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REDUCTION OF ENERGY USE IN INDUSTRIAL FACILITY

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ABSTRACT

Energy saving potentials related to steam generation and its usage in the medium size bakery are analyzed and presented. Input data needed for the investigation are gathered through detailed energy audit. Four energy savings measures are analysed in detail: 1) change of heat generator for space heating and domestic hot water preparation from steam boiler to condensing boiler, 2) reduction of heat losses from steam and condensate distribution lines, 3) heat utilization of return condensate and 4) replacement of the old, low efficiency steam boiler with high-efficient one. Implementation of these measures will result in substantial reduction of energy costs, ranging from 2.900 to 26.200 € annually. Interaction of all measures is analysed through energy efficiency improvement scenario, whose implementation will ensure significant energy cost savings, estimated at 40.793 € annually, with simple payback period shorter than 4 years. Implementation of presented measures will improve facility’s energy efficiency, represented through reduction of annual energy performance indicators by 6,14 %. Presented analysis revealed that steam generation and its usage in the industrial facilities offer a substantial potential for reduction of energy use and energy related cost.

Keywords: *Energy Audit, Medium Size Bakery, Energy Savings, Energy Performance Indicator*

INTRODUCTION

Increase of energy efficiency in Bosnia and Herzegovina (B&H) has become a topic of great importance in the previous period. To convey the requirements of European Directives related to the energy efficiency improvement in all sectors, Energy Efficient Law is adopted, along with energy efficiency action plans for particular regions and levels of jurisdiction in state. Energy efficiency improvement strategies and funding are in most cases related to the refurbishment programs of public buildings while industry sector was not the subject of wide-range activities. Industry sector in B&H is characterized by high energy intensity, with four times higher values than the average of the European Union [1]. Share of the final energy consumption of industry sector in B&H is 19 %, while worldwide values in developed countries reach up to 38 % [2], [3]. According to B&H National Energy Efficiency Action Plan (NEEAP), highest targeted energy savings potential over a 5-year period, in relative value of 17 % is expected in industry sector [2]. In order to achieve this goal, trustworthy analysis of the energy saving potentials in particular sectors has to be performed.

Industry sector provides a great basis for energy savings with numerous approaches and saving measures which can be applied. Utilization of waste heat for electricity production, hot water preparation, cooling or heating is a subject of analysis very often nowadays due to the large potential for energy savings[4]–[7]. According to [4], [7] waste heat in industry accounts for 10–50% of total fuel or energy consumption, which is in usual operation considered as wasted energy. An example of how to use the waste heat for electricity production is implementation of Organic Rankine Cycle (ORC). This case was numerically studied via thermodynamic modelling of system component in [5]. Analysis has shown that, using a heat source with temperature of 700 °C and mass flow rate of 0,23 kg/s, turbine power of ORC system is 5,2 kW, with average turbine efficiency of 50 %. Usage of ORC cycle for waste heat utilization decrease the environmental impact of factory due to the reduction of CO_2 emission. Maximum thermal efficiency of tested ORC system is 25 % so further enhancement of system component is needed. Another example of waste heat utilization is using turbine exhaust gases as heat generators for absorption chillers to provide factory cooling. Case study of such system with application in sugar industry is presented in [6], where turbine exhaust gases with temperature of 109 °C are used by vapour absorption refrigeration system. This system consumes only 2 % of electricity of comparable conventional vapour compression system. Due to high investment cost of these systems, usage of a waste heat as a heat source is economically favourable. Analysis has shown that usage of this system for cooling of one room with conditioned volume of 152 m^3, will reduce the

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fuel usage by 75 tons of coal per year with significant reduction of electricity usage. In [7], framework for decision making regarding the waste heat energy recovery solution, is presented. Framework encompassed four most important section for this particular issue: survey of waste heat sources in facility, assessment of waste heat quality and quantity, selection of appropriate technology and decision making and recommendations. This study has shown that it is possible to develop systematic approach when analysing implementation of energy recovery technologies in industry.

Improvement of EE and reduction of environmental impacts by introducing renewable energy sources to meet the energy need of the facility is studied experimentally in [8]. Analysis of the usage of solar assisted ground heat pump for heating, with combination of long-time measurements and modelling is presented. System components are analysed from the energy, exergy and exergo-economic factors, with clearly stated methodology which can be used for evaluation of other systems. Due to its low operation costs, it is expected that usage of heat pumps for heating and cooling in industrial facility in B&H will increase in the future.

