Active demand response strategies to improve energy efficiency in the meat industry

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Abstract: This paper is focused on the evaluation and assessment of different energy efficiency strategies applied to electrical appliances related to cool production and ventilation in industrial facilities which manufacture different types of meat products. Two strategies have been analyzed. Firstly, speed variation of fans in drying chambers, which implies modification of the on-off sequences in a way that the fans work for a longer time at a lower speed. A reduction of 1.65% in the total consumption of electricity is achieved. Lastly, use of flexibility in drying rooms based on the interruption of the electricity supply for the cooling production. Using this strategy saves of 5% in the total cost of electricity are achieved. Such results are very promising and demonstrate the effectiveness of these techniques, opening the gate to an innovative point of view about the management of this type of infrastructures to get significant energetic, economic and environmental savings with reduced and acceptable impact in the production process.

Keywords: *Full Food Industry, Power Demand, Energy Conservation, Electric Variables Control, Load Modeling*

1. Introduction

The meat industry is one of the most energy consumption intensive industrial sectors [1] and it is an industrial segment with one of the highest potentials for demand response (DR) implementation [2, 3]. It is the largest segment in U.S. agriculture [4], where poultry and pig meat segment represents the 16% in total World production [5]. The share for the European Union is similar, with the 18% in total World production. In the case of Spain, where techniques exposed in this paper have been tested, the elaboration of different pig meat products, as cured ham or deli products, is worldwide known. Spain produces the 3% of total pig meat in the world.

Regarding the type of energy sources used by such type of consumers, heating processes generally use fossil fuels, as natural gas or diesel, while electricity is mainly used for cooling. Refrigeration constitutes between 45% and 90% of the total final electricity consumption in working days [6], so that efficiency and saving actions must be focused on this energy source.

Different works have been presented in the past [7, 8] in order to evaluate customer demand response in different sectors (mainly for commercial and industrial segments). Nevertheless, they were not commonly applied to the meat industry processes since they are directly related to the final quality of the product, so customers were not willing to change any element or parameter of those processes.

In spite of that fact, these rigid industrial practices are being questioned because of the gradual increase in prices of energy, the higher concern in environmental issues as well as the evolution in technology solutions, so new actions, like the ones proposed in this paper, oriented to improve the energy consumption, start to be taken into account.

This paper presents such type of efficiency and saving actions as the effect of reducing the rotation speed of fans in drying chambers or the use of flexibility that customers may have under a novel approach focused on the identification of packages of energy [8] that could be reduced or eliminated for a period of time without impacting in production processes.

2. The drying process in a cured ham factory

The process of drying in a cured ham factory takes place in especially designed chambers and requires an accurate control of temperature, relative humidity and speed of air [9]. Historically, the process of drying was carried out in specific zones with Continental Mediterranean climate. The process started in December, where temperature and humidity are low, and it used to be completed in summer. Currently, artificial drying chambers reproduce such conditions permanently, so that a continuous production could be achieved.

2.1. The whole process: stages

The traditional Spanish dry-cured ham production is initiated with a salting process and storing of fresh ham at a low temperature before drying in order to stabilize the meat [10]. The temperature of the drying air is gradually increased during the drying process in order to accelerate the reduction of water in meat and the development of the typical aged flavor. According to available bibliography [9, 11] and after studying in detail the process of drying in different factories devoted to the production of Spanish cured ham, four drying stages can be identified for a typical plant, as shown in Fig. 1.

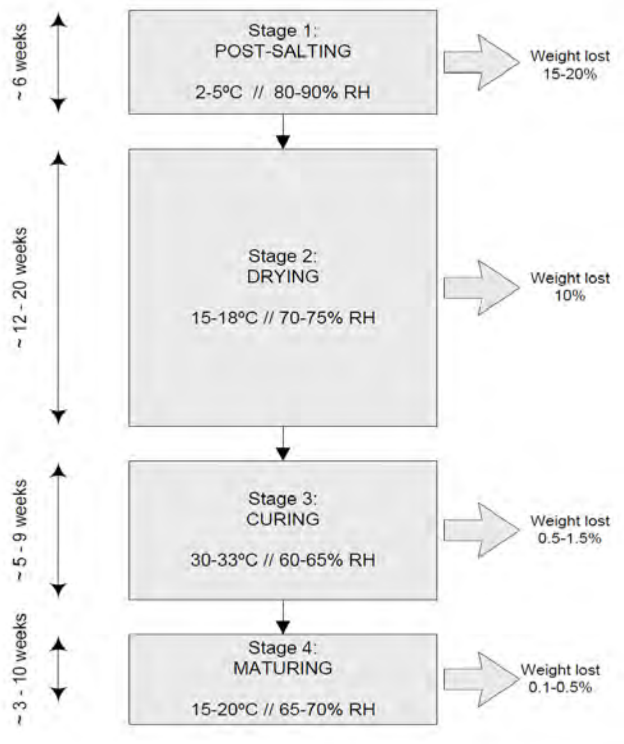

Fig.1. Drying processes in a typical cured ham factory.

