Impact of technical and technological changes on energy efficiency of production company – case study

K Szwedzka¹, J Gruszka¹ and P Szafer²
¹Poznan University of Technology, Faculty of Engineering Management, Strzelecka 11, 60-965, Poznan, Poland
²WSB School of Banking, 61-874 Poznań, ul. Al. Niepodległości 2, Poland

E-mail: katarzyna.szwedzka@gmail.com

Abstract. Improving energy efficiency is one of the strategic objectives of the European Union for rational energy economy. To make efforts to improve energy efficiency have been obliged both small and large end-users. This article aims to show the possibilities of improving energy efficiency by introducing technical and technological process changes of pine lumber drying. The object of the research is process of drying lumber implemented in a production company, which is a key supplier of large furniture manufacturer. Pine lumber drying chamber consume about 45% of total electricity in sawmill. According to various sources, drying of 1m³ of lumber uses about 30-60 kWh and is dependent of inter alia: the drying process itself, the factors affecting the processing time and the desired output moisture content of the timber. The article proposals for changes in the process of drying lumber pine have been positively validated in the company, and as a result their energy consumption per 1 m³ of product declined by 18%.

1. Introduction

Substances and waste discharged into the environment during the manufacturing process, contributing to the burden of anthropogenic coming to the ecosystem in the form of sewage, liquids, gases, carcinogens and toxic substances, radiation, vibration and noise, causing global warming and the reduction of the cover of the ozone [1]. The impact on the environment according to PN-EN ISO 14001: 2015 Environmental Management Systems, is understood as any change in the environment, favourable and unfavourable, that are wholly or partly due to the activities of the organization, its products or services. To prevent the contamination of the environment, the European Union has developed a package of documents concerning how to assess solutions in the fight against global warming, known as climate and energy package[2][3]. It covers not only purely functional, but also the impact on humans and the environment. Eliminating waste of electricity drawn from renewable resources and dissemination practices in the field of energy-saving technologies, it encourages companies to reduce the use of harmful production technologies [4][5].

Modern efforts for energy efficiency improvement are about changes and improvements in the facilities, technical devices or systems, resulting in energy savings achieved [6]. Big electricity recipients, for example industrial plants or local government units and government were forced to take action to improve the energy efficiency also. Projects for the situation improvement in this area, recorded in the latest law on energy efficiency include: insulation of industrial installations, lighting...
modernization, own equipment, industrial processes, local heating networks and local heat sources as well as energy recovery in industrial processes. The actions undertaken in energy efficiency by industry are leading to many direct economic benefits. They can be visible in the cost reduction of manufacturing of the product by increasing efficiency, modernization of machine parks in terms of energy-saving technologies, efficient competition on the market of goods and services as well as a new approach to energy management[7][8]. The use of environmentally friendly technologies, and consequently can reduce about 40% of total energy consumption in the company [9].

The article presents an analysis of actions taken to reduce electricity consumption during industrial drying of pine timber process on the example of existing dryers for wood. In the course of activities carried out in the company, reduced the number of micro cracks formed affecting the quality of the dried material and the reduced drying time timber.

2. Energy efficiency rating

Energy efficiency of manufacturing processes, transportation of goods, transport and usage of energy are the centre of attention of management team, because their financial value can be the basis for determining the indicators and measures of economic and performance indicators [10]. In order to assess the energy consumption, understood as the ratio of the energy put into the particular action to the effect of it, organizations use indicators and metrics tailored to a specific industry, trying to determine their own energy consumption level. Assuming [11], that the ratio of energy consumption for the industry is the ratio of electricity consumption to one hundred PLN production sold in a particular industry (1):

\[ e = \frac{E_W}{f} \]  

where:
- \( e \) – a direct indicator of electricity consumption per specified unit [kWh/ unit of reference],
- \( E_W \) – direct electricity consumption in the industry [kWh],
- \( f \) – effect – the volume of production sold (gross) in the industry [PLN].