In order to present energy saving potential and related energy costs savings in industry sector in B&H, detail energy audit in food processing factory is performed. This type of facility is chosen for analysis since the food and beverage sectors have highest turnover in industry [9]. According to [10] baking of bread, pastry and cakes is most energy intensive process in food and beverage production sector, so it offers high energy savings potential. Taking into a consideration that food demand is expected to increase by more than 50 % in the following decades [11] increase of its energy efficiency is of great importance.

CASE STUDY

Analysed facility is classified as medium size bakery, with annual production of baking goods of approximately 4500 t/a. Production comprises of two sectors: production of bread and rolls and production of semi-finished and finished products. Baking process is based on usage of industrial oven with total of 16 burners with natural gas and fuel oil as a fuel. Several auxiliary processes support the production process: 1) industrial steam generation in the boiler house, 2) generation of compressed air and 3) refrigeration system. Steam generated in the boiler house is used on the one hand directly for baking and fermentation, and on the other as an energy carrier for heating and preparation of domestic hot water (DHW) via heat transfer substation in administrative building and production sectors. Three low pressure steam boilers are installed in the boiler house, usually powered by natural gas as main fuel and fuel oil as back-up fuel. Fuel oil is used as back-up fuel in very rare occasions, so within this analysis it is assumed that energy is provided solely from natural gas. Two boilers have been in the operation for more than 25 years while one of them is recently out of order. Produced steam is qualified as low-pressure with values of pressure ranging from 0,3 to 0,5 bar and temperature of 110 °C, while steam flow rate needed for process is 3,06 t/h.

Breakdown of facility's final energy consumption has shown that gas consumption covers approximately 71,5 % of the total energy needs, electricity covers around 14,9 % and rest is a fuel oil [12]. Results imply that the highest energy saving potential is related to the natural gas utilization. Through data analysis preformed after the energy audit it is concluded that steam generation system is a source of substantial energy losses due to the low efficiency of all segments of a process: steam generation, process regulation, distribution lines and steam utilization. Therefore, the measures related to the improvement of steam generation and its utilization are analysed in details and presented in this paper.

In previously published work related to the findings of energy audit in the same facility following measures are analysed: 1) utilization of waste heat from baking oven's hot exhaust flue gases, 2) change of heat generator for space heating and DHW preparation from steam boiler to condensing boiler and 3) following measure of replacement of a low efficiency steam boiler with high efficiency steam boiler [12]. It is shown that 65 % of energy of hot flue gasses from baking oven can be used to preheat the air needed for fermentation process. This would result in reduction of natural gas consumption and reduction of energy costs by 3365 €/year. Analysis of change of heat generator for space heating and DHW system was simplified and based on monthly consumption profile of natural gas. Excessive natural gas consumption in the winter period was directly related to the energy consumption for heating, so savings in gas consumption are calculated from estimated gas consumption and increase of the system efficiency when applying energy improvement measure. Since this measure ensures substantial energy savings by reducing number of heat transfer processes and increase of overall system efficiency, this measure is analysed in details in this paper. Energy need for heating and DHW system for the administrative building is calculated using energy performance calculation methodology for non-residential building, as presented in standard EN ISO 13790. Based on calculated data, building's monthly and annual gas consumption need and related cost for natural gas are calculated. Following, the proper sizing of condensing boiler is ensured, so it is shown that needed nominal power of condensing boiler is 100 kW smaller than presented in [12] which results in smaller investment and operational costs. This approach combines result of energy need calculation of non-residential building and energy saving measures of industrial system. Similar study is presented in [13], where it is shown that energy savings in industry can be achieved via reconstruction of Heating Ventilation and Air Conditioning (HVAC) system in the facility's building along with the use of waste heat from the equipment installed in the facility. Study has shown that replacing conventional coal-based system with highly efficient boilers connected to renewable energy based system (heat pumps and solar thermal system) and introduction of waste heat recovery system from the compressors provides large energy savings together with other benefits, such as decrease of environmental impact of the facility's HVAC system.

Along with previous, following measures can assure energy savings in this particular industrial facility: 1) setting an insulation on a valves and pipes of the steam and condensate distribution system to reduce heat losses and 2) heat recovery of the condensate which will reduce flash steam losses. Also, replacement of an old steam boiler with new, high-efficiency steam boiler is analysed as a measure which will result in a substantial savings of natural gas consumption and related cost. Interaction of these measures is analysed within energy efficiency improvement scenario. For all measures and scenario, energy and energy cost savings are calculated and investment costs are presented along with Simple Payback period.