- Post-salting stage. Temperature inside the chamber is set between 2 and 5ºC while humidity remains controlled between 80% and 90%. The average duration of this stage is about six weeks, depending on the type of product. The amount of water contained in the meat is deeply reduced during this stage, reaching values between 15% and 20% in the total weigh of the product.

- Drying stage. The meat loses about 10% of weigh during this phase of the process. Temperature is maintained in 15-18ºC range and humidity take values of 70-75%. It usually takes between 3 and 5 months.
- Curing stage. Temperature is higher (30-33ºC) and humidity decreases up to 65% in this stage, with a typical duration of 5 to 9 weeks. Ham loses between 0,5 and 1,5% of weight in this phase.
- Maturing stage. The ham is introduced then in a maturing chamber until the experts consider that the product is finished. Therefore, the duration of this stage strongly depends on the particular situation of each product, as well as the type of final product to be obtained. Accordingly this stage could take from 20 to 70 days, depending on the type of final product and the amount of water it has already lost. Humidity is maintained below 70% and temperature reaches values of 15-20ºC.

A piece of ham loses during the whole drying process about 35% of the initial weigh that it had at the beginning of the process.

2.2. Psychrometric analysis of a drying chamber

Drying chambers are equipped with different air drying units, which are distributed on the ceiling of each room. Each device consists on a heat exchanger and a fan which forces the air to go through the unit. At the entrance of the unit, there is a first group of pipes containing cold water to cool the moist air and produce the condensation. At the exit, there is another group of pipes containing in that case hot water, which allow the dry air to recover the initial temperature.

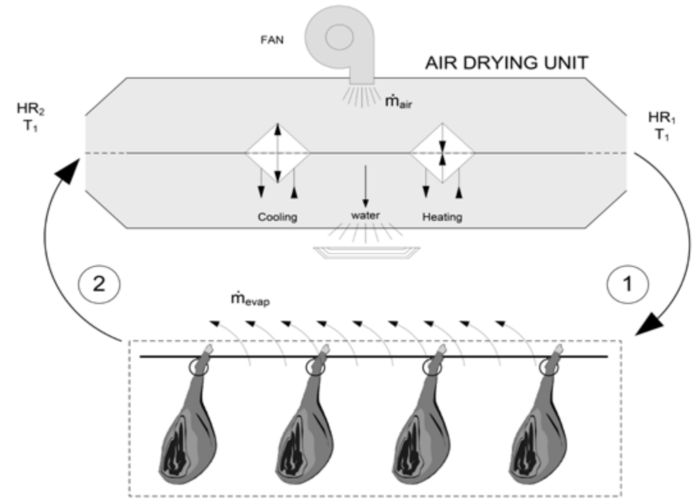

Fig.2. Meat drying process scheme.

The processes involved in a drying chamber facility, regarding the air parameters and flow, are schematically shown in Fig. 2. Dry air starts contacting with the surface of meat inside the drying chamber in point 1. Dry air absorbs the humidity from the surface of meat from point 1 to point 2 so that the humidity ratio ω grows adiabatically [11] from ω_1 to ω_2, as shown in Fig. 3, that depicts the psychrometric chart during the process.

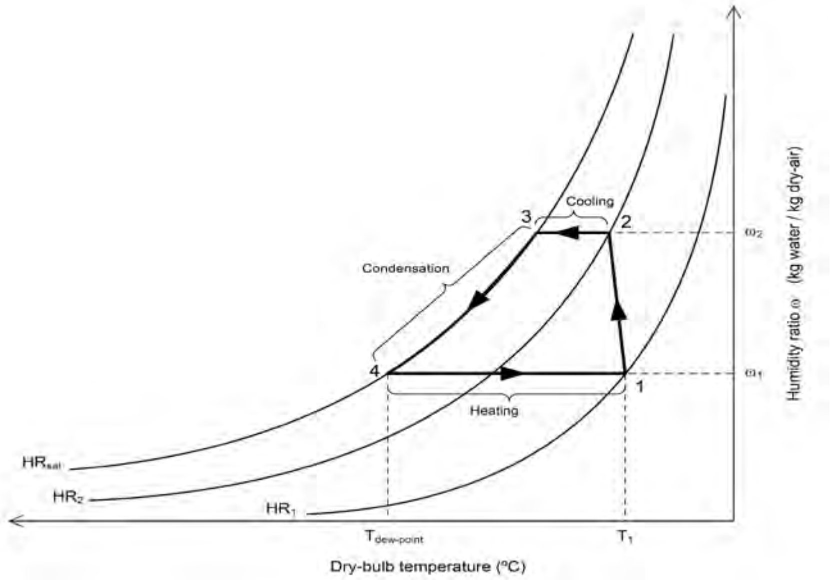

Fig.3. Psychrometric chart for a drying room.

