Solutions to recover the energy lost to an industrial consumer

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Abstract. Efficient capitalization of energy resources is a top priority and is the concern of specialists in all areas of activity, taking into account the current energy policies in the world. Although the technological race to optimize renewable energy solutions has engaged many countries, however, a concern to reduce energy consumption - under climate change - must become a necessity. To this end, the article highlights the importance of recovering the lost energy and exemplifies the capitalization of this energy potential to an industrial consumer. Following the experimental research, based on the analysis of the lost energy recovery solutions, the optimal solution was established. The analysis of energy consumption before and after installation of the optimal system indicates reductions in energy consumption with positive effects both on the environment and on the costs of the economic operator.

1. Introduction
Various health and environmental agencies and committees have produced a series of reports and communications, based on scientific evidence, confirming the worrying effects of air pollution on health [1-5]. Reducing negative environmental impacts caused by industrial production activities can be achieved by stimulating the investment in energy-efficient equipment.

Lately, due to high energy consumption, the recovery of heat lost through different systems is increasingly used in buildings in all sectors (residential, tertiary and industrial). As a rule, in the residential and tertiary sector, heat recovery systems are installed on the foul air exhaust circuits, but for industrial buildings where there are production facilities equipped with various installations, heat recovery can be done both on the foul air exhaust circuits as well as on hot gas exhaust ones. The recovered thermal energy from hot air or hot gases is used to preheat the air introduced into the rooms or into rooms with industrial technological facilities [1], [6], [7]. The air and gas streams are completely separated and may be oriented in cross or opposite direction, in which case the thermal efficiency increases. The percentage of heat recovery in the exhaust air or gas can reach up to 90%.

Worldwide, the industrial sector uses a significant part of the total energy consumed annually. Given that energy resources are limited, meeting energy demand for the industrial sector and minimizing its economic impact will be a challenge for the future [1], [7-9]. Therefore, as the cost of energy is rising, the demand for energy-efficient solutions is becoming more acute.

The main objective of the study is to establish local solutions for recovering lost energy from an industrial consumer. In this respect, air or hot gas exhaust circuits have been identified from energy-intensive energy technology such as DDB (dyeing/drying booths) [7], [9-10]. The energy is lost by
exhausting the hot air inside the DDB through the booth ventilation system, and the flue gases are evacuated into the atmosphere through the chimneys. From the thermography of the two exhaust circuits it was found that the lost energy represents a considerable amount, which can be recovered by using various systems [10]. In order to identify solutions for reducing energy consumption, an analysis of the consumption of electricity and natural gas was carried out, which was the basis for choosing the optimal version of the 4 analyzed solutions [7], [10].

2. Description of the analyzed industrial technological facilities
Industrial technology (IT) such as dyeing / drying booths in pressurized systems are high energy-consumers (electric and flue gas). The study was conducted at 4 dyeing / drying booths (DDB) and a drying oven made of fiberglass reinforced resin at the economic agent. The location of the 4 dyeing / drying booths in the production area is shown in Figure 1 [1], [7].

![Figure 1](image-url)

**Figure 1.** Dyeing/drying booth: a) DDB 1-DDB 4 (CV1J- CV4J) booths placement (location) within the production area and b) booth schematic diagram.

The components of the DDB are: the booth made of insulated metal panels, hot air generator, exhaust system, dry filtration system, electric drives and automation installations, electrical lighting installations, compressed air supply systems.

The monolith generator-extractor group is positioned behind the booth. The burners operate with gaseous fuel (natural gas type G20). Due to the large surface of the filter ceiling, a constant air flow is ensured under good filtration conditions. The suction solution through the rear wall provides a semi-vertical airflow inside the paint booths to create a suction front. The suction fronts ensure the suction of dyed particles during the dying process. Accelerating the air into the filter ceiling creates an internal overpressure that prevents dust from entering the outside of the booth and accelerates the displacement of particles loaded with paint vapors to the suction front. The exhaust fan is connected to the chimney hood of the suction wall through a galvanized sheet tubing. Filtration of foul air is performed with filters, and then discharged through a sealed tubing into the atmosphere at relatively constant speeds.

A general operating scheme, valid for all the DDBs existing at the economic agent, is presented in Figure 2 [10]. DDB dyeing / drying cabin burners have the following common features:

- fuel: natural gas fuel;
- pressure: \( p = 25 \text{ mbar} \);
- installed flow: \( q_i = 34,24 \text{ Nm}^3/\text{h} \);
- maximum power: \( P_{\text{max}} = 315\text{kW} \);
- fan flow hot air intake/foul air exhaust.

