The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2026

Volume 40, Pages 81-91

ICBAST 2026: International Conference on Basic Sciences and Technology

Improving the Energy Efficiency of a Distillery for the Production of Essential Oil

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Abstract: In this study, an energy audit of a distillery for production of essential oils from plant raw materials - rose and lavender was carried out. The equipment of the enterprise envisaged by the project will operate with two types of energy - electricity and thermal energy. Energy consumption analysis is based on electricity and heat consumption of lighting fixtures and technological equipment. The problem areas during the technological process for obtaining essential oils in the enterprise have been examined. The specific energy costs per unit of production and the total energy costs in the enterprise have been determined. Energy saving measures were proposed to reduce the energy costs of electricity and consumed heat energy (natural gas consumption) in distillery. A technical and economic analysis of the energy saving measures was carried out, calculating the total energy savings, economic profitability, payback period, energy savings ratio, energy savings potential and saved carbon emissions into the environment.

Keywords: Energy efficiency, Essential oil, Energy audit

Introduction

The main issues related to optimizing the workflow in essential oil distilleries are related to reducing energy costs in the enterprise and using technologies for processing the resulting waste. For the distillation process of the plant raw material, electrical and thermal energy (energy obtained from burning a certain type of fuel) are used. The reduction of electrical energy is associated with the use of high-efficiency pumps with frequency converters, included in the thermal scheme of the enterprise. In addition to production processes, highly efficient electrical equipment should also be used in the company's auxiliary installations - for example, installing highly efficient lighting fixtures, etc. (Berk, 2009; Ivanov et al., 2021). The reduction of required thermal energy in the enterprise is associated with the provision of cheap fuel and low fuel consumption for obtaining technological steam, necessary for the distillation process (Pipatpaiboon et al., 2025). Low fuel consumption should be ensured by using high-efficiency steam boilers (Chougule et al., 2016; Agustina & Kholifah, 2022; Akterian, 2020; Sichamnan et al., 2022).

The implementation of the described activities will guarantee the receipt of a quality final product (essential oil), an increase in the company's profit, and access of the product to more customers on global markets (Ordinance №E-RD-04-03, 2016; Baev et al.,2026; Kaloyanov et al, 2026; Iliev et al., 2026). This allows them to implement quality standards in their production and to sell their products on the European market (Rasheva, 2011).

Method

The object of the present study for energy efficiency of an industrial system is a distillery - essential oil manufacturer in Bulgaria. The investment intention of the company is to meet the increased production and consumer demand in the European and world markets for various essential products used both in the perfumery industry and for the production of ecological medicines. The geographical location and climatic conditions of

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

Bulgaria provide perfect conditions for the growth of oil crops, allowing the production of high-quality and high-yield essential oil products.

The distillation installation is designed to allow the processing of any type of oil product, regardless of its volume, but at the request of the client, the enterprise will mainly process the following essential oil crops:

- Lavender - 336,000 kg/year;
- Rose - 162,000 kg/year.
- In distillery the following technological processes are carried out:
- Distillation apparatus for distillation essential oil;
- Cohobation column for distillation of rose oil;
- Equipment for receiving and supplying process steam;
- Auxiliary equipment.

The choice of energy-saving measures, guaranteeing the highest value energy savings in the form of energy and low carbon emissions released into the environment, requires a detailed energy analysis of the enterprise's energy costs This analysis includes:

- determination of specific energy consumption depending on the production in destillery;
- determining the amount of energy savings as saved energy and as saved carbon emissions to the environment.

The determination of specific electrical energy consumption (SEEC) is carried out using the formula:

$$SEEC = \frac{EEC}{M}$$

where: EEC is electrical energy consumption, kWh/ year and M is manufactured output, kg oil/ year.

The determination of specific thermal energy consumption (STEC) is carried out using the formula:

$$STEC = \frac{TEC}{M}$$

where: TEC is thermal energy consumption, kWh/ year and M is manufactured output, kg oil/ year.

The determination of specific energy consumption (SEC) is carried out using the formula:

$$SEC = \frac{TC}{M}$$

where: TC is total consumption, kWh/ year and M is manufactured output, kg oil/ year.