Utilisation of renewable energy sources such as heat pump or solar panels is not analysed. Taking in-to account the importance the introduction of renewable energy sources in energy supply systems [14], and large energy savings which can be achieved [15], followed with reduction of CO_2 emission, this topic will be addressed in future studies related to this particular facility.

Energy Performance Indicators

In line with standard EN ISO 50006, facility's energy performance indicator can be expressed as absolute value of energy consumption (e.g. in GJ, kWh), specific energy consumption (SEC) (e.g. in kWh/unit) etc. It is common to express SEC as a ratio of consumed thermal and/or electric energy per one tonne of product [9] or per tonne of raw material (white flour in the analysed case) [16]. In order to ensure the energy performance indicators benchmarking, in this analysis it is chosen to use specific energy consumption expressed as total energy consumption per tonne of flour (SEC 1) and per tonne of product (SEC 2). Both indicators are shown on monthly basis in Figure 1 and Figure 2 along with data from other facilities.

In Figure 1, comparison of values of facility's SEC 1 and averaged values of three Slovenian bakeries are shown [17]. In Figure 2, values of facility SEC 2 are shown, along with values from EU bakeries [9]. There is a large inconsistency of published data for SEC, since it is highly affected by the company size and installed technology. Therefore, it is difficult to establish the common standard for SEC calculation and its expected values. In any case, it is visible that specific energy consumption of particular facility increases over the period of three years. Also, it has a substantial monthly variation and it is higher than values of other facilities for both SEC 1 and SEC 2. Taking into a consideration that some facility's auxiliary systems are suspended, such as mechanical ventilation system inside of the production building, energy consumption would be even higher in the full operation

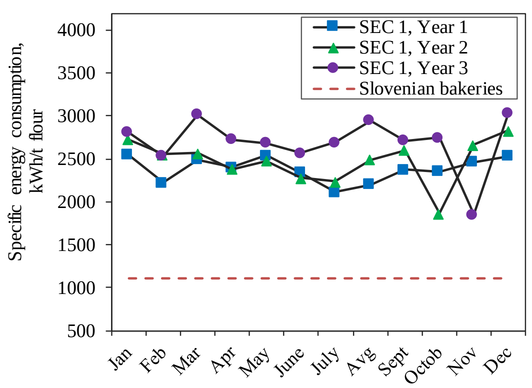

Figure 1. Specific energy consumption per tonne of flour, SEC 1

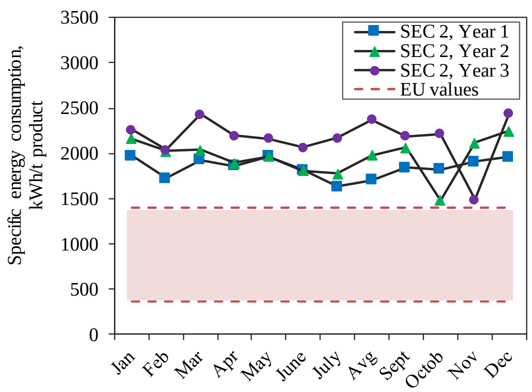

Figure 2. Specific energy consumption per tonne of product, SEC 2

Presented data also show that there is no strategy for achieving efficient specific energy consumption, which is visible through variation of indicators over the year and its increase over the three-year period. Therefore, targeted values of specific energy usage should be determined according to the values of similar facilities in region or in the EU countries. Targeted values could be achieved via increase of equipment and process efficiency and implementation of energy monitoring and management system.

Boiler House

Steam is generated in steam boilers and used in two ways: 1) directly in the production process or 2) as an energy carrier for baking and fermentation, process hot water preparation and heating and DHW preparation for administrative and production buildings. The indirect heating substation is installed to transfer the energy from generated steam to heating and DHW system.

