ANALYSIS OF ENERGY PERFORMANCE OF A COGENERATION SOURCE

FELEA Ioan[*], CRENCI Emil[**], SZABO Emeric[*]

* University of Oradea

** SC Zahărul Oradea SA

ifelea@uoradea.ro

Abstract - Knowledge of energy performance indicators is essential to substantiate investment decisions in energy facilities. Energy audit is the procedure by which energy performance indicators can be assessed and identified measures to improve them. Considering the share and the potential to improve the efficiency of cogeneration sources for the production of thermal and electrical energy, the determination of their performance indicators based on energy audits is essential for achieving the goals of reducing energy consumption. This paper is a synthesis of the results obtained in performing the energy audit of a cogeneration source serving an industrial consumer. After describing the general framework, the justification of the concern and the presentation of the defining elements of characterization of the analyzed installation, the second part of the paper refers to the specificities of the applied complex energy balance model. Next, reference is made to the methodology for obtaining input quantities in energy balance models and mass balance sheets. The final part of the paper presents the results obtained, the values of the performance indicators, the measures for improving the energy efficiency and the general conclusions of the analysis.

Keywords: source of cogeneration, energy audit, performance indicators.

1. INTRODUCTION

Sources of electricity generation (EE) and thermal energy (TE) in cogeneration (S-CGE) are considered advanced fossil and renewable energy conversion technologies in EE and ET with high energy efficiency potential [1 ÷ 5]. For this reason, cogeneration is one of the ways to increase energy efficiency and reduce energy consumption. All documents of the European Union and Romania referring to Sustainable Development and Energy Issues [6 ÷ 10] include explicit references, objectives and targets regarding the share of S-CGE in all the sources used for obtaining EE and ET respectively in the energy performance of them.

In [9,10] there are written the main ways of action for increasing the weight and performances of S-CGE in Romania:

Identifying and capitalizing on the national cogeneration potential;

- Energy audit of cogeneration units;
- Construction of new high-efficiency cogeneration plants.

In [9], the national target of 240 thousand toe energy consumption is assumed by promoting high-efficiency S-CGEs. The official regulations also specify the energy efficiency levels of these sources. In [9], the minimum value for the overall efficiency of ET and EE production in cogeneration is 70%, and an [75 ÷ 80]% range is allowed in [7]. In [9,10] it is set as a target for 2020, 75% ET produced in cogeneration in Romania.Cogeneration of high efficiency is an important concern, reflected also in the specialized scientific literature. For example, in [2,3,4,11], on the basis of theoretical and experimental evaluations, the indicative values of some indicators characterizing CET in cogeneration on solid fossil fuels are specified:

- Electric power: [0,5 ÷ 250] MWh;
- Global yield: almost 80%;
- Technological own consumption: [3-12]%;
- Cogeneration Index: [0,1 ÷ 0,6]

In [4] there are mentioned for these sources values of the overall efficiency in the range of [85 ÷ 90]%, to a cogeneration index of 0.25 and nominal power of [10 ÷ 150] MW. In [12], Siemens's analysts conclude that for a share of [35 ÷ 60]% of EE produced in CTE with state-of-the-art cogeneration, their overall energy efficiency may reach 90%. Under the BTE [13] for a biomass-fueled cogeneration power plant with a rated thermal input of 11,10MW and rated power of 5MW; with a similar destination to that analyzed in this AEC (for an industrial consumer); at a load of 99.2% and a cogeneration factor of 0.21, 87% was obtained - for the efficiency of the boilers and in turn, 85.7% - the overall yield. We mention that the equipment in this CET is of recent production (2010), the burning process being more efficient (eg the CO_2 content in GHG is only 7.45% and the temperature is 126 ° C). Fewer inferior performances of cogeneration groups recorded the groups of CETs built in Romania during the industrialization [1960 - 1985] [2,3,10,11,14]. For example, for CET1-Oradea, in Table 1 we have reproduced the yield values at CET1-Oradea - the last 9 years of operation in full configuration. Currently, within the S.C. TERMOFICARE SA, Oradea a local district heating operates, a state-of-the-art methane cogeneration power plant.

This paper is a synthesis of the Energy Audit documentation performed on S-GCE with the structural diagram shown in Figure 1 and the main features [15]:

- Boiler (CZ) is radiant LENTJES type, with mobile grill, with the characteristics:
  - Thermal rated output: 58 MWt;
  - Nominal steam flow rate: 64 t / h;
  - Nominal steam pressure and temperature: (60 bar; 455 ° C);
  - Nominal air supply flow rate: 84000 m^3 / h
- Turbine (TB):
  - Nominal flow:58 t/h
  - Pressure and nominal temperature: (66 bar ; 450 °C);
- Electric generator (G) :
  - Nominal power : 10,5 MVA/8 MW
  - Rated voltage: 10,5 kV
- Reduction (TBG) : 8000/1500 rot/min

- Exhaust transformer (TEV) : 10 MVA; 10,5 kV/ 6 kV;
- Own service transformer(TSP) : 2 MVA; 6 kV/ 0,4 kV;
- Power installed in consumers' own services (CSP) : 1600 kW;
- Diesel group for vital PSCs : 1MVA / 0,8 MW / 0,4 kV
- Cooling Reduction Station (SRR) – to adjust the steam parameters (P, θ) to the needs of the technological proces
- Other specific installations and equipment [15]

The technological process in which the energy produced by this S-CGE is used is the production of white sugar from sugar beet and raw sugar. This process is represented in Fig. 1 through the evaporator - the space in which most of the ET produced by S-CGE is transferred to the process.