From the operating regime point of view, the DDB burners have a random regime (flow and pressure), which varies according to the economic operator production requirements.
3. Identification of the recovered energy potential circuits for the analyzed industrial technological facilities

The identification of lost energy circuits to recover lost energy was performed by thermography using a FLIR infrared camera. The results of the flue gas circuit thermography are shown in Figure 3, and those of foul air exhaust circuit in Figure 4 [10]. The maximum flue gas temperature (Tga) at the burner outlet is around 140 °C [10].

![Block diagram of the existing plant at the economic agent](image)

**Figure 2.** Block diagram of the existing plant at the economic agent: Tga – flue gases temperature, p-pressure of GNC, q – installed flow of GNC.

**a) flue gases circuit**

**b) thermography**

**Figure 3.** Flue gas exhaust circuit thermography for Solution 1 and Solution 3 analysis.

**a) foul air circuit**

**b) thermography**

**Figure 4.** Foul air exhaust circuit thermography for Solution 2 and Solution 4 analysis.

Based on the thermographs analysis, it is noticed that the fluids exhausted into the atmosphere (foul air and hot gases) are carriers of thermal energy lost through exhaust into the atmosphere. Based on the results, solutions for energy recovery have been set, solutions that achieve reductions in final energy consumption to the industrial consumer.

On the other hand, by measuring the speed of the exhaust air through the ventilation system of the DDB booths, the kinetic energy of the air jet was identified as recoverable potential [11]. Therefore, two possible directions for recovering the lost energy exhaust into the atmosphere through exhaust channels have been identified.
4. Proposed solutions for recovering lost energy

For the two identified directions, four solutions have been proposed to reduce energy consumption [10]. Under real conditions of the operation and location of the dyeing / drying booths and their related facilities at the economic agent, it was analyzed the possibility of placing an economizer on the flue gas exhaust circuit and the foul air exhaust one, circuits on which important quantities are lost energy. In order to use the kinetic energy of the exhaust air jets at significant speeds, the possibility of installing a low power wind-power station to provide the electrical energy required for the DDB lighting was considered [10-11]. Thus, the following possible solutions were analyzed:

**Solution 1.** Insertion of the economizer on the flue gas exhaust circuit (Figure 5) [10].

![Figure 5. Block diagram proposed through Solution 1: Tga – flue gases temperature, Tgr – cooled flue gases temperature, p-pressure of CNG, qi- installed flow of CNG.](image)

**Solution 2.** Insertion of the economizer on the foul air exhaust circuit before the exhaust fan (Figure 6) [10];

![Figure 6. Block diagram proposed through Solution 2: Tga – flue gases temperature, p-pressure of CNG, qi- installed flow of CNG.](image)

**Solution 3.** Insertion of the economizer on the exhaust flue gases circuit and installation of the wind turbine at the foul air exhaust grid (Figure 7) [10];
Figure 7. Block diagram proposed through Solution 3: Tga – flue gases temperature, Tgr – cooled flue gases temperature, p-pressure of CNG, qi- installed flow of CNG.

Solution 4. Insertion of the economizer on the exhaust foul air circuit and behind the fan of exhaust foul air and installation of the wind turbine at the foul air exhaust grid (Figure 8) [10];

Figure 8. Block diagram proposed through Solution 4: Tga – flue gases temperature, p-pressure of CNG, qi- installed flow of CNG.

5. Analysis of proposed solutions and results interpretation
In order to analyze the proposed solutions, a number of significant parameters were monitored to assess the amount of energy recovered. Thus, the temperature of the flue gases, the temperature at the recovery reactor, the DDB lifetime, the average fuel consumption, the average hourly consumption of combustible natural gas and the temperature inside the cabin were monitored. For monitoring the temperatures, PT 100 temperature sensors mounted on the flue gas exhaust chimney on the inlet and outlet of the economizer were used and a temperature recorder YCT R1-6111Temperature + RTD Temperature Data logger was used to monitor the temperature inside the DDB. The natural gas fuel consumption was recorded by installing a G6 natural gas meter [7] and [10].

For dyeing / drying booths, Solution 1 is suitable both for the location of the equipment in the existing space and for the low operating cost. In order to illustrate the outlet temperature from the economizer, the circuit thermography was performed. The recorded values are shown in Figure 9 [10].
Figure 9. The tubing thermography at the blast-heating apparatus outlet.

