STEAM SYSTEM OPTIMIZATION OF AN INDUSTRIAL HEAT AND POWER PLANT

by

Risto V. FILKOSKI[a*], Ana M. LAZAREVSKA[a], Daniela MLADENOVSKA[b], and Dejan KITANOVSKI[c]

[a]Faculty of Mechanical Engineering Ss Cyril and Methodius University, Skopje, North Macedonia
[b]JSC ESM, Skopje, North Macedonia
[c]Balkan Energy Group, Skopje, North Macedonia

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Improvement of the energy conversion processes efficiency helps to achieve a more reliable energy supply, a cleaner environment, more competitive businesses, and higher living standard. Industry data indicate significant potential for improving the efficiency of steam systems and minimizing their operating costs by implementing various measures. The present work is a result of a systematic approach for energy performance analysis and identification of opportunities for optimizing the steam-condensate system of the combined heat and power plant ESM Energetika, Skopje, North Macedonia. The boiler plants provide superheated steam used in a hot-water station for the district heating system, for electricity generation, and as process steam for industrial customers. As the main operating costs of the plant stem from the natural gas consumption, the implementation of a set of energy efficiency measures will lead to its reduction, accompanied by less environmental impact. As a result of the system analysis, a number of energy efficiency measures have been identified. For each measure, the impact on individual parts of the system, as well as on the system as a whole, is evaluated using the steam system modeller tool. This paper elaborates some of the identified measures that are considered more reliable from an operational and financial aspect, mainly focused on steam production for the district heating system. Based on a conservative approach, significant potential for savings of natural gas, electrical energy, and treated water is estimated, which will lead to annual financial savings of about 245000 Euro.

Keywords: *boiler plant, steam system, condensate, optimization, natural gas, combustion, energy efficiency.*

Introduction

Being economically competitive in the global marketplace and meeting high environmental standards in order to reduce air, water and soil pollution are major driving factors for companies and organizations across sectors in their operational and capital cost decisions [1]. One of the ways to reduce costs and environmental impact is to enhance energy efficiency performances. Less energy consumed is manifested directly through better competitiveness,

*Corresponding author, e-mail: risto.filkoski@mf.edu.mk

reduced emissions, less waste and a healthier environment. The concept of energy efficiency is often misleadingly associated only with efficiency in the buildings sector, while, the problem of energy efficiency in industry is much wider, usually much more complex [2] and most often includes the steam-condensate systems as an important part of the industrial energy systems. Moreover, the steam-condensate systems are used not only in the industry but also in other areas, such as the health-care sector, hospitality (hotels, resorts, *etc*.), commercial buildings, agriculture (greenhouse facilities), *etc*., thus increasing the importance of the efforts to improve their efficiency. Steam is the most widespread among the energy media in the industry, due to its availability, thermophysical properties, as well as non-toxic and non-aggressive chemical structure. By its nature, it is very flexible energy transfer medium that can be used for process heating, as well as for power generation [3]. Saturated steam is an exceptionally efficient and cost-effective heating medium that keeps a constant temperature during heat transfer while condensing, and is characterised by a large amount of transferrable energy per unit mass (as latent heat), as well as by high heat transfer coefficients [3-6]. Given that analytical data show that average steam energy usage in the industry could be as much as 35-40% of the onsite total energy usage [4], it is very important to optimise the steam-condensate systems and minimise their operating costs [3].

In principle, the steam condensate system consists of four sub-systems: a steam generating facility, a distribution system, steam consumers, and a condensate return system [3, 4]. Despite the similarities, there are no two systems that are identical and it is very difficult to generalize between them. Methods for evaluating energy performance of steam boilers, as well as factors affecting boiler efficiency, are elaborated in many works [4-7]. Most of the research published in the literature tends to treat the components of the steam system as separate entities, rather than analysing, synthesizing and optimizing the entire system in a holistic way. Saidur [8] deals with an analysis of a set of energy-saving opportunities in industrial boiler plants, such as the flue gas temperature reduction, optimisation of excess air by the implementation of an oxygen trim system, application of variable speed drive for fans, *etc*., including the implications regarding the emission reduction. Price and Majozi [9] presents a technique for the process integration of steam systems by the use of conceptual and mathematical analysis while maintaining boiler efficiency. Wu *et al*. [10] deals with a multi-objective model for optimisation of steam systems with an idea to evaluate and simultaneously minimise energy consumption, operation costs, and environmental impact by the life cycle assessment method. A steam system of hydro-treating units in a refinery has been taken as a case study to demonstrate the reliability of the proposed method. Subiaco [11] presents a model of a steam system developed on the basis of steady-state thermodynamic models of the components. For each of them, a comparison with the behaviour of a real system is done by the use of a worked-out software tool. Once the reliability is tested, the model is used for the optimisation of the steam network of a large refinery.