Manufacturing companies, in described case, are starting with the basic data about consumed electricity and connect them into the structure of the media consumed per 1m³. This indicator allows comparison of energy consumption of the same devices in different time intervals [12]. It can be described by the formula (2):

\[ e_v = \frac{E_w}{V_y} \]  

where:
- \( e_v \) – indicator of direct electricity consumption per 1m3 of dried material,
- \( E_w \) – direct electricity consumption in one section of the production [kWh],
- \( V_y \) – the total annual volume of dried material.

The acquired data can be used for [13]:
- improving existing energy systems, both in the manufacturing process and in transport as well,
- implementation of new energy-efficient technologies,
- promotion of measures aimed at saving energy,
- coordination of energy consumption in the organization and methods of analysis and executions,
- prioritization of low power consumption approach in new technologies and equipment investments,
- raising awareness among workers on the protection of the environment area.
Information obtained during the analysis of the index may reasonably be used to secure or reduce energy consumption in the considered process. This ratio expresses the total energy consumption, but concerns directly fractional energy taken to produce a product at a given workstation [13]. Table 1, shows the energy consumption necessary for drying 1m$^3$ (required moisture content of 8%).

| No. of working days | 237 |
|---|---|
| Yearly energy consumption [MWh] | 27 233 |

| WorkCentre name | Process | No. of shifts | No. of work stations | Electricity consumption [KW] | Electricity per workstation [MWh] | Availability [h] | Average consumption per hour [MWh] |
|---|---|---|---|---|---|---|---|
| Drying kilns | Drying | 4 | 1 | 567 | 718 | 7 584 | 0,09 |

Using the formula (2) can be calculated indicator of electricity consumption per one cubic meter:

$$ e_v = \frac{718}{17090} = 0,042 \frac{MWh}{m^3} $$

The knowledge regarding electricity consumption in the process is the information necessary to analyze the future modernization solutions, which may relate to[14]:

- workstation - treated as a single device or group of devices working as one group in terms of technology,
- workcentre - which is one of the main unit can be equal to workstation or group of workstations performing exactly the same task,
- production department – group of workcenters in one area performing sequence of production steps,
- industrial plant - that is entirely conceived as the sum of all production departments with equipment and auxiliary facilities and the type of social administration.

3. Sawmilling industry and drying

3.1. Popularity of pine timber

Wood was used for the production of simple tools for centuries, it was a protection against wild animals, or fuel to generate heat for the preparation of hot meals. Over time, mechanically processed, it was used for furniture production [15]. Ecological properties, aesthetic and recycling, supported by physico-mechanical characteristics [16] allow the use of wood as a raw material for the production of highly processed products. The waste from the production is being used for briquettes or pellets derived from chemical and mechanical processing. The use of wood in specific areas in the European Union, breaks down as follows [17]:

- power generation: 42%
- fuel production: 1%
- pulp industry: 21%
- board industry: 12%
Favorable climatic conditions in Poland make the dominant coniferous species, with pine as the dominant one. They represent 69.1% of the total forest area in the country [18]. Due to the universality of the raw material, from the nineteenth century, production of lumber for construction of two coniferous species: Scots pine (Pinus sylvestris L.) and Norway spruce (Picea abies L.) dominates [17]. CSO data for the period 2008-2011, and for the year 2012 - according to the forecasts presented by the Polish delegation at the session of the Timber Committee of the United Nations Economic Commission for Europe (October 2012), concerning the production of sawn timber in Poland are shown in Table 2.

