the system's overall efficiency. To achieve peak efficiency, even the minimum energy loss points have to be evaluated. The consideration will have resulted in an accurate optimization of the machining system [175].

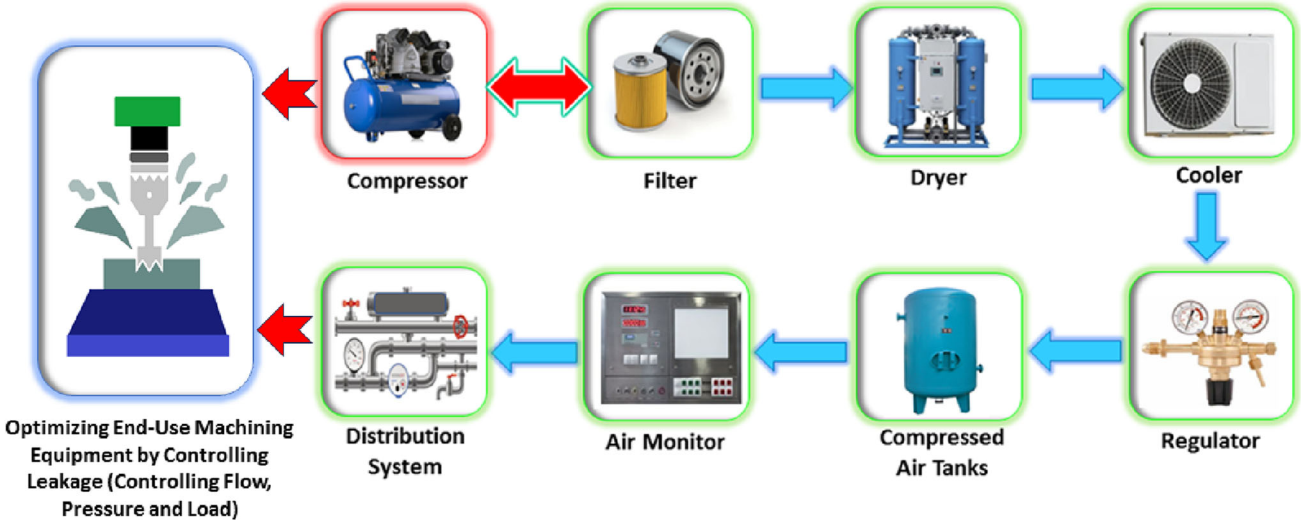


Fig. 6 Schematic diagram of the compressed air system

Determining the penalties of energy and non-energy factors of the system is the second energy-saving step. Correct size and/or scale, mechanical loss, optimum operation, technological suitability, lower operating hours, power quality, management of motors, personal attention, productivity, and system fatigue are some penalties which are directly or indirectly affect the efficiencies of machining [139]. The general efficiency studies of electrical motor systems in machining are shown in Fig. 5.

The energy efficiency is increased in the range from 3 to 35% by innovative EMS [144]. In some other multi-criteria analyses, the electrical gaining of energy is obtained from 1500 to 4500 kW hr/year [136]. And the total efficiency of the machining system can be increased by up to 40% [136, 141, 144, 175].

3.5 Compressed air system

CA system must be separated from the electrical motor system. This system transfers necessary energy not only to electrical motors but also to other devices like machining, air hammers, drills, wrenches, cylinders, etc., in industries [149, 150]. The usage purposes are related to many processes. Machining, ventilation systems, power transmission, cycling, network transport, and reduction of motor load are some good examples of the usage of CA systems [151]. The system configuration is given in Fig. 6.

Choosing the suitable compressor for the process, designing the compressed air networks appropriately, and increasing the use of waste heat of the compressor especially in the exhaust and cooling parts are the main energy-gaining points for the CA system [151, 153].

The optimizing CAES system is categorized into three sub-groups. The first group is defined as non-energy benefits such as production improvement, operation reduction, maintenance cost, improved work, and reduction of waste, water, and emission. Energy benefits can be obtained by controlling the air inlet (reducing inlet temperature, optimizing intake cooling, optimizing throttle inlet), compressor (shut in not use, using multiple, adjustable or auto controller, using high and dry air), and ancillary equipment (proper filter and dryer, unload unnecessary tool, part, and equipment, using flow controller). On the demand side as the third group, the benefits are made up of optimizing distribution lines, networks, or systems; optimizing end-use machining equipment by controlling leakage; controlling flow, pressure, and load [149, 151, 153, 155, 161].

