Elsevier Editorial System(tm) for Energy for Sustainable Development
Manuscript Draft

Manuscript Number:

Title: Key points on the energy sustainable development of sausages industry - the Portuguese case study

Article Type: Full Length Article

Keywords: Sausages industry; Energy efficiency; Sustainability; Refrigeration

Corresponding Author: Prof. Pedro D Gaspar, Ph.D.

Corresponding Author's Institution: University of Beira Interior

First Author: José Nunes, PhD

Order of Authors: José Nunes, PhD; Pedro D Silva, PhD; Luís P Andrade, PhD; Pedro D Gaspar, Ph.D.

Abstract: Sausage is an ancient food type that is nowadays considered as a delicatessen. Sausages are categorized within the deli sector as meat sub products. It is a food product preferred by consumers due to its nutritional value and organoleptic characteristics (wide range of flavours and textures). There are many types of sausages, with around 1200 different varieties (according to German classification), classified into types according to different criteria such as types of ingredients, consistency, and preparation (raw, cooked, pre-cooked, dry,...). In UK, 196152 metric tons of sausages were consumed during 2011, valued in $1.2 billion, while in the US this value was around $20.4 billion two years before. The heating and cooling processes during sausages production are indispensable technologies to ensure both the specific organoleptic characteristics and properties conservation through time. This paper characterizes the production process and the energy consumption of sausages processing industry in Portugal (20 industries) and discusses the average specific energy consumption (SEC) of electricity and its standard deviation. The average value of this indicator for the sample was 660 kWhe/ton raw material. The energy consumption of this type of industries is mainly of electricity (82%). Correlations have been developed that show the relationships between tons of raw material and electricity consumption, volume of cold stores, and compressors' nominal power. Several electricity savings, estimated in 23.9%, can be achieved by implementing simple practice measures in the refrigeration systems.

Suggested Reviewers: Sunday O Oyedepo PhD
Mechanical Engineering Department, Covenant University
Sunday.oyedepo@covenantuniversity.edu.ng
Research on strategies towards efficient energy usage

Moonyong Lee PhD
School of Chemical Engineering, Yeungnam University
mynlee@yu.ac.kr
Research on refrigerants used in industrial applications to improve the energy efficiency and heat transfer of the refrigeration system

Neeraj Agrawal
Department of Mechanical Engineering, Dr. Babasaheb Ambedkar Technological University

neeraj.titan@gmail.com
Research on the reduction of the impact of refrigeration industry in the environment through the improvement of refrigeration devices

Dear Professor Daniel. B Jones,

Enclosed is the paper entitled "*Key points on the energy sustainable development of sausages industry - the Portuguese case study*". The authors of this paper are J. Nunes, P.D. Silva, L.P. Andrade and P.D. Gaspar. Please accept it as a candidate for publication in the *Energy for Sustainable Development* journal.

This paper characterizes the production process and the energy consumption of sausages processing industry in Portugal and discusses its average specific energy consumption (SEC) of electricity and standard deviation. Mathematical correlations from the greatest number of data sets collected to date in Portugal have been developed. These correlations show strong relationships between tons of raw material and electricity consumption, volume of cold stores, and compressors' nominal power. Several electricity savings, estimated around 24%, can be achieved by implementing simple practice measures in the refrigeration systems. Thus, the correlations can be used to predict the energy performance of sausages industries. These predictions can be used to promote the energy sustainable development of meat industries by helping in the decision-making process of practice measures for the improvement of energy efficiency. Due to the high energy consumption of the food sector and the applicability of the results from a energy management point-of-view, we strongly believe the contribution of our study warrants its publication in the *Energy for Sustainable Development* journal.

Finally, this paper, if accepted for publication, will not be published elsewhere in the same form, in any language, without prior consent of the Publisher.

Yours Sincerely,

Pedro Dinis Gaspar

Highlights:

1. Energy consumption of sausages industry was compared and benchmarked.

2. The work consists in a large number of data sets collected.

3. Strong relationships between raw material, energy, volume and compressors power were established.

4. Correlations were developed to predict the energy performance.

5. The model can be used to promote the energy sustainable development of meat industries.

Key points on the energy sustainable development of sausages industry - the Portuguese case study

J. Nunes[1], Pedro D. Silva[2], L. P. Andrade[1], Pedro D. Gaspar[2, *]

[1]Politechnic Institute of Castelo Branco, Av. Pedro Álvares Cabral nº12, 6000 Castelo Branco, Portugal

jnunes@ipcb.pt, luispa@ipcb.pt

[2]University of Beira Interior, Electromechanical Engineering Department, Calcada do Lameiro, 6200-001 Covilhã, Portugal

dinho@ubi.pt, dinis@ubi.pt (* corresponding author)

Abstract

Sausage is an ancient food type that is nowadays considered as a delicatessen. Sausages are categorized within the deli sector as meat sub products. It is a food product preferred by consumers due to its nutritional value and organoleptic characteristics (wide range of flavours and textures). There are many types of sausages, with around 1200 different varieties (according to German classification), classified into types according to different criteria such as types of ingredients, consistency, and preparation (raw, cooked, pre-cooked, dry,…). In UK, 196152 metric tons of sausages were consumed during 2011, valued in $1.2 billion, while in the US this value was around $20.4 billion two years before. The heating and cooling processes during sausages production are indispensable technologies to ensure both the specific organoleptic characteristics and properties conservation through time. This paper characterizes the production process and the energy consumption of sausages processing industry in Portugal (20 industries) and discusses the average specific energy consumption (SEC) of electricity and its standard deviation.

The average value of this indicator for the sample was 660 kWh_e/ton raw material. The energy consumption of this type of industries is mainly of electricity (82%). Correlations have been developed that show the relationships between tons of raw material and electricity consumption, volume of cold stores, and compressors' nominal power. Several electricity savings, estimated in 23.9%, can be achieved by implementing simple practice measures in the refrigeration systems.

Keywords: Sausages industry, Energy efficiency, Sustainability, Refrigeration

1 Introduction

The industrial sector is comprised by a diverse set of industries that are globally responsible for 38% of a worldwide energy consumption and 36% of carbon dioxide emissions (CO_2) (Abdelaziz *et al.*, 2011). The main industries of this sector are manufacturing industries within which stands agrifood industries (Wang, 2008). At European level, the food industry represents an universe of 287000 industries with 4.25 million direct jobs and had in 2010 a turnover of 1017 billion euros (FoodDrinkEurope, 2012).

In Portugal, the food industries follow the European trend, being also the largest group of manufacturing industries in the country (13.2%). In 2011 reached a business turnover of 9340 million euros (INE, 2011). Within the food industry, the largest sector corresponds to the meat industry. In 2010 this sector was represented by 1159 industries with a turnover of 1130 million euros, representing 12.3% of total volume sales volume of food industries (INE, 2011; DGV, 2011).

The main products of the meat industry sector are the cured sausages. Based on the results of 2012, these industries produced 87400 tonnes of cured sausages, representing

46.8% of all industrial production of meat products and corresponding to a turnover of 249.4 million euros (INE, 2010). In Portugal, as in many European countries, there has been an increased production of cured sausages. It was registered an increase of 10.6% in 2012 comparing with the previous year (INE, 2013; Röhr *et al.*, 2005; Wilcock *et al.*, 2004).