Table 2. Timber production 2008-2012[18]

| Production volume estimations [m³] | 2008  | 2009  | 2010  | 2011  | 2012  |
|-----------------------------------|-------|-------|-------|-------|-------|
| Softwood lumber                   | 6915  | 6420  | 6650  | 6800  | 6820  |
| Hardwood lumber                   | 1405  | 1370  | 1400  | 1510  | 1580  |
| Together                          | 8320  | 7790  | 8050  | 8310  | 8400  |

Initially sawmills processing timber for construction purposes were located close to rivers, due to the use of the generated surplus energy from water wheels used for grains flouring. The force of water remained the primary source of energy of Polish industry until the mid-nineteenth century. The closeness of the rivers was caused by the transportation of large masses of cargo by water flow until the advent of steam era[19]. Until 1989, lumber dried in ceramic dryers and it was only about 9% of the harvested material. Drying was perceived as unprofitable action, and most of the raw material was sold immediately after sawing. Authorities tried to encourage drying of wood, but the lack of control over the dealings, meant that not fully dried wood was the main subject of trade, which in fact reduced the mechanical properties and quality of the furniture later. Breakthrough in drying and replacement of ceramic dryers occurred after 1989, when companies started to install locally produced metal segmented dryers[20]. Despite a slow drying facilities development, a lot of companies with foreign capital, decided to invest in the dryers for drying lumber and machinery for its further processing. The investments helped increase the degree of wood processing to give the opportunity to sell their products with higher prices, and in the case of cross-industry, reducing the cost of manufacture of the furniture and all sorts of semi-finished[16] and secondary choices derived from technological waste.

3.2. The process of drying pine lumber
An important element of the manufacturing process of wooden products is properly developed drying process as occurring defects in the dried wood determine its subsequent use and determine the quality level - ratio of waste. High energy consumption forces the optimization of drying processes, both in terms of economic as well as environmental and social (dimensions of sustainable development), the figure 1 presents electricity consumption in a typical sawmill.

The timber drying process consists of providing a large amount of heat and the application of the appropriate movement and the speed of the air, until reaching the humidity of timber itself. The optimum processing conditions depend of the absolute moisture content reduction of wood to a level corresponding to the optimum conditions of mechanical treatment, or to a level depending on its subsequent destination by using natural or artificial methods. Actions taken to protect the environment related to the drying process, focused on optimizing the consumption of electricity consumption (Figure 1), through the application of the regime of procedures and the possibility of heat supplied by the boiler burning biomass. The selection of heat transfer Q / h (heat per hour) to the chamber volume,
the type of the dried material, and its thickness greatly helped reduce the consumed electric power required to obtain proper wood moisture content (Figure 2).

**Figure 1.** Electricity consumption in a sawmill (basic on enterprise papers)

**Figure 2.** Diagram of the energy efficiency of the drying timber pine for the production of highly processed[27], where: T - total drying time, \( t_{\text{drying}} \) - drying time, \( W_p \) - moisture content of the material at the entrance, \( W_k \) - moisture content of the material at the output, \( Q \) - heat, \( Q_{\text{str}} \) - heat loss, \( E \) - emissions into the atmosphere, \( h \) - 1 hour drying cycle (own analysis)

In the process of drying air flow direction is clearly defined, and its speed determines the temperature and relative humidity[21]. Demand of the heat determines the supplied steam to the drying chamber[22]. To heat the dryer is used hot water or a wet saturated steam, and for humidifying the drying air is used cold water, heated water or the wet saturated vapor pressure-reduced[23]. Depending on the way of heat supply to the material and energy consumption the following dryer timber are available[24]:

- atmospheric and vacuum dryers,
- batch and continuous dryers,
- convection, contact, radiation, dielectric, sublimation drying,
- different solutions: chamber, tunnel, belt, shaft, drum, roller, pneumatic, spray, vibration, and others.

Example pine lumber drying chamber shown in figure number 3.
To achieve a proper course of drying, and actually transformations of swelling and shrinking of the dried wood while decreasing humidity, after determining the appropriate range of temperature and humidity, an important factor is time. Longin Glijer has pointed five main phases in drying process[23][25](Figure 4).

**Phase I (FI) – warming up**
It involves the application of heat which penetrates the wood structure in a certain time. It assumes that the total heating time of drying up to 35°C should not exceed 24 hours. Heating the dryer is carried out with air that a moisture content not exceeds 98%. At this stage of the process the humidity is maintained at a constant level, which means that the derivation of water from the timber is permitted. The end of the first stage is determined to achieve the temperature, measured with dry-bulb thermometer, equal to the initial temperature of phase III.

