

Potential of energy savings in Portuguese meat industry

J. NUNES^(a), P.D. SILVA^(b), L.P. ANDRADE^(a), P.D.GASPAR^(b)

^(a) Polytechnical Institute of Castelo Branco,

Quinta da Sr.^a Mercoles, 6000-909 Castelo Branco, Portugal

^(b) University of Beira Interior, Department of Electromechanical Engineering

Rua Fonte do Lameiro, Edifício das Engenharias, 6201-001 Covilhã

Portugal

dinho@ubi.pt

Abstract: - In Portugal the meat sector occupies the highest rank within the food industry having its electricity consumption grown at a high pace mainly due to the intense use of refrigeration systems. This paper assesses the electric energy consumption profile of Portuguese meat industries and estimates the potential savings with a set of simple energy efficiency measures which result from the best practices in the sector. Taking in account the fieldwork, some of the most relevant measures carried out are: to improve production process management in order to avoid the use of cold chambers partially loaded; to improve thermal resistance of the buildings envelope, cold chambers and refrigeration pipes; to avoid installation of condensation groups in warm places (exposed to solar radiation or in non-ventilated attics). The results show a potential reduction in electricity consumption of 24% for slaughterhouses (474 MWh), 13% for sausage houses (322 MWh), and 8% for ham production (708 MWh).

Key-Words: - Energy consumption, energy efficiency, electrical energy, refrigeration, cold chambers, meat industry.

1 Introduction

Consumer preference regarding the use of meat in their diet has grown in recent years. Between 1980 and 2005, the annual world average per capita consumption increased by 37.3%, with a peak in 2005 of 41.2 kg/capita/year [1]. Consequently, the global production of meat has also increased and is expected to reach, in 2050, 470 million tonnes, more than the double of the 229 million tonnes verified in 1999/2001 [2]. Currently, meat product industries play a major role in many global economies and, in many countries, it is the industry with a higher economic weight within the food industries.

In Portugal, the meat industry follows this trend, being composed in 2009, by a set of 619 licensed industries [3] and having achieved a sales volume of 21.3% considering the 8267 million euros obtained by food industry sectors [4]. The growth of this sector has been promoted by the increase of sausage production. In 2009, these products represent 24.5% of the 279265.9 tonnes of meat products production, with a strong contribution from the ham industry, which in this year increased 9.3%, compared to the previous year [4]. This evolution follows the trend of many European countries, with particular emphasis on the Mediterranean ones due to their long tradition in the manufacture of meat products [5,6].

The production of sausages and ham in Portugal is mainly industrial, although based on traditional elaboration processes. Changes introduced in the process of traditional elaboration relate mainly to the mechanization of processes and the use of drying and/or smoking mechanisms with temperature and humidity control. Thus, it enables a continuous production throughout the year, without the influence of climatic conditions, allowing its maturation to take place in any geographic area.

Refrigeration systems are indispensable within the production processes of the meat industry in order to prevent changes in meat composition, bacteria action and development of microorganisms and to obtain the stabilization and the organoleptic characteristics of the products [7]. The use of refrigeration systems is primarily responsible for the electricity consumption in these industries and may represent 60% to 90% of electricity use in slaughterhouses [8,9] and 40% to 50% for other categories of meat processing industries [10,11]. Furthermore, it should be noted that electricity costs may correspond to two-thirds of the total energy costs in meat processing industries [12]. In Portugal, there is a similar trend in the food sector, with an increase of 14% of electricity consumption, between 2008 and 2010, having achieved 1599 GWh in 2010 [13]. This increase in energy consumption is due to

an increase in fuel prices (in Portugal, between 2007 and 2011, the price of electricity and natural gas increased by 24% and 14.4%, respectively), having a significant impact on the competitiveness and sustainability of portuguese meat industries. In order to mitigate the effects of the rising cost of energy, programs are being implemented to improve energy efficiency in various sectors of economic activity, with special emphasis on the portuguese industrial sector. However, these programs are directed towards facilities of intensive energy consumption, being those that present an annual consumption of primary energy exceeding 500 toe (tonne of oil equivalent), leaving out more than 90% of food industries, with those being represented by micro and small enterprises.

The present study characterizes the energy consumption profile of meat industries that consume less than 500 toe. It particularly assesses the consumption of electric energy (energy which is mostly used by these industries); evaluates specific electrical consumption indicators; presents the potential of energy savings and a set of appropriate measures to improve their energy efficiency. This study intends to contribute positively towards a better understanding of the meat energy consumption profile in Portugal.

2 Productive processes

2.1 Meat production in slaughterhouses

The typical process of bovine, swine, sheep and goat slaughter in Portugal, essentially comprises the following operations: reception, ante-mortem inspection, animal's slaughter, carcasses and offal cleaning, post-mortem inspection, cooling, cutting, processing and dispatch. For each animal species there is a specific circuit where carcasses are moved through air rails into fast cooling tunnels and refrigeration or freezing chambers.

