Energy Management and Conservation Industrial and Building Sectors: A Review

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ABSTRACT

Energy conservation is essential in tackling the rising worldwide energy consumption, particularly in the industrial and construction sectors. This study examines critical ways to reduce energy usage by altering user behavior, eliminating energy waste, and implementing efficient technologies. The industrial sector, responsible for a substantial share of worldwide energy consumption, can realize cost savings and enhanced profitability by adopting Energy Management Systems (EMS) and efficiency initiatives. Innovations in the construction industry, including thermal insulation, LED lighting, and efficient HVAC systems, yield substantial energy savings, as seen by case studies of commercial buildings and hotels. Furthermore, successful programs like renewable energy integration and sophisticated energy management systems illustrate the economic and environmental advantages of energy saving.

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1. Introduction

Global energy use has experienced a significant surge in recent decades. In 2023, worldwide energy consumption increased by 2.2%, indicating the rising need for energy due to economic and demographic growth. Longitudinal trend analysis suggests that from 1978 to 2018, worldwide energy consumption surged by approximately 114% [1]. This surge exerts significant pressure on constrained energy supplies and necessitates improvements in energy management to promote more efficient energy utilization.

Addressing these difficulties, including implementing the Energy Management System (EMS) and energy saving, are essential measures. Energy Management Systems (EMS) empower organizations and nations to optimize energy use, minimize expenses, and enhance profitability and economic prosperity. EMS is a systematic framework that meticulously documents and evaluates energy flows, establishing a robust foundation for investments in energy efficiency [2]. Conversely, energy conservation emphasizes reducing energy consumption by a deliberate methodology that encompasses altering user behavior, minimizing energy waste, and employing energy-efficient technologies. The two approaches synergistically enhance energy efficiency across multiple sectors [3].

Due to the rise in operational expenses linked to energy consumption, energy efficiency has emerged as a critical priority across multiple industrial sectors in recent decades. A primary cause is the elevated energy costs associated with the production process. Initiatives to minimize operational expenses and enhance business earnings have intensified the focus on energy management and conservation [4]. Research by Aydin [5] indicates that adopting energy management and efficiency programs in the manufacturing sector has yielded energy savings and integrated energy conservation techniques into industrial processes.

In the industrial sector, the adoption of EMS has demonstrated tangible outcomes in decreasing energy usage and operational expenses. PT. PLN (Persero) in the metal sector has effectively diminished energy usage with the installation of capacitors and Variable Speed Drives (VSD), yielding annual savings of 5,028.48 kWh and 2,017,267.2 kWh [6]. Energy audits have effectively discovered and optimized energy waste in the bodywork business, reducing energy consumption intensity and operational expenses. Moreover, the construction and technology sectors possess significant potential for enhanced energy-saving measures [7].

This review study highlights that energy conservation can be efficiently executed across diverse industrial sectors. This study will analyze the implementation of energy conservation in building construction [8], the manufacturing industry [9], and technology [10] to determine how different conservation strategies can substantially enhance energy efficiency.

2. Energy Conservation in Building

Energy conservation in buildings is an effort to reduce energy consumption by using technology and practices that are efficient in energy use, such as good thermal insulation, the use of efficient electrical equipment, and the use of renewable energy sources [3]. Energy saving measures are divided into three main categories: current, primarily active and passive, and renewable energy saving measures [11]. Passive measurements mainly refer to the orientation of the building [11], reconstruction of building envelopes [12], and repairing and strengthening building structures, specifically including roof changes [13], exterior walls [14], and windows [15]. Active measures mainly refer to heating, ventilation, and air conditioning reform measures [16], [17], and lighting [18]. Active measures involve the application of technologies to improve energy efficiency, such as efficient HVAC systems, replacing old lighting with LED lighting, and using automatic timers. The case study of the IT Office Building in Balikpapan shows significant results from the implementation of this strategy: Energy Consumption Intensity (IKE) decreased from 28.09 kWh/m²/month in 2007 to 13.80 kWh/m²/month in 2017, and monthly electricity consumption reduced by 12% from 1,375 MWh (2007-2009) to 1,216 MWh (2010-2017) [19].