The amount of energy recovered from the application of Solution 2 evaluation was performed on the basis of monitoring the same parameters with taking into account both the thermography results of the foul air exhaust circuits (Figure 4) during the same periods considered for Solution 1.

During drying, inside the booths it is necessary to ensure a temperature of (40-60) °C, and for the dyeing operations, the required temperature inside the DDB is of 20°C. It has been found that temperature at the economizer outlet varies according to the technological operations that take place inside the DDB (drying), and thus, during the drying operations, temperatures ranging from 25°C to 30°C were recorded at the economizer outlet. In the dyeing case the temperature varied between (8-10) °C [10].

For the second direction taken into account, namely the conversion of the kinetic energy of the air jet exhaust by the DDB exhaust systems, the exhaust air jets speeds at different distances related to the exhaust grids were monitored. Considering the common fan characteristics of the DDB - fan air exhaust fan flow: 20.000 m³/h - in Figure 10 [7], [9-10] are presented the results of the exhaust air jet speed measurement for two of the analyzed booths.

Solution 3 and Solution 4 were obtained as a result of the Solution 1 or Solution 2 installation in the operating circuit of a wind power plant at the foul air exhaust grid. The installed wind-power station, model NE - 600M2, is a synchronous three-phase generator with a permanent magnet of 0.6 kW [10].

To achieve Solution 3, the economizer on the flue gas circuit was inserted, and a low power wind-power station was installed outside the production area at the foul air exhaust grid. The two circuits were treated and evaluated separately. For the economizer insertion on the flue gas circuit, the same parameters were analyzed as in Solution 1, and for the wind turbine, rotor speed measurements were made at different directions of the turbine blades relative to the air action direction. For the analysis of the heat recovery from the flue gas outlet, the results are presented in figure 11 [10].

Figure 10. Airflow rate monitoring.
Figure 11. Monitored parameters for the system proposed through Solution 3.

The low-wind power plant was installed in the proximity of the foul air exhaust grids in two of the analyzed booths, since the exhaust sections are located at the same height (2.5m from the normalized pitch). This location made possible to build a simple and mobile structure to support the wind power plant.

In order to eliminate any doubts about the effect of decreasing the air jet speed following the insertion of the economizer on the foul air exhaust circuit, Solution 4 was also analyzed, namely, the installation of the heat recovery system on the foul air outlet circuit and the wind turbine at the foul air exhaust grid [10].

From the comparative interpretation of the experimental results it was concluded that:

In the Solution 1 application case, the temperature range (35-40 °C) recorded at the outlet from the economizer on the inlet preheating air into the DDB does not depend on the alternation of the operations (painting / drying) that take place inside the DDB and contributes to a great extent, to the preheating of the air introduced into the booths.

With respect to the Solution 2 analysis, even if the recovery temperature ranges (25-30) °C at the economizer outlet during drying and (8-10) °C during dyeing operations are not negligible, there have been three major drawbacks concerning the Solution 2 implementation, namely [10]:

- loading the exhaust foul air with paint vapor that were deposited on the recovery filter;
- the air jet outlet speed reduction;
- the economizer insertion on this circuit involves providing an additional space that can affect the productive space organization at the economic agent.

For these reasons, Solution 2 has not been proposed for integration into the proposed system as an optimal system.

As a proposed optimum system, insertion of the economizer on the exhaust gas circuit was established and the installation of the wind power plant on the foul air exhaust circuit, i.e. Solution 3.

By taking into account the interventions at the economic operator installations, the verification of the CNG installations sealing with the TESTO 350S portable gas analyzer was carried out during the installation works. For the optimal system implementation, one of the booths was chosen based on the highest number of operation hours and the possibilities of installing the economizer without additional costs. The heat exchanger was located above the booth making short lines for both the flue gas exhaust circuit and the economizer outlet circuit and input into the DDB. The heat recovery unit uses two fans and two separate pipe systems for the flue gas circuit, respectively for the fresh air
circuit. For monitoring parameters on the flue gas exhaust circuit, temperature sensors were installed on the inlet / outlet paths of the economizer connected to a data acquisition station. For the evaluation of the kinetic energy conversion of the air jet exhaust by the foul air exhaust system, a low wind power plant was installed (Figure 12) [10].

Inlet and outlet temperatures at the economizer were monitored within one month (November 2017) (Figure 13) [10].