Rapid cooling is the most used method in portuguese industries and takes place in two complementary steps. The first, consists of rapidly lowering the initial temperature of 38°C/40°C to a temperature around 15°C to 20°C. The second step, relates to final stabilization of the meat's temperature to a value below 7°C in the centre of the meat. The first step takes place in a rapid cooling tunnel or in a cold chamber with strong air circulation. In both cases the temperature and relative air humidity inside, lies between -1°C to 2°C and 82% to 90%, during approximately 4 hours for bovine carcasses and 2 hours for pigs and sheep.

The second step takes place inside cold storage chambers with lower air circulation and with environmental conditions similar to those above. Freezing meat is a procedure carried out, most of the times, with prior refrigeration and is held in freezing chambers or tunnels with temperature and relative humidity values between -28°C to -40°C and 85% to 95%, respectively. Although freezing is not frequent in portuguese slaughterhouses, when it occurs, it requires the control of the relative humidity inside the chamber in order to avoid weight loss of the product. The final product is kept in cold storage chambers (temperature between -1°C to 2°C) or freezing (temperature of -18°C), and may thereafter go to the cutting room (only the refrigerated product) or be dispatched.

2.2 Traditional sausage production in sausage houses

In Portugal there is a great diversity of traditional sausages, produced with different raw materials and ingredients, but they all have the production process in common. The manufacturing process of sausages in Portugal comprises the following steps: receipt of raw material, preserving the meat in a refrigerator/freezer, choosing, cutting, spiciness and dough preparation, maturing, filling and drying, stabilization and final packaging and shipping. Cutting operations, mixing and filling are held in air-conditioned rooms with a temperature of 12°C maximum. In the maturation phase the mixture of meats with its condiments is kept in cold storage chambers, with temperatures between 1°C and 6°C and a relative humidity of 80% to 85%, from 24 to 48 hours. The drying process of sausages is accomplished by controlled atmosphere drying or drying through smoke. Controlled air drying consists of placing sausages in chambers with temperature and humidity control. The duration varies according to the dimensions of the products, typically between 5 to 15 days for thin products and 30 to 60 days for thicker products [15]. In Portugal, the final product presents a level of relative humidity between 30% and 40%. When drying with smoke, products are exposed, during 3 to 5 days, to the action of heat and smoke resulting from combustion of wood (oak, in Portugal). In both cases, after drying, sausages are placed in a cold chamber for final stabilization.

2.3 Ham manufacturing in the meat processing industries

Ham is a product obtained artificially in cold chambers from the ageing of the hind legs of white pigs during a approximately period 6 months. The production process consists of a set of operations with different values of temperature, relative humidity and air circulation. The main stages of the production process, include salting, post salting, drying and stuffing. Salting is intended to provide the proper amount of salt to the legs, keeping them involved in salt from 8 to 12 days. This phase takes place inside the cold storage chambers with high humidity and low temperature [15]. In the post salting phase, the salt diffusion towards the inner part of the leg takes place from 30 to 45 days. At this stage the legs remain inside the cold storage chambers to ensure low air temperature and high humidity (6°C and 85% relative humidity). In the next phase, the dehydration of the leg takes place slowly during a period of time of approximately 45 days. The temperature in the cold chamber is gradually increased until it reaches a value close to 14°C, and at the same time its relative humidity is lowered slowly until it reaches approximately 75%. Stuffing finishes the drying process and assigns special organoleptic characteristics of the ham for a minimum period of 15 days. In this phase, the temperature inside the chamber gradually increases up to a maximum value (about 26°C in portuguese industries) and the relative humidity is kept close to 75%. After finishing the manufacturing process, hams are kept inside cold storage chambers for final stabilization during a minimum period of 15 days.

3 Material and methods

In order to evaluate electricity consumption profile of meat processing industries, a survey was carried out to 33 units located in the Interior region of Central Portugal. According to the main activities and products developed, they were classified into three categories: slaughterhouses (mainly pigs, 4 units), sausage houses (20 units) and the manufacturing industries of ham (9 units).

The survey information had two phases: filling out a survey and measurement of parameters. The aim of the survey registers the infrastructure characteristics (location, age, type of materials, dimensions and location of cold chambers), activities (type and quantity of raw materials and products, production processes), characteristics of refrigerating systems (age, location, type of technology, cooling system and electrical power), cold storage chambers

conditions (temperature and relative humidity) and energy consumption (electricity, natural gas and other fuels – based on monthly invoices). The surveys were used to gather information regarding the production process as well as quantifying temperatures, relative humidity and time expended in the various stages of the process.