Table 1. Global yields values of CET1-Oradea - not upgraded [14]

Year / Ind.	2004	2005	2006	2007	2008	2009	2010	2011	2012
$\eta_b[\%]$	70,2	71	66	58,1	56,8	55,4	57,9	54,1	49,6
$\eta_n[\%]$	66,4	67,1	61,5	53,5	52,4	50,8	53,3	49,7	45,3
y_{CG}	0,21	0,18	0,19	0,23	0,25	0,26	0,27	0,23	0,21

(η_b, η_n) – gross and net yield; y_{CG} - cogeneration index
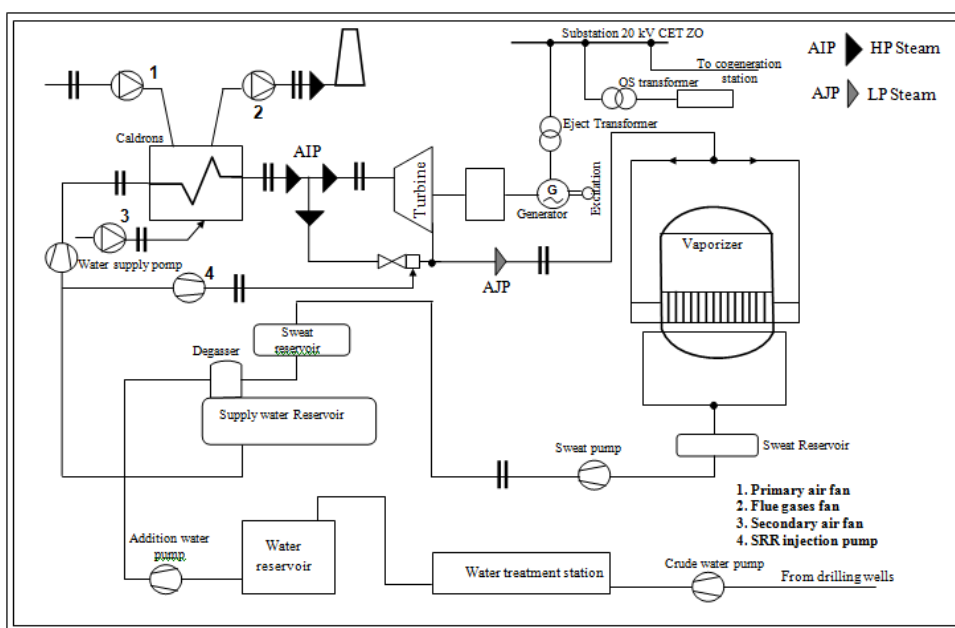
Fig. 1. Structural scheme of S-CGE

At nominal capacity, this S-CGE is characterized by the following :
- Consumption (inputs):
  - Charcoal: 4500-5000 kg / hour × 4300 hours / year = 19350-21500 tonnes / year
  - Biomass (optional, maximum 5%): 5.000 kg / h × 5% × 4300 hours / year = 1075 tonnes / year

- Calcium hydroxide: 65 kg / h × 4300 hours / year = 280 tonnes / year
- 30% hydrochloric acid: 5,000 l / month × 6 months / year = 30 m3 / year
- A45% sodium hydroxide: 2500 l / month × 6 months / year = 16 m3 / year
- Ammonia solution (ammoniacal water): 200 l per month; 1200 l / year

> ➢ Biocidal products - for water treatment
> ➢ Wood for starting the thermal power plant - maximum 6 tons per year (3 starts)
- Outputs:
  > ➢ Steam: 44 tons / hour × 4300 hours / year = 189200 tons / year
  > ➢ Thermal energy: 39 MWt × 4300 hours / year = 167700 MWt / year
  > ➢ Electricity: 4500 kW × 4300 hours / year = 19350 MWh / year
  > ➢ Used oils: 100 l per year
  > ➢ Ash (5.3%): 8 tons of coal / h × 4300 hours / year × 5.3% = 1823.2 t / year
  > ➢ Slag (7.8%): 8 tons of coal / h × 4300 hours / year × 7.8% = 2645.7 t / yeaan

The equipment used in the analyzed S-CGE is in a very good condition. The boiler is manufactured around 30 years ago, and the others are more recent. The S-CGE is equipped with a monitoring system (SM) that monitors and highlights on the monitors in the control room the vast majority of the dimensions that characterize its operationThe equipment used in the analyzed S-CGE is in a very good condition.

The boiler is manufactured around 30 years ago, and the others are more recent. The S-CGE is equipped with a monitoring system (SM) that monitors and highlights on the monitors in the control room the vast majority of the dimensions that characterize its operation.

