RANKING ENERGY PERFORMANCE OPPORTUNITIES OBTAINED WITH ENERGY AUDIT IN DAIRIES

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The food industry uses a considerable amount of energy and that amount has been constantly growing with further developments in the sector. The growth of the milk processing industries with the production of dairy products has followed the trends in the food industry in general. The authors made a systematization of the literature data on the most common energy efficiency opportunities (measures) in diaries. Authors also present a methodology for conducting an energy audit in dairies based on ISO 50002 which includes a multi-criteria analysis for ranking energy efficiency opportunities. The proposed methodology was applied to a case study dairy in central Serbia. Taking into account interactions between opportunities, implementation of the proposed energy saving opportunities can ensure 11-15% energy savings for electricity and 20-23% of heat energy annually.

Key words: *energy audit, energy efficiency in industry, food industry, multi-criteria analysis*

1. Introduction

The energy consumption in the food industry has been constantly growing due to population growth and improved living standards, but also due to changing eating habits of modern people who nowadays choose ready-made and outdoor meals more frequently instead of homemade food. Food industry and agriculture are responsible for 30% of the global final energy consumption of all industries. About 40% of this energy is consumed for food processing and production [1].

In the U.S., for instance, the food industry uses 19% of the total final energy consumed by the industrial sector [1] and is thus the fourth largest industrial energy consumer [2]. Its share in the total GDP is about 10% [3]. More than 17 million people work in the U.S. agriculture and food industry with more than 90% of them works in food processing and production [4]. The energy consumption has been constantly rising by about 23% per year. In Europe, the energy used for breeding, food processing and preparation has been estimated at 17% of the total energy consumed by industry [5]. The food and beverage factories participate in total energy use by industry sector with around 10%. In Europe, this sector employs about 8% of the population and participates in the total GDP with 6% annually (equivalent to €715 billion)[6]. The share of the food industry in the total industrial energy consumption is to 14% in France [1], 13% in Sweden [7] and 18% in England [8].

In Serbia, the food industry participates with 30% in the total energy consumed by processing industries [9]. It places its products, with an annual worth of about €1 billion, at the international market which makes it one of the greatest industries in the Serbian economy [9]. The sector employs more than 65,000 workers in 4,500 companies, with 20% of workers being engaged in food processing [9].

The growth of the milk processing industries with the production of dairy products has followed the trends in the food industry in general. According to the available data [10], global milk production goes above 800 million tons per year and the annual rate of production growth is supposed to reach 1.8% in the next ten years. It is expected that, during the following decade, the growth in dairy production per capita will reach 1% and 1.7% in the developed and developing countries, respectively. 24% of the globally processed milk is produced in Europe [11], with France, Germany, Italy, Great Britain and Spain responsible for 70% of this amount [12].

Serbia produces about 1.6 million tons of milk every year and 52% of that milk is delivered to diaries for further processing [13]. This sector includes 140 companies that employ about 6.000 people [14]. Tab. 1 presents the relevant data for 30 largest companies that produce over 10 tons of milk per day and process about 90% of milk in Serbia. The remaining 110 dairies are significantly less productive and are all micro-companies (the number of permanent employees ≤10 and income ≤700000 €/year). The table presents the indicators of business performance (i.e. income and costs) and the annual energy consumption. All the data were obtained from the official web sites and through interviews with the managerial staff. The table also shows the calculated ratio of energy costs in total production costs.

Table 1 – The indicators of business operations and energy costs for 30 largest diaries in Serbia [15]

Diaries	**Company category**	**Capacity [tons/day]**	**Total income [€]**	**Total costs [€]**	**Energy costs [€]**	**Energy consumption per total costs [%]**
AD IMLEK Beograd, Padinska Skela	Large	750	218,478,500	187,304,450	6,992,375	3.7
SOMBOLED, Sombor	Large	150	54,314,242	48,154,583	1,943,992	4.0
COMPANY BB DOO, Žitište	Medium	30	11,543,842	11,176,367	247,608	2.2
MLEKARA DOO, Leskovac	Medium	70	6,912,817	7,324,475	404,492	5.5
MLEKOPRODUKT DOO, Zrenjanin	Medium	100	17,971,492	17,869,683	810,000	4.5
AD MLEKARA, Šabac	Medium	136	26,820,300	25,992,225	1,209,017	4.7
MEGGLE SRBIJA DOO, Kragujevac	Medium	110	22,969,367	22,883,617	448,192	2.0
MILKOP DOO, Raška	Medium	80	9,087,158	8,894,675	142,150	1.6
EKO-MLEK DOO, Kaonik	Medium	50	10,732,392	10,199,733	404,150	4.0
MLEKARA-UB DOO, Ub	Medium	50	5,146,808	4,639,992	304,017	6.6
LAZAR DOO, Blace	Medium	50	10,971,350	10,571,292	679,075	6.4
KUČ COMPANY DOO, Kragujevac	Medium	100	15,303,508	14,959,133	755,775	5.1
GRANICE DOO, Granice	Medium	115	13,061,183	11,344,433	622,467	5.5
BIOIMLEK DOO, Priboj	Small	10	908,842	904,117	38,300	4.2
JTL ZLATIBORAC DOO, Smederevo	Small	10	1,247,775	1,211,108	45,425	3.8