In the second phase, visits to industries were carried out with the aim of measuring some relevant parameters. Environmental conditions of the interior and exterior of cold chambers were measured, namely temperature and relative humidity through a multifunction digital equipment (Testo 435-2), and probe with a temperature range of -20 to 70°C and 0 to 100% for relative humidity, with uncertainty of $\pm 0.3^\circ\text{C}$ and $\pm 2\%$ RH. To evaluate thermal losses, the temperature of the outer surface of cold chambers was measured, first through a general observation with infrared thermography equipment (Testo 880-4) and later, in the most sensitive points, with the digital equipment (Testo 435-2) and a contact probe with thermocouple (type k), with a temperature range of -60°C to 300°C and uncertainty of $\pm 2\%$. The interior dimensions of the cold chambers were determined with a range finder using the infrared technique (Bosch-DLE 40), with a range of 40 meters and an uncertainty of ± 1.5 mm. In particular for the mechanical refrigeration system, temperatures were measured at the compressor inlet and evaporator outlet, to assess the degree of superheat. The overall electricity consumption of the plants was also evaluated as well as the electricity consumption of the compressors. This measurement was carried out through a digital power analyzer (Elcontrol -Energy Explorer), for a range of values of 15 to 750 Volts and 20 to 1000 Amperes, with an error margin of 0.53 to 2 Volts and of 0.04 to 2 Amperes. Electrical power absorbed by the compressor was determined by measuring the voltage values (Volts) and intensity of electrical current (Amperes), measured with a digital ammeter clamp (Escort ECT-620). The value obtained was compared to information from catalogues and manufacturers' calculation software, based on the measured evaporation and condensation temperatures and superheat and sub-cool degree.

In order to compare the performance of different industries presented in this study, the following three indicators were introduced: specific energy consumption (SEC), volume usage rate of the cold storage chambers (EVU) and rate of electrical power absorbed by compressors per unit volume of cold storage chambers (EPCV). The specific energy consumption (SEC) is a physical indicator usually

referred in literature to evaluate the energy efficiency of industrial units or sectors [16]. This indicator was recently used in energy analysis of meat industries, with a particular focus on the industries of animal slaughter and also for energy evaluation of meat industries in different European countries [17]. The specific energy consumption (SEC) was evaluated by eq. (1),

$$SEC = \frac{E}{RM} \quad (1)$$

where, E represents the annual consumption of electrical energy, RM designates the annual production of hot carcasses (ton_{HSCW}) to the slaughterhouse or the annual quantity of raw material processed (ton_{RM}) for manufacturing industries of sausages and hams.

Another indicator calculated in this research was the effective volume usage of the cold storage chambers (EVU). This indicator is given by eq. (2),

$$EVU = \frac{RM}{V_{\text{total}}} \quad (2)$$

Where, V_{total} indicates the total volume of the industry's cold storage chambers. With this indicator it is possible to evaluate the handling level of raw material in cold chambers. Thus, within the same category of industries (using the same productive process), it estimates the greater or lesser use of cold chambers with the consequent implications at the level of energy consumption. Finally, another calculated indicator was the electrical power absorbed by the refrigeration compressors per unit volume of the cold chambers (EPCV) which is given by eq. (3):

$$EPCV = \frac{P_{\text{total}}}{V_{\text{total}}} \quad (3)$$

where P_{total} indicates the overall compressor power consumption of the industry. This indicator gives us an idea of the cooling capacity installed per unit volume: when used in industries that produce the same product (i.e., in the same category) by the same process, it can indicate quality of cooling system design; when applied to industries of the same sector but with different products (different categories), it indicates the cooling requirements for each meat product (a relevant piece of information for industries that intend to change their products, or decide to add another product using the same cold chambers).

4 Results and discussion

This section sets out the results of general information collected in 33 meat industries (slaughterhouses, sausages and hams) and encompasses the information of 355 cold chambers, 2 quick cooling tunnels and 226 refrigeration systems. Later, there will be a separate analysis of results regarding the production process. In general, the premises of portuguese meat industries are comprised of buildings with one floor, brick walls and roof assembly (galvanized, fiber-cement or red clay tile). A common feature to almost all industries is the reduced physical space between the concrete slab, or suspended ceilings, and the roof (usually non-ventilated attic) therefore originating the occurrence of high internal temperatures (in summer days we measured air temperatures up to 55°C). Typically, the buildings are divided into several support chambers inside, some conditioned rooms for the manufacture process, several cold storage chambers and some freezing chambers. Almost all the walls and ceilings of cold storage chambers and conditioned spaces are made of insulated (sandwich) panels, with insulating core made in rigid polyurethane foam and coating on both sides with metal sheet. The thickness of the walls is quite variable, being 40 mm for conditioned rooms, 60 or 80 mm for cold storage chambers and 80 to 100 mm for freezing chambers. The ground of the cold storage chambers consists of black agglomerate cork layers or high-density polyurethane boards (40 kg/m^3), including a vapour barrier (polyethylene film). In older industries, the walls of the cold storage chambers were built in brick masonry with cork agglomerate flooring. This kind of constructive solution presents insufficient thermal resistance (visible in thermal images) which penalizes the energy performance.