A specific approach for assessing the opportunities for efficiency improvement of a real industrial plant is demonstrated in [12]. It includes both conventional and advanced exergy analyses and exergy-economic method and provides useful information about interactions among the components, revealing the real potential for improvement of the whole system and its components. Recognizing the importance of measuring the energy efficiency of a process or system as an essential step towards controlling energy consumption, costs and emissions, a structured framework for more accurate energy efficiency measurement is proposed in [13]. However, mostly due to other priorities, many industrial companies lack appropriate methods to effectively address energy efficiency in a comprehensive and practical way [14], which is a serious limiting factor for efficiency enhancement. Experience in quantifying the concept for processes monitoring has highlighted that an adequate framework is required to define and measure energy efficiency more precisely [2]. The establishment of an energy management system, as a comprehensive way of organised management of energy flows, from the processes of energy production, through the transmission, distribution, and the energy consumption is a proper approach for optimisation and rationalisation of these processes, to achieve energy and financial savings and reduce environmental impact [15].

In general, there are a variety of evaluation approaches used to meet the specific requirements for the steam system optimisation. Various studies on the energy efficiency of industrial facilities that include steam systems often fall short of recognizing the complex physical and functional relations between the segments and components of the whole system [6]. A disadvantage of the common engineering approach to break down the system into its components, to optimise the components design or/and operation, and to assemble the components into the system, is that it overlooks the interaction between the components. In order to overcome such shortcomings, this work extends the plant energy performance analysis to a broader context by application of system approach, which involves a crucial understanding of the interaction between the system components. Although in the professional and scientific literature there are numerous examples of implemented measures to improve energy efficiency in boiler plants and steam-condensing systems, any new experience is welcome. This is particularly supported by the aforementioned finding that there are no two identical steam-condensing systems. In this respect, the present study is characterized by certain specificities, both in terms of the technical characteristics of the boiler plants, as well as on the side of the thermal energy users and other segments of the entire system. In this work, the analysis is focused on several options for the efficiency improvement within a complex steam-generating facility. In accordance with the system approach, for each of the measures considered, the impact on certain parts of the system, as well as on the system as a whole, is analysed using the steam system modeler tool (SSMT) [16].

Materials and methods

The primary function of the steam generation system is to convert chemical energy bound in the fuel to produce steam at high pressure and temperature. Steam is a key work fluid in the industry and other sectors because it is produced from water, which is widely available and relatively cheap, as well as due to its advantageous thermophysical properties, such as large specific heat capacity, large heat transfer coefficients, high critical temperature, and non-toxic nature [5]. Therefore, steam may be viewed as the most common medium for power generation and heat transfer. High thermal capacity of a working fluid generally results in smaller equipment for a given power output or heat transfer [5-7].

Steam system-general considerations

The steam systems usually consist of several subsystems that may be classified in the following general categories: generation, distribution, end-use, and recovery, fig. 1. The variety of energy sources, the fuel type and fuel handling, the pressure level, the high temperature nature of the thermodynamic processes and the complexity of sub-systems contribute to the challenging nature of the steam systems optimisation. Steam boilers (or steam generators) are complex chemical reactors and heat exchanger (HE) aggregates that use thermal energy to convert water into steam for a variety of industrial and non-industrial applications. Fossil fuels are used in most steam boilers, but waste process heat, electrical energy, variety of bio-

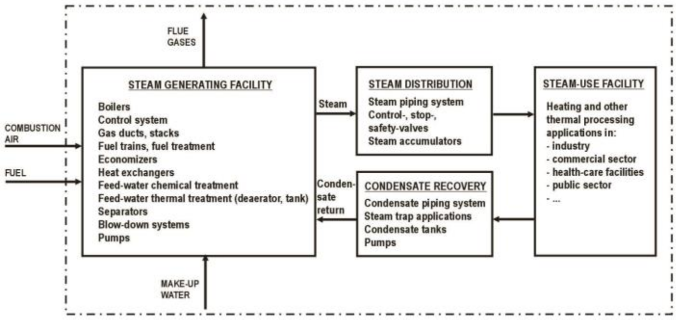

Figure 1. Main steam system components

mass matter and biomass products, process by-products and other resources may also be used as energy sources for steam generation. The steam generating facility is a section where a complex conversion of fuel chemical energy to heat takes place, which is transferred to the boiler feed-water to produce steam. It includes boiler(s), system for fuel treatment and supply, air system, feed-water treatment system, and combustion products treatment and transportation system. The steam generation area is very often the focus of steam optimization efforts, as a consequence of the number and magnitude of efficiency enhancement opportunities due to the complexity of energy conversion and other processes occurring there [2, 3].