The following are contributions to energy savings, as seen in Figure 1. Energy-saving measures in buildings include using thermal insulation on walls, roofs, and floors, high-quality windows to reduce heat and cold leakage, and efficient heating and cooling systems. In addition, replacing conventional lamps with energy-saving lamps, such as LEDs, and using energy-saving household appliances also play an essential role in reducing energy consumption. Energy efficiency policies, such as stricter building performance standards and financial incentives, also support energy savings in buildings.

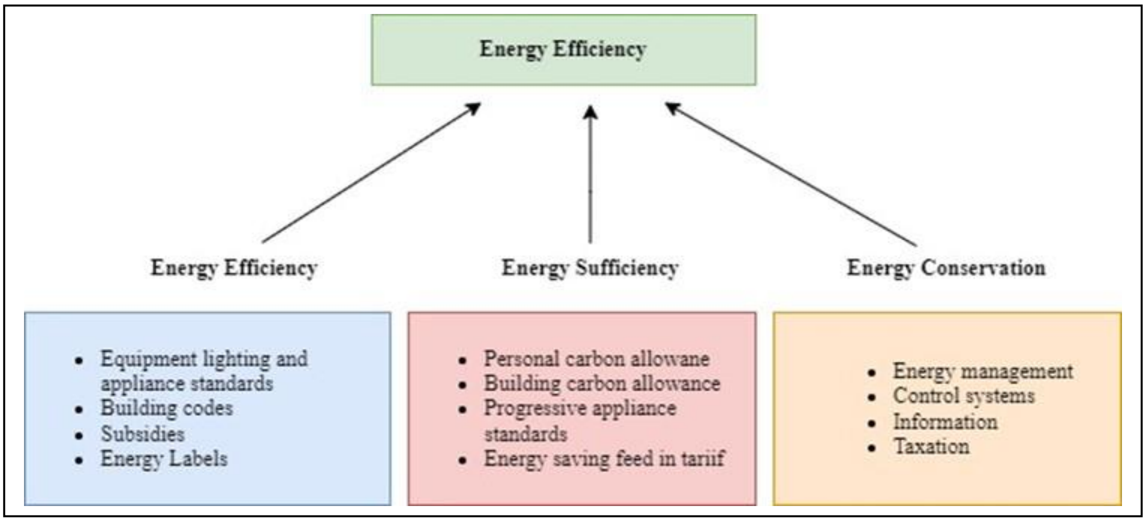

Fig. 1. Contribution to energy savings

Energy savings in buildings are achieved in several ways, including: (1) Thermal insulation: Installing insulation on the walls, roofs, and floors to reduce heat and cold leaks. This can reduce the need for heating and air conditioning. (2) Use of high-quality windows: High-quality windows can help reduce heat and cold leaks, reducing the need for heating and air conditioning. (3) Use of efficient heating and cooling systems: helps reduce energy consumption. (4) Use of energy-saving lamps: Replacing conventional lamps with energy-saving lamps such as LED lamps can reduce energy consumption. (5) Efficient use of household appliances can help reduce energy consumption [21], and it explains the development of policies to improve building energy efficiency. One proposed policy is the development of stricter building performance standards to ensure new and renovated buildings meet higher energy efficiency requirements [21]. The environmental impacts of high energy consumption in buildings include increased CO_2 emissions and the Impact of buildings on indoor air quality. High energy consumption in buildings can also cause an increase in urban temperatures (urban heat islands) and worsen global climate change

Policy mechanisms that can encourage energy efficiency and reduce carbon emissions, including energy and carbon taxes, have been proven effective in reducing energy consumption [20], [21], [22]. This tax provides a price signal that can encourage users to reduce energy consumption [23]. Minimum efficiency standards for equipment and building regulations have effectively reduced energy consumption [24], [25], [26]. These policies ensure that equipment and buildings meet specific energy efficiency requirements. Financial incentives, such as tax credits or subsidies, can encourage investment in more energy-efficient technology and equipment [24], [27]. Determining electricity tariffs based on actual consumption can encourage customers to regulate their energy consumption [24]. Energy savings optimization and evaluation methods are commonly used in energy conservation research in existing buildings [7].