The net present value (NPV) of energy saving measure is determined by the formula:

$$NPV = \sum_{i=1}^{n} \frac{B}{(1+r)^i} - I_0$$

$$NPV = B.\frac{1-(1+r)^{-n}}{r} - I_0$$

where: n – technical/ economic life of the facility, years, r - real interest rate, % and I_0 – investment costs, €.

Coefficient of net present value (NPVQ) is calculated according to the formula:

$$NPVQ = \frac{NPV}{I_0}$$

The pay back period (PB) of energy saving measure is determined by the formula:

$$PB = \frac{Io}{B}$$

Energy savings ratio (ESR) is calculated by formula:

$$ESR = \frac{TES}{TC}.100,\%$$

where: TES = B – net annual energy savings, kWh/year, TC - energy consumption of equipment covered by energy saving measures, kWh/year.

Energy savings potential (ESP) is calculated by formula:

$$ESP = \frac{TES}{TC*}.100,\%$$

where: TES = B – net annual energy savings, kWh/year, TC* - energy consumption of all equipment installed at the distillery, kWh/year.

The purpose of the study is to propose specific energy-saving measures for the distillery, to assess their economic profitability, to draw up an action plan for their implementation, and to assess the saving effect and the ecological impact of the energy-saving measures on the environment.

Results and Discussion

General Characteristics of the Distillery

The distillery is an existing facility that consists of a production area, a boiler room, an administrative area, and storage facilities for finished products. The distillery employs 6 workers on a permanent basis. The main workforce is seasonal pickers from the city and surrounding villages. The number of workers is determined by the picking company. According to the estimates, the working week will be 5 days, but if necessary, work will be done on weekends, and a rotating shift for pickers will be formed. The working day will continue depending on weather conditions and will last no more than 5 hours. On holidays and pre-holiday days, there will be on-call shifts. This requires the selected workers to have a wider qualification, be well-trained and disciplined. The management of the enterprise is carried out by a manager. An accountant deals with economic and commercial issues.

Water Supply and Sewage

The distillery requires water for drinking, domestic, production and fire-fighting needs. For the use of water for production needs, a borehole with a diameter of 150 mm and a depth of over 36 m is built in close proximity to the main technological consumers, equipped with the necessary facilities, shut-off valves, and automation. The water supply of the site with water for cooling and boiling is carried out with water from the borehole. For this purpose, a pumping station and cooling tower is built. In order to protect against carbonate deposits in the cooling system, the cooling water is subjected to sodium cationic softening. The autonomous groundwater softening installation is installed in the boiler room. The selected cooling tower is an open type with a capacity of 602,000 kcal/h, cooling water flow rate of 5.5 l/s, inlet water temperature 55 ˚C, outlet water temperature 30 ˚C. The domestic wastewater is treated in a modular treatment plant. A concrete pit - lagoon with a volume of up to 1500 m^3 is formed on the distillery, intended for the temporary storage of waste products /sludge/ during the processing of the rose.

Power Supply to the Distillery

The energy carriers used for enterprise needs are natural gas and electricity. The factory is fully gasified. Natural gas is used to obtain process steam. In connection with the technological needs to ensure the production capacity of the enterprise, it is necessary to ensure production with high-pressure saturated steam. Two high-pressure steam boilers are planned with a total maximum productivity of 1000 kg/h of steam and 1720 kg/h of steam. The compressed natural gas CNG will be supplied in batteries (modules) of bottles. One module contains: 2 batteries of 53 bottles and 90 l each; total geometric volume for 1 pc. (quantity of natural gas 2098.8 nm^3) owned by the supplier of compressed natural gas. The compressed natural gas from the cylinder modules, through a flexible gas connection between the cylinder batteries (on trailers) and the gas regulator station GRP 220/4 bar - 1 unit and a high-pressure hose DN ½" NPT, PN 350, a precision seamless steel pipe for high pressure connected to compression fittings with a cutting ring, will be fed to the gas regulator station (panel) GRP 220/4bar - open installation in a metal cabinet on a concrete platform. The latter is located in the northern corner of the concrete wall, enclosing from the west and part of the north, the concrete platform for the four platforms with modules containing compressed methane. Next to the GRP 220/4 bar, there is also a metal cabinet with dimensions LxWxH 1500x660x1000mm for the installation of 1 wall-mounted gas boiler. The latter isl for preheating the compressed natural gas with pressure 220 bar in a CNG heat exchanger with an external heat source - before pressure reduction.

