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Integracija toplotnih pumpi u postojeći energetski sistem u malim i srednjim preduzećima

Integration of a Heat Pump into the Existing Energy System in SMEs

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Rezime **-** Industrijske procese karakterišu velike količine energije koja se gubi kao otpadna toplota u okolinu. U industrijskim sektorima analiziranim u SAD, Kini i EU28 otpadna toplota niske temperature, ispod 230ºC, čini od 33% do 60% otpadne toplote. Korišćenje otpadne toplote niske temperature je obično složen proces, i na njega utiču zahtevi korisnika, neusklađenost između izvora otpadne toplote i potražnje korisnika, ograničen prostor za postrojenja za korišćenje otpadne toplote, konverzija toplotne energije nije efikasna za niskotemperaturnu otpadnu toplotu, period otplate i dr. Svrha ovog rada je da predstavi metodologiju za tehničko-ekonomsku analizu perioda otplate za iskorišćenje otpadne toplote. Da bi se rešilo pitanje razumnog kriterijuma, razvijena je metodologija prikladna za mala i srednja preduzeća i u ovom radu je predstavljena optimizacija koja integriše razmenu toplote, konverziju energije i skladištenje toplote. Studija slučaja iskorišćenja otpadne toplote iz sistema za hlađenje indukcione mašine je korišćena da bi se demonstrirala primenljivost predložene metodologije. Predložena metodologija može pojednostaviti proces integracije toplotne pumpe, a može se dalje proširiti i na druge industrijske procese za iskorišćenje otpadne toplote niskog kvaliteta.

Ključne reči - otpadna toplota, toplotna pumpa, industrija

Abstract **-** Industry processes are characterized by large amounts of energy losses dissipated as waste heat to the ambient. In industry sectors analysed in the US, China and EU28 low-temperature waste heat below 230ºC makes up from 33% up to 60% of waste heat. The recovery of low-temperature waste heat is usually complex, affected by the user demand, mismatches between the waste heat source and the user demand, limited space for heat recovery facilities, the heat-power conversion is not efficient for low-temperature waste heat, payback period, etc. The purpose of this paper is to present a methodology for technical and economic analysis of waste heat recovery. To address the issue of sensible criterion, methodology appropriate for small and medium enterprises is developed and in this paper, the user-friendly optimization integrating the heat exchange, energy conversion and heat storage is presented. A case study of waste heat recovery from an induction machine cooling system is used to demonstrate the applicability of the proposed methodology. The introduced methodology can simplify the heat pump integration process, and the proposed method can be further extended to other industrial processes for low-grade waste heat recovery.

Index Terms - Waste heat recovery, Heat pump, Industry

I INTRODUCTION

Small and medium enterprises (SMEs) and large manufacturing industries are two vital contributors of industrial growth and development of any economy [1]. However, industry processes, electricity and heat generation represent a substantial source of emission to the environment and it is necessary to continuously develop and improve these processes in order to enhance their overall efficiencies. In the EU28, it is estimated that 70% of total energy use in the industrial sector is used in thermal processes (furnaces, reactors, boilers and dryers) and up to a third of this energy is wasted through losses [2]. Furthermore, most of the energy sources in the industry are fossil fuels. All these processes are characterized by energy losses dissipated as waste heat to the ambient, mostly by cooling towers and cooling fans [3]. Possible applications of the waste heat are diverse and depend on the type and characteristics of the plant and on its thermodynamic properties.

Waste heat recovery is the process of collecting heat from different processes to be used later directly, upgrading it to a more useful temperature, and/or converting it to electricity or cooling energy. Thus, recovering waste heat can provide extra power, heat or cooling but this opportunity at the same time is a great challenge.

Three essential components required for waste heat recovery are: (1) an accessible source of waste heat, (2) a recovery technology, and (3) possibilities for the recovered energy to be used [4].

Installing additional heat recovery equipment can affect technical improvements, but despite many positive effects, there are practical and financial limitations that have to be carefully analysed [4].

The energy generated from heat recovery, if it is not required by the process or industrial site, must be exported to neighbouring facilities and/or distribution networks.

The waste heat recovery also implies financial savings as well as a reduction of GHG emissions, which significantly reduces the negative effect on the environment [5]. In the business context, the industrial sector shows an increasing interest in waste heat recovery, due to the need for consumption and cost reduction and increasing competitiveness.