From the heat generation unit, the steam is directed into the distribution system, which is the link between the steam generator and the end-users. Often, the distribution systems have several headers that operate at different pressures, depending on the end-users needs. Usually, each of them is equipped similarly, with various types of pressure-regulating valves, check and safety valves, measurement devices, *etc*. Effective performance of the distribution system is provided through proper steam pressure regulation, efficient and regularly maintained insulation, as well as through good condensate drainage system. Some potential issues that may be detected in the steam distribution system are lower steam pressure than needed by the end-users, an insufficient available steam-flow, operation in conditions of an oversized steam system, steam quality issues (such as wet steam entering the process), water-hammer emergence during the start-ups, *etc*.

The end-use part of the steam system may be very versatile. It may include process thermal treatment/heating for various purposes, heat transfer *steam-to-water* for spatial heating, direct treatment with steam, electricity generation (steam turbines), mechanical drive (pumps, fans), moderation of chemical reactions, fractionation of hydrocarbon components, *etc*. The widespread steam end-use includes equipment such as a variety of HE, various thermal processing devices, turbines, chemical reaction vessels, fractionating towers, strippers, *etc*. Even the same basic process and the equipment used may differ from one industry to another [3]. Although often directly related to a certain specific technology, in terms of the system approach, this subsystem should not be neglected when it comes to energy efficiency improvement.

The role of the condensate recovery system is to collect and return the condensate back to the boiler room. The perception of the condensate as a waste low-grade medium is completely wrong due to the fact that, basically, it is pure water, often representing the purest form of water in the given system. Overall, condensate recovery has the potential to be one of the major areas of steam system optimization (SSO). It is economically valuable due to several reasons [2-4]:

– The condensate temperature is usually much higher than the temperature of the make-up water and therefore, it contains a significant amount of usable heat.
– The condensate usually does not need any chemical treatment.
– Condensate collection and reuse reduces the problem of its disposal in the sewer system, including the need to cool down eventually before discharge due to thermal limitations of the sewer.
– In accordance with the good engineering practice, the condensate recovery is considered to be good when it exceeds 80% [2-4], but this may largely vary depending upon the steam-and-condensate system design, overall industrial plant size and design, type of processes, *etc*.

Scanning of the industrial steam and condensate system

The operation of the steam-condensate systems obeys the fundamental laws and principles of fluid dynamics, thermodynamics, heat and mass transfer and other disciplines, which are the cornerstone of any system optimization effort. Most often, it is not an easy task to perform a comprehensive and accurate analysis of a steam system manually. Therefore, experts usually need to use affordable software tools for this purpose, which is becoming a widespread approach today. Typically, the general approach to SSO begins with understanding the current state of the system and its management and operating practices [3, 5]. One of the first steps is to realize both the supply and demand sides of the system, as well as to identify the ultimate goals and targets that are crucial in the implementation of SSO measures.

Before performing any detailed analysis of the system, the expert team has to identify potential areas that have to be subjected to an in-depth investigation in order to quantify the energy and financial impacts on the system level. The SSO begins with a set of activities in order to get initial information about the process, managing practices, operation and maintenance, operators' habits, *etc*., that can be obtained in a diverse manner: face to face questions & answers session, phone interviews, questionnaire – filled up and returned by plant personnel, *etc*., or the best, by a combination of methods. One such tool that can be used to scope a system is the US Department of Energy Steam System Scoping Tool (SSST) [3, 16], a software-based questionnaire, designed to enhance the awareness relating general areas of steam system management. This tool was used in the initial stage of the present study. For a better understanding of the steam system, a schematic diagram with the needed level of detail should always be applied, such as the one presented in fig. 2. It should be a simplified representation of the overall system, with the main purpose to understand the system com-