When moist air gets in the air drying unit, the temperature decreases from point 2 to point 3, where the dew-point is reached. Moisture condensation occurs when moist air is cooled to a temperature below its initial dew-point [12]. From point 3 to point 4 temperature decreases while the air drives the water out since the humidity ratio is lower, as the capacity of the air to keep the water is reduced. Dry air is heated again from point 4 to point 1 in order to maintain the temperature inside the drying room, so initial conditions for the air are achieved to start the drying process again.

3. Proposed saving strategies

Two different strategies have been evaluated and assessed in order to achieve significant reductions in the electricity bill in factories devoted to the elaboration of meat products. In particular, speed variation of fans and flexibility strategies have been tested in different factories that produce Spanish cured ham, as it is exposed below.

3.1. Strategy 1: Speed variation of fans in drying chambers

Fans forcing the air to go through the drying units, located on the ceiling of the drying chambers, work intermittently according to the drying plan established by experts for the proper development of the process. The first action proposed is based on the modification of the on-off sequences in a way that the fans work for a longer time at a lower speed, so that the total amount of water extracted from the drying chamber remains constant.

The computation of boundary limits on possible savings with different operation conditions can be done according to the fan performance equations, and it can be summarized according to the following simple relationships linking fan capacity, speed and power:

- The airflow volume is directly proportional to the fan speed.
- The power required by fans is proportional to the cube of the fan speed [13]

In case the speed of fans were to be reduced, the duration of the ventilation cycle needs to be increased in order not to reduce the total amount of air required to remove all the water transferred by the ham, so the speed reduction would be achieved if fans were working at reduced regime for a longer time.

3.1.1. Obtained results

Results presented in this section have been obtained in a real factory which produces cured ham in Spain.
Four different drying chambers were studied in detail according to the design conditions of the considered factory. Table 1 shows the set point parameters for each one of these chambers:

Table 1. Set point parameters for the different drying chambers in a cured-ham factory.

Drying chamber / stage	Set point temp.	Set point humidity	Duration	Reduction of water
	ºC	*%*	*weeks*	*%*
Post-salting	*3.0*	*82.0*	*6.4*	*12.0*
Drying (I)	*8.0*	*77.0*	*7.1*	*9.0*
Drying (II)	*18.0*	*74.0*	*7.1*	*3.0*
Curing	*30.0*	*70.0*	*3.6*	*3.0*

A psychrometric analysis of each chamber, based on a methodology proposed by authors in [14], was performed in order to get the different values for points from 1 to 4, as described in section 1.2. Table 2 includes the humidity ratio, dry-bulb and humid-bulb temperatures, specific enthalpy and relative humidity for each drying chamber at a pressure of 760 mmHg.

Table 2. Set Characteristic points in the psychrometric chart for the different chambers.

Chamber	Point	Humidity Ratio ω	Dry-bulb temperature	Humid-bulb temperature	Enthalpy	Relative humidity
		kg-w/kg-da	*ºC*	*ºC*	*kJ/kg-da*	*%*
Post-salting	*1*	*0.00376*	*3.00*	*1.66*	*12.29*	*80*
	2	*0.00389*	*2.65*	*1.66*	*12.68*	*84*
	3	*0.00389*	*0.51*	*0.51*	*10.62*	*100*
	4	*0.00376*	*0.09*	*0.09*	*9.85*	*100*
Drying (I)	*1*	*0.00520*	*8.00*	*6.22*	*20.72*	*78*
	2	*0.00542*	*7.45*	*6.22*	*21.3*	*84*
	3	*0.00542*	*5.18*	*5.18*	*19.12*	*100*
	4	*0.00520*	*4.56*	*4.56*	*17.94*	*100*
Drying (II)	*1*	*0.00970*	*18.00*	*15.28*	*41.69*	*75*
	2	*0.01018*	*16.85*	*15.28*	*42.95*	*84*
	3	*0.01018*	*14.40*	*14.40*	*40.68*	*100*
	4	*0.00970*	*13.61*	*13.61*	*38.65*	*100*
Curing	*1*	*0.02019*	*30.00*	*26.23*	*79.58*	*75*
	2	*0.02140*	*27.20*	*26.23*	*82.85*	*93*
	3	*0.02140*	*26.08*	*26.08*	*82.13*	*100*
	4	*0.02019*	*25.23*	*25.23*	*78.06*	*100*