The project has selected high-efficiency steam boilers, gas burners with modulation of the thermal power, a new generation of water pumps and pink sludge, as well as the necessary automation for their proper management and reduction of their energy costs.

Description of the Production Process

To implement the production program, it is necessary to ensure our own production or supply of the following quantities of raw materials – Table 1.

Table 1. Installed electrical power of the facilities in the enterprise

Product	Distil-lators	Kg raw material/ cycle	Cycles/ day	Kg raw material/ day	Harvest days per season	Kg raw material/ year	Kg oil/ year
Lavender	2	1200	7	16800	20	336000	3360
Rose	2	550	6	6600	20	132000	40
Rose	1	250	6	1500	20	30000	9

The distillation process takes place under the following parameters:

- Temperature in the range of 25˚C – 32˚C. Maximum + 35˚C;
- Water vapor pressure 0.5 to 0.6 MPa;
- Primary distillation rate – 480 to 510 l/hour, 8 to 10%, - 7.5 s/l;
- Cohobation rate 8.0 to 9.0 s/l
- Distillation duration from 2.0 to 2.5 hours.
- Condensate outlet temperature between 26 ºC and 35 ºC
- Condenser outlet water temperature around 75ºC

The time required to perform the operations in the processing of a rose oil is shown in Table 2.

Table 2. Required time for technological operation – rose oil

Name of the technological operation	Time to perform the technological operation, minutes
Filling the distiller with raw material	20
Releasing steam and distillate flow	10
Distillation	120-150
Emptying and cleaning	15
Total duration, minutes	165-195

A control system has been installed, with the help of which the technological process can be optimally automated and the maximum effect can be realized with minimal energy consumption. For this purpose, the installation has the necessary control mechanisms /motor valves/, controlled by temperature sensors and electronic controllers. The temperatures in the heat exchange equipment is also continuously monitored with electronic thermometers. The ratio of raw material / water in the distiller is 1:4 to 5 parts. The process in the distiller is monitored by an electronic controller and when the set temperature (+ 30 ºC or another experimentally determined) is reached, the valve supplying direct steam to the vessel is fully opened. This time must coincide with the flow of the boiler. The controller maintains the set temperature of the outgoing primary distillate while simultaneously controlling the motor valve of the cold water. With the supply of direct steam, good mixing of the total mass is obtained and the process proceeds at a uniform speed, 8-10%, covering the water losses due to intensive evaporation.

The distillation of lavender is carried out with direct steam at a pressure of 0.5to 0.6 MPa, and its supply is carried out by gradually opening the steam valve. When an air jet starts to come out of the liquid and distillate begins to flow, the steam is reduced to ensure normal flow of the distillate and to avoid the risk of creating passages in the raw material. The aim is to achieve a 10% speed, which means 7.5 s/l or 480 to 510 l/h of distillation, in order to ensure a normal start of the process. The parameters for processing lavender are as follows:

- distillation rate - during the first 30 min. of the process it is 10%, which means 7.5 s/l , 500 to 510 l/h, after which the rate is reduced to 4-5%, or 200 to 250 l/h.

Control is carried out by the direct steam valve;

- the temperature of the distillate is maintained at 35ºC to 40 ºC.

It is regulated by the amount of cooled water supplied, by the temperature sensors and the electronic regulator of the motor valve;

- the duration of the distillation is from hour to hour and 20 min.

The time required to perform the operations in the processing of lavender is shown in Table 3.