2. THE MATHEMATICAL MODEL OF ELABORATED ENERGY

In order to identify the energy performance of S-CGE, its complex energy balance (BEC) was elaborated. Considering the structure of S-CGE, its block diagram was presented (fig. 2), in which the equipments and the sizes that intervene in the BEC were highlighted. The terms in figure 2 are: Q_i - unitary heat energy (power) [kW] (θ_i, P_i) - temperature (θ_i) and pressure (P_i) [° C; bar]; D_i - flow [kg / s] PA_i - pump; V_i - fans; RZp - main tank; ST - water treatment plant; DG - degasor

Taking into account the specific structure and processes as well as the methodology for elaborating the BEC [1,16 ÷ 20] for analyzed S-CGE, the following equations were used.
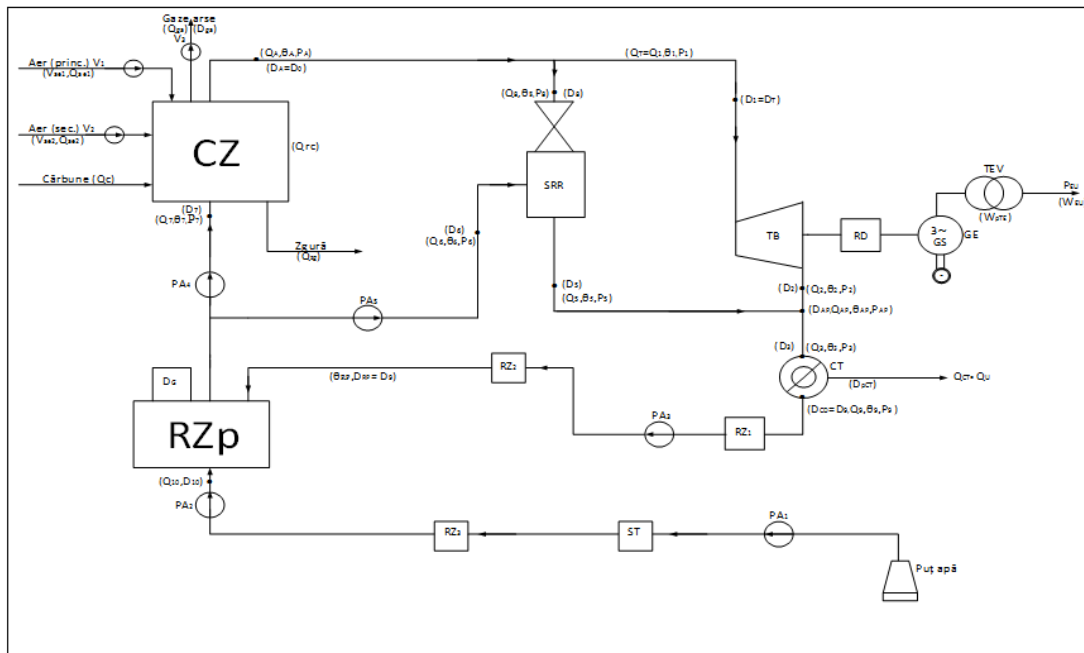

Fig.2. Block diagram of S-CGE

2.1. Energy balance

The equations of BE are:

$$\sum W_I = \sum W_U + \sum W_P + W_{CPT} \qquad (1)$$

$\sum W_I$ – the sum of the amounts of energy entering the contour; $\sum W_U$ – the sum of useful energy amounts; $\sum W_P$ – sum of energy losses; W_{CPT} – own technological consumption.

  a.) The energy enters the analyzed contour, mainly through the boiler, in the following ways**:**
  - The energy (heat) of the fuel (Q_C) ;

  - Sensitive heat of water supply to the boiler and water injected into the SRR (Qap);
  - Sensible heat of the boiler air (Qae);

There is also an electrical energy input component (W_{IE}) - through its own service transformer (TSP)

$$\sum W_I = Qc + Qap + Qae + W_{IE} \qquad (2)$$

The essential part is held by Qc.
  b.) Useful energy has two components:
  - Heat transmitted to the thermal consumer (Q_{CT}) – the process of manufacturing sugar;
  - Electricity injected into the SEE (W_{EN}).

Then, $\sum W_U = Q_{CT} + W_{EN}$ (3)

c.) **Energy losses can be grouped into categories, in line with equipment in the plant structure, thus:**

c1.) **The energy losses in the boiler** are in the form of heat and have the following components:

- Sensitive heat of combustion gases (Q_{ga});
- Heat lost through incomplete chemical burn (Q_{ai});
- Heat lost through radiation and convection of heated surfaces to the ambient environment (Q_{rc});
- Heat lost through purged water (Q_{apr});
- Heat lost through mechanical bindings (Q_{nm});
- Sensitive heat of the slag (Q_{zg})

Therefore, the energy losses (heat) associated with the boiler can be expressed as follows:

$W_{pcz} = Q_{pcz} = Q_{ga} + Q_{ai} + Q_{rc} + Q_{apr} + Q_{nm} + Q_{zg}$ (4)

c2.) **The energy losses on the generator group** [turbine (T) - reducer (RD) - synchronous generator (GE)] can be expressed with the relation:

$W_{pGG} = W_{pT} + W_{pRD} + W_{pG}$ (5)

c3.) **Power losses on the Exhaust Transformer** (WpTE) dissipate in its electrical and magnetic circuits. We will note with: WpCD - energy losses on CET-ZO connecting pipes; WCPT - own technological consumptionCPT of the power plant = EE consumption of components driven by electric motors (pumps, fans, GS excitement, lighting, etc.).