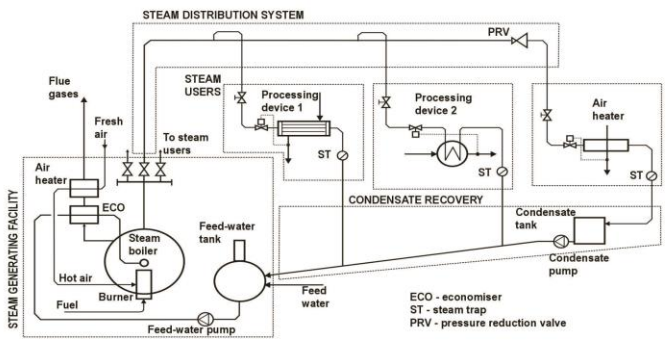

Figure 2. Example of a basic steam system line diagram, modified from [6]

plexity, structure, and operation, users' needs, condensate return line(s), *etc*., without getting into too many technical details and specific operating conditions.

The potential areas and options for steam system optimisation are then identified, further analysed and some of them implemented, to meet the plant operational demands in an efficient, reliable, safe and financially affordable manner. After the implementation of measures, as a final step, the overall system performance is continuously monitored and trends of changes of operation parameters are followed, to ensure that the system remains in its optimal configuration [3].

Modelling an industrial steam system

The next step of the process, upon gathering enough relevant data about the system, is developing a model that accurately represents the overall steam system in terms of energy and mass balance and system's components location. The model should contain sufficient detail to accurately present the energy, economic and environmental benefits of the optimisation measures. A variety of commercially available software tools exist, whose purpose is realistic modelling of industrial systems and providing the needed level of optimisation. Normally, an adequate level of expertise is necessary in order to be able to use these software tools. One such modelling tool is the US DOE’s Steam SSMT [3, 16], which is used in the present case study. It is intended to perform modelling of various SSO options, such as boiler efficiency enhancement as a function of different factors, boiler blow-down reduction, condensate recovery, waste heat recovery, vent steam, insulation efficiency impact, use of alternative fuels, steam traps programme, steam quality, steam leaks reduction, installation of backpressure turbines, cogeneration, *etc*. Among the other, it allows steam systems experts to develop realistic models of systems and quantify energy, cost and emission savings, enabling the user to perform a *what-if* analysis.

Due to the variety of steam systems configurations, magnitude, steam users, end-use applications, as well as management, operating and maintenance practices, there are accordingly many different ways to identify opportunities for steam system performance enhancement. The implementation of the system approach provides effective optimisation of the plant since it analyses both, the supply and demand sides, including their interaction, and essentially puts the focus on the performances of both individual components and the entire system. For example, an efficiency drop due to a heat loss across non-insulated pipelines affects also other parts of the system: reduces the energy available to the end-users, requires boilers larger fuel consumption to meet a given demand and sometimes provides lower quality steam (wet instead of dry steam). The most common energy efficiency improvement opportunities detected during scoping and detailed analysis of any industrial or other steam system are:

Generation area: optimisation of the excess air, clean boiler heat transfer surfaces, installation of flue-gas heat recovery equipment, improvement of water treatment to minimise boiler blow-down, energy recovery from boiler blow-down, improvement/repairment of the boiler refractory, optimal deaerator vent rate, *etc*.

Distribution area: optimal insulation of steam pipelines, insulation of valves, fittings, and vessels, regular reparation of steam leaks, minimal vented steam, implementation of an effective steam traps maintenance program, exclusion of steam lines that are not in operation, utilisation of the backpressure turbines instead of pressure reduction valves where feasible, *etc*.

Condensate recovery area: optimal condensate collection and return, utilisation of high-pressure condensate to 'produce' low-pressure steam.

Even at well-managed plants, the energy audits routinely identify many opportunities for energy savings through the adoption of proven, cost-effective energy-efficient technologies, operation strategies, and advanced maintenance programmes.

Case study: Optimisation of a complex steam system

The branch "Energetika" is one of the seven subsidiaries of the Joint Stock Company Power Plants of North Macedonia (AD ESM) and holds licenses for production, distribution, and supply of heat (hot water and process steam) and electricity. A similar case regarding several technical aspects of a combined heat and power (CHP) facility is presented in the work [17].