2.1. Multi-Objective Optimization

This approach optimizes several conflicting objectives, including energy conservation, expenses, and emissions. This study uses this strategy to ascertain the ideal solution for maximizing energy efficiency by evaluating multiple aspects. Methods for optimizing energy savings in existing buildings encompass Multi-objective Optimization (MO) and the Analytic Hierarchy Process (AHP). Multi-objective optimization (MO) enhances several conflicting objectives, including energy usage, cost, and comfort. A public building project in China employed an Artificial Neural Network (ANN)-based optimization method that achieved an annual energy savings of 210,000 kWh, enhanced Spatial Daylight Autonomy (sDA) by 11%, and decreased the cost of the building envelope. Conversely, AHP evaluates and ranks criteria like energy efficiency, expense, and ecological consequences. AHP has demonstrated the capacity to conserve 10-30% of energy, contingent upon the project’s magnitude and the used technology [28].

2.2. Analytic Hierarchy Process (AHP)

This methodology evaluates and ranks different variables influencing energy conservation. AHP entails the weighting and ranking of these criteria according to their significance. This strategy enhances decision-making efficacy in the formulation of energy conservation plans. The Analytic Hierarchy Process (AHP) evaluates and ranks multiple aspects influencing energy savings, including energy performance, cost, and environmental impact. The Analytic Hierarchy Process (AHP) is utilized in energy conservation initiatives to identify the optimal method for selecting efficient HVAC systems and insulating materials, considering thermal performance and maintenance simplicity. Implementing AHP demonstrates that this method can yield more effective decisions in energy-saving planning, potentially achieving 10-30% energy savings, contingent upon the project's scale and the technology employed [29].

2.3. Dynamic simulation

This method involves computer simulation models that consider variables such as temperature, humidity, and energy use in the building. By using accurate data, this method can help identify and optimize the most effective energy-saving strategies. By modeling environmental factors in real-time, dynamic simulation makes it possible to guess how temperature and humidity will change inside buildings. For instance, Model Predictive Control (MPC) is used in HVAC systems to consider outside things like people moving around and changes in the weather by using dynamic simulation. This test shows that using this method instead of traditional ones like Proportional-Integral (PI) control can make HVAC systems more efficient and save up to 20 to 30 percent of energy. Another way that dynamic simulation cuts down on running costs is by making equipment last longer [30].

2.4. Investment evaluation method

This method involves analyzing the costs and benefits of energy-saving measures. This research uses this method to evaluate the economic feasibility of energy-saving measures and select the most financially profitable solutions.

As shown in Fig. 2., the following study trends relate to energy savings in existing structures. Fig. 2. presents research findings related to energy efficiency in existing structures. This study trend indicates that various evaluation objectives, criteria, and other techniques must be employed to optimize energy savings in existing structures. Nevertheless, most of these assessments rely solely on simulation outcomes that need more verification. The assessment results show less energy savings because they must be confirmed and maintained during their lifetime. This hinders the process of reaching energy-saving goals. Enhancing operations and management can prove that energy simulations are accurate [7].

Research trends indicate that energy simulation is frequently employed to forecast building energy reductions. Nevertheless, simulation outcomes are sometimes inadequately validated during the building's lifespan, leading to less energy savings than anticipated. Consequently, sustained verification via efficient operation and management is essential to guarantee simulation outcomes' precision and maximum energy savings.