The location of cold chambers within the premises is based on the type production circuit process: reception, production, processing, ageing, drying, storage and dispatch. These industries have 3 cold levels: freezing (-18°C), refrigeration (0°C to 6°C) and cooling (12°C). The mechanical cooling systems are the vapour-compression refrigeration type. The difference between the values measured for the power absorbed by the compressor and the corresponding value indicated by the software/catalogue of the manufacturers are less than 10%. In general, the evaporators are inside the cold chambers and have defrosting systems (where electrical devices are the most common). Condensation groups and compressors are usually found outside the premises (some of the condensation groups are exposed to direct sunlight,

others in close proximity, see Fig. 1) though there have also been situations where these elements are placed above cooling chambers in non-ventilated attics. The lack of equipment maintenance is illustrated in Fig. 2. In this situation the supplying of cold air to the storage chamber is made from the outside of the plant. Thermal imaging allows us to highlight the gains resulting from sections of ducts with thermal insulation already damaged. It is important to refer that the location of these ducts are directly above the condensation groups. Any of these situations penalizes the efficiency of the refrigeration system. Below the results are presented separately for each type of industry: slaughterhouses; sausage and ham houses. Later, a comparative analysis will be carried out.



Fig. 1. Condensation groups in close proximity.

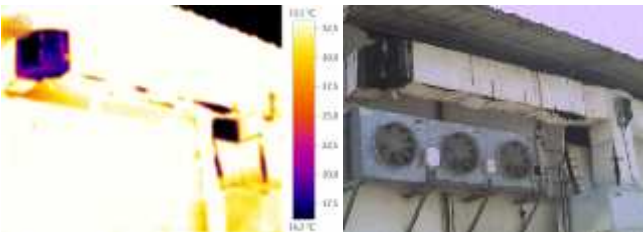


Fig. 2. Thermal image of the external ducts.

4.1 Slaughterhouses

The visited slaughterhouses were units with large facilities, generally horizontal type in which all slaughter operations are developed on the same floor. These slaughterhouses include reception rooms attached to the main building and specific air lines for each animal species to perform transportation along the production process. The main activity of these four plants is the production of meat, as whole or cut carcasses, chilled or frozen. Its main characteristic is the high movement of the products. Hence the energy consumption associated to each product is therefore reduced.

The main types of energy consumed by these plants are electricity for powering electric motors of the refrigeration systems, air lines for animal transport, electric saws, air compressors, lighting and fuels (natural gas, propane, heating oil) for water heating. The energy balance made to these industries indicates that, on average, 66.5% of the energy consumed is electricity.

The information collected at slaughterhouses in the region shows that the annual electrical consumption of slaughterhouses is from 208.4 MWh and 1176 MWh and that the overall compressor power lies between 28 kW and 260 kW. Specific consumption values of electricity for this category are presented in Fig. 3. Results indicate a SEC variation between different industries, from 84.3 kWh/ton_{HSCW} to 249 kWh/ton_{HSCW}, with an average value of 149 kWh/ton_{HSCW}. The biggest SEC difference is between plant 1 and plant 3. Plant 3 presents a value of this indicator superior to 57.4% when compared to plant 1. In particular, plant 3 has older equipment and facilities, bigger dimensions, and cold storage chambers built in brick masonry coated with cork boards (instead of sandwich panels of polyurethane, as others plants). Although plant 3 has the greatest number of operating chambers, it was observed that its use is made in partial load, therefore presenting the lowest value of EVU (see Fig. 6). This poses an energetic penalty because it would be possible to make a more effective use of fewer chambers to treat the same production. Analyzing the SEC behaviour we verify that there is a potential energy consumption reduction by simply making industries that show specific consumptions above average to apply the good practices adopted by the others industries that, in the same category, featured the best energy performance. In fact, the potential savings in an industry correspond to the difference between the value of individual consumption of this industry and the average amount of energy consumption in this category. When applying this procedure to slaughterhouse industries, there is an estimated electricity saving of about 24% of the current consumption (474 MWh reduction). If we take as a reference the average specific energy consumption of OECD countries, for pig slaughter, with an average power consumption of 139 kWh/ton_{HSCW} [16], when adopting the best practices of these countries' industries, the estimated savings would be even greater namely 27% (524 MWh). The SEC average value of portuguese industries and benchmarking for OECD countries are also represented in Fig. 3.