We will not evaluate the energy losses in the SRR, the connecting components (pipes) between the main equipment of the CHP by radiation, convection (these being short) and the CPT of the low-power elements, assuming that their share is error tolerable for BE [1]. If, in the end, we find BE inclusion errors higher than the admissible errors, then we will investigate these losses.

2.2. Mass balance (debit)

Based on the scheme of Fig. 2, it can be written:

$$\begin{cases} D_A = D_0 = D_1 + D_8 \\ D_2 = D_1 \\ D_3 = D_2 + D_5 = D_{AP} \\ D_5 = D_6 + D_8 \\ D_3 = D_9 + D_{pCT} \\ D_9 = D_{CD} = D_{RP} \\ D_{RP} + D_{10} = D_6 + D_7 \end{cases}$$ (6)

2.3. **Computational characteristics of BE components**

Energy in. The calculation relationships taken from [2] are adapted for the calculation of momentum power (power) and will be used as such. By multiplying the values obtained with the time interval, obviously the values of the energies are obtained.

The power input through fuel is calculated by the relation:

$Qc = D_c \cdot q_c$ (7)

D_c – fuel flow [kg/s], qc – the calorific power of the fuel [kJ/kg]

$Q_{ap} = Q7 + Q6 = (D7 \cdot \theta 7 + D6 \cdot \theta 6) \cdot c_a$ (8)

where: (D7,D6) – water flows [kg/s]; ($\theta 7, \theta 6$) – water temperatures [°C]; ca – the specific heat of the water [kJ/kg·°C].

$Q_{ae} = Q_{ae1} + Q_{ae2} = \lambda(V_{ae1} + V_{ae2})Dc \cdot c_{ae} \cdot \theta_{ae} = \rho_{ae} \cdot D_{ae} \cdot c_{ae} \cdot \theta_{ae}$ (9)

where:

λ – the equivalent excess air ratio measured at the exhaust of the combustion gases;

(V_{ae1}, V_{ae2}) – theoretical fuel air volume (Dc), introduced through the two fans [m_N^3/kg]; cae – the specific heat of the air at the boiler inlet temperature [kJ/kg·°C];

θ_{ae} – the inlet air temperature in the boiler [°C];

D_{ae} – the flow of air introduced into the boiler [m_N^3/s];

ρ_{ae} – air density at θ_{ae} [kg/m_N^3].

The absorbed electrical energy entering the EEA outline (WIE) will be measured in the primary service transformer (TSP). If it is not possible to measure in the primary, then the value measured in the secondary one will add the power losses on the transformer.

Useful energy

$Q_{CT} = Q_3 - Q_9 = D_3 \cdot i_3 - D9 \cdot i_9$ (10)

P_{EU} și W_{EU} are obtained from records of power and energy injected into SEN

The losses on the generator group are calculated directly with the relation:

$W_{pGG} = \frac{1 - \eta_T \cdot \eta_{RD} \cdot \eta_G}{\eta_T \cdot \eta_{RD} \cdot \eta_G \cdot \eta_{TEV}} \cdot W_{EU} = Q_1 - (Q_2 + W_{EU} + W_{pTE})$ (11)

Where:

$Q_1 = D_1 \cdot i_1$; $Q_2 = D_2 \cdot i_2$ (12)

$i_1 = f(p_1, \theta_1)$, $i_2 = f(p_2, \theta_2)$ (η_T, η_{RD}, η_G, η_{TEV}) – turbine efficiency (η_T), reducer (η_{RD}), generator (η_G) and TEV (η_{TEV})

The energy / power returned is the energy / power that condensate contains when reintroducing into the process / circuit. Will be calculated with the relation:

$W_{CD} = D_{CD} \cdot c_a (\theta_{RP} - \theta_{10})$ (13)

Output energy / power is calculated with the relation:

$\sum W_{IS} = \sum W_U + \sum W_p + W_{CD}$ (14)

The S-CGE's own technological use (CPT) is obtained by measuring EE in contour in the primary of own service transformer(T_{SP}). So,

$$W_{CPT} = W_{IE} \qquad (15)$$

2.4. Energy Performance Indicators

Expressed in accordance with [1].

- **Gross energy yield**

$$\eta_b = \frac{\sum W_U + W_{CPT}}{\sum W_I} \, 100 \quad [\%] \qquad (16)$$

- **Net energy yield**

$$\eta_n = \frac{\sum W_U}{\sum W_I} \, 100 \quad [\%] \qquad (17)$$

- **Specific gross consumption of energy**

$$c_{bx|y} = \frac{Q_c + W_{IE}}{\sum W_U} \, 100 \quad [\%] \qquad (18)$$

- **Specific net consumption of energy**

$$c_{nx|y} = \frac{Q_c}{\sum W_U} \, 100 \quad [\%] \qquad 19)$$

- **Specific fuel consumption to produce energy**

$$c_{c|z} = \frac{D_c}{\sum W_U} \quad [t/tep] \qquad (20)$$

- **Cogeneration Index**

$$y_{CG} = \frac{W_{EU}}{Q_{CT}} \qquad (21)$$

- **Loading rate**

  ➢ Of the boiler

  $$g_{IC} = \frac{Q_A}{P_{ICZ}} \qquad (22)$$

  ➢ Of the generator group

  $$g_{IGG} = \frac{Q_1 - Q_2}{P_{IT}} \qquad (23)$$

(P_{ICZ}, P_{IT}) - the powers installed in the boiler and the turbine

3. ABOUT THE MEASUREMENTS MADE

Most of the components required to evaluate the components of the BEC, according to the model presented in points 2 and 21, were taken from the beneficiary's database and recorded by the S-CGE monitoring system (SM). The other sizes were measured with the following devices: Network Analyzer (AR), Chauvin Arnoux CA 8230; Debit meter (DB), FLUXUS 608; Thermometer (TM), FLUKE Ti10; Gas analyzer (AG), TESTO 350 CU. The characteristics of these devices are given in [21].