In general, industries in this sector use two types of energy: electricity and fossil fuels. The electricity is used primarily on operating the cooling systems to comply with food safety requirements due to the high degree of spoilage of meat (Wang, 2008; Talon *et al.*, 2007; Toldrá and Hui, 2007). In the particular case of cured sausages manufacture, about 25% of the total industrial energy is used for cooling and refrigeration processes, and 48% for food processing (Okos *et al.*, 1998). However, during the production period, the cooling systems can consume 45% to 90% of total electricity. In non-production periods (retention periods), they are responsible for all electricity consumption (Pagan *et al.*, 2004; Ramírez *et al.*, 2006).

The energy consumption in sausages factories depends on various factors such as the type of production process, the size and structure of the product, the chemical and physical properties of raw materials, type technology used, the mechanization level of the factory and the usage of installed capacity (Houska *et al.*, 2003; Li *et al.*, 2010; Wojdalski *et al.*, 2008; Wojdalski *et al.*, 2013). In order to maintain a sausages industry competitive taking into account the rising of energy costs, it is necessary to have a good energy and environmental performance. Thus, these industries should use the best available techniques and production practices, with major emphasis for its energy efficiency (Canales *et al.*, 2005; EC, 2005; EC, 2006; EREN; 2008; Pagan *et al.*, 2002; Pimentel *et al.*, 2008).

In general, for evaluating the energy efficiency of an industrial unit is common to use a normalized scale, often defined by the ratio of energy expended during production and the result obtained from such production (Reindl *et al.*, 2005; Ramírez *et al.*, 2006; Wodjalski *et al.*, 2013). Thus, indicators of Specific Energy Consumption (electrical and thermal) are obtained, that allow the evaluation of the performance of a industrial unit by comparison with indicators that belong to others units with the same category for similar activities and technologies (Wodjalski *et al.*, 2013).

There are some SEC values for these two types of energy in related literature, although they correspond to industrial units with different dimensions, level of technologic and world regions, which difficult a comparative analysis (Singh, 1986; Ramírez *et al.*, 2006; EC, 2006; Fritzson and Berntsson, 2006; Wodjalski *et al.*, 2013). Nevertheless, the indicators allow to find the best practices and procedures for the reduction of energy consumption in this type of industry. Fritzson and Berntsson (2006) estimated that in the energy consumption related with the cooling of meat products, it is possible to achieve 10% of energy savings in modern industries and 15% in the oldest ones.

In Portugal, the industrial food sector is made up mostly by micro, small and medium industries, that having energy intakes lower than 500 toe do not require an evaluation of their energy performance. For this type of industries, it’s not known the energy profile or the main features that contribute to its energy performance, with special attention to refrigeration systems.

The present study uses the results obtained in a set of 20 sausages factories located in central region of Portugal to assess the characteristics of energy consumption, with particular emphasis on electrical energy. Thus, the characteristics of the infrastructures, refrigeration systems, energy consumption, energy performance and potential savings of electricity it will be analyzed. Also it is presented a set of mathematical equations that relate the main parameters that influence the performance of cooling systems, such as: raw materials, cold rooms' volume, electrical energy consumption and the nominal compressors power.

2 Material and methods

In order to evaluate the profile of electrical energy consumption in processing industries of cured sausages and to characterize their cooling systems, audits were performed in 20 sausage factories located in central region of Portugal. Industries, named CS1 to CS20, do the same type of activity and have a similar production process.

The audits were developed in two phases. In the first phase, each company was visited for the purpose of filling in an inquiry with a set of pre-defined questions. Specifically, the following aspects composed the inquiry: i) identification and location of the facility; ii) infrastructure characterization; iii) characterization of the activities developed; iv) identification and characterization of the production process; v) identification and quantification of energy types; vi) characterization of the electrical tax and its consumption; vii) disaggregation of consumption by sector and equipment; viii) characterization of cold rooms; ix) determination of the environmental conditions inside and outside of industrial facility and within the cold rooms; x) identification and characterization of refrigeration systems; xi) characteristics of compressed air systems; xii) practice measures of energy efficiency already implemented.

In the second phase, industries were visited again but now with the objective of measuring the relevant parameters for its characterization. Thus, in this second stage and with the assistance of several measuring equipment, the following parameters were quantified: i) dimensions of cold rooms; ii) inside and outside rooms temperatures and relative humidity; iii) electricity consumption of different equipment, in particular of cooling systems; iv) nominal compressors power and v) overheating degree of the refrigerant. Additionally, facilities were inspected in order to check for any failures in the surroundings of cold rooms and possible maintenance flaws in refrigeration systems.

Air temperature and relative humidity were measured using digital multifunction equipment, Testo 435-2 with temperature (-20 to +70ºC) and relative humidity (0-100%) probes with accuracy of ±0.3°C and ± 2%RH, respectively. It also was measured the outside surface temperature of cold rooms to evaluate thermal bridges. A general observation with infrared thermography equipment, Testo 880-4, was performed and then, in more sensitive areas, the surface temperature was measured with the Testo 435-2 equipment using a contact temperature probe (-60 to 300ºC) with accuracy of ± 2%. In particular, to evaluate the overheating level of the refrigerants, the temperature and suction pressure at the compressor inlet and temperature at the evaporator outlet were measured.

The inner dimensions of cold rooms were determined with an infrared rangefinder with a maximum range of 60 meters and an accuracy of ±1 cm.

Global consumption of industries as well as the partial energy consumption in refrigeration systems were measured using digital power analysers, Elcontrol - Energy Explorer, with a measuring range of 15-750V and 20-1000A with an accuracy of 0,53-2V and 0,04-2A, respectively.

The nominal electric power of the compressor was determined based on the measured values of the evaporation and condensation temperatures, and the overheating level, by consulting catalogues and using specific calculation software provided by compressors' manufacturers. To validate this methodology, some compressors were randomly selected and the nominal electrical power was determined through experimental measurement of characteristics, namely: voltage, electrical current and power factor, using a digital multimeter and a clamp meter, Escort ECT-620.

The comparison between nominal power values obtained by these two methods allows to conclude that the difference between the calculated and measured values is below 10%, thus validating this approach.

In order to evaluate the energy performance of the industries in this case study, the following three indicators were introduced: specific electrical energy consumption (SEC), usage of cold rooms' volume (UCR) and nominal power of compressors per cold rooms' volume (NPC).

The SEC is an energy indicator commonly reported in the literature to evaluate the energy efficiency of industrial facilities or economic sectors (Nanduri *et al.*, 2002; Maxime *et al.*, 2006; UN, 2010). This indicator was recently used in the energy analysis in meat manufacturing industries (Ramírez *et al.*, 2006; Nunes *et al.*, 2011), in horticultural industries (Nunes *et al.*, 2014) and in cheese industries (Neves *et al.*, 2014a) as well as in the development of computational tools for the energy efficiency assessment in the agrifood sector (Santos *et al.*, 2013; Neves *et al.*, 2014a, 2014b, 2014c). The SEC value is determined by Equation (1).

$$SEC = \frac{E}{RM} \quad (\mathrm{kWh/ton_{RM}}) \tag{1}$$

Where E represents the annual electrical energy consumption (kWh), and RM designates the annual amount of raw materials processed ($\mathrm{ton_{RM}}$).