Description of the considered steam system

Originally, the industrial CHP plant ESM Enegetika was part of the former metallurgy complex Mines and Steelwork – Skopje, built in the middle 60's, which was later disintegrated into a number of different privately owned entities. In 1997 ESM Enegetika fell under the authorities of the state-owned AD ESM, as one of its subsidiaries. The plant was designed and built in order to provide a supply of electricity, steam and hot water to the consumers of Mines and Steelwork – Skopje. The majority of the installed equipment is based on relatively old technology with significant improvement opportunities and includes the following main components, fig. 3:

– Three gas-fired steam boilers (assigned as G32), manufactured in the late 60's, originally designed as steam generators for energy recovery of metallurgical off-gas, with natural circulation and production capacity 3×32 t per hours superheated steam at $p = 60$ bar and $t = 500$ °C.
– Reconstructed back-pressure turbines (10.2 MWe and 10.4 MWe).
– The 2×110 kV substations (110/35/6kV and 110/6kV).
– Main hot-water station (HWS) with four HE *steam-hot water* (4×18.6 MWth).

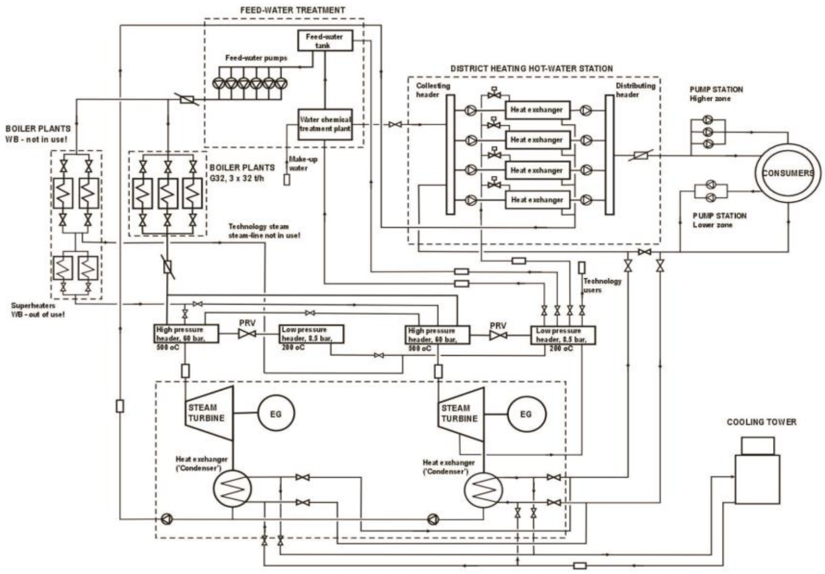

Figure 3. Schematic representation of the main equipment in the considered plant

With revitalisation works in the late 90's natural gas is introduced as a primary fuel and heavy fuel oil is kept as an alternative fuel. The boilers provide superheated steam for several purposes: in a HWS, for heating water distributed to the city district heating network; for electricity generation; for on-site consumption; and for production of saturated steam at 8 bar used for technological needs inside the steelworks. However, due to the specific circumstances, variable load and other working conditions, the boilers often operate in *problematic* modes, accompanied by increased losses. Very often the process takes place only for the district heating and technology purposes, thus the steam boilers operate at a pressure around 43 bar, instead of the designed 60 bar. In such conditions, finding ways to reduce energy and fluid losses was a specific challenge [18].

Elaboration of some identified measures

The energy audit in the company ESM Energetika was conducted on the basis of the directions and recommendations given in [3], which covers the operation of typical industrial and non-industrial steam systems. The audit covered steam generation, steam distribution, steam use, condensate recovery and CHP generation. Its sole purpose was to identify, quantify and achieve energy and cost savings through proper operation and controls, system maintenance, the appropriate process uses of steam and application of state-of-the-art technologies in an industrial steam system. Based on the preliminary analysis of the plant operation, conducted with the use of SSS tool [3, 16], performance improvement opportunities were identified in each of the above-mentioned areas that lead to the optimization of the overall steam system. In general, the identified losses were categorised into two groups:

- in-plant energy losses and
- energy losses in the heat distribution network.

The in-plant energy losses can be further summarised into two groups:

- plant process losses that include boilers energy losses (flue-gas losses, convective and radiative losses, blow-down losses, *etc*.), thermal losses of the piping and equipment, in-plant water and steam losses, *etc*. and
- own energy consumption, which becomes very significant in certain operating modes, in particular when the ambient temperature falls below 0 °C, when steam is used for protection of the equipment.