Figure 3. Two steam boilers installed in the boiler house

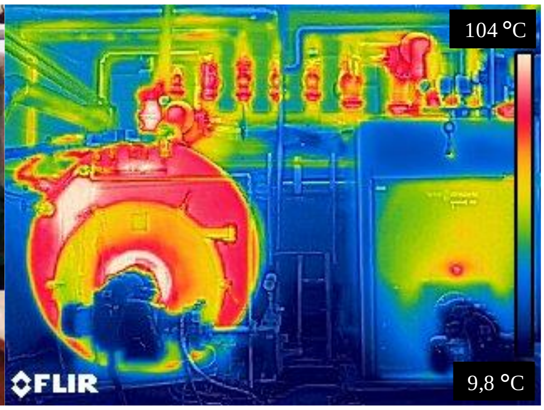

Figure 4. Thermal image of boilers and steam distribution lines

Three low pressure steam boilers are installed in the boiler house. During the investigation presented in [12], all three boilers were in operation, but since recently boiler 2 is out of order. Most important technical data of steam boilers and their current state are given in Table 1. Two boilers are shown in Figure 3 (boiler 1 is on right hand side and boiler 2 in on left hand side, with numeration following Table 1), together with thermal image in Figure 4 taken by thermographic camera. The latter figure shows high temperature of shell of boiler 2, which was in operation at the time when the pictures were made.

Boiler efficiency is determined by applying indirect method, based on measured values of flue gas composition, its temperature and boiler shell temperature. Other two boilers are older than 25 years, outdated and with reduced efficiency, as shown in Table 1. Annual efficiency of both currently working boilers (boiler 1 and boiler 3) is estimated according to measurements and [18]. Boiler 2 is currently out of order, while boiler 3 is working with 55 % of nominal capacity.

Table 1. Most important parameters of installed boilers

No, Producer	Year	Nominal power	Efficiency	Note
-	-	kW	%	-
Boiler 1, Viessman	2004	900	85	In operation
Boiler 2, Toplota Zagreb	1973	1000	-	Out of order
Boiler 3, TMA	1980	2300	75	Operating with 55 % of nominal capacity

Energy Need for Heating and DHW System of The Administrative Building

Generated steam in the boiler house is used as a heat carrier for heating and DHW system in the administrative building, via heating substation. Due to two-steps heat transfer process (one time in the boiler and second time in heating substation), together with low efficiency of steam boilers, the overall system efficiency is rather low.

Visual representation of administrative building is shown in Figure 5. It is a brick-wall building with two adiabatic back walls with useful heated area of 3.238,6 m2. Windows are metal framed, double glazed and 12 years old. Heating substation provides heat for radiators, fan-coil, mechanical ventilation system in kitchen and for DHW system, via heat exchanger with nominal power of 300 kW, shown in Figure 6.

Figure 5. Photo of facility's administrative building

Figure 6. Heating substation in administrative building

There are no heat measuring instruments installed so actual heat supplied to the object is not known. Therefore, energy need for heating is calculated in line with EN ISO 13790 and local climatic data. All important architectural data are included in calculation, such as building envelope construction, area, orientation, data related to the window conditions, which influence both transmission and ventilation heat losses, and data related to the mechanically ventilated spaces and technical characteristic of the installed equipment. Based on the input data, values of building transmission and ventilation heat losses and heat gains are calculated on the monthly base. Following, taking into a consideration the user thermal comfort and building use pattern, energy need for heating is calculated, as shown in Figure 7. It is noticeable that highest energy need for heating is calculated for January and December, and it decreases gradually for other months. This is in line with expected results, since the average temperatures for these months are the lowest, when compared to other months in the winter period.

Energy need for DHW system of administrative building is calculated in line with by-law on technical requirements for thermal protection for non-residential buildings as [19]:

$$Q_{\mathrm{W}} = 4{,}182 \cdot V_{\mathrm{W,f,day}} \cdot f \cdot \left(\theta_{\mathrm{w,del}} - \theta_{\mathrm{w,o}}\right) \cdot \frac{d}{3600}, \left(\frac{\mathrm{kWh}}{\mathrm{year}}\right) \tag{1}$$

where $V_{\mathrm{W,f,day}}$ is daily water consumption, calculated as $V_{\mathrm{W,f,day}} = 16\ (\mathrm{l/users})$, f is number of employees, $\theta_{\mathrm{w,del}} = 60\ °\mathrm{C}$ *and* $\theta_{\mathrm{w,o}} = 13{,}5\ °\mathrm{C}$ are the temperatures of delivered hot water and fresh cold water, respectively, and d is number of working days.