There are many known technologies for waste heat recovery from combustion exhaust gases, cooling liquids or exhaust steam, depending mostly on the type of heat carrier, amount of heat available and temperature. While applying special equipment, waste heat may be utilized for electricity generation either the production of cooling or heating media.

Recently the role of SMEs in the transition to renewable and sustainable energy systems has been recognized. The manufacturing industry needs to support sustainable development by reducing energy consumption and improving efficiency. Hence, attention has been shifting to SMEs, which can successfully commercialize new technologies, but doing so is complex and quite challenging [6].

Waste heat recovery is most often one of the energy saving measures analysed within the energy management system. Direct tangible benefits of implementing an effective energy management system also include:

- Savings on energy costs;
- Optimal use of energy sources;
- Reduction of energy consumption;
- Increasing energy efficiency and performance;
- Reduction of environmental pollution;
- It helps to harmonize energy consumption with the legal provisions [7].

With the energy efficiency program (a planning document that an oblige of the energy management system adopts for a period of three years), company can provide reduction of energy consumption per unit of product that brings a reduction in financial costs for procurement of energy sources and reduction of CO_2 emissions per product unit. It also can enable a company:

- To achieve significant financial savings and to become competitive on the market;
- To achieve effective compliance with the law regulations and technical recommendations;
- To reduce energy consumption, that guarantees sustainable development of the company and significant environmental progress;
- To become one of the carriers of energy efficiency development in the region [8].

However, companies in Serbia are faced with many problems: the under developed market, unfair competition, uncontrolled import of products, and therefore a small portion of their profits to invest in increasing energy efficiency and waste heat utilization. In addition, a big problem is the lack of information and resources especially in SMEs. It often happens that the management pays the energy costs, believing that these costs cannot be optimized [9].

Since implementation of energy management system and designated energy efficiency program is not expected to be generally found in SMEs, one of the solutions could be provision of private consulting experts and ESCO companies. There are certain shifts in private sector in Serbia and utilization of the ESCO companies. The management of SMEs places a high value on the consulting services that ESCO companies provide in the selection of machinery, electricity providers, etc. [10].

As mentioned above, small business owners often lack the tools, information or funds to adapt their practices, so the authors of this paper aim to contribute to the utilization of low-grade waste heat energy in SMEs.

The waste heat is generally classified into high-temperature (> 650°C), medium-temperature (230–650°C), and low-temperature (< 230°C) waste heat [11].

The recovery techniques for high- and medium-temperature waste heat are well developed and analysed; the higher the temperature, the higher the quality of the waste heat and the easier is the optimization of the waste heat recovery process [12]. The research activities in this field are intensive, due to the many waste heat exploitation options that are available [13]. Compared with low-temperature waste heat, high-temperature waste heat is more accessible to be recovered. Due to its high energy level, it could be used for power generation (and cogeneration) with relatively mature technologies that provide high efficiencies such as a steam turbine (Rankine Cycle) or Organic Rankine Cycle [14], waste heat recovering from exhaust flue gases [15], industrial high-temperature heat pumps [13], absorption chillers [16], absorption heat pumps [17], etc. For the same reason, the application of low-temperature waste heat recovery is limited by its temperature level: suitable user demand is not always available, and the heat-power conversion is not efficient for low-temperature waste heat. Because of its low exergy, the low-grade waste heat below 200°C, especially below 150°C, is difficult to be effectively utilized [18]. All these issues lead to difficulties and challenges in effectively achieving low-temperature waste heat recovery.

However, according to Xu Z.Y., et al. [19] in industry sectors in the US, low-temperature waste heat below 230°C makes up ~60% of the total waste heat. In China ratio of waste heat below 150°C is in the range from 44% to 66% (depending on the industrial sector) and in the 28 countries in European Union, one-third of the waste heat has a temperature level below 200°C. Therefore, finding potential applications of waste heat can greatly reduce the shortage of high-grade energy and improve serious environmental pollution effectively [20].

The recovery of low-temperature waste heat is usually complex, affected by the user demand, limited space for heat recovery facilities, payback period, etc. The decision to invest in heat recovery is challenged by many barriers of different nature. Here are listed three most common barriers that prevent wide applications of low-temperature waste heat recovery:

(1) There is a lack of methodology for the heat exchange network optimization when the heat-work conversion is concerned.

(2) Distributed waste heat recovery increases the installation space requirement, initial investment and operation costs.