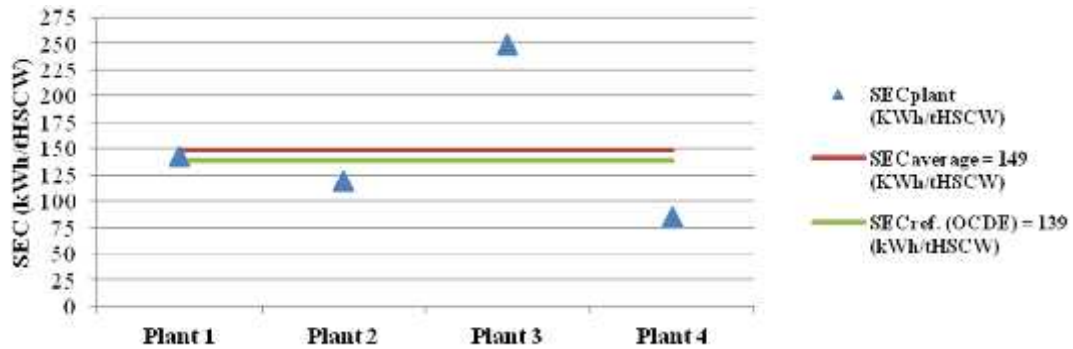


Fig. 3. Values of the specific electricity consumption (SEC) on each portuguese slaughterhouse plant visited, the average value and a reference value from OECD countries [11].

4.2 Sausage houses

Sausage houses are small industries with old facilities, an area between 500 m² to 1500 m² and in average five cold chambers (conservation chambers), one drying room and one smoke room. These units are mostly family-oriented and located in regions with strong tradition of meat product manufacture and do not have a strong production. The chamber dedicated exclusively to drying, uses compact refrigeration units that allow the control of air temperature and humidity within the room, through the use of secondary condensers (for air heating) and evaporators (for air cooling/drying). Energy consumption in these industries is electrical (operation of the components of the mechanical refrigeration systems, compressed air production, lighting and fans and equipment for cutting, mixing and filling) and thermal (water heating). The electrical component is the most relevant, representing, on average, 85% of the energy consumption.

The information concerning sausage houses shows that the annual consumption of electrical energy of sausage houses is between 12.6 MWh to 673.3 MWh and that the overall compressor power lies between 3.8 kW to 126.7 kW. This range of values is due to the different sizes of the industries in this category. The SEC present values between 248 to 1840 kWh/ton_{RM}. Plant 8, for example, with a specific energy consumption of 1840 kWh/ton_{RM}, the highest value registered, is above the average value of these industries, in this case 660 kWh/ton_{RM}, as depicted in Fig. 4. Although this company is not the oldest, it presents some special characteristics. It has the merit of scrupulously following the temperature process; however, it presents an inappropriate location of the condensation groups. In fact, these groups are, oddly enough, located within the premises, in air-conditioned areas. In this particular case, it turns out that there is high energy saving potential. Another

important aspect is the thermal resistance of the infrastructures (buildings envelope and cold chambers) in the energy performance of the industries, and it is illustrated by plant 10, one of which features smaller SEC. The buildings' walls are made of 120 mm polyurethane sandwich panels, as well as the refrigeration and freezing chambers which have thicknesses of 100 mm and 120 mm. The roof also uses the same type of panel, with a thickness of 40 mm, and having a ventilated attic. Extending the analysis to all industries and whereas the same procedure was adopted for the slaughterhouse industries, the expected potential for reducing the overall consumption of electricity would be around 13% (322 MWh). Once again, it should be noted that this procedure assumes sharing the best practices in the sector.

If we take as a reference the average value of specific electrical power consumption for the meat industries in Spain, in this case from 465 kWh/ton_{RM} [17], the power for reducing energy consumption is 27% (683 MWh). The reference value of the meat industry is also shown in Fig. 4. It should be noted that spanish industries incorporate in the productive process other forms of energy in addition to the electrical one [17]. Moreover, the drying process of portuguese sausages rarely takes place in natural environments. These two features justify the large difference of SEC values between the industries of both countries (660 kWh/ton_{RM} against 465 kWh/ton_{RM}).

4.3 Ham industries

The ham production industries are plants of large dimensions with a great number of cold chambers (on average 17 chambers). The type of productive process (several stages) and the long period necessary to obtain the ham requires that these industries have a high number of cold chambers.