3.1. Sizes taken from records of SM-CET-ZO

There are two categories of sizes to be used in the BEC model and can be downloaded from the SM-S-CGE's customer database:
• Registered or calculated online counts at one-second intervals;
• Registered off-line, daily

For power AEC (momentary) performance at three load levels, the on-line records taken from the SM-S-CGE completed with the records of the above-mentioned additional devices were used. SM-S-CGE highlights most of the S-CGE statuses that can be tracked on monitors in the control room. For example, in Fig. 3, one of the eight screens to highlight, at operator's request, the S-CGE state sizes. The other screens are shown in [21].To perform BEC based on power (momentum) at 3 levels of load, records were selected from [14.11.2017, 15:59 ÷ 15.11.2017, 15:59]. Figure 4 shows the state of the S-CGE statuses in that range. The MS-based sizes are structured into four categories: measured as inputs and outputs from the process (D_7 ------ θzg); measured in-house process (D_A ----- Ptb); electrical quantities that characterize the generator group (P_{EN} -------- I_T); calculated sizes (D_6 ---- D_3).
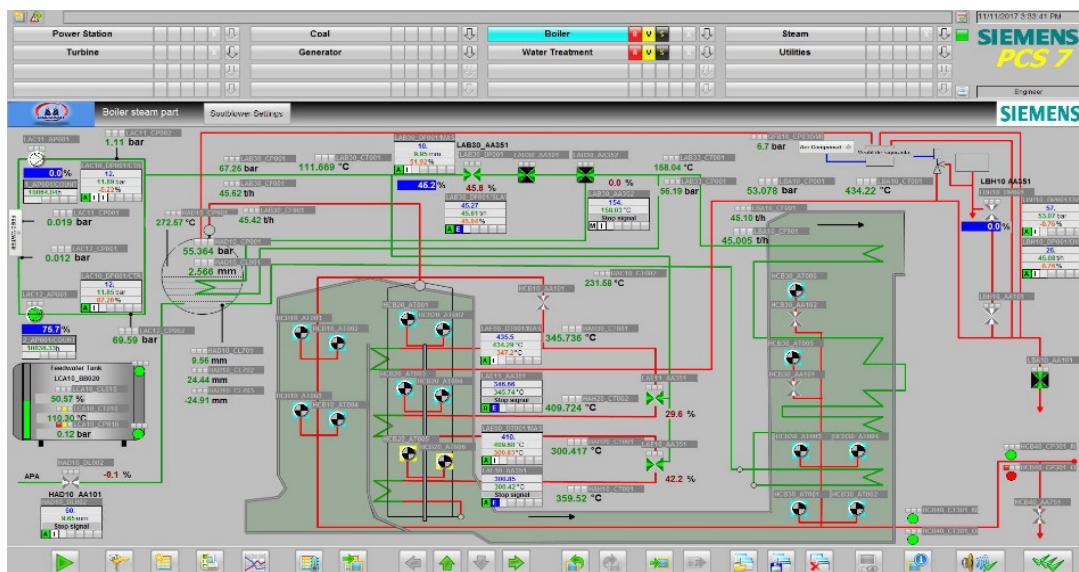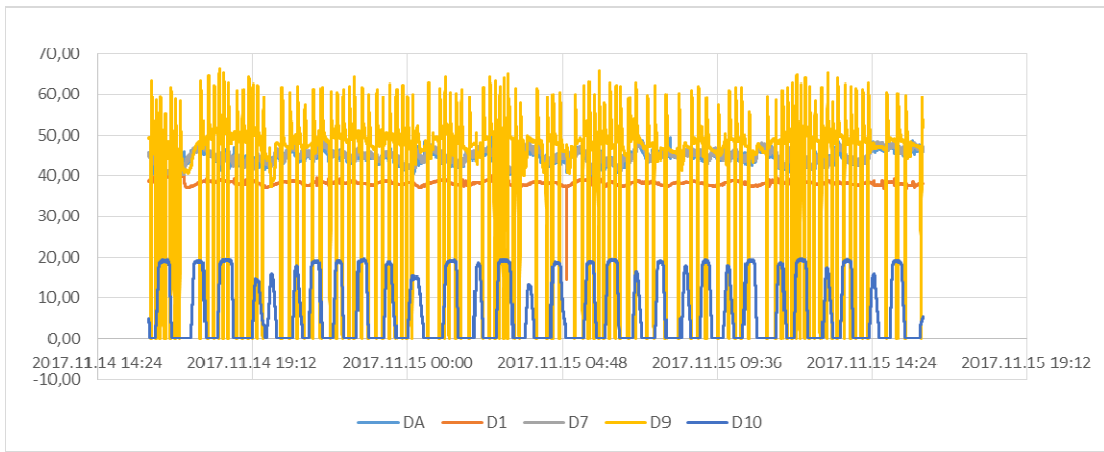