(3) Mismatches between the waste heat source and the user demand on time, space and energy grade limit the potential of

waste heat recovery [19].

Significant savings can be achieved when companies take the time to analyse their energy consumption but for SMEs, energy management is still an unresolved issue due to competing priorities, lack of appropriate methodologies and scarcity of specialist knowledge and financial resources. Knowing types and the amount of energy used in the company represents a significant first step towards improving energy efficiency [21].

Low-grade waste heat as a major untapped source of energy in industry and SMEs could be recovered with mechanical heat pumps, absorption heat pumps, and absorption heat transformers, however, there are few guidelines on the selection and integration of heat pumps in industrial processes [22].

According to Wang M., et al. [22] a sensible criterion (thermodynamic and economic characteristics considered simultaneously) can help industries to select and integrate heat pumps into processes.

The purpose of this paper is to present a methodology for technical and economic analysis of waste heat recovery in SMEs. To address the issue of sensible criterion, methodology appropriate for SMEs is developed and in this paper, the user-friendly optimization integrating the heat exchange, energy conversion and heat storage is presented. A case study of waste heat recovery from an induction machine cooling system is used to demonstrate the applicability of the proposed methodology. The introduced methodology can simplify the heat pump integration process, and the proposed method can be further extended to other industrial processes for low-grade waste heat recovery.

II METHODOLOGY

The integration of industrial low-temperature waste heat into the energy supply is of great importance for sustainable development and for moving from a growth-driven toward an impact-driven approach. However, measures can only be taken and evaluated after a detailed, specific and case-by-case analysis and study of production companies and processes. Our approach was to make a simple methodology that could be used in SMEs for preliminary cost-benefit analysis based on data collected from power monitoring. With this methodology, we aimed to better couple the waste heat source and user demand time-scale using a heat pump and heat storage, promoting simple and user-friendly optimization.

Presented optimization methodology with preliminary cost-benefit analysis (Figure 1) is based on waste heat recovery from cooling systems using vapour compression heat pump.

The proposed methodology could be divided into three segments – thermodynamic, technology and economic analysis.

Thermodynamic analysis: To make the optimal connection between the waste heat source and user demand it is necessary to provide analysis of waste heat source (power monitoring data, orking hours of waste heat equipment) and user demand time-scale (climate data analysis for the region and user demand in winter, summer and transition season conditions). Collected data allows handling working hours/schedules and selection of representative days/hours to calculate necessary power of waste recovery equipment (heat pump in this case).

Technology assessment: For clear technology assessment for decision makers, besides heat pump, different technologies that are also appropriate for application in the cooling system have been also offered for the selection (chiller and cooling towers). To optimize technology selection in all cases is proposed application of buffer tanks as auxiliary equipment.

In recent decades, heat pumps have been increasingly applied to improve the energy efficiency of industrial processes through low-grade waste heat recovery [22] and thus are analysed as the main potential technology. Even though heat pumps are a rather known and simple technology, almost all projects involving waste heat utilization are retrofitting projects where the space is often limited and the network required to recover waste heat could be too complex, which would reduce profits so these factors should be concerned [3]. In addition, after the heat pump has been selected and integrated, there are different proposed criteria for performance evaluation.

