Relation between Energy Efficiency and Industry 4.0

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The industrial sector is the most energy-consuming sector before the transport and residential sectors. It accounts for about 31% of the overall energy consumption. For this reason, manufacturers are placing increasing emphasis on energy efficiency through improvements in energy management, energy devices, and insulation. Energy efficiency improvement is the application of engineering principles and best practices to control the energy consumption of a facility. It is a continuous process that requires the full involvement of all stakeholders (managers, engineers, workers, etc.) to identify, formulate proposals, and implement energy efficiency technologies and practices to reduce energy consumption. Many technologies and practices are currently available and in development that could save energy if adopted by industry, classified into two main categories: energy management technologies and energy devices. In addition, various tools and methods are used, such as energy monitoring tools, process modeling and integration, optimization and simulation tools, energy analysis and decision support tools, etc. One of the recent innovations is the introduction of Industry 4.0 in manufacturing, in other words, the transition to the new industrial era.

energy efficiency | Industry 4.0 | wood industry | Energy Management 4.0

1. Introduction

Due to the increasing cost of energy, low price competition [1][2], and environmental legislation [2][3], the goal of the manufacturing company is to reduce the total cost of production while maintaining the same quality. On the other hand, the higher objective is the sustainable manufacture of goods with minimum energy [4][5] by developing methods to reduce energy consumption and improve energy efficiency. This can only be achieved by adopting a fully transparent energy consumption in plants, facilities, and machines. Here, energy management is necessary. A data and network management system can control production. Computer systems can be integrated into plants and machines. They can receive values measured by sensors (smart sensors) and controllers, record product data, and operate complex systems. In Industry 4.0, energy management requires an independent platform for remote accessibility of the plant [6].

Therefore, Industry 4.0 is applied to the energy efficiency domain in two ways: energy management and energy devices.

2. Energy Efficiency

According to the Quebec Ministry of Energy and Natural Resources, energy efficiency aims to "*make the best possible use of available energy to obtain a better energy yield. Energy efficiency is improved when producing the same good or service with less energy* [7]".

In general, energy efficiency uses the best technologies or controls to reduce energy consumption (LED lighting, hybrid system, management software). Energy efficiency makes operations competitive and economically sustainable by including energy management [8]. Energy management is the continuous monitoring, maintenance, and improvement of energy performance [9]. Its objective is to organize industrial facilities to integrate energy efficiency into their management practices [10].

In industry, energy efficiency can be improved in thermal processing systems through better operation and maintenance practices, process optimization, and good insulation [11]. Energy efficiency is expressed as a ratio of an output (performance, service, goods, or energy) to an energy input [12].

3. Industry 4.0 Concepts to Improve Energy Efficiency

Regarding energy management (EM), ISO 50001:2011 norm defines it as the "sum of fully integrated or interacting elements leading to the introduction of an energy policy and strategic energy objectives, as well as processes and procedures to achieve these strategic objectives [13]". The pillars of EM are measurement, monitoring, evaluation, and control of energy in manufacturing while maintaining the same production requirements such as quality, cost, and delivery [14]. Energy management aims to guide industrial facilities to integrate energy efficiency into their management practices [10]. In Industry 4.0, energy management will be referred to as Energy Management 4.0. The role of Energy Management 4.0 is to provide energy data-driven decisions, monitor energy systems, optimize energy consumption autonomously [1][15], and improve energy efficiency. Energy data must be collected and synthesized from smart meters, sensors, and other tools (energy devices) [16][17] and then integrated into production management [16].

Energy efficiency addresses three cases: building, machinery, and process.

4. Buildings

Buildings are important energy systems, with the latest research showing that they are responsible for 40% of total energy consumption and 36% of greenhouse gas emissions [18]. New buildings' energy efficiency technologies are more accessible to implement than old buildings or renovations [11][18][19]. Thus, controlling and reducing the energy consumption of buildings is a real headache. There are three main actions to improve energy efficiency in buildings. The first is to improve insulation to reduce heating and cooling costs. The second is to adapt the automatic control systems of building management. The third is to modify the energy technologies used by changing the lighting devices (installing LED lamps) and using sensors and actuators to automate energy management. In the past, installing sensors and actuators required a significant modification of the building structure. However, newer technologies introduce so-called "smart" sensors and actuators and can use wireless

communications, which has a technology and cost advantage. The integration and development of IoT-based smart sensors, devices, and protocols can help in the transition to smart buildings [18]. In addition, Energy Management 4.0 is designed to control heating, cooling, ventilation, and thermodynamic systems by using data received from sensors and devices and processing them with artificial intelligence technology [20][21]. It allows organizing energy activities between consumers and suppliers by coordinating energy production capacities and consumers' needs [21].

5. Machinery

Nowadays, economic energy consumption is one of the main concerns of industrial companies in Industry 4.0 manufacturing systems [16]. The energy consumption of machining must be monitored in real-time to achieve efficient energy consumption (energy-efficient production). Nevertheless, it is not easy to establish an energy consumption model. Therefore, Industry 4.0 can provide a solution by deploying various smart sensors, collecting energy consumption data, and applying an AI method to determine energy demand characteristics. For example, a deep neural network (DNN) is a machine learning method that processes and analyzes Big Data to define manufacturing equipment's energy consumption characteristics or trends based on the data obtained from energy consumption monitoring [15]. It proceeds afterward by modifying and optimizing the equipment parameters without human intervention [18].

6. Process

Manufacturing processes involve many physical mechanisms to transform raw material into a finished product by changing its form and/or composition [22][23].

Compared to the total energy consumed, the energy spent in the process itself is small [23]. However, it is not negligible because the energy consumption of various industrial processes varies with time and the dynamic nature of the process energy [19][24].

Energy consumption awareness should be raised first, and then energy consumption should be monitored and analyzed in real-time to improve energy efficiency and optimize manufacturing processes' energy consumption [25]. Most standard production systems cannot collect energy consumption data in manufacturing processes [25][26]. In this regard, Industry 4.0 contains dynamic, efficient, automated, and real-time process communication for managing and controlling a dynamic manufacturing environment using the IoT [16].

In addition, the IoT uses data acquisition and control systems to sense, collect, store, analyze, display, and control facility processes [27][28]. Data are collected by smart sensors or other measurement equipment [27] and processed to provide information. The data collected from smart sensors are stored as Big Data by analysis tools [15] in the cloud [16]. Then, they are monitored and analyzed in real-time, integrated into energy management tools (e.g.,

energy management software, simulation tools), and defined into strategies and practices to improve energy efficiency [16] and reduce energy consumption [18].

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