MASTER MILK DOO, Blace	Small	30	3,402,842	4,178,508	102,158	2.4
EKOFIL DOO, Beograd	Small	50	7,011,050	6,699,700	60,483	0.9
MLEKARA AD LOZNICA, Loznica	Small	25	4,305,283	4,145,067	303,925	7.3
MLEKARA DOO PANČEVO, Pančevo	Small	40	6,882,225	6,843,950	565,167	8.3
MIHAJLOVIĆ DOO, Paraćin	Small	30	2,713,267	2,667,050	181,400	6.8
MILKI DOO, Kraljevo	Small	16	2,296,858	2,293,575	73,133	3.2
STARA PLANINA, StaraPlanina	Small	7	1,181,850	1,164,617	84,650	7.3
EKOMIL, BačkaPalanka	Small	15	983,500	968,217	60,608	6.3
MLEKARA GLOŽANE, Gložane	Small	30	3,380,942	2,930,592	179,950	6.1
MLEKARA MAESTRO, Sakule	Small	25	3,770,633	3,678,917	163,067	4.4
BENI-KOMERC, Sjenica	Small	10	922,508	714,908	35,633	5.0
MLEKARA MORAVICA, Arilje	Small	16	2,310,717	2,298,858	175,167	7.6
JASTREBAČKI EKO BISERI, Kruševac	Small	30	2,967,542	2,925,250	152,417	5.2
MAKSI MLEK DOO, Kruševac	Small	10	945,508	987,583	38,775	3.9
SPASOJEVIĆ DOO, Bajina Bašta	Small	15	4,216,625	4,099,725	124,983	3.0

On average, the energy costs amount to 5% of the production costs. The obtained value is two times lower than the average value for the Serbian food industry in general [15]. Despite the fact that energy costs have a relatively low share in total production costs, due to a huge number of companies and facilities, diaries in Serbia have a significant share in the total energy consumption among food industry branches. Their energy costs are about €20 million each year.

Many governments all over the world have recognized that the reduction of energy consumption in the food industry could be the most lucrative and easy mean for solving numerous energy issues, including energy security, social and economic consequences of high prices of energy and climate changes [1]. Energy efficiency increase is expected to enhance the competitiveness of a business and promote customer benefits [16].

Energy audit of industrial facilities can provide clearer insights about the conditions of energy efficiency. These observations are crucial for decision-makers since they may have an essential impact on the selection of measures that would be implemented to reduce energy consumption [17, 18]. Energy auditing was performed in different types of industrial companies, and the results show that energy efficiency potentials are about 20 –25% [19, 20]. Payback time was taken as a criterion for ranking the proposed energy efficiency opportunities since this is what managements generally request. Nevertheless, for companies with limited financial resources and opportunities to take loans, a level of investment is also an important criterion. Sometimes decision-makers also have to think about other social and environmental factors, such as CO_2 emission and primary energy consumption reductions, etc. This is what governments, community and customers may request. Therefore, it is necessary to introduce more realistic ranking methods. Multi-criteria decision making (MCDM) has been used in different energy planning processes that involve multiple objectives. Different MCDM methods could be used, including Weighted Sum Method, AHP, ELECTRE, TOPSIS, FAHP, VIKOR, etc. [21]. Weighted Sum Met (WSM) is the well-established, simple MCDM method that does not require specialized decision-making software for implementation.

Considering all the above-mentioned, authors of the paper propose a methodology of energy auditing in dairy based on ISO 50002 (international standard on energy audit) which includes the usage of WSM multi-criteria decision making in the process of prioritizing defined energy efficiency opportunities.