**Phase II (FII) – Pre-humidification**
In the process of absorption of a flow of moisture to the surface layer of wood, reducing the propensity for cracking and reducing the surface tension. Omission of this step is possible in the case of drying the wood immediately after sawing.

**Phase III (FIII) – proper drying**
Determination of the physical parameters of the drying air at this stage of the process depends on the moisture content, thickness of dried wood species and required quality characteristics. The desorption
process, which by providing the appropriate amount of heat, resulting in the conversion of water into steam, the release of water in the timber comes by sliding of water layers located deeper up.

**Phase IV (FIV) - moisturizing compensation (air conditioning)**

In this part of the process the wetting of subsurface layers of dry wood happens. It is being done to partially compensate the moisture level at thickness of element and reduce the internal stresses which could cause cracking of wood. It is assumed that the temperature of the air in the humidification compensatory is equal to a final temperature of phase III. The duration of the drying phase in the case of normal of about 2 hours to 1 cm thickness of softwood.

**Phase V (FV) - cooling**

Cooling occurs as a result of lowering the temperature of the air in the dryer, not faster than 6°C per one hour. Cooling is completed when the temperature in the dryer is not higher than ambient temperature or storage, plus approximately 25°C.

Proper drying process depends of the proper selection of the parameters in the whole range of changes to the set humidity, and maintain high technical efficiency of machines and devices and their respective metering [21]. The difficulty in controlling the drying process means, that despite its automation, every phase is carried out under strict supervision and requires manual corrections. Shortening the drying cycle without deep technical knowledge usually leads to a reduction of the raw materials quality intended for further processing, and is present in the form of: micro-cracks (cracks internal front, radial), the warp of longitudinal and transverse, knots loosing and leakage of resin, blue stain and mold. When dried sawn wood is designated for further lacquering, part of the existing defects in the drying process is acceptable and does not affect the performance of the product, but mechanical damage in most cases eliminate the raw material in a further stage of the furniture production. The chambers that are not properly handled by maintenance services and process supervisors, generate a higher power consumption required to operate the fan, resulting in the disruption of the proper process of drying and leading to a temperature deficiency. As a result, fans are working much longer, power consumption increases and, consequently, the process takes longer than planned.

**4. Energy efficiency of the proposed solution**

Actions taken to improve energy efficiency in the company are based on the philosophy of continuous improvement Lean and assume minor maintenance performing by line operators. These include cleaning the workplace, control action components (visual and acoustic), dosing oils and similar actions to prevent the occurrence of accidents resulting reporting errors, reporting ideas for device improvement [26]. According to the policies of the organization, the operator becomes the owner of the device in the course of their work and takes full responsibility of it. The actions undertaken are carried out by:

- Training operators by the maintenance department to realize that operators are the eyes and ears of the device. Operators have the best qualifications for giving opinions regarding operation of the device that they are responsible for. Their reaction may prevent the emergence and costly failures and ideas for improvements can improve the comfort of work in the future,
- Instructions to support the maintenance of the appropriate machine parameters. Creating a template instructions drawn up by the organization (Figure 5). The instructions must be clear, brief and understandable. Its content should inform how the material should be used (with the name, type) and a photo of view of the place to which special attention should be paid.
Activities for drying process support based on the knowledge of operators are supported by the actions of maintenance services, which include:

- **Conditioned - Based Maintenance (CBM) - Conditional support.** Perform service operations, i.e. replacement of spare parts, maintenance. Consists of reading data from control and measurement instruments. It requires constant measurement and when parameters exceed the accepted limit corrective action should taken. The method is considered to be expensive because it requires the stock of spare parts,
- **Time-Based Maintenance (TBM) - regular servicing.** Parts replacement, repair or maintenance, are held in strict time limits resulting from the TBO. The technical condition of the machine has no influence on the course of renovation work. Time is already planned and calculated in the manufacturing process of the product,
- **Prevention Maintenance (PM) - prevention maintenance (Fig. 6).** On the basis of technical machines used and knowledge, in the newly deployed devices eliminates the most common errors incurred.

