Energy use and management in dairy farms

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Abstract
This study aimed to investigate the energy demands in dairy cow farming to define the energy intensity of different categories of farms by efficiency indicators, identifying the critical operations and suggesting technologies that could be appropriate for energy savings. The electricity consumptions of a set of fourteen dairy farms, ranging from 40 to 300 milking cows, were analysed for one year with reference to the main operations (milking, milk cooling, lighting, ventilation, manure handling) and the equipments used. The overall electricity consumptions accounted for 466 kWh/cow·yr, ranging from 314 to 630 kWh/cow·yr. Milk productions, which ranged between 270,000 and 3,030,000 kg/yr per farm, required on average 5 kWh/100 kg·yr. The highest energy demands were associated to milk harvesting (refrigeration and milking procedures) which account for 41% of total, while lighting showed the lowest.

Keywords*:* efficiency, electricity, milk production.

Introduction

The analysis of the overall energy flows involved in agricultural processes is the basic tool to evaluate quantitatively the energy efficiency and the sustainability of a production process. Agriculture contributes for about 3% to the national primary energy consumption and about 11% of agricultural final energy uses is due to electricity (*Enea*, 2006). In recent times the role of agricultural sector in the world energy scenario has been emphasized because it can contribute to improve energy balance as producer of bio-energies. On the other side the energy management of agricultural activities plays a strategic role for the future of agriculture by reducing the production costs and supporting the sustainability of rural development.

Animal farming is evolving to more energy demanding forms of management which result in higher economic and environmental costs. Intensive mechanization has reduced the incidence of labour requirement for livestock activities and increased the utilization of electricity, natural gas and other fuels. The evolution of energy prices in this last years has affected the production costs, reducing process profitability and farmer's net income. A survey on bovine milk production costs in some Italian regions found that the rates of direct energy and water increased of 12-13% in the period 2004-06 (*Ismea, 2008*).

Proactive strategies for lowering the operating costs and reducing the consumptions require the assessment of the overall energy uses in a farm.

This study investigates the electrical energy demands in dairy farming with the aim of defining the energy intensity of different categories of cow farms by efficiency indicators, identifying the critical operations and suggesting technologies that could be appropriate for energy conservation.

Materials and methods

The investigation has been carried on in Sardinia region, where economical and productive performances of dairy farms were found to be similar to the northern Italy ones (*Ismea, 2008*). The electricity consumptions of a set of fourteen dairy farms, ranging from 40 to 300 milking cows, were analysed for one year with regard to the main procedures: milking, milk cooling, lighting, manure handling and ventilation. The energy audit was performed in each farm on the basis of a questionnaire where data about organization, structure characteristics, equipments and ways of management were analytically described. Some information were collected by interviewing the personnel directly involved in farming operations, while data about electrical power, consumption and expenditure were obtained by the monthly energy bills. Household uses have been excluded from the computation considering the number and the consistency of families. Detailed consumption of specific equipments (as vacuum pumps equipped by variable speed drivers) have been measured by an using electrical energy meter

The farm efficiency figures were expressed by mean of energy utilization index (EUI), namely the amount of electrical energy used per cow (kWh/cow yr) and per mass of milk produced (kWh/100 kg·yr), calculated either on annual or daily base (*Edens at al., 2003; Ludington, 2003*). The incidence of electricity cost on milk income was also estimated as well as the proportion of the most demanding activities on the total energy requested.

Results and discussion

Table 1 summarizes the technical characteristics and the energy performances of the audited farms grouped in two size categories, <100 cows and >100 cows, which correspond to a total milk production less and over 10^6 kg/yr. Livestock management techniques were similar in all farms. The producing animals were housed in free stall barns and milked twice a day in herringbone milking parlours, except in one case where a rotary platform milking machine was installed. Direct refrigeration milk tank coolers were used in all farms, most of them equipped by a heat recovery system for producing hot water for milking center utilizations. Animal feeding was based on total mixed ration distributed on through by mixer trailers.

Livestock manures, after mechanical removal from cowsheds and storage in unroofed structures, were utilized for land application as fertilizers; equipments for slurry collection and treatment, like pumps and centrifugal separators, were installed only in three farms. Climate control systems were present in 6 farms, based mainly on forced ventilation inside milking areas and in cowsheds and only in one case on nebulisation by water sprinklers.