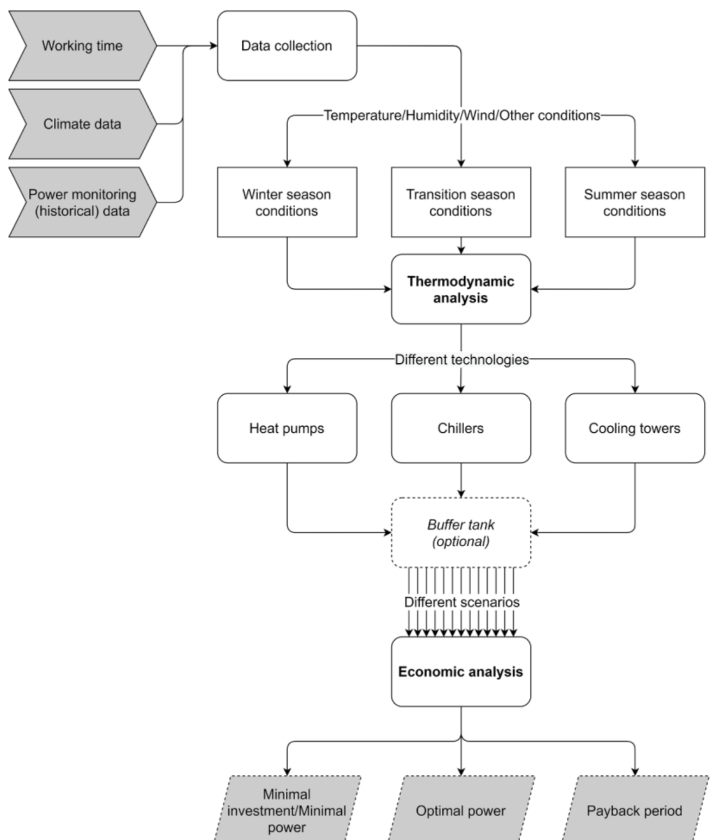

Figure 1. Proposed methodology

Economic analysis: With data acquired from two previous steps, cost-effective analysis has been developed and potential savings of energy and payback time have been calculated.

The main objective of the proposed methodology is to help decision makers to decide whether waste heat is worth utilizing as an energy resource. Given the amount of waste heat and heating demand, a simple calculation could be performed and determined if they should invest in the equipment (heat pump).

After that, they could take into account other factors such as environmental and social benefits.

The proposed methodology is already implemented in different SMEs with different operation processes (induction heating machines, printing machines, dairy, food and beverage industry, etc.). For easier demonstration here is presented a use case with induction machines.

III Use Case – Methodology Implementation

In Serbia, there are significant, locally available sources of energy: waste heat from industrial plants, municipal waste, waste heat from waste water treatment plants; none of the above energy source is used in Serbia [23]. Here, with the use case, it is demonstrated how to analyse the amount of low-grade waste heat using the proposed methodology in a company that uses evaporative cooling towers for cooling induction machines.

The company has been a specialized manufacturer of safety parts – ball joints, tie rods, torque rods, suspension joints, radius arms and repair kits. For over half a century, it has been meeting the very strict demands of the automotive industry. A broad product range, with more than three thousand items, encompasses nearly all types of commercial vehicles of the European manufacturers.

Two parts of the production process (Figure 2) are the main sources of waste heat (Process of cutting, heat-treating/ forging, pressing and thermal treatment and Finalizing the process of surface protection – coating) and they are analysed and subjected to the proposed methodology. In the use case – a plant with three operating sections (Figure 3), for cooling induction machines, furnaces, presses, and other equipment of nominal power 1.350 kW is used as an open evaporative-tower water system with a plate heat exchanger.