Table 3. Required time for technological operation – lavender

Name of the technological operation	Time to perform the technological operation, minutes
Filling the distiller with raw material	20
Releasing steam and distillate flow	10
Distillation	60-80
Emptying and cleaning	15
Total duration, minutes	105-125

The distillation process is optimally automated to changes in the technological process, minimizing the subjective factor in its operation and achieving maximum energy savings:

- automatic maintenance of a constant water level in the cold water tanks, through a float system controlling the supply pump of the softening installation, each vessel being equipped with a level indicator tube and an discharge system;
- automatic control of the filling of the distillers with cold/hot water, through a flow meter controlling the hot water pumps to the hot water tank;
- automatic maintenance of the temperature of the primary distillate, through a temperature sensor controlling an electronic regulator and the motor valve of the cooling water of the condenser;
- automatic maintenance of the temperature of the secondary distillate, through a temperature sensor controlling an electronic regulator and the motor valve of the cooling water of the cooler of the cohobation column;
- manual control of the steam shut-off valves;
- automatic stepless regulation of the speed of the water pumps for the primary distillate in order to ensure the most favorable flow rate for the secondary distillation in the cohobation column;
- continuous visual control of the temperature in the heat exchangers by means of electronic thermometers;
- automatic protection of the water pumps by means of a high pressure switch, stopping it when all consumers are turned off;
- automatic protection of the water pumps from low water level by means of a low level switch, mounted on each vessel;
- continuous visual control of the level in the receivers, by means of a level indicator pipe;
- continuous protection of the vessels from overflow, by means of a structurally implemented overflow;
- emptying system connected to the production sewage system of the building;
- manual control of all electrically controlled control devices.

Energy Consumption Analysis

In Table 4 installed electrical power of the facilities in the distillery are shown.

Table 4. Installed electrical power of the facilities in the distillery

Name	Value	Power, kW	Total power, kW	Operating hours, hours/year	Total power, kWh/ year
Technological equipment					
Gas modulating burner, monoblock Q_t = 110-1250 kW; V = 11-125 Nm^3/h	1	1.81	1.81	960	1738
Gas modulating burner, monoblock; Q_t = 80-2000 kW; V = 8-200 Nm3/h	1	3.40	3.40	960	3264
Hot water transfer pump Flow rate 6.8 m^3/h; Head 16.7 m, 230 V 50 Hz	2	0.75	1.50	600	900
High pressure feed pumps for steam boilers	4	2.50	10.00	600	3000
Submersible drainage pump Q = = 5 m^3/h H=10 m	1	0.50	0.50	560	280
Open type water cooling tower V =3 6 m^3/h Q = 540000 kkal	1	2.20	2.20	600	1320
Water circulation pump for hot water	2	2.20	4.40	560	2464
Water circulation pump for primary distillate	2	1.50	3.00	560	1680
Water circulation pump - for rose water	1	0.35	0.35	560	392
Submersible drainage pump V = 5m^3/h H = 10m	1	0.50	0.50	560	280
Pumping-hydro system (1 working + 1 spare pump) V = 20 m^3/h H = 40m, N = 4 kW complete. available with electric panel and expansion tank 200 l + automatics-pressure operation	1	2.00	2.00	600	1200
Submersible drainage pump V = 5m^3/h H = 10m	1	0.50	0.50	560	280
Pumping-hydro system for hot water (1 working + 1 standby pump) V = 20 m^3/h H = 25m, N = 4 kW complete with electric panel automatics-new on a drawing tank	1	2.00	2.00	600	1200
Electric hoist for monorail (load capacity 3 tons)	1	3.00	3.00	960	2880
Harnessing unit for 2.00 m^3	1	3.00	3.00	960	2880
Electronic scale - desktop	3	0.10	0.30	960	288
Electronic scale – for monitoring	3	0.10	0.30	960	288
Electric water heater 10 liters	2	3.00	6.00	300	1800
Vertical electric water heater 50 liters	1	3.00	3.00	300	900
Vertical electric water heater 80 liters	3	3.00	9.00	300	2700
Computer	5	0.35	1.75	150	262.5
Printer	5	0.35	1.75	150	262.5
Total usable power			60.26		30259

		Lighting equipment			
LED light 40W, IP21	12	0.04	0.48	960	192
LED light 24W, IP44	36	0.024	0.864	960	69
LED light 2x30W IP65	27	0.06	1.62	960	144
LED light 2x24W IP65	19	0.048	0.912	250	120
LED light 10W	1	0.010	0.010	250	216
LED light 12W, IP 44	3	0.012	0.036	250	405
LED floodlights 100W	4	0.10	0.40	250	228
LED floodlights Ex 2x 36 W	2	0.072	0.144	250	3
LED floodlights Ex 100 W	3	0.10	0.30	250	9
LED 1x8W, for evacuation lighting with pictogram IP65	40	0.008	0.32	250	80
Street light 80W, IP66	36	0.08	2.88	250	720
Total usable power			7.966		2186
Total power			68.226		32445

Based on the data from the previous table, percentage distribution of energy consumed in distillery is presented on Figure 1.