Fig.3. Quantities state

Fig. 4. The debits recorded by SM-CET-ZO (DA,D1,D7,D9,D10)-[t/h]

3.2. Other sizes used for BEC.

a.) Quantities taken from beneficiary's multiannual database

The energy service of the beneficiary keeps track of the main sizes that characterize the energy performance of the S-CGE. These are: D_C [t/day], Q_C [MWh], D_A [t/h], Q_A [MWh/day] , D_3 [t/h], Q_3 [MWh/day], W_{EN} [MWh/day]

b.) Calculation sizes obtained from other measurements

Recordings with ARs were performed in the secondary service transformer (TSP) and SP receivers with significant nominal power. For the TSP, besides the load curves, the variation of the quantities that characterize the quality of the electric energy was also observed (fig. 5 and fig. 6).
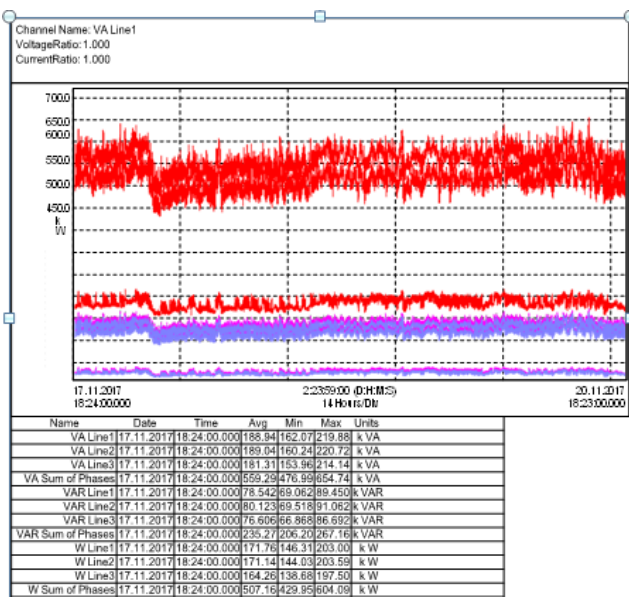

Fig. 5. Load curves TSP-S-CGE

c). Measurements with infrared thermometer

Using a Ti20-Fluke infrared thermometer, point-temperature measurements of S-CGE equipment and installations were performed, where temperatures are required to complete the AEC map and, respectively, where the measured values are useful for identifying measures to reduce energy losses. Let's take the example in Figure 7. such an image.

d). The content of the combustion gases determined by the TESTO 350 CM has the following composition.

Total GES (EFFn) = 91,3%, Water content (qA) = 8,7%, O_2 = 5,79%, CO_2 =14,82%, CO = 587 mg/m³, NO= 155 mg/m³, NO_x = 237 mg/m³, SO_2 = 553 mg/m³, H_2 = 6 ppm.

e). Other sizes used in BEC

• The quantity (fuel) used for feeding CET-ZO is taken from the records of the beneficiary who introduces the huila into the boiler after weighing 3 times a day. For the time interval for the recordings of MS; the average value is: D_C=113,14 t/zi = 4,71 t/h=1,31 kg/s ; with calorific power q_c=29.015,59 MJ/t

• The temperature of the slag measured by the beneficiary is: θ_{zg}= [250 ÷ 280]°C. Average value used: θ_{zg}= 265°C.

• The flow of the purge at the time the measurements were made was: D_{pj}=0,4 t/h = 0,11 kg/s

• From the beneficiary's assessments, it was found that the share of slag and ash in relation to the fuel entering the boiler (coal) is: Slag : p_{zg} = 7,78 % ; Ash:p_{ce}= 0,95 %

• The addition water is extracted from the well, from 170 m, it is passed through the water treatment line and then pumped into the main tank (RZp) has the parameters: θ_{10}=14°C ; p_{10}=5,1 bar

• During the time interval of MS sampling of the state quantities, the ambient temperature values (θ_{ae}) – taken from the zonal meteorological station were those specified in [21].

• Based on the November 2017 records of the SM, the mean values of the sizes entering the BEC equations were determined - Table 2.