2. Methodology

Based on the ISO 50002:2014 [22], energy auditing methodology should include the following stages (*Fig. 1*):

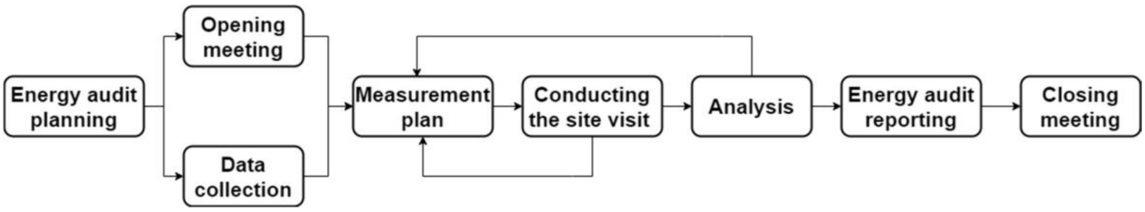

Figure 1 – Energy audit process [22]

The analysis stage includes the analysis of current energy performance, identification of improvement opportunities and evaluation of improvement opportunities. The analysis of current energy performance requires a breakdown of the energy consumption by use and source as well as energy uses accounting for substantial energy consumption. Since the dairies most commonly produce a wide array of different products, it is crucial to determine the energy consumption of all the operations at each production stage for all the products. The processing operations, which require heat energy are pasteurization and cooking. The most dominant electricity driven operations in diaries are cooling processes and product cooling, homogenization, separation, mixing, transport (via pumping) and packaging. The use of electricity by each device, due to the changeable nature of their load, should be measured in real conditions and with proper measuring equipment (e.g. three-phase power analyser, etc.). It can also be calculated based on nominal power and annual operating hours.

For electric devices, in which energy use depends on several factors (e.g. with cooling systems where energy consumption depends on the quantity and temperature of raw substance, outside temperature, etc.), the measuring process should be performed over longer time intervals (at least one month), or be calculated (Eq. 1):

$$E = Q \cdot COP^{-1} = M_c \cdot c_p \cdot \Delta t \cdot COP^{-1} \tag{1}$$

Similarly, the heat energy consumption equals the energy needed to heat the product from the starting temperature to the temperature proscribed for the given processing technology (Eq. 2):

$$Q = M_h \cdot c_p \cdot \Delta t \cdot \eta^{-1} \tag{2}$$

It is necessary to be precise with the values of specific heat capacities that will be used since they vary significantly in different stages of each production process. For the temperature range in milk processing, the values of specific heat capacities for different dairy products are given in Tab. 2.

Table 2 – Mean specific heat capacities for dairy products [23, 24]

	Specific heat capacity [kJ/kgK]
Whole Milk	3.914
Skimmed milk	3.970
Yoghurt	3.5
Cheese	3.27
Cream	3.51–3.56
Sour milk	3.5
Quark cheese	3.5

Once the amounts of electricity and heat energy used by all individual devices are determined, the indicators of specific consumption should be calculated (kWh/ton of processed milk, kWh/ton of final product, etc.) [25, 26]. After the share of individual devices in total energy consumption is obtained, one should map the locations (critical points) that provide opportunities for increasing energy efficiency. Tab. 3 presents the systematized data available at USDOE IAC web site [27] (i.e. the results obtained from energy audit in 116 dairies in the United States) and additional sources. These results provide a valuable insight into the most common opportunities (measures) (ECMs) found to be relevant for this branch of the food industry.

Table 3 – Most common energy efficiency opportunities (measures) in dairies [27]

Measure	Potential reduction of energy consumption [%]	Mean payback time [y]	Number of companies	Additional sources
Energy efficiency measures – steam systems				
Repairing or replacing steam traps	1%	0.52	11	[28]
Repairing and eliminating steam leaks		0.3	24	
Installing/repairing insulation on steam lines	5%	2	2	
Using minimum steam operating pressure	2.58	0.6	2	[28]
Using heat from boiler blowdown to preheat boiler feedwater	1–4%	0.8–2.7	4	[29]
Using waste heat from hot flue gases for preheating	1–5%	2-3	25	[30, 31]
Improving process control	1.5–3%	<1		[30]
Improving boiler maintenance	5–10%	<1		[30]
Improving boiler insulation	6–26%	<1		
Installing condensate return systems	4–10%	1–3		[28]
Energy efficiency measures – compressed air systems				
Eliminating or reducing compressed air usage		0.73	56	
Installing compressor air intakes in coolest locations		0.6	33	[32, 33]
Eliminating leaks in inert gas and compressed air lines/valves		0.3	49	[33]
Upgrading controls on compressors	5–15%	<1	9	[30]
Using/purchasing optimum sized compressors		1.36	7	[33]
Not pressurizing the system during a non-productive period	2–10%			[30]
Energy efficiency measures – pump systems				
Using most efficient type of electric motors	2–10%	1–2	24	[30][33]
Using adjustable frequency drive or multiple speed motors on	15–45%	2–3	29	[30][33]
Using properly sized pumps/motors	5–25%			[30]
Improving maintenance and monitoring	2–10%	<1		[30]
Energy efficiency measures – cooling systems				
Modifying a refrigeration system to operate at a lower pressure		0.8	18	
Isolating hot or cold equipment		<1	3	
Using cooling tower or economizer to replace chiller cooling		0.3	1	
Shutting off cooling if cold outside		<1	3	
Improving maintenance and monitoring	3%	<1		[31]
Energy efficiency measures – lighting				
Utilizing higher efficiency lamps and/or ballasts	50–80%	3.5	70	