Another indicator using in this work is the usage of cold rooms' volume (UCR). It is a physical indicator determined by Equation (2).

$$UCR = \frac{RM}{V_{total}} \quad (\text{ton}_{\text{RM}}/\text{m}^3) \tag{2}$$

Where V_{total} indicates the total volume of cold rooms. This indicator helps to evaluate the greater or less usage of cold storage with consequent implications for the energy consumption level.

The third indicator was calculated as nominal power of compressors per cold rooms' volume (NPC) which is determined by Equation (3):

$$NPC = \frac{P_{total}}{V_{total}} \quad (\text{kW/m}^3) \tag{3}$$

Where P_{total} is the nominal electric power of all refrigeration compressors. With this indicator it is possible to quantify the cooling power installed per unit of cold room volume and therefore express the quality of the sizing/usage of cooling systems. The statistical analysis of all data collected was performed using the SPSS program. In the correlations development, the points that don't satisfy the Chauvenet's criterion were excluded from the sample (ASHRAE, 1986).

3 Results analysis and discussion

The two phases of the survey carried out in the processing industries of cured sausages provided a wide range of about these industries, which stands out: the year of facilities construction, amount of raw materials processed annually, number of cold rooms; total volume of the rooms, nominal electrical power of compressors, annual electrical consumption, SEC, UCR and NPC indicators. This data is shown in Table 1 and is analyzed in detail in the following subsections along with other data collected.

3.1 Facilities

According to the survey, 45% of the sausage factories feature a covered area up to 1000 m^2 and 55% between 1000 and 2000 m^2. As shown in Table 1, most of the plants have 11 to 20 years old (50%) and 21 to 30 years old (30%). The walls of buildings are mostly built in brick masonry. Only 20% of plants have building walls constructed with polyurethane panels. The largest constructive solution for building covers is the fiber cement sheets (75%). In general, the zone between the cooling chambers ceiling and loft is not ventilated.

Globally, there are 138 cold rooms, i.e., an average of 7 cold rooms per plant with an average volume of 67 m^3. The construction characteristics of these cold rooms are divided in 45% of brickwork coated with cork panels or polyurethane panels (55%) with thicknesses between 60 and 80 mm. Some of the cold rooms of older facilities show clear signs of quality loss of the thermal insulation (cracks and thermal bridges), visible through images obtained with the thermographic camera. Furthermore, the door seals of the cold rooms are damaged in its majority, and do not use any protection device to prevent from thermal entrainment in open door position.

Insert Table 1 here

3.2 Refrigeration systems

The sausages factories use four levels of temperature: freezing (-18°C), cooling (0-6°C), controlled atmosphere (14-26°C) and climate (12°C). In general, these industries use cooling systems to perform the treatment and conservation of raw materials and processed products and to air conditioning in processing rooms and corridors.

As the required cooling capacities are small, due to the small quantity of products to cool and air volume to be conditioned, the type of refrigeration system preferred is the individual small refrigeration unit (condensing units or refrigeration plants with a compressor or small refrigeration plant).

The industries analyzed in this study use the following cooling systems: 31 vapour-compression refrigeration systems with one compressor (29%), 29 condensation units (27%), 18 direct cooling circuit plants (17%), 14 air handling units with air-to-air heat pump (steaming and drying) (13%), 12 air handling mini-units (steaming and drying) (11%) and finally 3 refrigeration systems of compact type (3%).

Globally, the cooling systems contain 128 compressors: 29 hermetic type (22.5%), 89 semi-hermetic (69.5%) and 10 of open type (8%). The nominal electrical power of the industrial refrigeration compressors lies between 4 kW and 127 kW.

The operation time of the compressor has the following distribution: 41% have a running time between 21-40 years, 49% between 11-20 years and only 10% has a running time between 1 and 10 years. From these results it appears that a large number of compressors has a high operation time committing their energy performance. According to Coquinot and Chapon (1992), the average life of most equipment used in cold systems production should be between 15 to 20 years (compressors, fans, air treatment units) and beyond this period their energy efficiency decreases.

The refrigeration systems use 107 condensers, all cooled by forced air. The most commonly refrigerants used are the R22, R404a and R134a.

In addition to the thermal equipment already presented, some industries still have greenhouses that can be heated by electrical energy or using firewood.

Throughout the fieldwork it was found that many compressors suffer from a lack of maintenance and had oil leakage, some condensers were dirty and clogged and were installed in poorly ventilated areas or near heat sources, and finally, the cooling systems had a long time of operation (i.e., old equipment).

3.3 Energy consumption

The results show that all factories use electrical energy, propane gas or heating oil. Some factories still use firewood to cure the sausages. The electric energy is used to power the electrical equipment of which stands out cooling systems, such as compressors, evaporator fans, condensers, electric heaters, air treatment units, electric saws, grinders, mixers, filling machines, compressed air systems, lighting, pumps and office equipment. Propane or heating oil are burned in heat generators (boilers) for water heating to use in the process (cooking the cured sausages) or cleaning operations. Firewood is also used in drying operations.

From Table 1 it can be seen that the electric energy consumption of sausages factories lies between 13 MWh and 673 MWh with an average value of 127 MWh.

Figure 1 shows the individual and average electrical and fuels consumption (propane gas or heating oil) from sausages factories of this study. The results show that the average annual electrical energy consumption is 82% and the fuel consumption is 18%. Some sausage factories use electrical energy only because they use electric water heating cylinder (CS6, CS12, CS14 and CS15) as shown in Figure 2.

Insert Figure 1 here

In sausages factories, most of the equipment (grinder, mixers and fillers) works only during certain time periods of day or week. Refrigeration systems works continuously most of the time. Figure 2 shows the balance of energy consumption in sausages industries. The set of industries consumed during the year, a total 667.4 toe distributed by 548.7 toe of electricity (82%), 108.3 toe of propane (16%) and finally 12.4 toe of heating oil (2%). In average, each industry consumed 33.4 toe annually.

Insert Figure 2 here

Figure 3 shows the annual average distribution of electricity consumption by the main energy consumers of a typical sausage factory processing 2066 ton of raw materials and consuming 1037 MWh of electrical energy. As shown in Figure 3, electrical energy is the main type of energy used by the sausages factories and the larger consumers are the refrigeration systems (48.5%) and electric motors (38.7%). However for smaller sausage factories with less activity, the distribution of consumption changes with cooling systems assuming even a greater share of the electricity consumption. For a sausage factory with an annual processing of 104.8 ton of raw materials and electric power consumption of 4.42 MWh the distribution of consumptions is 79.2% for cooling electrical systems, and 11.1% for electric motors. These results confirm that cooling systems are the major electrical energy consumers as referred by Okos *et al.* (1998), Pagan *et al.* (2004) and Ramirez *et al*. (2006).

Insert Figure 3 here

From the analysis of the industry electrical taxes, it appears that they use mostly hourly tariffs, with contracted power lies between 19 kW and 190 kW, with an industry average of 55.3 kW.