A compressor needs to work for a long time to prevent the pressure drop caused by air leaks. Air leaks are causing the highest energy losses in CA systems. According to many studies, approximately 25% of the CA produced is lost due to leaks [149]. The Optimizing CAES is decreasing energy consumption by around 70% of the total energy needed [150]. Fluid mechanics is an essential scientific aspect of the CA system, which involves the study of fluid behavior and its effects on different structures and systems [154]. With appropriate improvements in airflow, the energy and exergy efficiencies are increased respectively with values of 27.3% and 60% [153, 154, 161]. Using a finned piston increases energy efficiency with a value of 78.4% [153]. In general, the various features of the CAES system, operate under isothermal, adiabatic or diabatic conditions, depending on the air pressure, temperature and flow rate. The optimization of the machining system can be achieved through the adjustment of thermal conditions and finding the optimum

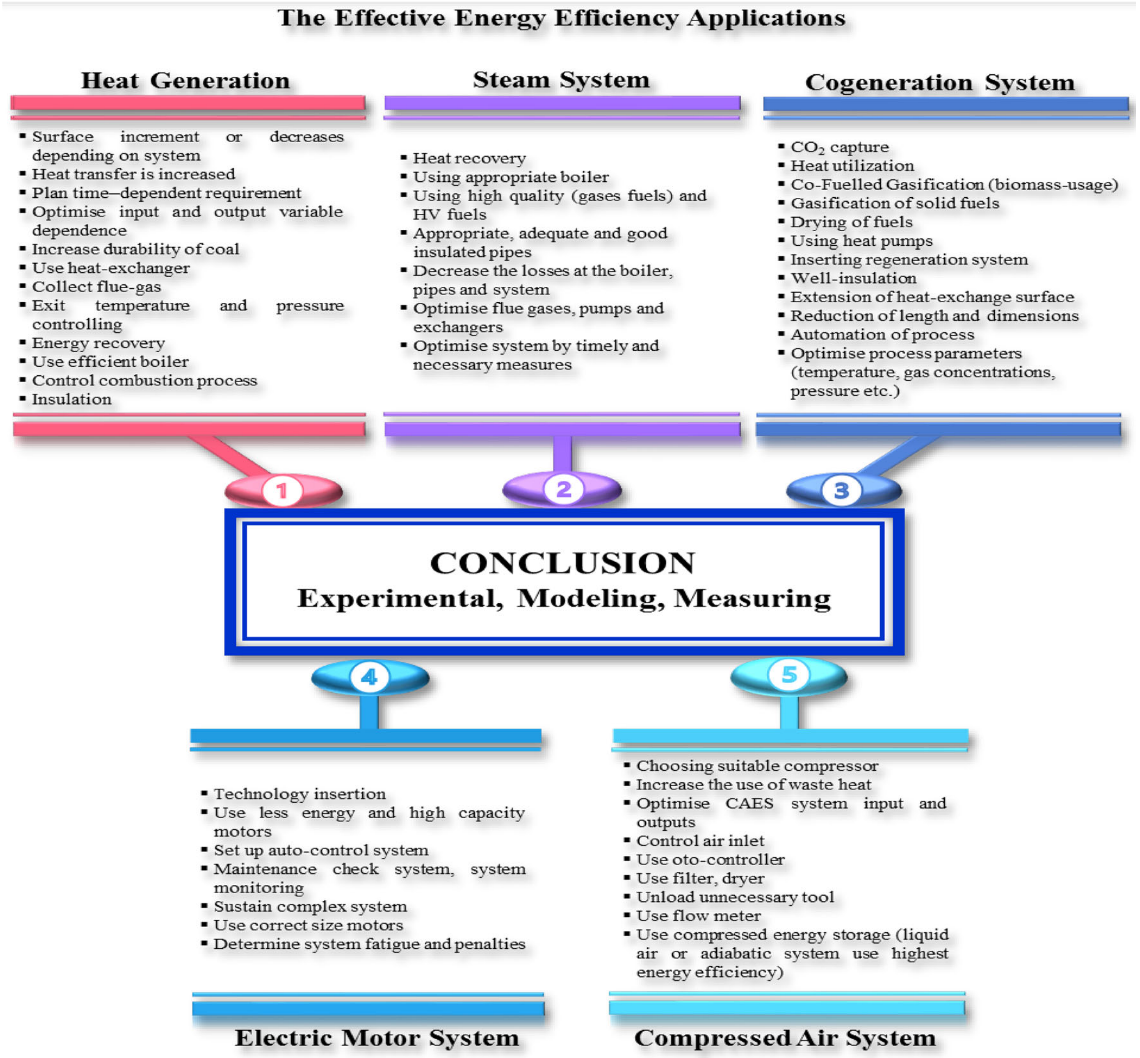


Fig. 7 The conclusion of energy efficiency reviews in industries

pressure by analyzing operating conditions. More than 90% energy efficiency can be achieved with an appropriate CAES system mostly in isothermal and high-pressure conditions for machining purposes [176]. By the way, energy efficiency with compressed energy storage is obtained at 60% [151]. The liquid air energy storage system boosts energy efficiency up to 76.6% by creating a thermal energy reservoir and regenerating electricity as needed. The biggest disadvantage of this system in machining is that it is on a large scale [164]. It is possible to achieve a significant increase in energy efficiency up to 95% by utilizing an adiabatic energy storage system [157].

4 Conclusion

After the review of many scientific articles, the first energy-saving points are stated as re-using and/or recycling the energy in the system. Heat recovery, insulation, auto control and fuel gasification are the top applications of energy-saving methods. The technological improvement of machining is also increasing energy efficiency. Different scientific studies are showing that 90% of energy gain could be possible in old industries with appropriate utilization, optimization, and consistent replacement by considering the system parameters separately. The mass, energy, and exergy analyses are general methodologies to determine the indicators of system efficiency. The following Fig. 7 gives the general conclusion for this study. The main aim is to increase the efficiency of the machining system. The thermal parameters of the machining system are the main indicators to determine the system's efficiency. Optimization for energy efficiency involves considering dynamic behavior, effectiveness, and thermal capacity limitations. The dynamic