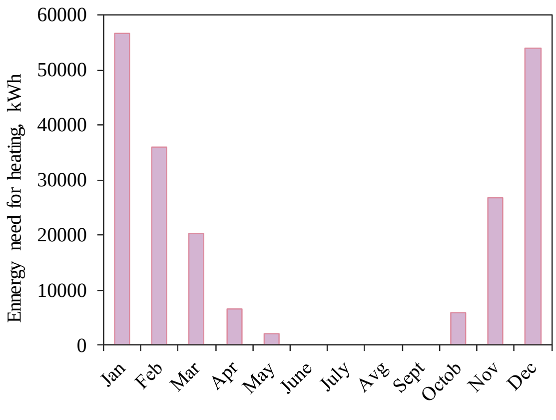

Figure 7. Energy need for heating of administrative building

Values of calculated energy needs for heating and DHW system are shown in Table 2. These values are used for calculation of delivered energy and natural gas consumption both for the current state of facility and for the state after implementation of energy saving measure, as described in following sections.

Table 2. Calculated data for heating and domestic hot water system of administrative building

Parameter	**Value**
Building heated gross volume, m^3	10.120,70
Building shape factor, m^{-1}	0,32
Building heated area, m^2	3.238,60
Energy need for heating, kWh/year	225.316
Specific energy needs for heating, kWh/m^2year	67,54
Energy need for DHW system, kWh/year	21.607
Specific energy needs for DHW system, kWh/m^2year	6,67

Energy Efficiency Improvement Measures

Several technical measures for energy efficiency improvement and reduction of fuel consumption are proposed: 1) reduction of number of heat transfer processes by changing heating and DHW boiler system from the one based on a steam boiler and heating substation to the system with the condensing boiler only, 2) setting an insulation on a valves and pipes of a steam and condensate distribution system and 3) heat recovery of the condensate which will reduce flash steam losses. Also, replacement of the old steam boiler with new, high-efficiency steam boiler is analysed as a measure which will result in a substantial reduction of natural gas consumption and cost savings. Interaction of these measures is analysed as an energy efficiency improvement scenario. Detail analysis of proposed measures and scenario is presented in the following chapters.

Installation of Condensing Boiler for Heating and DHW System of Administrative Building

Based on the calculated data of energy needs for heating and DHW system and values of overall system efficiency, delivered energy needed is calculated, with corresponding annual natural gas consumption and annual costs. Results are shown in Table 3 representing both current state and predicted values after the implementation of EE measure in the facility. Current state is characterized with low system efficiency since 2,3 MW steam boiler is working on the 55 % of boiler capacity and efficiency of distribution and regulation systems is also rather poor. In the state after implementing improvement measures, system efficiency is significantly improved due to the high efficiency of condensing boiler and high distribution and regulation efficiency. Comparison of energy needs, annual gas consumption and annual gas costs reveals that this measure will ensure high energy and energy cost savings. Nominal power of condensing boiler needed to cover the energy need for heating and DHW system in administrative building is 300 kW.

Table 3. Energy and cost savings for installation of condensing boiler

Parameter	Value	
	Current state	After the improvement
Energy needs for heating and DHW system, kWh/year	246.923	246.923
System efficiency, %	67,7	92,0
Delivered energy for heating and DHW system, kWh/year	364.666	268.394
Natural gas consumption, m^3/year	38.711,9	28.492,0
Natural gas costs, €/year	21.468,00	15.800,00
Nominal power of condensing boiler, kW	300	

Reduction of Energy Losses in The Steam and Condensate Distribution System

Steam and condensate distribution system in boiler house is thermally poorly graded, with visible flash steam losses and missing thermal insulation. From thermal images (Figure 4. and 8.) it is visible that some parts of installation have elevated surface temperature, higher than 100 °C, which results in substantial heat losses.

Energy losses on distribution system (valves, flanges, uninsulated pipes and condensate recovery tank) in the current state are determined as 26,49 kW (Table 4). After applying thermal insulation, energy losses will reduce to 3,36 kW as shown in Table 4. Insulation thickness is chosen as an economic solution for temperature of outer pipe surface and its diameter for insulation material with thermal conductivity of 0,04 W/mK [20].