It was still found that 8.7% of industries pay reactive energy due to a power factor less than 0.92. This cost can easily be avoided by installing a capacitors battery.

Figure 4 shows the graph relating the contracted power, the nominal electrical power of compressors and also the electrical energy consumption for the industries in study. As shown in Figure 4, there is a very narrow relationship between the two types of power and with the electrical energy consumption. This relationship allows to conclude that the electrical power of refrigeration compressors takes a leading role both in the choice of contracted power and the in the electricity consumption.

Insert Figure 4 here

3.4 Specific indicators

The specific consumption of total energy (electrical and heat) of sausages factories of this study lies between 248 kWh/ton and 2080 kWh/ton. These results are higher than the values (110-760 kWh/ton) presented by benchmarking (IFC, 2007).

Figure 5 shows the value of SEC of sausages factories and its average for all the sausages factories industries analysed. The SEC is between 248 to 1840 kWh/ton$_{RM}$, with an average value of 660 kWh/ton$_{RM}$, which is within the range reported by Toresen *et al.*, (2010), 600-1040 kWh/ton$_{RM}$, and by López *et al.* (2005), 460 kWh/ton$_{RM}$.

As can be seen in Figure 5, there is a wide range of SEC value among the different industries. During the fieldwork, the sausages factories that present the highest and lowest SEC values were analysed in detail.

Insert Figure 5 here

By comparing the SEC values of the sausages factories, it is possible ascertaining the most efficient and what are the main factors contributing to the differences in energy efficiency between themselves.

The sausage factory that has the lowest value of SEC, CS10, was constructed in 1995, and has the surroundings and cold rooms constructed in polyurethane panel with a thickness of 120 mm and the polyurethane cover with 40 mm panels. In addition, it also has a loft of identical height to the work zone (4 m) and is well ventilated. This industry also uses thermal energy from a boiler in air treatment units used in drying the cured sausages. It even has a program for managing the production activity, which consists of performing manufacture on certain days of the week and inactive in the remaining days in order to minimize the use of refrigeration systems. It has a direct-circuit cooling plant and maintenance plan of refrigeration systems. All these positive factors provide this industry with the lowest SEC value, 262 kWh/ton_{RM}. This result allows to conclude that the quality of the infrastructure materials, namely of walls, roof and cold rooms are a major factor in achieving these results. Furthermore, the energy use of thermal energy for the cure of sausages, and the use of a centralized refrigeration equipment, with a good energy management and maintenance contribute to an improved energy efficiency.

The sausage factory that has the highest SEC value is CS8. The infrastructure of this sausage factory was built in 1994 with masonry and with a metal cover plate. The cold rooms are made of polyurethane panels with 60 mm thick. It also has an unvented loft, where temperature reach values higher than 50ºC. Furthermore, it has a compact cooling equipment installed inside the facility, resulting in heat dissipation of the condenser inside the facility as a result of a faulty location of the equipment. To maintain the interior environment of the climatic facilities, particularly of the processing room and hallways, the temperatures in these spaces are set to 8-10ºC (below the standard temperature of 12ºC). This industry also works below its nominal capacity as shown in Table 2, with the lowest value of UCR, which is 0.15 ton/m^3. On the other hand, it is also one of the industries that have the lowest NPC, 0.054 kW/m^3. Improper installation of refrigeration equipment and the use of low evaporation temperatures, combined with a large thermal load inside the facilities, force the cooling systems to present a high consumption of electrical energy. All these factors contribute to this industry present the largest SEC, 1840 kWh/ton$_{RM}$, far above the average of 660 kWh/ton$_{RM}$.

Another example of an industry with a SEC value above average is CS5. The infrastructure of this sausage factory was built in 1992 in double masonry wall and a marseille tile roof, it was a well ventilated loft and a concrete slab separating the loft from the working area. Despite showing infrastructure in good conditions of conservation and possessing excellent materials for the cold rooms (polyurethane panels with 80 mm thick), the refrigeration systems have a high operation time and without planned maintenance in such way that the condensers of the refrigeration systems were clogged. These factors affect the energy efficiency of refrigeration systems and, in particular, the energy performance of the facility. Consequently, this plant presents a SEC value well above average, 898 kWh/ton$_{RM}$. From this example it is concluded that the operation time of refrigeration equipments and it maintenance are also two key factors for the energy performance of refrigeration systems.

The set of factors described above are some examples that contribute to the result of the energy performance of sausages industries. These results allow to conclude that there are potential savings of electrical energy that can be achieved if the several inefficiencies detected were corrected. Assuming that all industries with a higher value than the average SEC (see Figure 5) implement practice measures to improve the energy efficiency in order to achieve this average value, it should be expected an overall potential of 24% of reduction consumption of electrical energy. In this case, the procedure presupposes sharing the best practices of energy use in this sector. This savings translates into an annual value of 337 MWh. In relation to the reference value (Singh, 1986), where the average value of the electrical energy consumption for the sausages processing is 465 kWh/ton$_{RM}$ (see Figure 5), the value of energy savings obtained is 37%, corresponding to an annual value of 1812.7 MWh. It should be noted that the Spanish industries incorporate in the production process other forms of energy besides electricity (Singh, 1986), contrary to Portugal where the energy sources rely primarily on electricity and some biomass to perform the drying and smoking operations. This feature explains the large difference in electrical consumption observed between the industries of the two countries.

Figure 6 shows the UCR results. The UCR values show that not all sausages factories have a proper volume utilization of cold rooms in a similar manner. This result shows that the total installed capacity of sausages factories is not used (low UCR value). Consequently, sausages factories working below the nominal capacity show higher SEC values, meaning a decrease in their energy efficiency. For example, CS4, CS7, CS10, CS11, CS12 and CS14 have higher SEC values than CS2, CS8, CS13, CS15, CS17 and CS20. From this analysis it is concluded that for the activity of sausages factories, the partial load contributes to reduced energy efficiency. Globally, the average UCR value is 0.712 ton$_{RM}$/m^3.

Insert Figure 6 here

Figure 7 shows the NPC results. It can be seen that there is a certain uniformity of results for this indicator, from which it can be concluded that the sizing or the cooling capacity used for activity of sausages factories presents a certain standardization. Exceptionally, CS11 and CS14 have much higher values than the other sausages factories. However these two sausages factories also have the highest values UCR and the results are in agreement. Globally, the average NPC value is 0.1 kW/m^3.

Insert Figure 7 here

3.5 Refrigeration system modelling

Table 2 shows the mathematical equations that relate the various variables and other indicators obtained during the statistical analysis of results.

Figure 8 shows the graphical representation of experimental values of sausages industries and the linear regression obtained by the model and the upper and lower limits that correspond to a confidence interval of 95% for each one of the relationships. Figure 9-a) shows the relation between volume of cold rooms (m^3) and raw material (ton); Figure 9-b) relates nominal power of compressors (kW) with raw material; Figure 9-c) relates the electrical energy consumption (MWh) versus raw material; Figure 9-d) shows the relation between electrical power of compressors and volume of cold rooms; Figure 9-e) relates the electrical energy consumption and the volume of cold rooms and finally Figure 9-f) relates the electrical energy consumption with the electrical power of the compressors.