Installing occupancy sensors	10–20%	1.5	36	
Installing timers on light switches in less used areas	5–15%	2	5	

Based on these data, at least one measure of energy efficiency was implemented in the systems of compressed air in each dairy under investigation. Actually, these measures are the most common in general. They most frequently involve the detection and elimination of leaks. This measure was implemented in 83% of the analysed facilities and the mean payback period was less than 5 months. Eliminating or reducing the use of compressed air was also a frequent measure. The payback period of the measure varied from several months to a maximum of one year.

ECMs in lightning systems were also commonly implemented in all analysed facilities despite the fact that the energy consumption of these systems was evaluated at 1 – 2% of the total electricity consumption. The most frequent measures were the replacement of the existing system with LED lightning (payback period of 2 – 3 years [34]) and the instalment of the occupancy sensors (payback period of about 18 months).

The energy auditors also recommend the measures which would provide energy savings in the systems of hot water or steam distribution and cooling. Most commonly these measures refer to the insulation of hot water and steam lines and the elimination of leaks (payback period of less than a year). Besides, the waste heat recovery measures are proposed (from flue gas, process, condensers of cooling devices and waste water).

In 30% of the analysed dairies, the measures included raising the user awareness about the importance of saving energy and using the equipment and energy efficiently.

According to ISO 50002, the evaluation of improvement opportunities includes their ranking. This paper proposes a multi-criteria decision making (MCDM) using Weighted Sum Method (WSM) that takes into account decision-maker preferences in determination of the weights of the criteria. The WSM has been a very frequently used MCDM method in energy systems [21] since it is relatively simple and provides relevant and reliable results. For each proposed ECM, a WSM score S_i [-] is calculated as:

$$S_i = \sum_{j=1}^{n} \mathrm{w_j x_{ij}}, \qquad \mathrm{i=1,2,\ldots,m} \tag{3}$$

where n [-] is the number of criteria, m [-] is the number of proposed ECMs, w_j [%] is the weight of performance of j-th criterion and x_{ij} [-] is the normalized value of i-th ECM in terms of j-th criterion. The higher a score of an ECM, the higher the priority of its implementation would be (Eq. 3).

It is crucial to select the criteria based on which the ECMs will be evaluated. Four criteria were selected: payback period, implementation costs, primary energy savings, and annual CO2 emission reduction, since their values are usually determined during the techno-economic evaluation of each proposed ECM in industrial auditing. The values of weight factors w_j are determined by expert opinion according to their importance (their sum should be 100%). In industrial energy auditing, the values of weight factors should be determined in an interview with the management. Nevertheless, the other more advanced techniques could be used to analyse weight factors (such as Analytic Hierarchy Process (AHP), Decision Making Trial and Evaluation Laboratory (DEMATEL), Step-wise Weight Assessment Ratio Analysis (SWARA), Best Worst Method (BWM), Full Consistency Method (FUCOM), etc.)[35]. In addition to being more complex and more time consuming, they all are also subjective methods.

To ensure the comparability of criteria, it is necessary to adjust the obtained values to the same scale. The linear normalization is used for these purposes. For the criteria like payback period or CO_2 emission, where the lowest value is the most desirable one, a normalized value x_{ij} is the ratio of minimal value of all proposed ECMs and the value obtained for the given ECM. With criteria where the highest value is the most desirable one, a normalized value x_{ij} is the ratio of real value and a maximum value for all ECMs.

3. A case study: a dairy in Central Serbia

The methodology proposed here was used in a case study of a diary from Central Serbia, a medium company that employs 230 workers (70% in production) and produces about 100 tons of processed milk daily. Raw milk is treated by numerous energy-consuming processes (e.g. pasteurization, cooking, cooling, separation, homogenization, etc.) to obtain diverse products (e.g. cheese, cream, yoghurt, sour milk, etc.) (Fig. 2).