Table 4. Energy losses of the uninsulated parts of steam distribution system

Parameter	Current state	After improvements
Energy losses from valves and fringes DN 25 – DN 200, total no. 54, from uninsulated pipes 15 m and uninsulated condensate recovery tank, kW	26,49	3,36

Thermal image of condensate return tank (Figure 8.) shows that some parts of condensate tank have outer surface temperature higher than 100 °C, which indicates that condensate return temperature is elevated when compared to normal operational mode. This results in higher heat losses through the tank envelope and presence of flash steam losses since condensate tank is vented to the atmosphere. In Figure 9. vented pipe located outside of the boiler house is shown. Elevated temperature of pipe surface is visible along with substantial flash steam, which also presents the system heat losses.

Potential for energy savings related to the condensate return system is calculated as a difference between current state, with elevated condensate return temperature, and situation where temperature of condensate is 90 °C for which steam flash losses are minimized:

$$E_l = \dot{m}_{cond} \cdot (h_{curr} - h_{need}), \text{(kW)} \quad (2)$$

where $\dot{m}_{\text{cond}} = 0{,}36$ (kg/s) is condensate flow rate, $h_{\text{curr}} = 439{,}29$ (kJ/kg) is enthalpy of condensate at 105 °C and $h_{\text{need}} = 376{,}99$ (kJ/kg) is enthalpy of condensate at 90 °C and atmospheric pressure. In line with previous, potential for energy savings is 22,41 kW which includes the energy losses related to the flash steam of 7,23 kW and corresponding steam losses of 11,5 kg/h.

Condensate flow rate is taken from the facility's design project documentation. These values could not be verified on field, since there are no measuring devices on water fill up and water treatment system.

Installation of heat exchanger at the entrance of condensate storage tank will ensure the utilisation of energy of condensate, which could be used for heating of fill-up water before it enters the boiler. This will ensure increase of enthalpy of feeding water at the boiler entrance, and will reduce the delivered energy and natural gas consumption. This effect, along with average annual working hours of facility is taken into account when calculating energy and energy costs savings for this measure. Nominal power of heat exchanger is 22 kW.

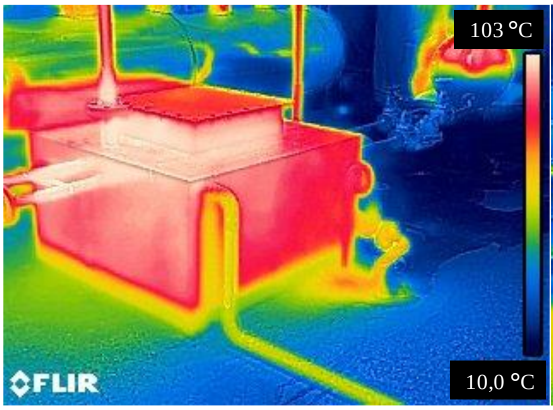

Figure 8. Thermal image of condensate storage tank

Figure 9. Thermal image of vented pipe and condensate flash losses

Replacement of Low Efficiency Steam Boiler

Low efficiency of steam boiler results in an increase of natural gas consumption. Taking into account that the currently operating steam boiler is older than 25 years and working with 55 % of its nominal power, its annual efficiency can be estimated at 75 %, while average efficiency of the two operating boilers in the boiler house is 80 %.

Table 5. Natural gas consumption and related costs for steam boiler replacement

Parameter	Current state	After the improvement
Boiler efficiency (average efficiency of two boilers), %	80	88
Natural gas consumption (total for two boilers), m^3/year	511.018	462.970
Natural gas cost (total for two boilers), €/year	283.383	256.738
Nominal power of new steam boiler, kW	1.250	

Replacement of low efficient steam boiler with new boiler with annual efficiency of 91 % will improve overall efficiency of energy conversion in facility, reaching 88 % and decrease annual gas consumption and its cost, as shown in Table 5. It is visible that natural gas consumption will reduce from 511.018 m3/year to 462.970 m3/year with resulting reduction of gas cost from 283.383 €/year to 256.738 €/year. Therefore, reduction in gas consumption is 48.048 m3/year, with resulting gas cost reduction of 26.645 €/year. Nominal power of new boiler is 1.250 kW as shown in Table 5.

Energy Efficiency Improvement Scenario

The considered energy efficiency improvement scenario for the analysed facility consists from following measures: 1) installation of condensing boiler for heating and DHW system of administrative building, 2) setting an insulation on steam and condensate recovery distribution lines and 3) installation of heat recovery system on condensate return line. By applying the suggested scenario, steam production in the boiler house will be reduced by 4,4 % on a yearly basis. Reduction comes as a result of decrease of steam needs since heating system of administrative building will be detached from steam generation system. Installation of heat exchanger for preheating of feeding water will result in reduction of delivered energy need for boiler, through increase of enthalpy of feeding water at the boiler inlet. Setting a thermal insulation will increase an efficiency of distribution line.