Insert Figure 8 here

As shown in Figure 8, the data points are concentrated within the range of 95% confidence. The high values of the coefficients of determination R^2 indicate a good relationship between the experimental points and the model equations.

4 Conclusions

In this study we have analyzed 20 sausages factories sector located in the centre region of Portugal. The analysis considers infrastructures, manufacturing processes, refrigeration systems, energy consumption, and evaluation of specific indicators. Mathematical correlations were developed that serve to characterize the energy performance of refrigeration systems and particularly these industries.

The sausages factories of this study, and generally in Portugal, are small industries that process annually an average value 255 ton of raw material, and have a covered area around 2000 m^2. They are usually built of masonry and have fibrocement covering. The cold rooms are constructed of polyurethane panels with a 60 to 80 mm thickness and have an average volume of 67 m^3.

The main products are dry cured sausages. These products involve conservation operations of meat, cutting, mixing, salting, maturing, filling, steaming and drying. These last two operations are usually performed in flues or controlled atmosphere rooms.

The refrigeration systems are of classic type for conservation operations and air handling systems of air-air heat pump type are used for drying.

The main type of energy used in this industry is electricity (82%) and fuel in a smaller scale (18%). The major electrical energy consumers are the refrigeration systems (48.5 to 79.2% of total electricity consumption).

The specific total energy consumption (electricity and heat) is between 248 kWh/ton and 2080 kWh/ton. These results are higher than benchmarking considered as reference. Thus, the sausages factories in this study consume more energy. It must be highlighted that the consumption also depends manufacturing process.

The specific electrical energy consumption (SEC) value is between 248 to 1840 kWh/ton$_{RM}$, with an average value of 660 kWh/ton$_{MR}$. These values are within the range of other values found in literature.

It is predicted that sausages industries that consume more energy than the average value, adapt best energy practices to reach that amount, would save approximately 24% of electricity equivalent to 337 MWh annually. In relation to other literature, the savings would be 37% or equivalent to 1813 MWh annually.

The regression equations obtained allow to evaluate the energy performance of the sausages industries and their refrigeration systems. It can be used to evaluate an existing facility or as a predictive tool to obtain the quantities of a particular facility which eventually will be build.

Throughout our study, several inefficiencies were identified that negatively influence the energy efficiency of sausages factories, in particular: infrastructure with weak thermal insulation capacity (masonry walls, fiber cement roofing and sheet metal) reduced thickness (60 mm) of cold rooms walls, loft without ventilation when very high temperatures were detected (above 50°C), refrigeration equipment poorly located with particular emphasis on condensers installed indoors or near heat sources, refrigeration equipment with large operation time and without proper maintenance, compressors with long use, with large oil leaks, vibrations and continuous leakage of refrigerant and the use of cold room partially loaded. The results were presented can help for the energy sustainable development of meat industries, since same inefficiencies may exist in other companies in other countries despite the differences that may exist both on processing methods or cold storage conditions.

References

[1] Abdelaziz, E.A., Saidur, R., Mekhilef, S., 2011. A review on energy saving strategies in industrial sector. Renewable and Sustainable Energy Reviews 15(1), 150-168.

[2] Wang, L., 2008. Energy Efficiency and Management in Food Processing Facilities. CRC Press, Boca Raton, FL., USA.

[3] FoodDrinkEurope, 2012. Annual Report 2012. Food Drink Europe, Brussels.

[4] INE, 2011. Anuário Estatistico de Portugal 2010. Instituto Nacional de estatística, IP, Lisboa (in portuguese).

[5] DGV, 2011. Estabelecimentos aprovados que utilizam géneros alimentícios de origem animal. Direcção Geral de Veterinária. Ministério da Agricultura, do Desenvolvimento Rural e das Pescas, Lisboa (in portuguese).

[6] INE, 2010. Estatisticas da Produção Industrial 2009. Instituto Nacional de Estatistica, I.P., Lisboa (in portuguese).

[7] INE, 2013. Indicadores económicos: Produtos produzidos na indústria por Tipo de produto (Por CAE Rev. 3); Anual INE, Instituto Nacional de Estatística, I.P., Lisboa (in portuguese).

[8] Röhr, A., Lüddecke, K., Drusch, S., Müller, M.J., Alvensleben, R.V., 2005. Food quality and safety-consumer perception and public health concern. Food Control, 16(8), 649-655.

[9] Wilcock, A., Pun, M., Khanona, J., Aung, M., 2004. Consumer attitudes, knowledge and behaviour: a review of food safety issues. Trends in Food Science & Technology 15(2), 56-66.

[10] Talon, R., Lebert, I., Lebert, A., Leroy, S., Garriga, M., Aymerich, T., Drosinos, E.H., Zanardi, E., Ianieri, A., Fraqueza, M.J., Patarata, L., Lauková, A., 2007. Traditional dry fermented sausages produced in small-scale processing units in Mediterranean countries and Slovakia. 1: Microbial ecosystems of processing environments. Meat Science 77(4), 570-579.

[11] Toldrá, F., Hui, Y.H., 2007. Handbook of fermented meat and poultry. Blackwell Pub.

[12] Okos, M., Rao, N., Drecher, S., Rode, M., Kozak, J., 1998. Energy Usage in the Food Industry. American Council for an Energy-Efficient Economy.

[13] Pagan, R., Prasad, P., Price, N., Kemp, E., 2004. Eco-efficiency for the Queensland Food Processing Industry. Queensland Government.

[14] Ramírez, C.A., Patel, M., Blok, K., How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries, 2006. Energy 31(12), 2047-2063.

[15] Houska, M., Sun, D.-W., landfeld, A., Zhang, Z., 2003. Experimental study of vacuum cooling of cooked beef in soup. Journal of Food Engineering 59(2-3), 105-110.

[16] Li, C.B., Zhou, G.H., Xu, X.L., 2010. Dynamical changes of beef intramuscular connective tissue and muscle fiber during heating and their effects on beef shear force. Food and Bioprocess Technology 3(4), pp. 521-527.

[17] Wojdalski, J., Drózdz, B., Grochowiez, J., Magrys, A., Ekielski, A., 2013. Assessment of Energy Consumption in a Meat-Processing Plant-a Case Study. Food Bioprocess Technology 6(10), 2621-2629.

[18] Wojdalski, J., Drózdz, B., Brocki, H., 2008. Effectiveness of electrical energy and water consumption in a small-size dairy processing plant. TEKA Kom. Mot. Energ. Roln.-Ol Pan 8, 303-309.

[19] Canales, C.C., Vidal, A.P., 2005. Guía de Mejores Técnicas Disponibles en España del sector cárnico. Ministerio de Medio Ambiente. España (in spanish).

[20] EC, 2005. Integrated pollution prevention and control. reference document on best available techniques in the slaughterhouses and animal by-products industries. European Commission (EC). Brussels.

[21] EC, 2006. Programa Europeu Motor Challenge-Módulo de Sistemas Frigorificos. European Commission (EC), Brussels.

[22] EREN, 2008. Plan de Assistencia Energética en el Sector Cárnico, Ente Regional de la Energía de la Castilla Y León. Madrid (in spanish).