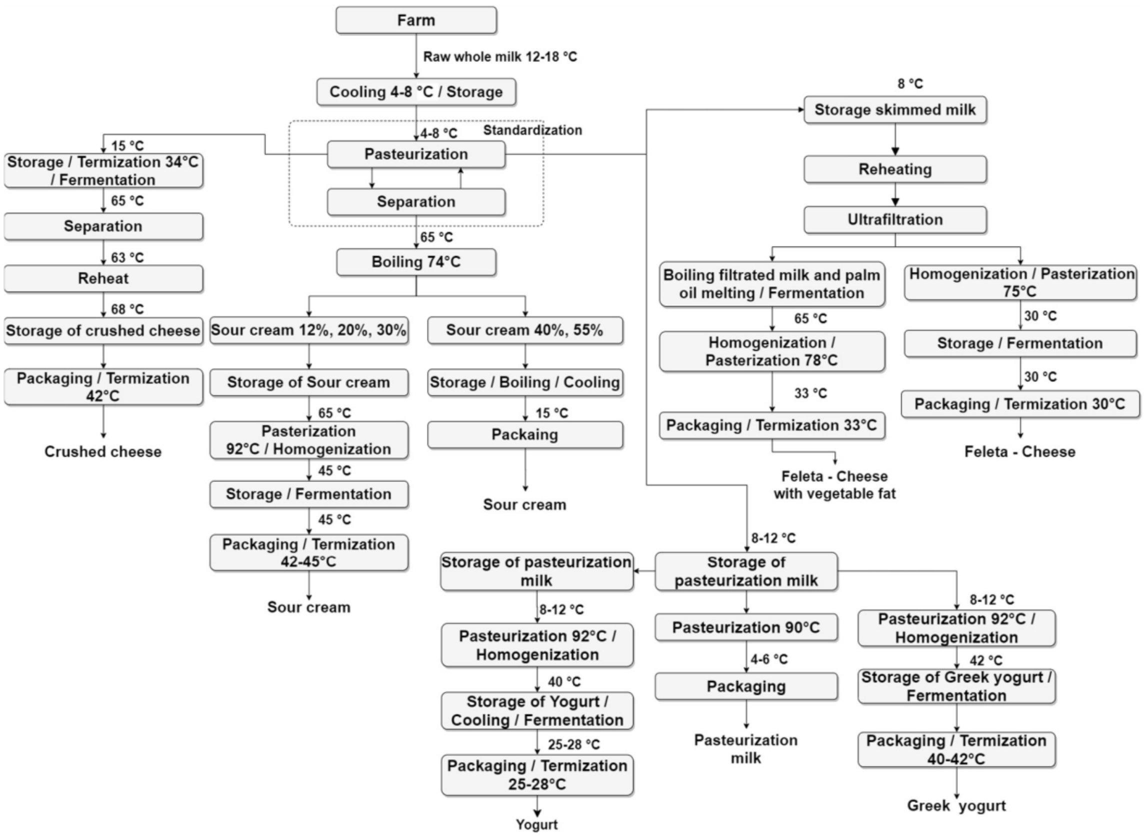

Figure 2 – Production lines and processes in the analysed dairy

At the pre-stocking reception, the whole quantity of milk is subjected to cooling until it reaches the temperatures from 4 – 8 °C. Then, depending on the production plan, the whole quantity of milk is pasteurized and standardized to the desired percentage of fat. Due to the diversity of technologies involved in the production of each dairy product, all products are manufactured in a different production line. After the production process is finished, all final products are deposited in a cold store where they are once again cooled to 4 °C. The diary production processes require the series of operations involving intermittent cooling and warming. Actually, these processes require the highest amount of energy used in dairies. In addition, a considerable amount of energy is used to perform homogenization, separation, packaging, as well as for operating pumps and compressors.

Wood briquettes, electricity and water are the most used sources of energy in the dairy. Two boilers whose rated power is 500 kW each are used to burn briquettes. This satisfies all the requirements for thermal energy (both for production processes and for heating the facility). About 3 tons of briquettes are used daily. The production volume is constant throughout the year, but the volume of briquettes increases during the winter months when the facility needs heating.

Further analysis of the bills has shown that the dairy uses 38 tons of briquettes annually for heating the facility. Taking into consideration that the estimated average boiler efficiency is 75% and that the lower thermal power of the briquettes is 18 MJ/kg (as declared by their manufacturer), it may be concluded that the company uses 140 MWh for building heating annually which is 3% of its total heat consumption. The remaining 97% is used for warming raw substances which is a vital component of the processing technology. For every process which requires heat energy, the amounts of heat were calculated using Equation 2 and the values of specific heat presented in Table 2. After measuring the temperatures and the flow in pasteurization unit subsections, it was calculated that 80% of heat is recovered by the unit. Theoretically, a well-designed milk pasteurization unit can recover up to 95% of energy [36].