As S Nakajima stated [27] "mode and details of the use of TPM system in order to maximize the efficiency of machinery and equipment in practice is tailored to the individual capacity of the enterprise." In our case, the company has developed its own plan of actions, taking into account the needs and problems specific to the company, industry, manufacturing methods and the type and condition of own machines and equipment. Keeping proper supervision over the work of drying chambers is a basic action aimed for systematizing the process and also allowing the process to be modified by improving equipment operations. In the course of maintenance work, the company has made modernization ventilation chimneys, improved control system and sprinklers and insulated chambers in order to eliminate heat loss. Actions taken as a result of drying department workers suggestions and application of regimes to streamline the process to shorten the drying cycle, as shown in Table 5. Electricity consumption for devices such as lifts, air compressors, lighting or even lands and buildings are not possible to influence directly, but by shortening the drying time for the total cost of one meter model confirms the overall energy efficiency on the volume of production gross.

The change in electricity demand for drying kilns shows the difference between the value of one cubic meter 0,042MWh (42kWh) and reduced by 6,9kWh for one cubic meter after the change implementation. The total analysis of energy consumption made only based on general data on energy consumption, technical information of equipment and information about the time of the drying cycle.
Described above improvement actions performed by experienced professionals in the area of wood drying, health surveillance and maintenance, reduces consumption of electricity companies in the area of approx. 18%, despite the fact the company has to pay slightly more for the use of electricity is emissions GHG emissions per product obtained decreases. To dry a similar number of cubic meters of grated regime, the organization would consume 874MWh. The difference is 156MWh. Analyzing the energy consumption of the Reference Index Unitary Emissivities CO\(_2\) for the production of electricity [28], which amounts to 0.812 Mg CO\(_2\) / MWh, made the reduction of carbon dioxide emissions by 127 Mg, which is about 127 tons of CO\(_2\) per year.

**Table 3.** Chambers capacities after changes (own analysis)

| Warming up [h] | Drying [h] | Cooling [h] | Full cycle [h] | Cycles per month | Drying chamber capacity (m³/month) |
|----------------|------------|-------------|----------------|------------------|----------------------------------|
| Summer         | 6          | 116         | 6              | 128              | 5,6                              |
| Winter         | 6          | 126         | 6              | 138              | 5,2                              |

**Figure 6.** Examples of maintenance documents for drying kilns (basic on enterprise papers)
Registered electricity consumption is: 731 MWh, what leads to:
\[ e_v = \frac{731}{20817} = 0,035 \frac{MWh}{m^3} \]

5. Conclusions
Presented example shows only one aspect how company can deal with energy savings. Insulation drying chambers and heat pipes allowed to shorten phases of drying cycle, minimize fans usage and increase capacity of own drying department. Base for analysis were data that are available in each company as electricity consumption and output of work centers. In fact result could be measured by many others KPIs as OEE for example. Taken actions increased availability of kilns, so OEE increased. KPIs related with money value are the most suggestive in companies that has not implemented rules of Lean. Proper interpretation of result by translating it to figures as electricity per cubic meter and savings in that area represented as value of CO\(_2\) emission builds awareness that by actions taken by company are not only decreasing production costs, increasing capacities but mainly allow limiting GHG (Green House Gas) emission. Proper drying process means right quality of dried material, what is equal to minimized scrap level of furniture production and that leads to more attractive product end price.

One batch for drying kilns is minimum 50 m\(^3\). Any mistake in drying process is not only energy loss that kiln consumes during one cycle. It is a sum of energies needed to grow the forest, to harvest it, transport and saw. Recalculating it to CO2 emission value increases many times. Energy saving that are measurable by smaller bills for electricity are growing in perspective of whole planet.

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