[23] Pagan, R., Renouf, M., Prasad, P., 2002. Eco-Efficiency Manual for Meat Processing. Meat and Livestock Australia Ltd, Austraulia.

[24] Pimentel, D., Williamson, S., Alexander, C.E., Gonzalez-Pagan, O., Kontak, C., Mulkey, S.E., 2008. Reducing Energy Inputs in the US Food System. Human Ecology 36(4), 459-471.

[25] Reindl, D.T., Jekel, T. B., Elleson, J.S., 2005. Industrial Refrigeration Energy Efficiency Guidebook. IRC, Industrial Refrigeration Consortium. The University Wisconsin, Madison.

[26] EC, 2006. Integrated pollution prevention and control. Reference Document on Best Available Techniques in the Food, Drink and Milk Industries. European Commission (EC), Brussels, 149-151.

[27] Fritzson, A., Berntsson, T., 2006. Energy efficiency in the slaughter and meat processing industry--opportunities for improvements in future energy markets. Journal of Food Engineering 77(4), 792-802.

[28] Singh, R.P., 1986. Energy accounting of food processing operations. In Energy in Food Processing (Ed R. Paul Singh) Elsevier.

[29] Maxime, D., Marcotte, M., Arcand, Y., 2006. Development of eco-efficiency indicators for the Canadian food and beverage industry. Journal of Cleaner Production 14(6-7), 636-648.

[30] Nanduri, M., Nyboer, J., Jaccard, M., 2002. Aggregating physical intensity indicators: results of applying the composite indicator approach to the Canadian industrial sector. Energy Policy 30(2), 151-163.

[31] UN, 2010. Global Industrial Energy Efficiency Benchmarking, United Nations (UN) Industrial Development Organization, Austria.

[32] Nunes, J., Silva, P.D., Andrade, L.P., 2011. Energetic efficiency evaluation in refrigeration systems of meat industries. in 23rd IIR International Congress of Refrigeration. Refrigeration for Sustainable Development, August 21-26, Prague, Czech Republic.

[33] Nunes, J., Silva, P.D., Andrade, L.P., Gaspar, P.D., Domingues, L.C., 2014. Energetic evaluation of refrigeration systems of horticultural industries in Portugal. in 3rd IIR International Conference on Sustainability and Cold Chain (ICCC 2014), June 23-25, London, United Kingdom.

[34] Neves, D., Gaspar, P.D., Silva, P.D., Andrade, L.P., Nunes, J., 2014. Computational tool for the energy efficiency assessment of cheese industries - Case study of inner region of Portugal. in V Congreso Iberoamericano de Ciencias y Técnicas del Frío (CYTEF 2014), June 18 - 20, Tarragona, Spain.

[35] Santos, R., Nunes, J., Silva, P.D., Gaspar, P.D., Andrade, L.P., 2013. Computational tool for the analysis and simulation of cold room performance in perishable products industry. in 2nd IIR International Conference on Sustainability and the Cold Chain (ICCC 2013), International Institute of Refrigeration (IIR), April 2-4, Paris, France.

[36] Neves, D., Gaspar, P.D., Silva, P.D., Nunes, J., 2014. Predictive evaluation of the energy efficiency of Portuguese industrial companies in the meat food sector", Energy Conversion and Management. (submitted)

[37] Neves, D., Gaspar, P.D., Silva, P.D., Andrade, L.P., Nunes, J., 2014. Computational tool for the analysis of the energy performance of portuguese agrifood industries", Energy Systems Conference, June 24-25, London, UK.

[38] ASHRAE, 1986. Engineering Analysis of Experimental Data. ASHRAE Guideline 2. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta.

[39] Coquinot, J.P., Chapon, J.F., 1992. Entreposage frigorifique des pommes et des poires: equipement, 1. ed. Ctifl-Centre technique interprofessionnel des fruits et légumes, Paris.

[40] IFC, 2007. Environmental, Health, and Safety Guidelines for Dairy Processing. International Finance Corporation (IFC). World Bank Group. Washington, USA.

[41] Toresen, K., Kjött, N., Herlevsen, S., Pontoppidan, O., Hansen, P.I.E., 2010. Nordic slaughterhouses BAT document. The Danish Meat Research Institute, Roskilde, Denmark.

[42] López, A., Esnoz, A., Carles, B., Coronas, A., 2005. Estudi tecnològic del fred a la indústria agroalimentària i les seves millors tecnologies disponibles en consum d'energia. Institut Català d'Energia. Sociedad Espanola de Ciências y Técnicas del Frio.

Table 1: Characterization of sausages plants based on the data collected locally and on calculated indicators.

Plant	Year gf construction	Raw material (ton_{RM}/year)	Number of cold rooms	Total volume of cold rooms (m^3)	Compressors nominal power (kW)	Electricity consumption (MWh/year)	SEC (KWh/ton_{RM})	UCR (ton_{RM}/m^3)	NPC (kW/m^3)
CS1	1998	38.5	4	80.0	7.8	23.7	616	0.48	0.098
CS2	1992	45.3	4	188.0	11.8	38.2	844	0.24	0.063
CS3	1997	104.8	5	172.7	8.6	44.1	421	0.61	0.050
CS4	1992	877.2	12	675.0	44.0	245.0	279	1.30	0.065
CS5	1990	76.5	6	248.6	19.0	68.7	897	0.31	0.076
CS6	2003	450.4	9	679.0	71.6	232.4	516	0.66	0.105
CS7	1998	149.9	4	126.0	17.8	47.4	316	1.19	0.141
CS8	1994	78.5	8	516.0	27.8	144.5	1840	0.15	0.054
CS9	1995	198.0	6	547.0	31.6	66.1	334	0.36	0.058
CS10	1995	315.8	6	321.0	27.2	82.8	262	0.98	0.085
CS11	1998	55.5	3	26.0	9.3	27.3	491	2.14	0.358
CS12	1995	1040.9	9	850.0	94.6	258.0	248	1.22	0.111
CS13	1982	178.3	7	866.0	55.4	194.1	1088	0.21	0.064
CS14	1990	31.1	2	14.0	3.8	12.6	405	2.22	0.271
CS15	1970	178.1	9	764.0	24.5	145.8	818	0.23	0.032
CS16	1993	80.3	4	173.0	13.3	39.5	491	0.46	0.077
CS17	2003	45.5	4	175.0	12.9	25.5	560	0.26	0.074
CS18	1995	68.0	4	122.0	4.2	33.5	494	0.56	0.034
CS19	1995	1003.0	23	2077.0	126.7	673.3	671	0.48	0.061
CS20	1986	92.3	9	510.0	21.4	148.7	1611	0.18	0.042

Table 2: Correlations for characterization of the refrigeration systems of sausages industries (Correlations significant at 0.01 level).