For the purpose of the overall system optimization at ESM Energetika, a model was developed using the SSMT [16] and subsequent analysis was performed [18]. As a result, a number of possibilities were identified, such as the deployment of a burners combustion control system to optimize excess air, installation of variable frequency drives (VFD) on primary rotating equipment (fans and pumps), installation of verified and calibrated metering and regulation equipment, reduction of boiler blow-down rate by installing automatic water quality control, insulation of bare steam and condensate valves, improvement of the low pressure condensate recovery, initiation of steam traps and leak management programme, as well as a range of low and no-cost options that will result in fuel, electricity and water savings. The impact from the implementation of each measure on separate parts of the system as well as on the system as a whole was analysed using SSMT. Based on the analysis carried out, an assessment was made of the potential energy and financial savings. This paper elaborates some of the identified measures considered as most viable from a financial, operational and practical point of view, focused mostly on the steam generation for district heating [18].

Deployment of a combustion control system on the steam boilers to reduce excess air level

The efficiency of the combustion process in the steam boilers is not monitored by any kind of equipment whatsoever, and the process control is performed manually. There is no relevant air flow regulation and an appropriate burner management system. There are no on-site measurement and metering devices of O_2 content and flue gases temperature, t_{fg}. Based on the periodic measurements of emissions by stationary sources (mandatory to be performed by an accredited laboratory once a month) and experience-based data from the plant engineers, the following values for t_{fg} and O_2 content were adopted: t_{fg} = 110 °C, O_2 ~ 16%. The suggested concept is presented in fig. 4.

Installation of equipment for oxygen trim control is recommended since this concept enables the automatic operation of the boiler through optimisation of excess air at the burner and more efficient combustion. The implementation of this measure implies a reduction of energy loss with flue gas, reduction of natural gas consumption and higher specific steam production per unit of fuel. The goal is to control excess air-flow for the combustion process and to reduce O_2 content in flue gases down to an acceptable level (~5%). This would lead to a slight increase in the flue gas temperature at the boiler outlet, but the flue gas enthalpy will decrease as a result of the significantly lower gas flow. It should be emphasized here that the site visits have shown that there is a significant unorganised influx of cold air into the boiler gas tract in the area of economizers and air-heaters. Therefore, it is hard to calculate the overall impact of the proposed measure on boiler efficiency very accurately. Under assumptions adjusted to the actual boiler operating conditions, it was calculated that the flue gas energy loss

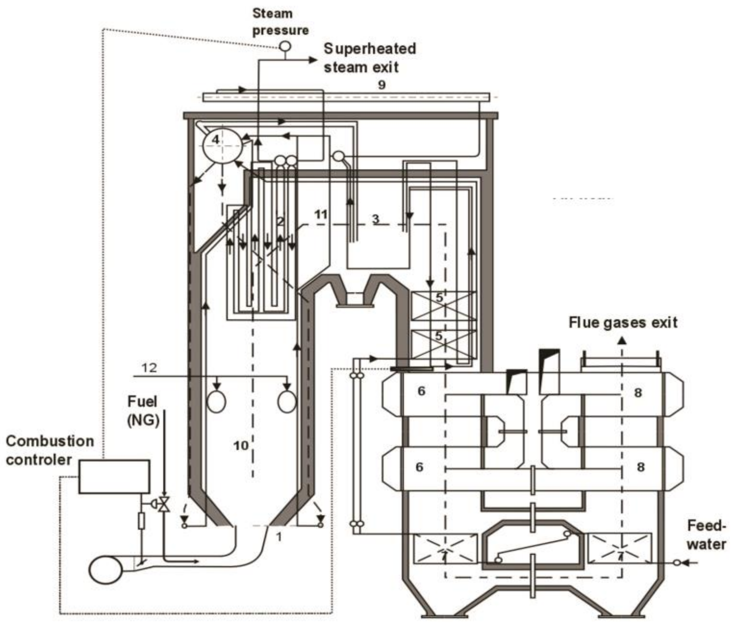

Figure 4. Steam boiler scheme and combustion management:
1 – natural gas burner, 2 – superheater II, 3 – superheater I, 4 – boiler drum, 5 – economizer II, 6 – air heater II, 7 – economizer I, 8 – air heater I, 9 – steam temperature regulator, 10 – boiler furnace, 11 – convective evaporator, and 12 – fuel oil burners

could be reduced by approximately 7.0 % and the boiler efficiency would be improved by the same value, which will have a direct impact on the reduction of natural gas consumption. By means of the upgrade of the combustion control to oxygen trim control, the plant will save approximately 138000 €/annually, at an average price of natural gas of 200 €/1000 Nm^3. It is clear that the techno-economic analysis of this measure must include the costs of boiler recovery to reduce the unorganized air flux in the gas tract in the area of low-temperature HE.