Electricity was entirely provided by energy distributing companies; none of the investigated farms had installed facilities for self-producing energy as photovoltaic systems or anaerobic digesters. Most of the farmers had signed a supplying contract with the main national energy operator, while 5 of them had chosen two other distribution companies. Power supply per farm varied between 11 and 62 kW, corresponding to an average value of 0.27 kW/cow. As expected, due to economy of scale in larger farms, this value was lower in farms sized >100 cows (0.22 vs 0.30 kW/cow).

All energy contracts were based on a constant kWh tariff applied all day, with variable fare calculated for blocks of monthly consumptions. The charge of fixed quota differed in relation to the farm power supply, mainly when it was lower than 16.5 kW. In some cases a discount was offered when annual consumption were more than 20,000 kWh.

Table 1. Overall electricity consumption related to dairy farming

Herd Size	Total Heads (N°)	Cows (N°)	Milk Production (1000 kg/yr)	Electricity demand (kWh/yr)	Power supply (kW)	Energy Utilization Index		Energy cost
						(kWh/cow yr)	(kWh/100 kg milk)	(€/100 kg milk)
>100 lactating cows	770	300	3,030	167,917		559.72	5.55	0.95
	600	260	2,340	127,542	47	490.55	5.45	0.94
	450	210	2,352	75,699	30	360.47	3.22	0.55
	450	170	2,300	100,452	62	590.89	4.37	0.75
	256	128	1,300	56,712	25	443.06	4.36	0.75
	252	121	1,270	71,601	33	591.74	5.64	0.97
	235	115	1,016	53,878	27	468.50	5.30	0.91
<100 lactating cows	190	98	1,000	35,169	11	358.87	3.52	0.60
	180	90	900	37,320	16.5	414.67	4.15	0.71
	156	78	820	24,548	25	314.72	2.99	0.51
	160	70	570	43,970	38	628.14	7.71	1.33
	140	70	679	33,524	16.5	478.91	4.94	0.85
	70	40	330	25,270	16.5	631.75	7.66	1.32
	60	37	270	13,334	11	360.38	4.94	0.85

Considering the whole annual expenditure, the final price paid by farmers for the energy consumed varied between 0.162 and 0.176 €/kWh, corresponding to an average value of 0.172 €/kWh, including taxes and additional fees. The average price of electricity paid in Italy for non household uses results about 24% higher than the average European price and this can put Italian dairy farmers at a disadvantage when competing on international markets.

The comprehensibility of the monthly energy reports that retailers sent to the users was in some case rather inadequate, particularly when the consumptions were presumed and not registered for a long time.

Electrical consumptions and efficiency indicators

The total amount of energy consumed in the audited dairy farms was comprised by 13,334 and 194,917 kWh per year, the highest levels related to the largest livestock (Fig. 1).

Monthly electrical consumptions, calculated as average values for the two reference categories of farm size, are depicted in figure 2. Milk was produced through all year and the associated amount of electricity averaged between 2570 and 5430 kWh per month, respectively for herd sized <100 cows and > 100 cows. The slight increase during summer period (about 1.2 times compared to winter) was due to a larger usage of water pumps and climate control systems.

While the regression analysis showed a direct relation between herd size and kWh consumed per year, there was a wide variation in the annual energy demand per cow because of the numerous variables, like type of facilities and operative choices, influencing the energy intensity of the productive process.

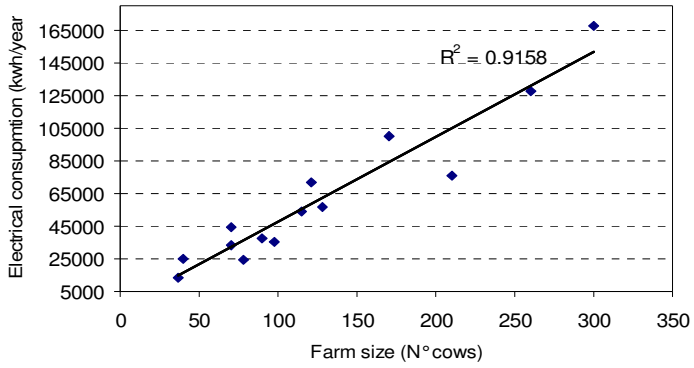

Figure 1. Total annual electricity demand per farm

These values, referred to overall consumptions, ranged from 314 to 631 kWh/cow · yr, lower than EUI reported in previous studies for US dairy farms (*Lundigton, 2003; Edens et al., 2003*) and similar to the data recorded in France (*Dolle and Duyck, 2007*). The average EUI was 10% higher for the category >100 cows (500 kWh/cow · yr) than for <100 cows (455 kWh/cow · yr). Based on these data, the daily cost of electricity can be estimated about 0.23 € per lactating cow, varying from 0.15 €/cow day in the most efficient farm and doubling to 0.35 €/cow in the less efficient one.