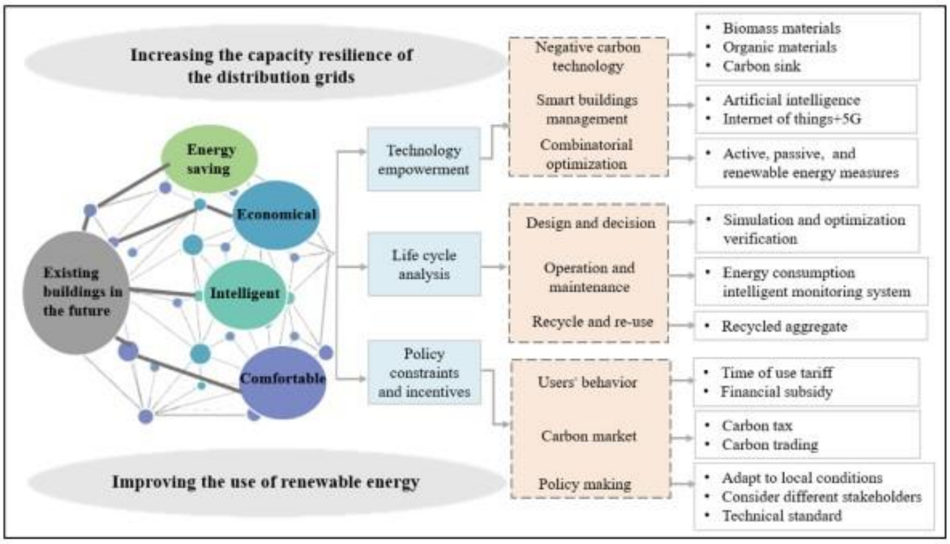

Fig. 2. Research trends on energy savings in buildings [7].

2.5. Hotel Building

Energy conservation is critical to environmental management strategies to reduce expenses and save resources [28], [29]. Energy conservation started with so-called "eco techniques," or modifications to fundamental hotel technologies and policies, and then developed into part of environmental management. Later, it grew into part of the Environmental Management System (EMS), which calls for the close involvement of all stakeholders methodically, along with other aspects of environmental management (such as water conservation and waste management) [31].

The problem with hotel building conservation is that the structure and design of hotel buildings need to consider energy conservation at the construction stage. This has led to the need for stricter energy regulations. Additionally, older hotels tend to be reluctant to add energy-saving features because of the cost and time required to make changes to construction and design [33]. Hoteliers have two options for energy conservation measures: proactive and reactive [34]. According to the reactive method, hotels implement energy-saving strategies in response to external, concrete pressures from different stakeholders [35]. Proactive measures are not only about complying with regulations and standard industry practices; the main focus is creative problem-solving and close collaboration with various stakeholders [34].

Energy conservation in hotels involves implementing various measures to reduce energy consumption, which include:

a. Implement energy audits to understand energy consumption patterns, evaluate their relationship to other operational variables, and implement pricing strategies for high energy-consuming services [33].

b. Rigorously integrate environmental considerations into hotel licensing decisions, including promoting behavioral change among hotel guests and staff and implementing reward systems for pro-environmental behavior [34].

c. Invest in solar panels or other renewable energy systems to reduce dependence on fossil energy sources and greenhouse gas emissions.

d. Uses an energy management system (EMS) to monitor and control energy usage in real-time, optimizing energy consumption based on occupancy levels and guest preferences.

e. Energy-efficient lighting systems such as LED lights and motion sensors or timers should be installed to control lighting in unused areas [34].

3. Energy Conservation in Industry

Energy conservation in industry is an effort to reduce energy use by increasing energy efficiency in production processes and industrial operations. Some steps that can be taken to achieve this goal include using more efficient technology, updating equipment, optimizing production processes, and better energy management. One example of implementing energy conservation in industry is using an energy management system (SME) based on the ISO 50001 standard. SME helps companies identify and reduce energy waste and increase awareness and commitment to optimizing energy use [35].

Energy conservation strategies in industry include several approaches, including industrial energy management strategies, industrial structure adjustments, and technology promotion policies. Industrial energy management strategies involve uncertainty analysis to identify factors influencing industrial energy consumption, thereby helping set realistic energy conservation targets [36]. Several factors influencing industrial energy consumption include external uncertainty, industrial structure uncertainty, and technical parameter uncertainty. Changes in the macroeconomic situation can affect the prices of energy and industrial products, introducing external uncertainty [37]. In addition, fluctuations in industry structure predictions also cause industry uncertainty [38].