Installation of variable frequency drives on the primary rotary equipment

The VFD are installed on 4 (out of 8) circulation pumps in the HWS. However, due to the improper functioning of the steam-flow regulating valves at the HE, the VFD could not be effectively used for water flow regulation in the HE. The annual electricity consumption in the HWS is quite large, for instance, over the 2014/15 heating season it was 2781.104 MWh. Given that before the 2015/16 season, new actuators were installed and VFD devices were enabled to operate, the electricity consumption had decreased at 2480.295 MWh, which is a 12% reduction. Also, there are no VFD on the booster pumps. The recent average annual electricity consumption in the HWS was 105.104 MWh per heating season. There are no VFD installed on the air intake fans (3 × 90 kW) and flue-gas fans (3 × 290 kW) as well.

The proposed measures include installation of VFD on the mentioned rotating equipment. The measure 1 consists of an installation of appropriate actuators on the steam regulation valves at the HE inlets in order to enable water-flow regulation via VFD. This leads to a reduction in electricity consumption by at least 10%, thus the minimum electricity savings are 278.11 MWh, implying annual costs savings of 12070 € (conservative approach) since the electricity price per kWh at the time of the energy audit was 4.34 c€/kWh. As a result of the investment in new actuators, achieved saving in electricity consumption during the 2015/2016 heating season was 12% (about 300 MWh). As a measure 2, it is expected that the installation of VFD on the static pressure and booster pumps will reduce the electricity consumption by at least 10%, thus the minimum electricity saving will be 10.51 MWh per heating season, implying annual costs reduction of 450 €. As a measure 3, the installation of VFD on the air intake and flue gas fans will reduce electricity consumption by at least 10%, thus the minimum electricity savings are 183.38 MWh, implying annual costs savings of approximately 8000 €. However, a detailed analysis prior to the implementation of this measure is recommended, given the potential threats to combustion stability. Energy and financial savings resulting from the presented measures are given in tab. 1.

Table 1. Energy and cost savings as per VFD measures [18]

Equipment on which the installation of VFD is recommended	Annual electricity consumption [MWh]	Electricity savings upon implementation [MWh]	Cost savings [€]
Circulation pumps in HWS	2781.10	280-300.8	13055
Static pressure- and booster-pumps	105.10	10.5	450
Intake and flue-gas fans	1833.78	183.4	8000
Total	4719.98	475-495	21505

Installation of heat meters on the booster system

The aim of the booster system in the pump station is to maintain a constant hot-water flow through the system via constant make-up water injection (preheated at around 35 °C) directly into the heat distribution network, at the connection point between the HWS and the distribution network. The temperature of the soft water is ~15 °C, *i e*. the temperature difference is 20 °C. Currently, a significant amount of water, approximately 45000 m^3 per season, injected in the heat distribution network with a large energy potential (over 1030 MWh), is not been measured and charged. Via the installation of calibrated and verified ultrasonic heat meter, fig. 5, [18], the company will be able to start charging previously unmetered heat distributed towards the end-users. The additionally charged delivered heat would be over 1030 MWh, which is equivalent to 140053.27 Nm^3 natural gas and will allow charging of approximately 28000 €/annually.

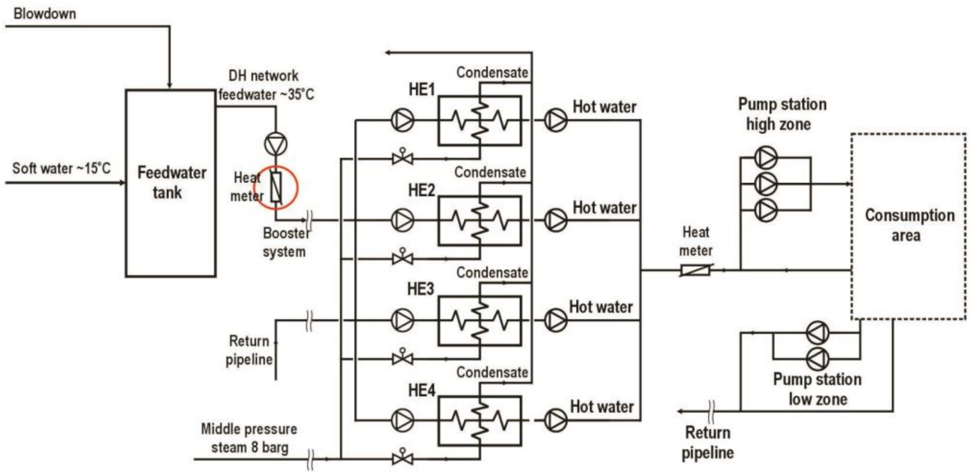

Figure 5. Suggested location for installing a verified and calibrated heat meter on the booster system in the hot-water station in ESM Energetika