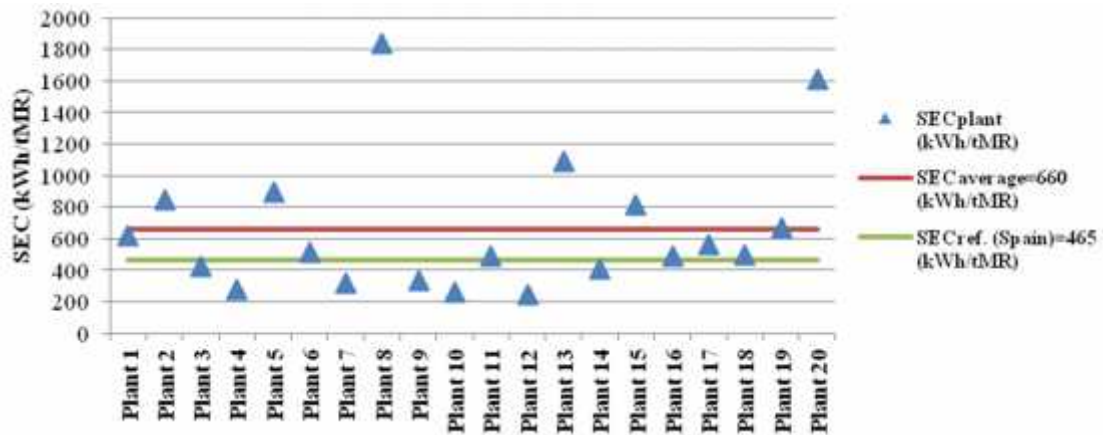


Fig. 4. Values of the specific electricity consumption (SEC) on each portuguese sausage manufacturing plant visited, the average value and a reference value from Spanish industries [17].

The chambers where the post-salting, drying and stuffing is carried out differ from the cold storage chambers because they allow the cooling and heating. It is important to mention that the temperatures needed for the portuguese ham stuffing stage require auxiliary heating systems, usually electric resistances integrated in the compact unit.

The energy consumption in the portuguese ham industry is predominantly electric, corresponding on average to 92.5% of the overall energy consumption. For these industries, the consumption of electric energy is comprised between 336.1 MWh and 2565.6 MWh. The overall compressor power is between 93 kW and 346 kW. In Figure 5, we present the individual values of SEC obtained by eq. (3.1). The SEC values from these industries are comprised between 310 kWh/ton_{RM} and 2202 kWh/ton_{RM}, with an average value equal to 1208 kWh/ton_{RM}. Despite developing the same productive process and using similar mechanical refrigeration equipment, there is a great difference in the energy consumption between these industries. This fact suggests that some industries are consuming more

energy than the one necessary to carry out its activities. In particular, it was observed that plant 1, plant 5 and plant 8 have oversized facilities compared to the raw-material processed. As a result, they present the higher SEC values (and lower EVU values). Based on the SEC distribution for this category, the potential reduction of electric energy consumption is estimated around 8% (708 MWh).

In Fig. 5, a SEC average value of the ham production industries in Spain is also presented, namely 336 kWh/ton_{RM} [17]. This value is considerably below the average value found for the portuguese ham industry, in this case 1208 kWh/ton_{RM}. Besides the fact that Spanish industries use a significant percentage of other energy forma that can reach around 50% [17], the major difference of specific consumption average values between the two countries is related to the different methodologies in obtaining the environmental conditions used in some production process stages, specifically for ham drying and stuffing.

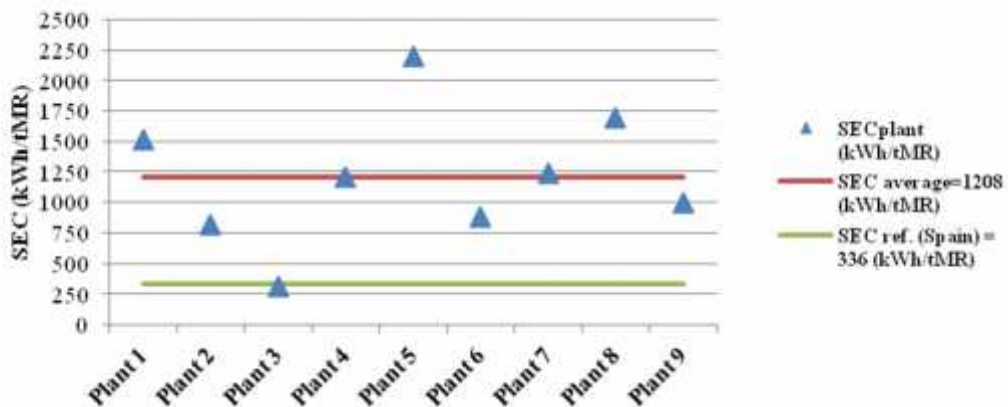


Fig. 5. Values of the specific electricity consumption (SEC) on each portuguese ham manufacturing plant visited, the average value and a reference value from Spanish industries [17].