The sub-fab energy recovery system is a technology utilized for energy conservation in the semiconductor industry. According to research [41], energy recovery technology functions by absorbing and reutilizing heat produced during the manufacturing process, which is typically squandered. This method facilitates a substantial decrease in energy use by harnessing lost heat. This technology enhances energy efficiency and diminishes carbon impact.

4. Iron and Steel Industry

The iron and steel industry is an industry with high energy density [42], [43], an industry with high carbon emissions [44], and industries with high material density [45]. Over the past twenty years, steel production in the world has more than doubled, and steel production will continue to increase along with economic growth and infrastructure development [46], [47]. Being the industry with the highest energy and emission levels, the rapid expansion of steel manufacturing has significantly strained the environment [47]. For example, in the industrial sector, ISI ranks first in CO_2 emissions and second in energy consumption. Better management of energy and alternative fuels can also help reduce energy consumption in the iron and steel industry. Fig. 3. shows some measures to conserve energy in industry.

Based on Fig. 3., Energy conservation measures in iron and steel: scrap steel recycling: Collecting and recycling scrap steel can reduce the energy consumption required in production. Increased energy efficiency: Adopting more efficient technologies and practices in steel production can reduce energy consumption. Use of alternative raw materials: Finding and using alternative raw materials that are more environmentally friendly and sustainable can help reduce iron and steel consumption. Lighter product designs: Developing and using more delicate, efficient strategies can reduce the need for iron and steel. This can be achieved using more lightweight alternative materials or optimizing product structure and design. Improved waste management: Properly managing waste and production scrap can help reduce the need for new steel production. Iron and steel consumption can be reduced by recycling waste and reusing production scraps [48].

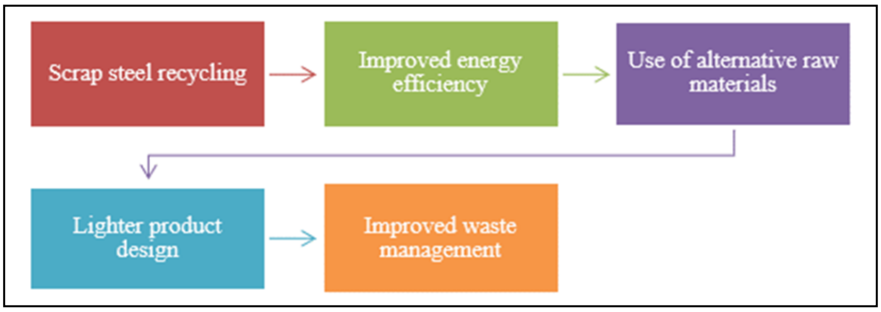

Fig. 3. Energy conservation measures in iron and steel

In addition to those above, the first table displays the number of specialized technologies and innovations implemented to effectively reduce energy consumption and emissions in the industrial and commercial sectors. For example, using hydrogen as a reduction agent has demonstrated the ability to reduce CO_2 emissions by up to 91%. The optimization of the construction process and the development of solar technology can assist in reducing the amount of energy consumed and the emission of greenhouse gases, as well as in reducing operational costs. The utilization of biomass and biochar as alternative fuel sources has the potential to reduce CO_2 emissions by up to 50%, as well as to increase production and reduce energy costs [49]. This technology does not merely benefit the environment by reducing carbon emissions and providing significant economic benefits by optimizing energy efficiency and reducing operational costs.