Implementation of these measures will provide a good basis for replacement of current, low efficiency steam boiler with new, highly efficient boiler, with significantly smaller installed power than the current one. As shown in Table 6. nominal power of new steam boiler should be 1.100 kW, instead of current 2.300 kW, so the total installed nominal power of boilers in the boiler room will be 2.000 kW. Also, replacement of the existing boiler will result in more efficient natural gas utilisation visible through increase of average boiler efficiency, so substantial savings of natural gas consumption and related costs will be achieved, as shown in Table 6. Implementation of these measures will provide the reduction of natural gas consumption from 511.018 m3/year to 437.457 m3/year with resulting reduction of gas cost from 283.383 €/year to 242.590 €/year. Total gas consumption encounters the natural gas consumption of steam boilers and gas consumption of condensing boiler for the heating and DHW system for administrative building. In line with previous, reduction in gas consumption is 73.561 m3/year, with resulting gas cost reduction of 40.793 €/year.

Table 6. Natural gas consumption and related costs for energy efficiency improvement scenario

Parameter	Current state	After the improvement
Boiler efficiency (average efficiency of two boilers), %	80,5	88,0
Natural gas consumption, m^3/year	511.018	437.457
Natural gas cost, €/year	283.383	242.590
Nominal power of steam boiler, kW	2.300	1.100

Cost Benefit Analysis

Energy efficiency improvement measures will provide energy and energy costs savings, as shown in Table 7. Energy cost saving are calculated from reduction of natural gas consumption, which is a result of delivered energy savings. For each measure the investment cost are shown along with simple pay-back period.

Values are presented for following measures:

- **Measure 1**: Installation of condensing boiler (nominal power 300 kW) for heating and DHW system of administrative building. This measure will increase system efficiency through reduction of heat transfer process steps. Energy cost saving for implementing this measure is 5.667 €/year, while investment cost is 18.500 €. Simple pay-back period for this measure is 3,30 years.
- **Measure 2:** Insulation of valves, fringes, pipes and condensate tank. Uninsulated steam distribution parts are a source of substantial energy losses so setting an insulation on these parts will minimise the energy losses and increase an efficiency of distribution lines. This measure is easy to implement, with small investment cost of 2.400 € and with favourable simple payback period, shorter than one year.
- **Measure 3:** Heat recovery from condensate by installing the heat exchanger with nominal power of 22 kW for preheating of boiler feeding water. Heat recovery system on condensate return will prevent flash losses and also it will ensure increase of enthalpy of feeding water at the boiler entrance, which will reduce the natural gas consumption for steam generation. Investment cost for this measure is 2.200 € and provides favourable simple payback period of 0,54 years.
- **Measure 4:** Replacement of low-efficiency steam boiler with new steam boiler with nominal power of 1.250 kW. Implementation of this measure will result in an increase of efficiency of energy conversion in boilers with decrease of natural gas consumption for steam production, as presented in detail in previous sections. With investment cost of 128.000 €, calculated simple pay-back period for this measure is 4,8 years.
- **Energy efficiency improvement scenario:** When applying Measures 1 and 3, steam production in the boiler house will be reduced by 4,4 % annually. Energy savings generated by implementing Measure 2, together with the measure of replacement of low-efficiency steam boiler with new steam boiler of 1100 kW nominal power are also counted within this scenario. Replacement of the existing boiler will result in more efficient natural gas utilisation so substantial energy cost savings will be achieved, as presented in detail in previous sections. With investment cost of 151.000 €/, calculated simple pay-back period for this measure is 3,70 years.