**Table 2. Averages for November 2017 of BEC calculation quantities**

Symbol [UM]	P_{EU} [MW]	Q [MVAr]	p_2 [bar]	p_5 [bar]	Θ_5 [°C]	p_3 [bar]	Θ_7 [°C]	p_7 [bar]	D_9 [t/h]
Value	4,8	1,28	1,65	1,6	135,3	1,54	112	67,25	44,54
Symbol [UM]	D_{10} [t/h]	D_{ae} [m^3_N/h]	p_{tb} [bar]	P_8 [bar]	Θ_5 [°C]	D_6 [t/h]	Θ_3 [°C]	D_A [t/h]	Θ_A [°C]
Value	6,01	51417	55,25	51,27	135	10,75	126	45,3	442
Symbol [UM]	p_A [bar]	D_1 [t/h]	Θ_1 [°C]	p_1 [bar]	Θ_2 [°C]	D_{emed} [t/h]			
Value	53	38,14	439	52,55	151	109,15			
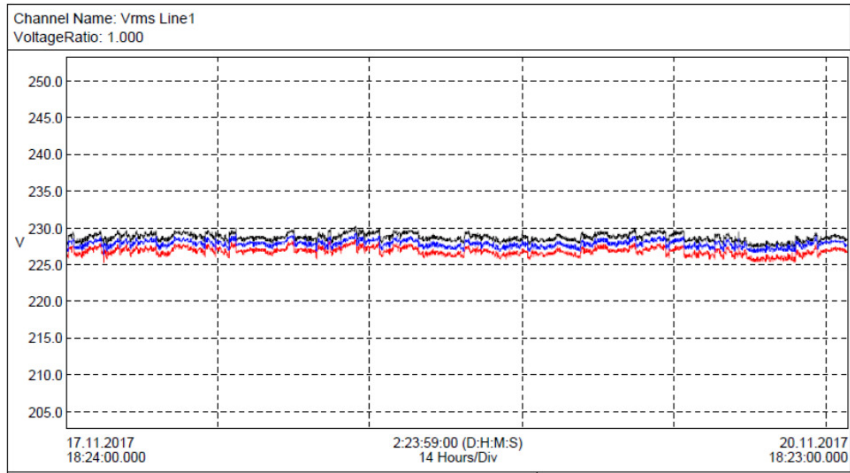
a). Voltage variation
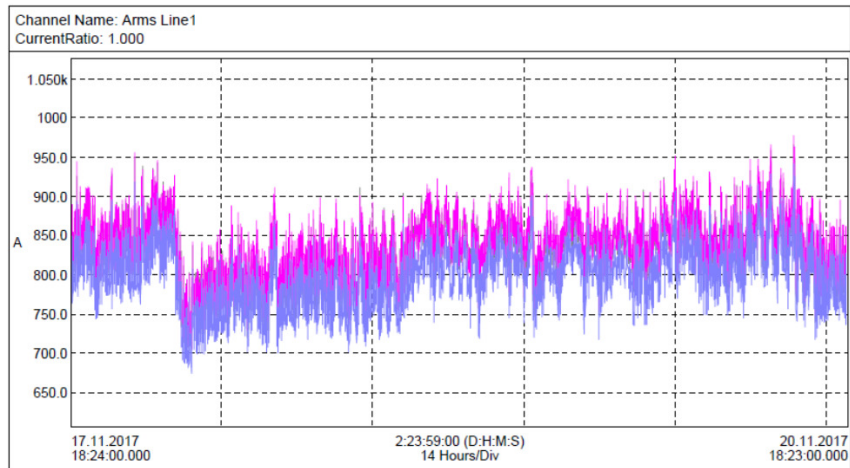
b). Current intensity variation
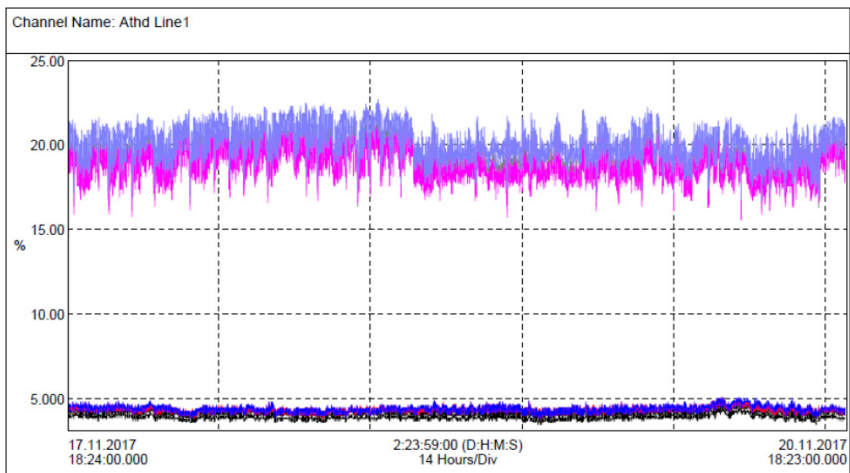
c). The THD indicator