		Cold rooms' volume V (m^3)	Compressors power P_{comp} (KW)	Electricity consumpt. E (MWh/year)
Raw materials *RM* (ton)	Formula	V = 4,3795 RM - 87,42	P = 0,0702 RM+11,492	E = 0,2376 RM + 24,18
	R^2	0,82	0,68	0,92
	Error (standard deviation)	130,53	14,20	23,24
	Lower limit of confidence interval (95%)	-244,70	2,76	8,11
	Upper limit of confidence interval (95%)	69,86	20,22	40,25
	Spearman correlation coefficient	0,83	0,86	0,93
	Significance	0,00	0,00	0,00
	n	12	19	15
Cold rooms' volume *V* (m^3)	Formula		P = 0,0572 V+ 3,4135	E = 0,3243 V - 6,8444
	R^2		0,93	0,96
	Error (standard deviation)		4,06	17,34
	Lower limit of confidence interval (95%)		-0,06	-21,47
	Upper limit of confidence interval (95%)		6,88	7,78
	Spearman correlation coefficient		0,92	0,91
	Significance		0,00	0,00
	n		15	16
Compressors power *P* (KW)	Formula			E = 2,9045 P + 11,323
	R^2			0,90
	Error (standard deviation)			25,68
	Lower limit of confidence interval (95%)			-8,01
	Upper limit of confidence interval (95%)			30,65
	Spearman correlation coefficient			0,92
	Significance			0,00
	n			17

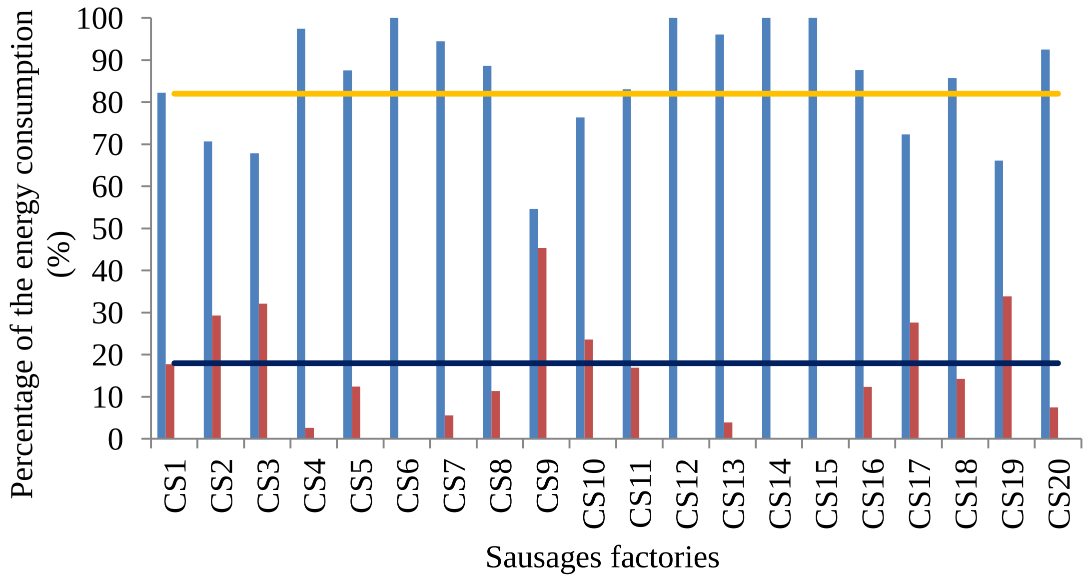

Figure 1: Consumption profile of electrical and fuel in sausages factories. (■: Electricity; ■: Fuel; ■: Average electricity; ■: Average fuel)

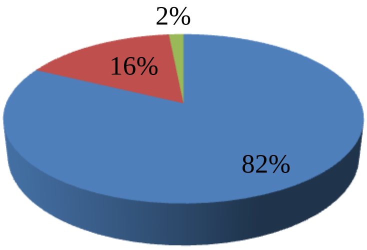

Figure 2: Balance of energy consumption in sausages factories (■: Electricity; ■: Propane; ■: Diesel).

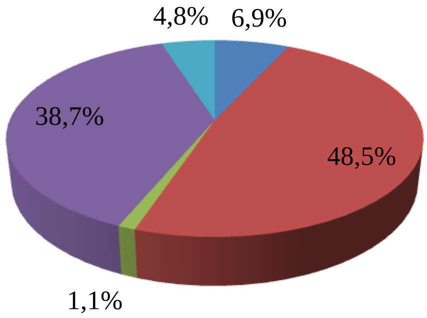

Figure 3: Annual distribution of electricity consumption for sausage factory -2066 ton_{RM} and 1.037 MWh_e- (■: Refrigeration system; ■: Motors; ■: Lightning; ■: Compressed air; ■: Other).

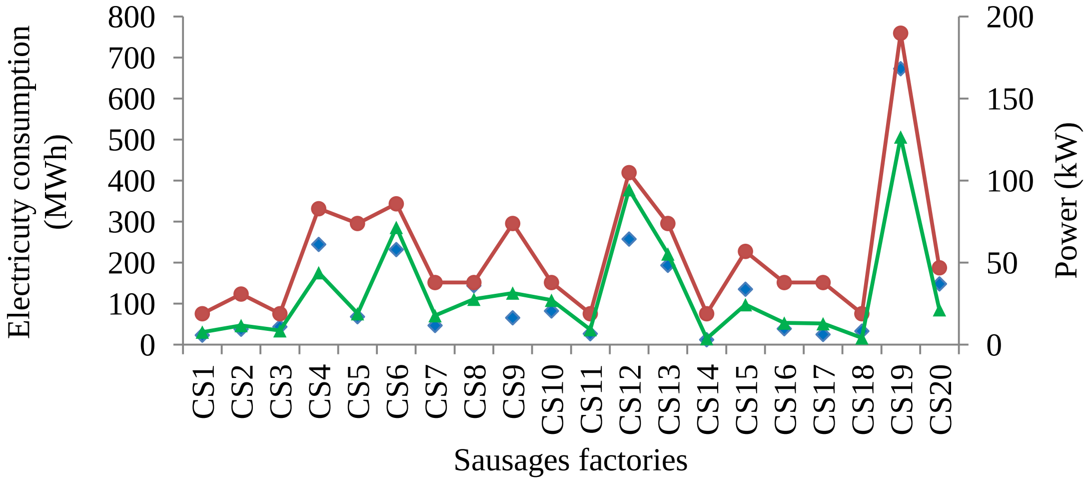

Figure 4: Relationship between contracted power (■), nominal power of compressors (▲) and electricity consumption (◆).

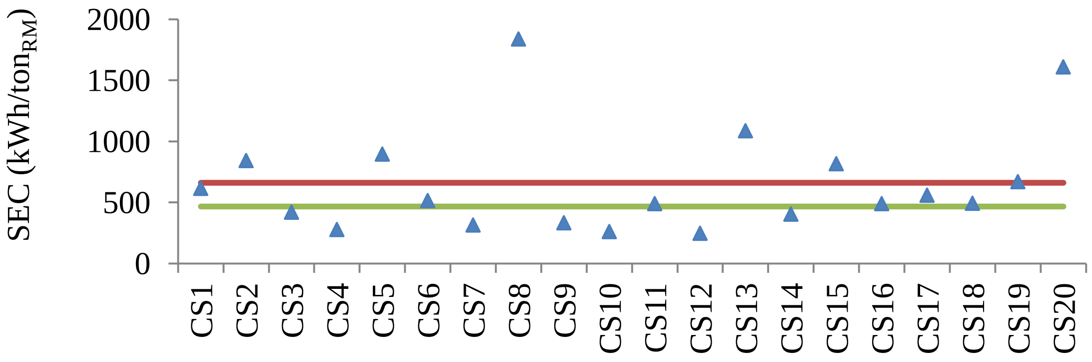

Figure 5: SEC values of sausages factories (▲: SEC of sausages factories; (–: average SEC; –: reference SEC).