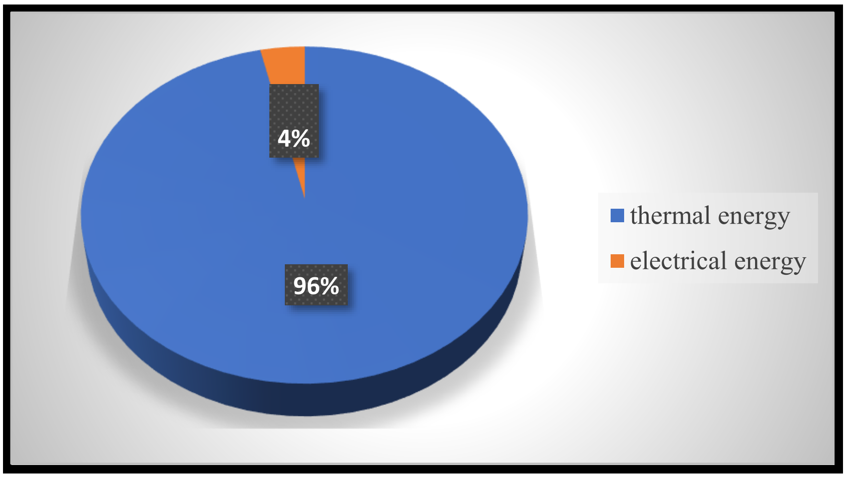

Figure 1. Percentage distribution of energy consumed in distillery

The data shows that thermal energy is used as a priority at the distillery. On Figure 2 a percentage distribution of electrical energy consumed in distillery is shown.

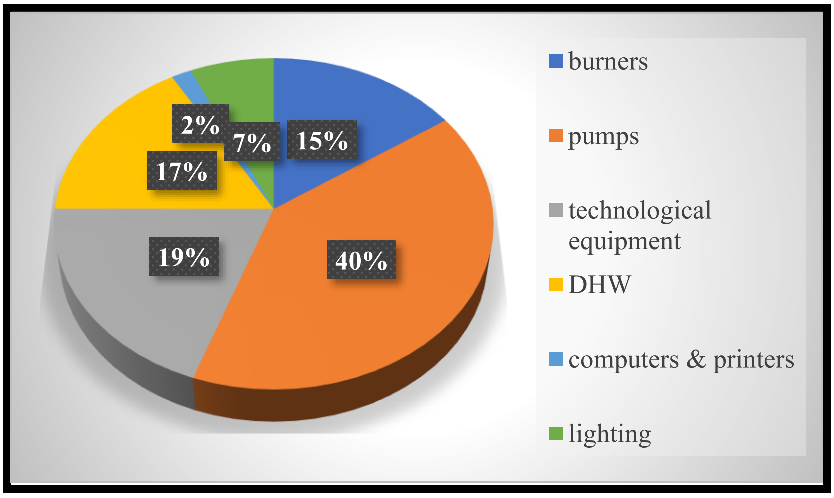

Figure 2. Percentage distribution of electrical energy consumed in distillery

The data shows that 40 % of electrical energy in distillery are consumed by different pumps in distillery. On Figure 3 a percentage distribution of thermal energy consumed in distillery is shown.