Figure 2. The production process in the plant

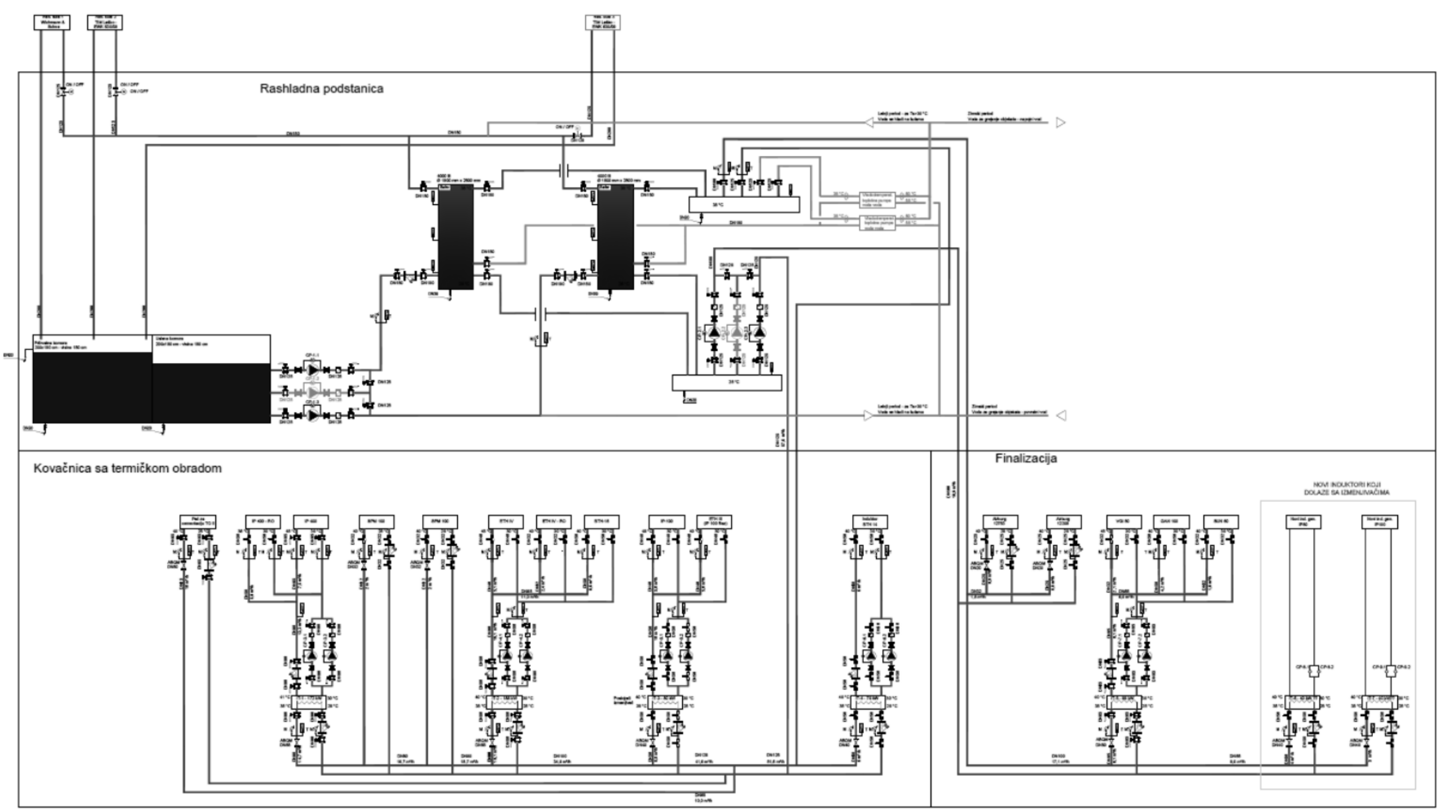

Figure 3. The layout of the plant

The existing plant cooling system consists of three independent cooling systems each connected to its own cooling tower, with independent circulation pumps and pipelines. Coldwater is supplied to consumers at a maximum temperature of 30°C. The temperature of the output water sent to the towers from the consumers is in the range of 35-45°C. The existing plant cooling system was detected as a potential source of waste heat.

According to measurements, the maximum electric load does not exceed 500 kW. Since the cooling capacity of the individual cooling tower is greater than 500 kW of cooling energy, it is concluded that with the central cooling system and the current intensity of work, one tower in operation will be enough for the cooling needs of all consumers. Currently, due to separate cooling systems, all three towers are in operation, since at least one consumer in each plant section is in operation. The disadvantage of the existing decentralized cooling system is also in the unreliability of the system, considering that due to the failure or maintenance of one of the cooling towers, the entire plant section connected to that tower stops working.

An additional reason for analysis is that in periods of high outdoor temperatures when it is not possible to provide cooling water of 30°C with existing cooling towers, there is a downtime in the operation of production plants.

The first step in methodology implementation was the installation of power monitoring equipment for four months and collecting data on working hours in the plant. The second step was gathering weather data for the local area. The result of this methodology segment is the number of working days/hours of the specific equipment (heat pump, chiller, cooling towers) in different seasonal conditions and the definition of a typical day/hour.

As already mentioned for the clarity of decision making in the segment of technical assessment three scenarios were considered:

- Scenario 1: implementation of high capacity buffer tanks and use of existing cooling towers;
- Scenario 2: using a heat pump and existing cooling towers for the cooling system and space heating;
- Scenario 3: using a chiller and existing cooling towers for the cooling system.

In the last segment of the proposed methodology, potential savings of electricity and natural gas (due to space heating of the plant with heat pump in winter) and the payback period of the equipment are calculated.

Results of methodology implementation in the use case

To avoid downtime due to high outdoor temperatures and to improve the efficiency and reliability of the cooling system, one central cooling system has been suggested, to which all three existing cooling towers are connected. The reconstruction envisaged that the cooling towers will remain in the places where they are currently located, and the cold water from the cooling towers will be led to the central open reception tank (3.5 m^3) located in the cooling facility. For the accumulation of cooling water two heat storages (buffer tanks), with a volume of 4.0 m^3 each, were designed. Buffer tanks will be connected with a heat pump, which would provide reliable cooling of equipment even at high outdoor temperatures in the summer and the use/recovery of waste heat for the heating production plant in the winter.