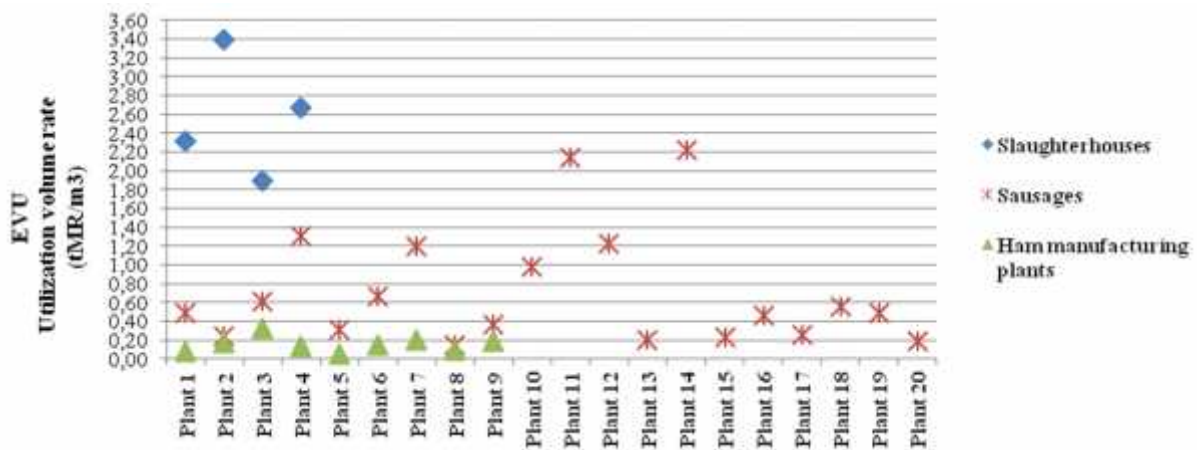


Fig. 6. Utilization volume rate (EVU) of the cooling chambers in the meat industry.

In Spain, these stages are carried out in physical environments (cellars) with strong use of natural climatic conditions and also making use of some thermal energy, contrary to Portugal, where all the production process stages take place in artificial environments. This is the reason why one of the industries visited (plant 3) present a SEC value considerably below its counterparts since, as verified, the drying and stuffing processes are carried out almost without using refrigeration equipment (compact type).

They take advantage of the physical environment conditions (cellars) for the maturation process stage and, when necessary, use thermal energy to produce of hot water that flows in additional heat exchangers located inside the chambers. If this procedure was applied to the remaining industries of this category the potential reduction of electricity would be 50% (4688 MWh).

4.3 Comparative Study

Next, the general results for the set of the three industry categories will be analyzed, including the EVU and EPCV indicators. The effective volume usage of the cold storage chambers (EVU), obtained in eq. (2), varies with the activity and shows large amplitude in the slaughterhouse and sausage house, as observed in Fig. 6. This EVU amplitude is originated either by an incorrect sizing of the number of chambers regarding the production, or due to a poor management of the production that originates an inadequate use of the cold chambers (in various situations it was observed that inside the same industry there was more than one cold chamber working with partial load. However, the consequences bring on a decrease in the industries'

energy efficiency and in particular the refrigeration systems. The average value of the EVU is 2.57 $\text{ton}_{\text{HSCW}}/\text{m}^3$ for slaughterhouses, 0.712 $\text{ton}_{\text{RM}}/\text{m}^3$ for sausage houses and finally 0.15 $\text{ton}_{\text{RM}}/\text{m}^3$ for ham production industries. The highest EVU value presented by the slaughterhouses is due to a high transfer of raw material (short period inside the chambers, on average 12 to 24 hours), which is a characteristic of the production process in these industries (daily slaughter of animals). On the other hand, the low occupation rate of the chambers' volume in ham production industries, is also related to the type of productive process, in this case, it forces the maintenance of the products inside the chambers during longer periods (around 6 months), therefore a reduced transfer of raw material is observed inside the cold chambers. Overall, hams are the products with higher need of cold maintenance and its production is, consequently, the most energy-intensive. Any change in the production process that optimizes the permanence in the cold chambers will have a significant impact on the energy cost of this product. Also, the overall compressor power of the plant per unit of volume (EPCV) depends on the type of activity, and are shown in Fig. 7 for each of the three meat product categories. The average EPCV indicator values for the slaughterhouse and ham production industries are 0.072 kW/m^3 and 0.043 kW/m^3 . The major shifts inside each category correspond to plant 3, for slaughterhouses 8 (discussed above), and to plants 11 and 14 for the sausage houses (since they are the smallest industries – with the lowest cold room volume and lowest quantity of processed raw-material). The average value of this indicator for the sausage houses (not taking into consideration the two industries considered unusual) is 0.072 kW/m^3 .