behavior of a system can be determined by monitoring physical quantities such as temperature, pressure, and flow rate over time. The machining tools are intensive energy-consuming types of equipment and mostly consume electricity in manufacturing industries. Therefore, any type of dynamic parameter can affect energy consumption and production within the machining system. The optimization can be also increased by innovative EMS. The simple cooling of the motor has sometimes presented a consequent important energy gain in the machining. It is also highly preferred the decrease friction in the machining processes. Since the complex characteristics of the machining process are present in different types of industries, the adaptation of energy consumption characteristics depends on process parameters, which determine how the energy efficiency applications, modifications and optimization are taking place in industries.

The review has shown that the highest energy losses are observed at the combustion of fuels. The high rate of heat transfer waste can be avoided by integrating systems that sustain a stable combustion process, depending on the air mixture, temperature, and boiler type. The steam efficiency can be increased by selecting the appropriate boiler and high-quality fuels. The well-monitored steam system is also very effective for energy recovery. Energy-efficient machining is very important in manufacturing industries to conserve energy. The general approach for cost-effective planning is to set a complete energy-efficient system. The modeling studies have indicated considerable economic savings. Mass, energy, and exergy analyses are the general bases for the efficiency consideration of heat generation. Effective machining, such as micromechanical systems and hybrid systems, can recover up to 20% of overall energy losses. If the general usage of steam to produce electricity is considered, controlling the existing configuration will improve energy efficiency by applying quantitative optimization of the electricity usage. This quantity can be increased by an extra 20%. To optimize the entire cogeneration or trigeneration machining system, a holistic approach is needed that improves the system's energy efficiency by up to 65%. The energy efficiency is increased in the range from 3 to 35% by innovative EMS. Air leaks are causing the highest energy losses in CA systems. An appropriate CAES system can achieve more than 90% energy efficiency, particularly under isothermal and high-pressure conditions for machining purposes. Moreover, the recovered energy will mitigate GHGs. And it is strict that, any developing plan of countries which contains an energy efficiency strategy, is necessary to sustain a habitable earth.

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Declarations

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