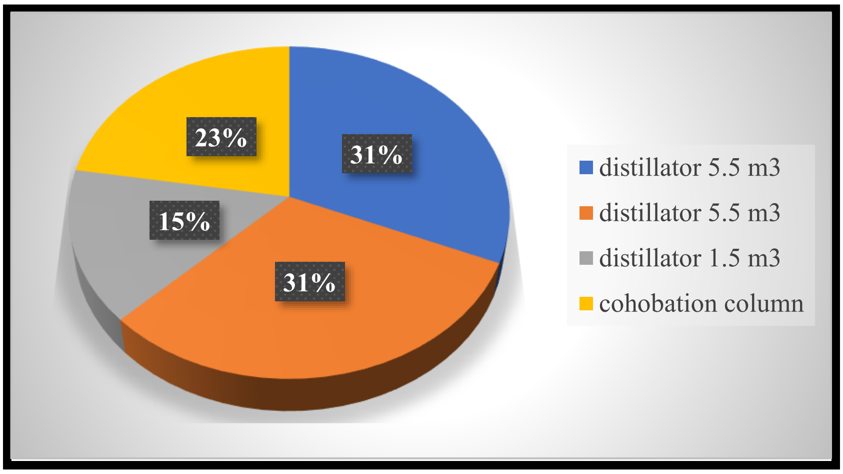

Figure 3. Percentage distribution of thermal energy consumed in distillery

In Table 5 total thermal power for steam boilers are shown.

Table 5. Total thermal power for steam boilers

Name	Value	Steam production, kg/hour	Total power, kW	Operating hours, hours/year	Total power, kWh/ year
Three-pass steam boiler with steam production 1000 kg/hour of steam, working pressure 12 bar.	1	1000	708(+1132)*	300	552000
Three-pass steam boiler with steam production 1720 kg/hour of steam, working pressure 12 bar	1	1720	1132	300	339600
Total usable power					891600

* For lavender processing, both boilers operate simultaneously.

In Table 6 total thermal consumption for distillation apparatus and cohobation column is shown.

Table 6. Consumed electrical energy after energy-saving measures

Name	Value	Steam consumption, kg/hour	Total thermal consumption, kW
Distillation apparatus with a capacity of 5.5 m^3	1	840.00	555
Distillation apparatus with a capacity of 5.5 m^3	1	840.00	555
Distillation apparatus with a capacity of 1.5 m^3	1	400.00	264
Cohobation column with a capacity of 2.5 m^3/hour	1	600.00	396

Proposed Energy Saving Measures

After analyzing the energy consumption of the site, the following conclusions can be made:
- The site will consume a greater amount of thermal energy than electrical energy;
- Electrical energy is primarily consumed by the pumps in the distillery.

Energy-saving measures are proposed to improve the efficiency of steam boilers, as well as to reduce the electrical energy consumed by the various pumps in the distillery. In this sense, proposals for reducing the energy costs of the enterprise can be made in the following directions:

ESM 1: It is proposed to install economizers – 2 pcs. (flue gas – water heat exchangers), which will utilize the waste heat from the flue gases of the steam boilers. In economizer, the flue gases are cooled to condensation temperature of water vapor contained in them, and the heat released from the cooling of the flue gases and the condensation of the water vapor is transferred through a heat exchange surface to the incoming feed water. This directly affects the natural gas consumption of the modulating burner of the steam boiler, namely – savings of 11% (98076 kWh/year) of the total thermal energy generated by the two boilers are expected. Part of the hot water obtained in the economizer can be used to heat domestic hot water in 3 volumetric boilers, each with a capacity of 80 liters with a built-in coil. The expected savings of electricity for heating water in the boilers is 90% (2430 kWh/year) of the total electricity consumed by the three boilers.

ESM 2: It is proposed to install frequency inverters on the electric drives of each of the four linear feed pumps for the steam boilers. As a result of the implementation of the measure, a 50% reduction in the electricity consumption of the pumps (1500 kWh/year) is expected.

ESM 3: It is proposed to install frequency inverters on the electric drives of the two linear transfer pumps for hot water. As a result of the implementation of the measure, a 50% reduction in the electricity consumption of the pumps (450 kWh/year) is expected.

ESM 4: It is proposed to install frequency inverters on the electric drives of each of the four pumps of the pump hydrophore systems. As a result of the implementation of the measure, a 50% reduction in the electricity consumption of the pumps (1200 kWh/year) is expected.

ESM 5: It is proposed to install a frequency inverter on the electric drive of the cooling tower fan. As a result of implementing the measure, a 50% reduction in the fan's electricity consumption (660 kWh/year) is expected.

Technical and Economic Analysis of Energy Saving Measures

A comparison of specific energy consumption before and after energy saving measures is shown in Table 7.