The next step was to calculate the value of reduced speed at which fans need to be adjusted. The rated power of motors is 1 HP at 1500 rpm. The initial time during that fans are switched on is equal to 50% of the stage for post-salting and drying (I), 40% for drying (II) and 35% for curing. The evaluation has been performed by considering that fans will be switched on for the 80% of the duration of each drying stage. Table 3 shows below the variations that affect to speed, power a duration of the different drying stages after implementing the speed reduction of fans.

Table 3. Ratios of speed, power and time after applying the proposed actions.

Drying chamber / stage	**Reduced speed** *rpm*	**Speed ratio**	**Δ power** *%*	**Δ time** *%*
Post-salting stage	*938.0*	*1.6*	*-37.5*	*60.0*
Drying stage (I)	*750.0*	*2.0*	*-80.8*	*100.0*
Drying stage (II)	*656.0*	*2.3*	*-92.5*	*128.6*
Curing stage (I)	*563.0*	*2.7*	*-91.8*	*166.7*

The application of these actions would allow the customer to save 172458 kWh every year, which supposes the 1.65% in the total consumption of electricity. Such savings imply reductions of 13642 € in the annual electricity bill, as well as 67.2 tCO2 are avoided to be emitted into the atmosphere a year.

As shown in this section, significant energy savings can be obtained. However, it is important to take into account that too high reductions of speed, as obtained for the curing stage, could result in the stratification of the air in the chamber and the inappropriate development of the drying process. For that reason, additional ventilation or a lower reduction of power must be assessed in order to apply this type of actions.

3.2. Strategy 2: Use of flexibility in drying rooms

This strategy is based on the interruption of the electricity supply for the cooling production so that the thermal inertia of the system could be used to keep both temperature and humidity inside under limits. Temperature and consequently the humidity ratio for point 4 increases when the cool production is interrupted. Therefore, the duration of this action will depend on the ability of the product not to be affected by that action. Interruptions of about 1 hour do not have negative effects on this type of products. Similarly, the cooling activity will be more intensive during the subsequent minutes after the interruption (payback period), so point 4 will decrease until the set-point is achieved again.

3.2.1. Obtained results

After a period of pre-evaluation which proved the effectiveness of proposed actions [1], the implementation of an intensive campaign of interruptions was carried out in order to reduce the monthly electricity bill. During the whole month of February 2010, two interruptions a day of two ours each interruption were performed in working days. Fig. 4 shows different daily load profiles when interruptions were performed, as well as an average profile and the standard deviation, represented below.

Interruptions were carried out on peak periods, which are established in the contract from 10:00 AM to 1:00 PM and from 6:00 PM to 9:00 PM in January, February and December. As daily interruptions of 6 hours were considered unacceptable, only the last two hours of each peak period were used for flexibility purposes. Consequently, the reconnection of cooling devices took place on shoulder period where prices are lower. As can be checked in fig. 4 the energy saved during each interruption is much higher than the one consumed during the recovery period.

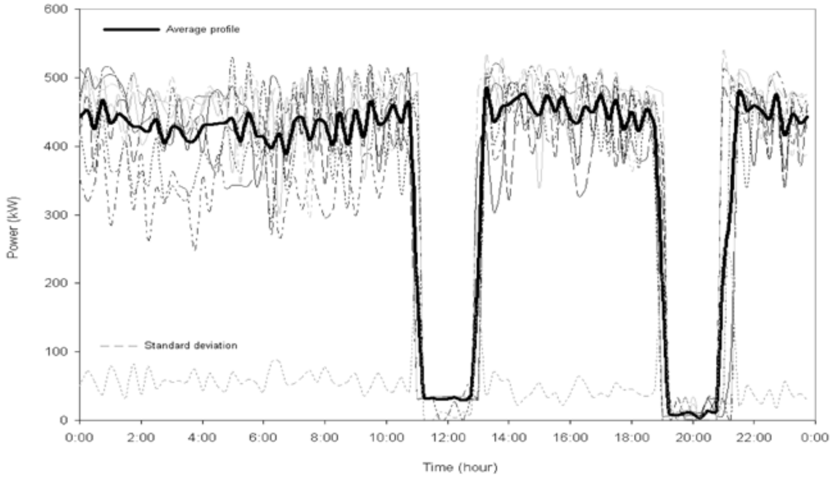

Fig.4. Daily electricity profiles during the campaign of interruptions in February 2010.