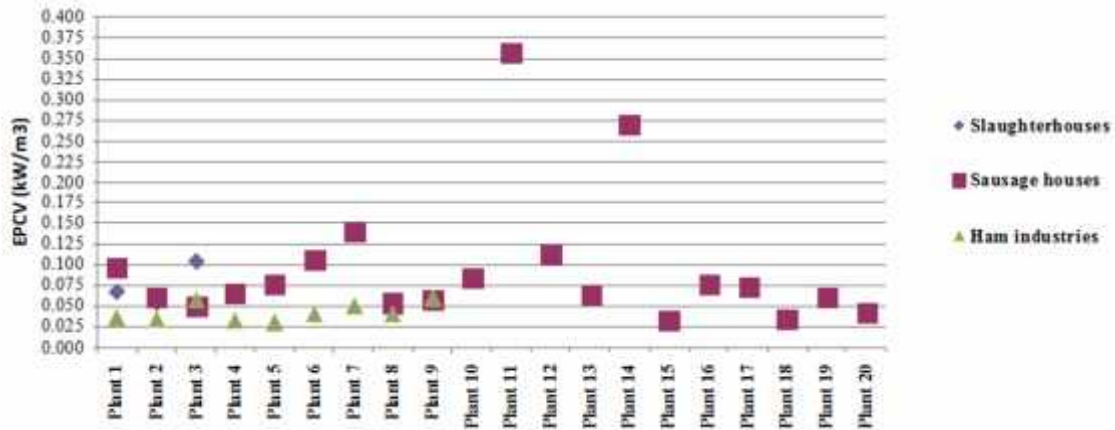


Fig. 7. Power absorbed rate by the compressors per unit volume (EPCV) of each industry.

The proximity of the average indicator value (EPCV) in slaughterhouse and sausage house categories was not expected since cooling requirements are substantially different: slaughterhouses require a higher cooling capacity per unit of chamber volume in order to produce a fast cooling of the animals' carcass (from the initial temperature 38°C to 40°C, to values lower than 7°C); the sausage houses only deal with cold conservation or drying processes requiring lower cooling capacity. Fig. 8 shows the average values of the electric energy annual consumption and SEC values for each category. The average values found for the electric energy consumption were 491.1 MWh (slaughterhouses), 127.1 MWh (sausage houses) and 1034 MWh (ham industries). We can conclude that industries developing meat processing activities, such as sausage houses and ham production industries present a SEC value higher than industries that are only devoted to meat production, such as slaughterhouses. The ham production industries are, therefore, the category that presents simultaneously the highest electric energy consumption and the highest SEC value, being the category that requires greater concern in terms of energy efficiency measures in order to improve the competitiveness of these industries.

Based on the study carried out and related to energy savings, some of the most recommended actions are: to improve production processes management in order to avoid the use of cold chambers with partial load; to improve the thermal resistance of the buildings envelope, cold chambers and refrigeration pipes; to avoid condensation group installation in warm places (exposed to solar radiation, in non-ventilated attics or exposed to exhaust air from similar groups).

4 Conclusion

The energy consumption profile of meat industries is analyzed, based on a study of 33 industries in the Central Region of Portugal, divided in three categories: slaughterhouses, sausage houses and ham production industries. The energy balance made to these industries shows that electric energy is the highest form of energy used on average, and accounts for 66.5% of the overall energy consumption in slaughterhouses, 85% in sausage houses and 92.5% in ham industries. The average value of the specific electricity consumption (SEC) found for the slaughterhouses was 149 kWh/ton_{HSCW}, 660 kWh/ton_{RM} for sausage houses and 1208 kWh/ton_{RM} for ham production industries.

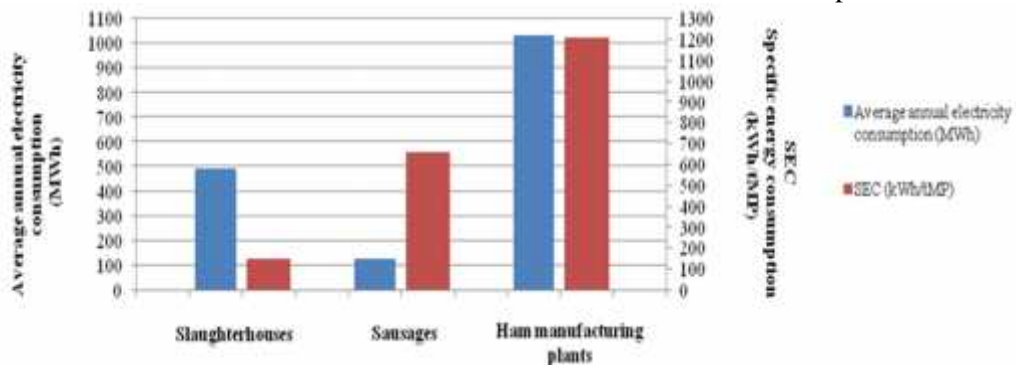


Fig. 8. Annual average of the specific electricity consumption (SEC) of the meat industry.

These SEC values are higher than the reference values, found in the literature. Throughout the field study various aspects were identified which, if improved, will allow a significant improvement in the energy performance of these industries, specially, inadequate infrastructures, incorrect management of cold storage chambers, erroneous decision regarding the positioning of some refrigeration components, refrigeration pipes with damaged insulation among others. On behalf of these industries, there was an estimation of a potential reduction in the electric energy consumption achieved by carrying out a number of best practices. This potential reduction was estimated in 24% for the slaughterhouses (corresponding to an energy reduction of 474 MWh), 13% for the sausage houses (322 MWh) and 8% for the hams (708 MWh).

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