Regarding the monitoring of the operating parameters, the wind turbine rotor speed was recorded with a non-contact electronic tachometer, at different values of the air jet speed. The results of the monitoring are shown in Figure 14 [9].

From the analysis of the speed variation according to the location distance (Figure 10) and the speed of the wind-power station (Figure 14) it is observed that at a distance of 0.5 m from the position relative to the exhaust grid, the air jet speed is about 13m/s (speed that corresponds to the nominal wind turbine value) at which the speed will be about 750 rpm.

The power produced by the wind-power station is stored in 2200Ah batteries and converted to AC
by the Axpert EX-MEX + 1 kVA -3kVA inverter. Until connections to the cabin lighting system are done, the wind power system supplies a 100W consumer used to illuminate the outer areas at night (Figure 15) [10].

Figure 15. Electrical installations for illuminate the outer areas.

6. Conclusions
Starting from the global concern about the current state of pollution, we believe that any approach in order to limitate it is favorable. Although general attention is directed to the use of renewable energy sources, we also consider the focus on reducing consumption by recovering lost energy.

In support of the need for energy efficiency through the efficient use of energy to large energy consumers, the article addresses the issue of energy efficacy by capitalizing the lost energy to an industrial consumer. The main results of the study resulted in the following results:

- identifying and proposing for each analysis direction solutions integrating energy recovery systems (Solution 1, Solution 2, Solution 3 and Solution 4);
- establish and analyze the optimal solution.

The identification of areas with unused energy potential and the proposal of lost energy recovery systems was carried out in order to reduce the industrial consumer energy consumption. In situ measurements at the DDB booths provided important information on the possibilities of recovering lost energy during their operation. Based on these analyzes, the optimal solution - Solution 3, was established both constructively and functionally. The data obtained will be analyzed by further
research on the basis of which decisions will be made regarding the opportunity of installing the recovery systems and other technological endowments at the industrial consumer.

In conclusion, the issue of climate change - which is already too visible - obliges industrial consumers to make technological systems and equipment more efficient by implementing measures for the rational use of energy resources and also for recovering some fractions of lost energy.

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References
[1] Tokar A, Negoiţescu A, Retezan A and Doboşi S I 2017 Concept de economisire a consumului de gaze naturale combustibile la cabine de vopsire/uscare, Conferinţa cu participare internaţională Știinţa Modernă şi Energia SME, Cluj-Napoca, Romania, pp. 217-224
[2] Wang J 2015 The Health Impacts of Energy Choices – Healthy Energy Initiative, Health Care Without Harm (Oct.) 4-7
[3] Health and Environment Alliance, Activity Report 2015 Promoting Public Health Through a Healthy Environment in Europe and Beyond 1-5
[4] The 2016 New Climate Economy Report – The Sustainable Infrastructure Imperative, New Climate Economy 69-83
[5] IEA 2017, Energy and CO2 emissions in the OECD, OECD/IEA 2-7
[6] Negoiţescu A, Tokar A, Negoiţescu D and Hamat C 2017 Energy Efficiency of Technological Equipment at the Economic Agent by Identifying the Points with Recoverable Heat Potential, Analele universităţii “Eftimie Murgu” Reşiţa XXIV(1) 257-266
[7] Tokar A 2016 Raport ştiinţific şi tehnic privind implementarea proiectului Nr. 74BG/2016, cod: PN-III-P2-2.1-BG-2016-0254, în Etapa I
[8] Pellegrino J L, Margolis N, Justiniano M and Miller M 2004 Energy Use, Loss and Opportunities Analysis, U.S. Manufacturing & Mining, Energetics Incorporated
[9] Tokar A, Negoiţescu A, Negoiţescu D and Adam M 2017 An Approach Regarding the Application of Energy Efficiency Measures to Industrial Consumers, Conferinţa “Instalaţii pentru Construcţii şi Confortul Ambiental”, Timişoara, România, Aprilie 6-7, pp. 223-230
[10] Tokar A 2017 Raport ştiinţific şi tehnic privind implementarea proiectului Nr. 74BG / 2016, cod: PN-III-P2-2.1-BG-2016-0254, în Etapa II
[11] Negoiţescu D, Tokar D, Tokar A and Negoiţescu A 2017 Aspects Regarding the Valorisation of the Air Jets Energy Potential from Industrial Technological Equipment, Analele Universităţii “Eftimie Murgu” Reşiţa XXIV(1) 267-277