The heat energy for thermization is supplied by electric convective heaters. The amount of energy used to renew this process was evaluated based on the nominal power of the heater and its daily operating hours.

Electricity consumption is on average about 200,000 kWh per month. Most of it is used for the cooling processes and for cooling final products. It was necessary to make a series of measurements and calculations to determine the share of individual users in total electricity consumption. Three-phase power analyser (Extech 38091) was used in real exploitation conditions to measure the electricity use of each electricity-driven device involved in the production line. The distributions of both electricity and heat energy use are presented in Fig. 3.

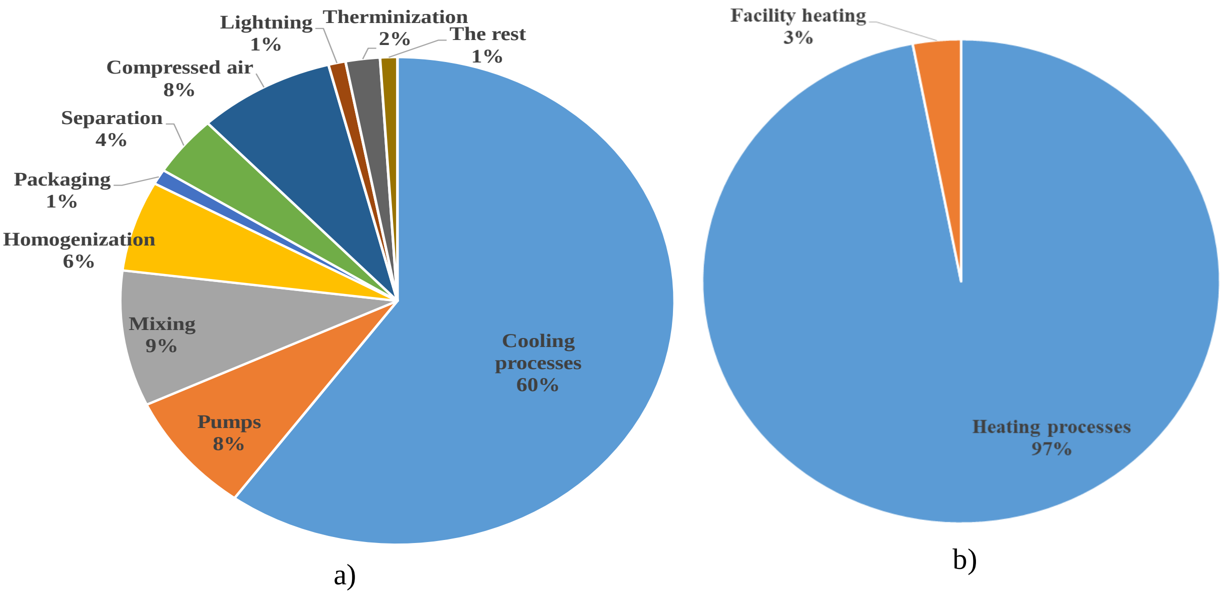

Figure 3 – The distribution of a) electricity and b) heat energy users

The value of specific energy consumption with respect to product mass and raw milk mass was calculated for every product. The results are presented in Tab. 4.

Table 4 – Data on energy consumption for all the products

Product	Pasteur. milk		Yogurt		Sour cream 40 – 55%		Sour cream 12 – 30%		Crushed cheese		Feta Cheese		Fetela Cheese		Greek Yogurt	
Daily energy consumption	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%
Pumps	15	2	34	1	2.8	3	4	1	38	2	167	9	183	8	9	1
Mixing	18	3	90	3	6.8	7	26	8	35	1	109	6	142	7	34	5
Separation	20	3	26.7	1	26.7	26	27	9	81	3	26.7	1	26.7	1	26.7	4
Homogenization	/	/	140	5	/	/	30	10	/	/	75	4	72.3	3	56	8
Packaging	4.5	1	10.5	/	5.4	5	8	3	11	/	17.6	1	19.8	1	4.2	1
Process cooling	288	43	1391	45	35	35	128	42	340	20	545	28	731	33	297	43
Process heating	324	48	1404	45	24.3	24	83	27	1927	74	988	51	1016	47	265	38
TOTAL		100		100												
SEP kWh/kg of product	0.0877		0.1896		0.0808		0.0971		0.612		0.6882		0.3759		0.1199	
SEP kWh/kg of raw milk	0.0877		0.1824		0.0060		0.0184		0.1307		0.1835		0.1504		0.117	

The mean specific consumption of final energy is 0.12 kWh/kg of processed milk. Different authors have compared the indicators of energy consumption in different dairies around the globe [25, 37, 38]. They have determined that there are huge variations in specific energy consumption which indicates that there are significant potentials for saving energy in this industrial sector. The data from several sources are systematized in Tab. 5.