Table 7. Energy and cost savings for proposed energy efficiency improvement measures

No.	Energy efficiency improvement measure	Delivered energy savings	Energy cost savings	Investment cost	Simple pay-back period (SPB)
		kWh/year	€/year	€	Year
1.	Installation of condensing boiler (nominal power 300 kW) for heating and DHW system of administrative building	96.272	5.667	18.500	3,30
2.	Insulation of valves, fringes, pipes and condensate tank	49.873	2.927	2.400	0,82
3.	Heat recovery from condensate, installation of heat exchanger of 22 kW	69.090	4.067	2.200	0,54
4.	Replacement of low-efficiency steam boiler with new boiler with nominal power of 1250 kW	452.615	26.645	128.000	4,80
5.	Energy efficiency improvement scenario: Measures 1 to 3 and Measure 4 with boiler nominal power of 1.100 kW	692.944	40.793	151.100	3,70

Implementation of energy efficiency improvement scenario will result in a reduction of annual specific energy indicators, as shown in Table 8. Annual values of two SEC are shown for a period of three years for two cases: current state and after implementing the energy efficiency improvement scenario. It is shown that annual values of SEC will be reduced by 6,14 % in average, which results in reduction of energy costs and environmental impact of facility.

Table 8. Values of specific energy consumption after applying energy efficiency improvement scenario

Parameter		Year 1	Year 2	Year 3	Average reduction
SEC 1, kwh/t flour	Current	2.383,5	2.473,6	2.692,9	6,14 %
	New	2.228,9	2.319,0	2.538,3	
SEC 2, kWh/t prod	Current	1.845,8	1.965,6	2.172,0	
	New	1.723,4	1.843,2	2.049,6	

CONCLUSION

Results of detail analysis of energy savings gathered through energy audit are presented. Analysis has revealed that there is a large potential for energy and energy cost savings, particularly in the steam generation and steam use sector. Energy efficiency improvement measures are analysed and validated via calculated energy savings and related energy cost savings.

Following measures are analysed in detail: 1) change of heat generator for space heating and DHW preparation from steam boiler to condensing boiler, 2) reduction of heat losses from steam and condensate distribution lines, 3) heat utilisation of condensate and 4) replacement of an old, low efficiency steam boiler with highly efficient boiler. Investment costs for these measures range from 2.200 € to 128.000 € with annual energy cost savings ranging from 2.900 to 26.200 €. Simple payback period for all measures is shorter than 5 years, while measures related to the improvement of efficiency of distribution lines and heat utilisation of the condensate have SPB period less than 1 year.

Interaction of all measures is analysed through improvement scenario, whose implementation will ensure significant energy cost savings, estimated at 40.793 € annually, with simple payback period shorter than 4 years. Implementation of presented measures will improve facility's energy efficiency, represented through reduction of annual specific energy performance indicators by 6,14 % in average.

Proposed measures and scenario will ensure more efficient utilisation of fuel and reduction of facility's operational costs with favourable investment payback period. Presented analysis revealed that steam generation and its usage in the industrial facilities offer a substantial potential for reduction of energy use and energy related cost.

Limiting factor for deeper analysis is the lack of measuring equipment for energy, fuel consumption or water usage for particular sectors. For example, actual annual energy consumption for heating system, actual steam consumption and condensate recovery flow rate are not verified by field measurements. For the purpose of this analysis, values from design project documentation are used, together with data gathered through the facility field visit and calculated values. As an example, energy needs for heating and DHW system and condensing boiler's nominal power for administrative building is calculated following performance calculation methodology used for energy auditing in non-residential buildings.

Monitoring of energy consumption of particular sectors should be installed to ensure the validation of energy savings after the implementation of proposed measures. Future analysis should be devoted to the energy savings potential related to incorporation of renewable energy sources, such as ground heat pump in a factory energy supply system, and further investigation of waste heat recovery system.

NOMENCLATURE

E_l	Potential for energy savings, kW
f	Number of employees, $-$
h	Enthalpy, kJ/kg
$\dot{m}$	Mass flow rate, $\mathrm{kg/s}$
SEC 1	Specific energy consumption per tonne of flour, kWh/t flour
SEC 2	Specific energy consumption per tonne of product, kWh/t product
Q_W	Energy need for domestic hot water system, kWh/year
$V_{W,f,day}$	Daily water consumption, l/day
θ_w	Temperature of water in the domestic hot water system, °C
Abbreviations	
B&H	Bosnia and Herzegovina
DHW	Domestic Hot Water system
HVAC	Heating Ventilation and Air Conditioning
NEEAP	National Energy Efficiency Action Plan

ORC	Organic Rankine Cycle
SEC	Specific energy consumption
SPB	Simple Payback period
Subscripts	
cond	Condensate
curr	Current state
del	Delivered
need	Needed/Desired state
w	Water
0	Inlet

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