Improvement of the condensate recovery and reduction of the boiler blow-down rate

At present, condensate recovery in the plant is approximately 80%. Since the make-up water cost is 10 €/m^3, further improvement of the condensate recovery, as well as blow-down rate reduction proves to be very beneficial. Minimizing losses in the medium-pressure steam lines hold the potential to improve the condensate recovery by at least 5%. In addition, the reduction of the boiler blow-down rate, assessed at 5.3%, will be a significant energy and water savings opportunity.

The recommendation to the company is to improve the medium-pressure condensate recovery, with simple maintenance measures, by an additional 5% [18]. It should be emphasized that the implementation of such a measure should be followed by the process of proper chemical treatment of feed-water, as well as installation of automatic water quality control, thus enabling discharging of the water-flow with suspended solids from the boiler with optimum blow-down rate. By implementing this measure, the annual water savings shall amount to approximately 4141 m^3 per year, while the annual cost savings will amount to approximately 46500 €.

Initiation of steam trap and leak management programme

The company has not implemented a steam trap and steam leak survey programme nor performed a detailed and comprehensive steam traps inspection and reduction of failures recently. Many steam traps are probably partially or completely dysfunctional for a long time since they have not been serviced or replaced. Implementation of a steam trap and steam leak survey programme will provide annual energy savings at an amount of 385 MWh/annually, while annual cost savings amount to approximately 10500 €/annually. The expected savings due to this measure are presented in tab. 2. One of the proposed measures to the company management that is not directly related to energy savings is to establish solid and reliable practices in terms of data collection and performing certain more precise analyses on a daily, monthly and annual basis.

Table 2. Calculated savings as per steam trap and steam leak survey program

Item	Quantity
Boiler load reduction [kW]	93
Energy savings [MWh]	385.11
Cost savings [€]	10500

The herein elaborated measures in terms of boiler's combustion management, implementation of VFD, additional heat meters installation, blow-down rate reduction, as well as steam trap and steam leak survey programme, contribute to significant energy saving and the consequent potential annual cost savings are estimated as 244500 €. It should be pointed out that the investment costs are not included in the calculation. Hence, although the boiler's combustion management has the largest share in calculated savings (56%), this measure also requires significant investment in proper control equipment, as well as an additional examination and recovery of the boiler air and flue gas ducts. In terms of blow-down rate reduction, which is typical small-cost or even no-cost measure, and to a certain extent in terms of steam trap and steam leaks survey programme, the investment cost is not an issue, thus the achieved savings are an example of *low hanging fruits*. Such measures should always be the first priority when it comes to the steam system optimisation. In general, regardless of the complexity of the problem, the majority of investments in energy efficiency are low-risk investments with quite certain and acceptable payback periods and an internal rate of return.

Conclusion

A subject of the analysis in this work was the complex steam-condensate system of a CHP plant in ESM Energetika-Skopje. The technical age of the plant, drastically changed initial design and operating circumstances, the variations in load, the intermittent energy requirements of the consumers, the natural gas price fluctuations, and other factors strongly influence its operation, efficiency, and profitability. The main aim of the conducted analysis was to identify opportunities to save energy by detecting primarily no-cost and low-cost measures. The conducted survey and prepared study, by means of SSMT, have shown that there are significant possibilities for energy efficiency improvement and water saving. From a number of identified opportunities, this work elaborates on the following measures: boiler's combustion management, implementation of VFD, additional heat meters installation, boiler blow-down rate reduction, as well as steam trap and steam leak survey programme. Based on a conservative approach, implementation of the envisaged measures has significant potential for savings of natural gas, electrical energy, and treated water, which will lead to annual cost savings of about 245000 €. Additionally, one of the proposed measures to the plant management, that are not related to direct energy savings, is to establish solid and reliable practices in terms of energy data collection and performing more precise analyses on a daily, monthly and annual basis. All identified and herein presented measures are a solid start for creating a systematically organized energy management scheme, that will contribute not only in the further efficiency improvement and cost reduction but also in the reduction of the environmental footprint.

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Nomenclature

DH – district heating
DOE – department of energy
HWS – hot-water station
JSC – joint stock company
PRV – pressure reduction valve
SSMT – steam system modeller tool
SSO – steam system optimisation
SSST – steam system scoping tool
VFD – variable frequency drive

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