Table 5 – The indicators of specific energy use for different dairy products

Dairy product	Specific energy consumption values [kWh/kg product]
Fluid milk	0.06 – 2
Yogurt and other fermentation dairies	0.3 – 0.5
Cheese	0.5 – 1.2
Butter	0.27 – 0.36
Concentrated milk	0.5
Milk powder	1.4 – 2

In the analysed dairy, the annual use of water is about 108.000 m^3. This quantity is equivalent to 3 litres per one litre of processed milk. In the dairies analysed in the available literature, specific water consumption (l water/1 processed milk) ranges from 0.5 to 6 (Tab. 6) [39].

Table 6 – Benchmarking of average specific water consumption in dairy plants

Country	Water consumption (l water/l processed milk)		
	Milk and dairy drinks	Cheese and whey products	Milk powder, cheese and/or liquid dairy
Sweden	0.98 – 2.8	2.0 – 2.5	1.7 – 4.0
Denmark	0.6 – 0.97	1.2 – 1.7	0.69 – 1.9
Finland	1.2 – 2.9	2.0 – 3.1	1.4 – 4.6
Norway	4.1	2.5 – 3.8	4.6 – 6.3
Poland	0.5 – 0.75	2.22	1.8 – 5.3
Australia	1.05 – 2.21	0.64 – 2.9	0.7 – 2.7
Canada (total)		1.0 – 5.0	

As a part of energy auditing, ECMs were identified and evaluated (Tab. 7). For the calculation of primary energy savings in electricity, the value of 2.5 for the ratio between final and primary energy is used.

Besides these ECMs, regular maintenance and monitoring of cooling systems and electric motors were also proposed. Since these measures do not require additional costs they were considered for immediate application and they will not be further analysed.

Table 7 – Summary of measures

	ECM		Primary energy savings [MWh/year]	Costs [€]	Payback period [year]	CO_2 reduction [tCO_2/year]
1	Compressed air	Turning down the compressors when not in use	147	300	0.06	47
2		Eliminating air leaks	96	220	0.06	31
3		Reducing the use of compressed air	346.8	7000	0.56	111
4	Pumps and electric motors	The use of variable frequency drive	77.5	7990	2.86	24.8
5	Boiler and hot water supply	Insulating the boiler and pipes	284.7	2000	0.52	56.9
6		Introducing a biomass boiler	379.6	17600	2.3	113.9
7	Cooling system	Pipeline insulation	180	1200	0.22	57.6
8	Lightning	Led pipes	36	2400	1.8	11.5
9		Occupancy sensors	7	300	1.67	1.6
10	Waste water	Waste water recuperation	545	2000	0.2	174.4

In the analyzed dairy, the use of compressed air has 8% share in electricity consumption. The compressed air is primarily used for the operation of pneumatic valves and the packers. The daily hourly engagement of the compressor is greater than designed and it operates for 6 hours a day even when there is no need for compressed air. The automatic shutdown of compressors when there is no need for compressed air could provide energy savings of about 30%. Compressed air leaks were also detected and their reparation could provide 20% savings. The possibility of reducing the use of compressed air by replacing pneumatic valves with solenoid ones was also taken into consideration. This measure could save about 70% of electricity. The payback time was calculated based on the average electricity price of €0.09/kWh calculated for the company.

The electric motors use about 27% of electricity (9% is used for mixing, 8% for pump systems, 6% for homogenization and 4% for separation). 12% of motors (out of 80) have variable frequency drive control (VFD); mostly motors of a higher power over 10 kW. The opportunities for saving energy by introducing the VFD to all pumps over 1kW rated power that are engaged for over 5 hours a day were also taken into consideration here. Based on the nominal power and daily hourly load profile, the estimated savings of electricity would be 20% or 31000 kWh. Regular monitoring and maintenance may provide a 5% reduction in electricity consumption.