The application of such actions allowed the customer to save 1555 kWh every working day in February, equivalent to savings of 207.3 € and 1.52 tCO2 a day. The customer saved 4147 € during February, equivalent to a reduction of 6.21% in the monthly electricity bill. This percentage would be reduced to about 5% if these results are extrapolated for the whole year because the periods defined in the contract are different in other seasons and the difference between peak and shoulder prices is not as high in warmer months as in winter.

4. Conclusions

The use of electricity for intensive cooling processed in the meat industry has been analyzed in this paper, as well as different actions aimed to the improvement of energy efficiency in this sector have been proposed.
This paper provides empirical evidence about the importance that the use of flexibility in such a promising sector as the meat industry could represent in order to reduce the consumption of primary energy and emissions into the atmosphere, at the same time that attractive reductions in the electricity bill are achieved by customers.
Two strategies have been analyzed. Firstly, speed variation of fans in drying chambers, which implies modification of the on-off sequences in a way that the fans work for a longer time at a lower speed. Using this strategy, a reduction of 1.65% in the total consumption of electricity is achieved. Secondly, use of flexibility in drying rooms based on the interruption of the electricity supply for the cooling production obtaining saves of 5% in the total cost of electricity.

Such results are very promising and demonstrate the effectiveness of these techniques, highlighting that a different management of this type of infrastructures can be performed to get significant energetic, economic and environmental savings with reduced and acceptable impact in the production process.

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References

[1] Alcázar-Ortega, M., Escrivá-Escrivá, G., Álvarez-Bel, C., Domijan, A. "Evaulation and assessment of flexibility potential in the meat industry: application to intensive cooling processes", submitted to IEEE Trans. on Power Systems in April 2010.

[2] The birth of a EUropean Distributed EnErgy Energy Partnership that will help the large-scale implementation of distributed energy resources in Europe (EU-DEEP), the European Project supported by the Sixth Framework programme for Research and Technological Development. http://www.eu-deep.com

[3] Afonso, D., Pérez-Navarro, A., Encina, N., Álvarez, C., Rodríguez, J. and Alcázar, M. "Methodology for ranking of customer segments by their suitability for distributed energy resources applications", Elsevier Energy Conversion and Management, 48, pp. 1615-1623, January 2007

[4] The United States Meat Industry. American Meat Institute AMI. March 2009 Report. Available on http://www.meatami.com

[5] FAOSTAT. Food and Agriculture Organization of the United Nations. Annual Statistical Report, 2005. http://faostat.fao.org, accessed on February 2009.

[6] 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 for European countries". Elsevier Energy, 31, pp. 2047-2063, September 2006

[7] Álvarez, C., Alcázar, M., Escrivá., G, Gabaldón, A. "Technical and economical tools to assess customer demand response in the commercial sector". Elsevier Energy Conversion and Management, 50, pp. 2605-2612, July 2009

[8] Álvarez, C., Gabaldón, A., and Molina, A.: "Assessment and simulation of the responsive demand potential in end-user facilities: Application to a university customer", IEEE Trans. Power Syst., vol. 19, no. 2, pp. 1223-1231, May 2004

[9] Comaposada, J. "The Sorption Isotherms and Water Diffusitivity in Muscles of Pork Ham at Different NaCl Contents". Ph.D. Dissertation, Dept. of Thermal Engines and Machines. Univ. Polit. Cataluña. 1999

[10] 1Arnau J., Gou P., Comaposada J. "Effect of the relative humidity of drying air during the resting period on the composition and appearance of dry-cured ham surface". Elsevier Meat Science, 65 (4), pp. 1275-1280. January, 2003.

[11] Ventanas, J. "Tecnología del jamón ibérico". Ed. Mundi-Prensa, Madrid, 2001. ISBN 8471149443

[12] ASHRAE. "Psychrometrics - SI Units Edition" in Fundamentals Handbook Ed. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2005. Chapter 6, pp. 6.1-6.17.

[13] Naughton, P., Wang, R.D., Filipovic, A., Hundt, A. and Cooper, D.W. "High efficiency particulate air (HEPA) filter velocity reduction study". International SEMATECH manufacturing Initiative (ISMI). August, 2006. Available in www.ismi.sematech.org

[14] Alcázar-Ortega, M., Escrivá-Escrivá, G., Álvarez-Bel, C., Domijan, A. "A case of improvement of efficiency in the meat industry: Speed variation of fans in drying chambers", submitted to ELSEVIER, Energy Conversion and Management in May 2010