Table 7. Comparison of specific costs before and after energy saving measures

	Before ESM			After ESM			
	Energy consumption for related with measures activities	Produced output	Specific energy consumption	Corrected energy consumption for related with measures activities	Energy consumption for related with measures activities	Produced output	Specific energy consumption
	kWh/year	kg/year	kWh/kg	kWh/year	kWh/year	kg/year	kWh/kg
ESM 1	894300	3409	262.3	894300	793794	3409	232.9
ESM 2	3000	3409	0.9	3000	1500	3409	0.4
ESM 3	900	3409	0.3	900	450	3409	0.1
ESM 4	2400	3409	0.7	2400	1200	3409	0.4
ESM 5	1320	3409	0.4	1320	660	3409	0.2
Total:	901920	3409	264.6	901920	797604	3409	234.0

The parameters of the energy efficiency measures are calculated based on the following data:

- Carbon dioxide (CO_2) emissions of electricity are 0.819 $kgCO_2/kWh$, and for natural gas are 0.202 $kgCO_2/kWh$;
- Price of electricity supply – 0.22 €/kWh;
- Price of compressed natural gas supply in bottles – 0.25 €/kWh;
- Heat of combustion of natural gas fuel - 9.305 kWh/ Nm^3;
- Duration of technical/economic life of the facility is n = 20 years;
- Real interest rate, r = 3.00 %.

Calculation whether the measures are cost-effective (values of NPV, NPVQ) and their payback period (PB) are presented in Table 8.

Table 8. Assessment of the economic effectiveness of energy saving measures

	B, kWh/year	B, €/year	I_0, €	PB, years	NPV, €	NPVQ, -
ESM 1	100506	25053.60	77572.00	3.1	+296246.87	3.8
ESM 2	1500	330.00	2200.00	6.7	+2709.57	1.2
ESM 3	450	99.00	970.00	9.8	+211.86	0.2
ESM 4	1200	264.00	2200.00	8.3	+502.87	0.2
ESM 5	660	145.20	475.00	3.1	+1727.65	3.6
Total:	104316	25891.80	83417.00	3.2	-	-

The values of energy saving ratio (ESR), energy saving potential (ESP) and ecological equivalent (t CO_2/ year) of energy saving measures are shown in Table 9.

Table 9. ESR, ESP and ecological equivalent of energy saving measures

Energy saving measures	Energy carrier	Energy savings			Ecological equivalent
		TES, kWh/year	ESR, %	ESP, %	t CO_2/ year
ESM 1	electricity+thermal	100506	11.2	-	21.8
ESM 2	electricity	1500	50.0	-	1.2
ESM 3	electricity	450	50.0	-	0.4
ESM 4	electricity	1200	50.0	-	1.0
ESM 5	electricity	660	50.0	-	0.5
Total:	-	104316	11.6	11.3	24.9

Conclusion

The energy audit of the distillery showed the following results:

- Although the system has the necessary automation to control the technological process, it can be optimized by increasing the efficiency of steam boilers and by installing controllers for frequency control of the pump motors in the distillery;
- The net present value of each of the measures is a positive value, this means that all energy-saving measures are economically profitable;
- The sequence for implementing the measures according to the values of the net present value coefficients should be: first implemented measure is ESM 1 (3.8), followed by ESM 5 (3.6), ESM 2 (1.2), ESM 3 (0.2) and ESM 4 (0.2);
- The payback periods of the measures vary from 3.1 to 9.8 years, and for the entire package of energy-saving measures the payback period is 3.2 years.
- After implementing the described measures, annual savings of:

*98076 kWh of thermal energy are expected, which is equivalent to savings in the consumed natural gas in the amount of 10540 Nm^3. The total annual savings from the reduced consumption of natural gas are in the amount of 24519.00 €.

* 6240 kWh of electricity. The total annual savings from the reduced consumption of electricity are in the amount of 1372.80 €;

- The total annual costs for the distillery are reduced by 25891.80 €.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest.

Funding

* This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Basic Sciences and Technology (www.icbast.net) held in Konya/Türkiye on April 02-05, 2026.

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To cite this article:

Valchev, S. (2026). Improving the energy efficiency of a distillery for the production of essential oil. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 40,* 81-91.