Table 1. Environmental and Economic Impacts of Energy Technologies and Innovations

Technology/Innovation	Environmental Impact	Economic Impact
Hydrogen as Reduction Agent	Reduce CO_2 emissions by up to 91%	Reduce operational costs
Combustion Process Optimization	Reducing exhaust emissions and ineffective energy	Reduce energy costs
Biomass and Biochar	Reduce CO_2 emissions by up to 50%	Reduce energy costs and improve processes
Heat Recovery Technology	Reducing exhaust emissions and ineffective energy	Reduce operational costs

5. Energy Conservation In Power Plants

In addition to those above, the first table displays the number of specialized technologies and innovations implemented to effectively reduce energy consumption and emissions in the industrial and commercial sectors. For example, using hydrogen as a reduction agent has demonstrated the ability to reduce CO_2 emissions by up to 91%. The optimization of the construction process and the development of solar technology can assist in reducing the amount of energy consumed and the emission of greenhouse gases, as well as in reducing operational costs. The utilization of biomass and biochar as alternative fuel sources has the potential to reduce CO_2 emissions by up to 50%, as well as to increase production and reduce energy costs [49]. This technology does not merely benefit the environment by reducing carbon emissions and providing significant economic benefits by optimizing energy efficiency and reducing operational costs.

Reliance on fossil fuels is becoming acknowledged as a significant concern. Conventional fossil fuel power generation, including coal, oil, and natural gas, substantially contributes to greenhouse gas emissions, exacerbating climate change. Actions must be implemented to diminish this reliance. Integrating renewable energy sources, including solar, wind, hydro, geothermal, and biomass, into the power generating system is an expanding initiative that minimizes emissions and fosters future energy sustainability [50].

Integrating renewable energy with fossil-fuel-based power generation via hybrid designs is an increasingly prevalent strategy. The amalgamation of concentrated solar power (CSP) with natural gas-fired power generation in a solar-integrated combined cycle (ISCC) system has demonstrated enhanced energy efficiency and diminished carbon emissions. The Sarir power station in Libya integrated CSP technology with a Siemens SGT5 PAC 4000F gas turbine, resulting in notable enhancements in energy efficiency and reductions in carbon emissions [51], [52].

Moreover, hybrid power plants integrating CSP with biomass have been suggested as a versatile and cost-effective alternative. In Brazil, CSP-biomass hybrid power plants enhance renewable energy integration in semi-arid areas at reduced installation costs compared to independent CSP systems [53].

Numerous instances of the incorporation of alternative renewable energy sources have favorable outcomes. Solar energy, via solar photovoltaic (PV) panels, directly turns sunshine into electricity, considerably contributing to the decarbonization of the energy system by substituting fossil fuels like coal and natural gas, thus markedly decreasing CO_2 emissions. Wind energy, which transforms the kinetic energy of wind into electricity via wind turbines, enhances the energy mix and diminishes reliance on conventional energy sources [54]. Hydroenergy harnesses water movement to rotate turbines and produce power with little greenhouse gas emissions, rendering it a sustainable energy source [55].

Furthermore, biomass energy from organic materials like agricultural wastes and forest debris is incinerated to generate heat that powers turbines. This technique is deemed carbon neutral since the CO_2 emitted during combustion corresponds to the CO_2 absorbed by the plant throughout its growth [55]. Geothermal energy is a dependable and consistent energy source that is well-suited for supplying the base capacity of renewable energy systems. It generates electricity by harnessing the heat from within the earth. Integrating these renewable energy sources reduces dependence on fossil fuels, diversifies the energy mix, supports sustainable development, and reduces greenhouse gas emissions [56].

6. Conclusion

Energy management and conservation are essential for attaining sustainability objectives and mitigating environmental repercussions. Implementing Energy Management Systems (EMS) and energy efficiency technologies has yielded measurable advantages, including energy conservation, diminished operational expenses, and lowered carbon emissions across multiple sectors, such as industry, buildings, and power generation. An exemplary demonstration of effective energy conservation measures is using hydrogen as a reducing agent in the iron and steel sector, resulting in a 91% reduction in CO_2 emissions. Furthermore, in the construction industry, the implementation of efficient heating and cooling systems, along with the utilization of LED lighting, has decreased energy usage by 12%, as evidenced by a case study of an IT office building in Balikpapan. Life cycle assessment and continuous maintenance are crucial to guarantee sustained energy savings throughout the system's lifespan.

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