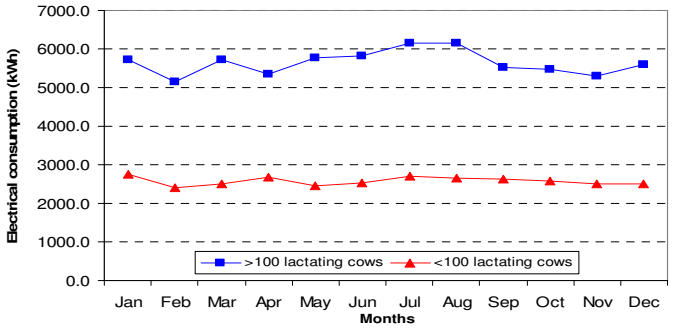

Figure 2. Average monthly electrical consumption

Referring the annual energy demand to the quantity of milk, which ranged between 270,000 and 3,030,000 kg/yr per farm, the EUI resulted on average 5 kWh/100 kg·yr (50 Wh/kg). Individual values started from a minimum of 3 kWh/100 kg rising to a max value of 7.7 kWh/100 kg in two farms sized 40-70 cows.

The related costs varied between 0.50 to 1.31 €/100 kg of milk and considering an average milk sale price of about 0.38 €/kg, the rate for the electricity weigh on average 2.2% upon milk gross income.

Energy demands by equipment categories

The main operations absorbing electrical energy in the audited farms have been grouped as follow: milking, milk cooling, manure handling and lighting. Equipments that were not

present in all farms or which consumptions could not be accounted because a lack of reliable information about the actual use, have been included in the category miscellaneous. Depending from the farm organization this category could comprise facilities for climate control, ventilation, slurry separation and water pumping. Differently from other surveys, water heating was excluded from the computation because in 80% of farms it was based on refrigeration heating recovery systems, with an average reservoir capacity of 500 dm^3, while only three farms used conventional gas heaters.

The four major categories of electrical usages accounted for 55% of the total demand in farms sized <100 cows and 48% in farms sized >100 cows, where the higher technological level has a bearing on explaining the largest miscellaneous quota (Fig.3).

The largest energy demand was associated to milk harvesting -refrigeration and milking procedures- which accounted for 36-46% of total consumptions, depending on herd dimension.

Except for the case of rotary milking machine, milk cooling was the prevalent energy consumer in all farms with conventional milking parlours. In this cases refrigerating milk to 4°C required on average 96.7 kWh/cow·yr and 1.1 kWh/100 kg, corresponding to a share of 23% of the total electric energy absorbed.

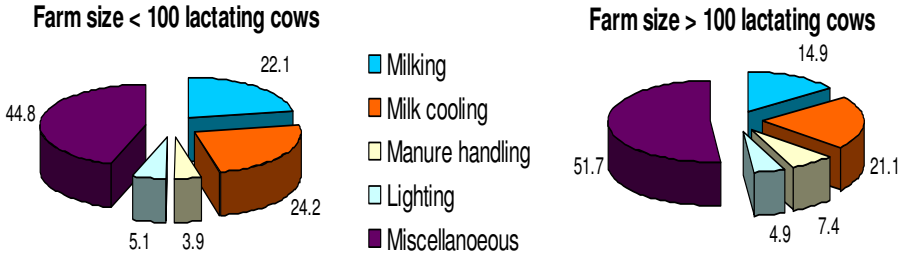

Figure 3. Annual electricity use by equipment category

About 65% of farms used two cooling tanks instead of one, which increases specific energy consumptions and costs. Analysing for each installation the ratio between daily milk production and tank nominal volume, the annual average filling coefficient varied between 0.58 and 0.98. In 5 farms it was lower than 0.75, this last value being considered as the limit for a rational utilization of tank capacity.