The heat pump capacity was calculated through two steps:

- Step 1 defines the minimum heat pump power. The minimum theoretical power of the heat pump (for a specific use case), is approx. 99 kW of heat and approx. 29 kW of power. This heat pump is not recommended, as it would require a significant investment in a high capacity buffer tank.
- Step 2 defines the practically usable, optimal heat pump power, based on the average days (Mon - Fri) and the load during those days. According to the data (Figure 4), the highest heat load occurs on average Monday at 9 o'clock (159 kW). This value does not correspond to the maximum heat load during the observed period (January - April 2019) which is about 280 kW, but this heat load can be removed by a heat pump of 159 kW (adopted power of 200 kW) with a buffer tank of appropriate dimensions.

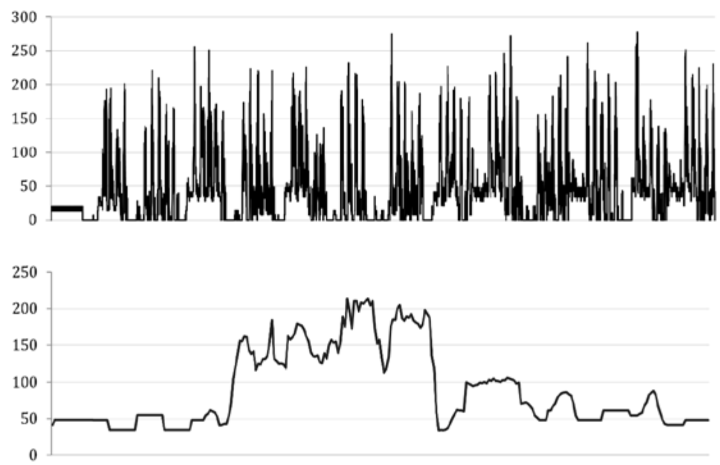

Figure 4. Quarterly (above) and 24h load (bellow) of induction heaters (kW) in use case

The follow-up procedure, (step 3) defined the planned operating time of the heat pump during the working week (Mon-Fri) which influences the equipment payback period.

In this specific use case, the reconstruction of the cooling system and optimization of heat pump and cooling tower operation would result in annual electricity savings of 121,434 kWh. In addition, thermal energy produced by heat pump would be used for office building heating (natural gas is used for office building heating now). With savings in electricity and natural gas, the payback period of the investment would be 2.04 years. Energy savings will increase with more work hours, and vice versa.

IV Conclusion

A large industry has been cutting costs for decades and actions waterfalls to smaller companies that are pressured in also acting costs to stay competitive. Since the big industry has its own R&D departments or finances R&D projects, SMEs need user-friendly methodology, which could motivate them to join the movement of the energy transition. With the energy transition, more pressure will be put on using electricity but also to use it wisely and waste heat recovery with heat pumps is the technology that will be on the rise.

In this paper, we have set out a methodology that we recommend to be used in SMEs during energy management survey to make the first assessment of amounts of waste heat and necessary investments in heat pump as a relatively simple, mature, reliable and low-cost technology (suitable for those reasons to be implemented in SMEs). We have found out that methodology is particularly suitable for early assessments for energy efficiency improvement projects and plant refurbishments.

The methodology presented here intends to help companies dimension solutions that would save energy. Such assistance for SMEs is more than necessary for several reasons. The main reason is that the approach to proper sizing of heat pump for waste heat recovery, as a rule, remains unclear and there are few guidelines [22]. Although the decision-makers are often familiar with possible solutions and ways in which they could benefit from the implementation it ends in precautionary oversizing or even leaves space for equipment suppliers to deliver the equipment with a capacity larger than necessary.

When designing this methodology, special attention was paid to user-friendliness and transparency, to enable decision-makers and implementing engineers to approach the introduction of changes in the plant with full understanding and to empower them during negotiations in the procurement of equipment.

To sum up the present situation, the waste heat recovery in SMEs is still in a preliminary stage. For the quality approach, energy data statistics is essential and the use of reasonable technology – the technological guidance on utilization of waste heat should be established. Finally, a stimulating mechanism is necessary – a market mechanism to speed up the promotion of waste heat recovery in industry and SMEs to boost energy transition.

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