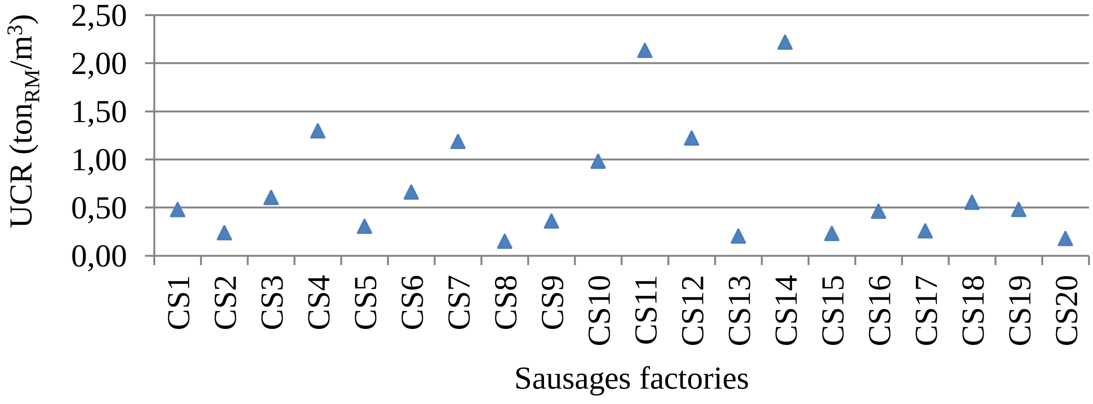

Figure 6: UCR values of sausages factories.

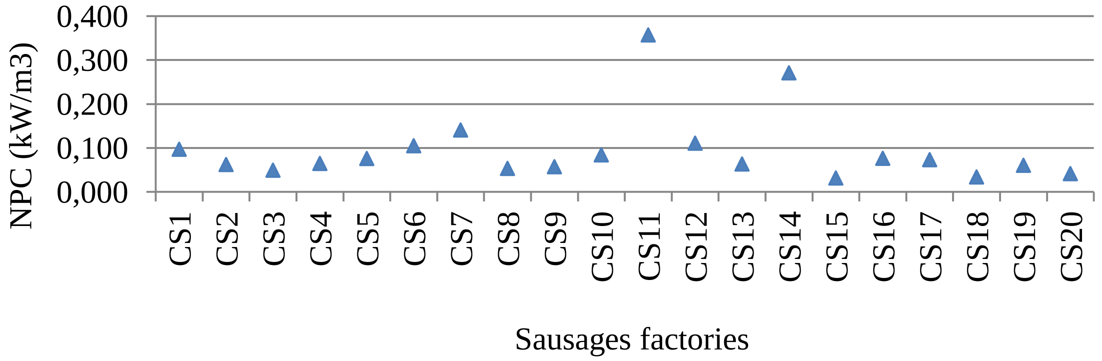

Figure 7: NPC values of sausages factories.

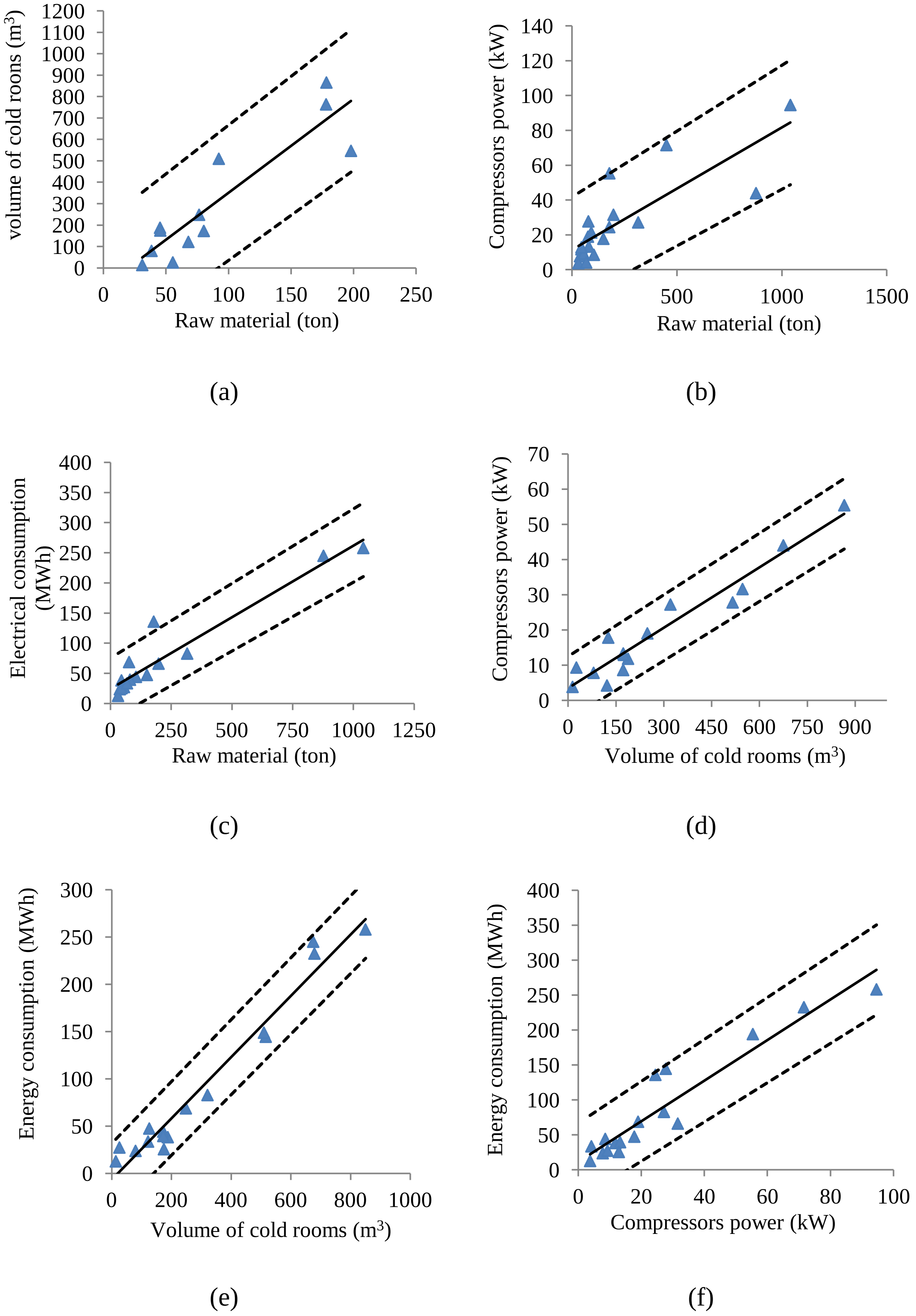

Figure 8: Correlations for characterization of the refrigeration systems of sausages industries.