65% of the total final energy is consumed for heating. The estimated energy efficiency of the heating system is about 60%. Thus, numerous measures for increasing energy efficiency were taken into consideration. The insulation of heat lines, tank and boiler can save 5 – 7% of the thermal energy. The replacement of boilers with more efficient ones was also proposed. Introducing two new more efficient biomass boilers (84% average efficiency) requires an investment of €17,600 so the payback period would be 2.3 years.

The systems for process cooling and final product cooling as well as pipeline insulation were taken into consideration. These measures could reduce electricity consumption by 3% and 5 %, respectively. In both cases, the calculated payback period is less than one year.

When it comes to lightning systems, the proposed ECMs are replacing the existing fluo tubes with LED tubes [34] and to install occupancy sensors. The replacement of 130 fluo tubes could provide the reduction of electricity consumption by about 10,300 kWh per year. The expected payback period is evaluated at 1.8 years.

In addition to the aforementioned measures for saving heat energy and electricity, this case study also included the opportunities for utilizing waste heat. During the separation process involved in the production of crushed cheese, 6 t/h of whey is being separated for 3 hours. Its temperature is 65°C and it is not used at all. In addition, we have evaluated the opportunities from rescheduling the process of dairy-free cheese production in order to integrate the processes between two production lines. The potential for thermal energy savings is 272 MWh/year and the payback period for the investment is 2 months.

In an interview with the management, the criteria and weight factors (Tab. 8) were evaluated in order to rank the ECMs. Payback time and implementation costs are equally important for dairy management. Those criteria are more important to them then CO_2 emission and primary energy consumption reductions.

Table 8 – The weight of importance of each criterion

Criterion	Payback period	Costs	Primary energy savings	Annual CO_2 emission reduction
Type	non-beneficial	non-beneficial	beneficial	beneficial
w_j	45%	45%	5%	5%

The values for each criterion were normalized. The calculated normalized values coefficients (Tab. 9) were used to rank the ECMs. The results show that the introduction of more criteria into a ranking procedure changes the order of the proposed measures in terms of their implementing priority. ECMs concerning compressed air, installation of occupancy sensors and insulation of hot and cooling water lines are a priority in this case study. Our findings eventually emphasize the need for conducting multi-criteria analyses in energy auditing.

Table 9 – Ranking of ECMs

ECMs	Payback period	**RANK** by payback period only	Implementation cost	Primary energy savings	Annual CO_2 emission reduction	S_i	**RANK** by all criteria
1	0.056	2	0.330	0.013	0.013	0.807	2
2	0.064	1	0.450	0.009	0.009	0.861	1
3	0.56	6	0.014	0.032	0.032	0.123	7
4	2.86	10	0.012	0.007	0.007	0.035	10
5	0.52	5	0.050	0.026	0.016	0.140	6
6	2.3	9	0.006	0.035	0.033	0.084	8
7	0.22	4	0.083	0.017	0.017	0.242	5
8	1.8	8	0.041	0.003	0.003	0.062	9
9	1.67	7	0.330	0.001	0.00	0.346	3
10	0.2	3	0.050	0.05	0.050	0.276	4

4. Concluding remarks

The energy costs of dairies in Serbia participate with only 5 – 8% in the total costs. However, due to the large number of dairies, the energy use of this sector cannot be neglected. Huge opportunities for saving energy have been noted in the available literature on the topic. In addition, for the majority of the analyzed measures, payback time is less than two years.

A detailed energy audit can determine the possibilities for implementing energy efficiency measures precisely. Multi-criteria decision making and ranking opportunities based on the criteria whose weight is selected by the management can thus be extremely helpful.

The case study for this investigation was a medium dairy production company from Central Serbia. Ten measures were ranked based on the given criteria. Taking into account interactions between opportunities, the proposed ECMs can ensure 11-15% energy savings for electricity and 20-23% of heat energy annually. In terms of primary energy consumption, the savings can be in the range of 1697 to 2099 MWh/year representing 15-19% of total annual primary energy consumption.

The method presented here is universal. As such, it can also be used in other industrial facilities.

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Nomenclature

E	- Electricity consumption [kWh]
Q	- Energy consumption, [kWh]
COP	- average coefficient of performance, [-]
M	- mass of the substance, [kg]
c_p	- specific heat, [J/kgK]
Δt	- temperature change, [K]
$\mathrm{S_i}$	- weighted sum method score, [-]
n	- the number of criteria, [-]
m	- the number of proposed ECMs, [-]
$\mathrm{w_j}$	- the weight of j-th criterion performance, [%]
$\mathrm{x_{ij}}$	- the normalized value of i-th ECM in terms of j-th criterion, [-]

Greek symbols

η	- average heating system efficiency, [-]

Subscript

c	- cooling
h	- heating

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