Only 20% of the dairies had installed a plate heat exchanger to pre-cool milk with well water before entering the tank, reducing in this way the energy required for milk refrigeration.

The energy demand for milking operation was dependent mainly from the vacuum pump size. The average EUI account for 84 kWh/cow·yr with a nominal vacuum pump capacity of 208 l/min per milking unit; the values recorded in all installations ranged from 124 kWh/cow·yr to 52 kWh/cow·yr.

The best efficiency results (52-58 kWh/cow year) were found when the vacuum pump was equipped by a variable frequency drive (VFD) that adjust the pump capacity with the actual need of air removal during milking. This technology allowed to reduce of about 60% the pump capacity per milking unit (85-94 l/min·unit) as well as the kW/milking unit (from 0.4 to 0.2 kW/unit), cutting off the half of the milking energy consumptions (Figure 4).

Manure removal from cowshed was generally performed by automatic scrapers driven by electricity while 35% of farmers used a tractor equipped by a frontal blade; slurry

treatment was made by using electrical agitators in five farms and only three of them used pumps and separator. Electricity demand for manure handling was about 23 kWh/cow yr, weighing on average 5.6% of total consumptions till a maximum value of 12% in those farms were pumps were used for slurry transport.

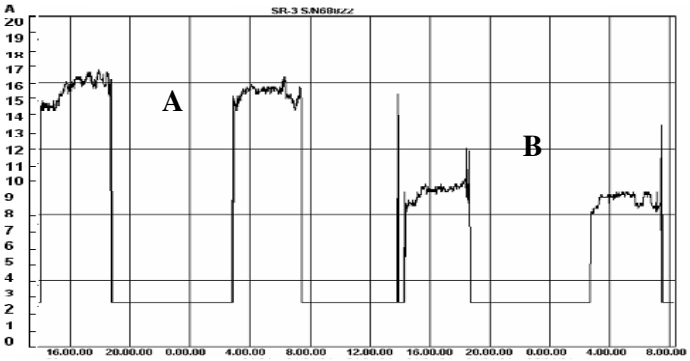

Figure 4. Milking electricity demand profile: (A) vacuum pump and conventional regulator; (B) vacuum pump equipped with variable frequence drive

In the audited farms 95% of light points inside the milking area and the cowsheds mounted 36-45 Watt tubular fluorescent lamps, while incandescent and halogen lamps were used in external areas. Fluorescent lighting systems require less power and have a longer life if compared to the other type of lamps, providing a better energy efficiency and lower operating costs. Lighting consumption accounted for 5% of total energy demand, with an average EUI= 21 kWh/cow year.

Conclusions

Dairy farmers should apply proactive measures for energy conservation, by integrating efficient technical solutions and effective management strategies.

According to the results of our investigation the quantity of electricity required in dairy farms vary widely with the herd size, the technological level and the type of management. Energy efficiency indicators were not related with herd size and large margins of improvement subsist.

Applying the best EUI found for each group of farms, a potential energy saving of about 180,000 and 61,000 kWh/year can be estimated respectively for the total of herds >100 cows and <100 cows. Based on these estimate energy saving, the annual cost reduction per farm would roughly result of 4,000-1,550 €/year.

Energy efficiency of milk production relies on numerous and different factors which have to be carefully assessed and combined to improve farm performances. For each facility the power demand, the hours of use, the electrical rate do influence the extent of energy savings that can be realized as well as the daily peak energy use.

Milking and milk cooling are the critical operations for reducing the farm energy intensity. Equipments like VFD both reduce energy demand and lower the farm power load, realizing an economical benefit as bigger as the vacuum pump capacity is over-dimensioned respect to the actual need. This technology can also be used for milk pump motor. Considering the increasing trend of electrical tariff and some state financial support for energy saving, the investment for VFD installation can be easily repaid.

The results indicates the convenience of heat recovery from refrigeration for water heating using systems that, at the same time, improve the performance of the refrigeration unit by removing heat from the refrigerant. Lowering milk temperature to 18 °C by pre-coolers had reduced the energy requirement for milk cooling and, as a consequence, could allow the installation of smaller compressors. Another active measure for reducing the power of the refrigeration units is the use of more energy efficient compressors like the scroll type, that was installed only in one of the investigated farms.

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