Fig. 6. Elements of EE quality characterization in the TSP-S CGE secondary
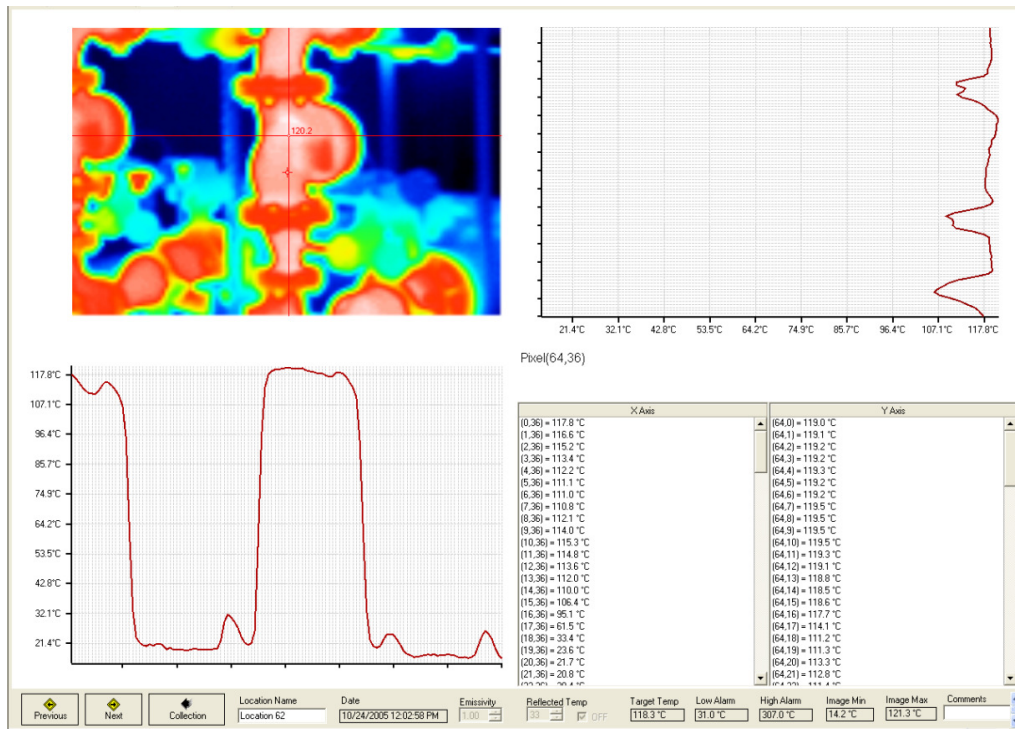
Fig.7. Condensate pipe line – leaving the factory [Θ$_{max}$ =121,3 °C]

4. THE RESULTS OBTAINED WITH THE ACTUAL BEC

On the basis of the measurements made, the calculation quantities taken from the bulletins and the database provided by the beneficiary, using the BEC model, the numerical values of the BEC components were determined. We present in the paper, by way of example, part of the obtained results, structured as follows:

- BEC of powers (currently), at a minimum, medium and maximum load;
- BEC of average energy loads for one day (average).

For BEC of power and average energy value (energy per day), the SM-S-CGE on-line measurements are used, completed with measurements and analysis bulletins. For the energy BEC, at monthly average load, the values used in the beneficiary's multi-annual BD.Tables 3 ÷ 5 and Fig. 8 present the results of the BEC evaluations at three levels of the load.

Table 3. Real Power BEC Results for S-CGE [Maximum Load]

|	**Characteristic quantities**	**[kW]**	**[%]**
1.	Input power [$\sum P_I$]	51449,20	100,00
a)	By fuel [Q_c]	42502,40	82,61
b)	Through the water [Q_{ap}], din care	8049,20	15,64
b1)	In the boiler [Q_{apcz}]	6093,20	11,84
b2)	In SRR[Q_{apSRR}]	1956,00	3,80
c)	Through ventilation air [Q_{ae}]	284,70	0,55
d)	Electric power for SP [P_{IE}]	612,90	1,19
2.	Out power [$\sum P_{IS}$]	52864,28	102,75
2.1.	Useful power [$\sum P_U$] from which	41913,50	81,47
a)	thermal [Q_{CT}]	37173,50	72,25
b)	Electric [P_{EU}]	4740,00	9,21
2.2.	Power losses [$\sum P_P$] from which	3971,81	7,72
a)	Associated with the boiler [Q_{pcz}], from which	2902,23	5,64
a1)	Through combustion gases and incomplete chemical combustion of fuel [Q_{gai}]	1929,90	3,75
a2)	By purge [Q_{apr}]	365,80	0,71
a3)	Prin nearse mecanice [Q_{nm}]	1,21	0,00
a4)	Through slag [Q_{zg}]	37,70	0,07
a5)	By radiation and convection [Q_{rc}]	567,62	1,10
b)	On the generator group [P_{PGG}]	437,10	0,85
c)	Pe transformatorul de evacuare [P_{PTE}]	42,60	0,08
d)	On pipes [P_{PCD}]	589,88	1,15
2.3.	Returned from the trial [P_{CD}]	6978,97	13,56
3.	Technological own consumption [P_{CPT}]	612,90	1,19
4.	Total out + CPT [$\sum P_{IS} + P_{CPT}$]	53477,18	103,94
5.	Closing error [$\Delta P = \sum P_I – (\sum P_{IS} + P_{CPT})$]	-2027,98	-3,94

Table 4. Real Power BEC Results for S-CGE [Minimum Load]

	Characteristic quantities	[kW]	[%]
1.	Input power [$\sum P_I$]	42919,59	100,00
a)	By fuel [Q_c]	35690,14	83,16
b)	Through the water [Q_{ap}], din care	6516,84	15,18
b1)	In the boiler [Q_{apcz}]	5166,50	12,04
b2)	In SRR[Q_{apSRR}]	1350,34	3,15
c)	Through ventilation air [Q_{ae}]	277,15	0,65
d)	Electric power for SP [P_{IE}]	435,46	1,01
2.	Out power [$\sum P_{IS}$]	43876,52	102,23
2.1.	Useful power [$\sum P_U$] from which	30785,00	71,73
a)	thermal [Q_{CT}]	25555,00	59,54
b)	Electric [P_{EU}]	5230,00	12,19
2.2.	Power losses [$\sum P_P$] from which	7077,82	16,49
a)	Associated with the boiler [Q_{pcz}], from which	4762,22	11,10
a1)	Through combustion gases and incomplete chemical combustion of fuel [Q_{gai}]	1620,57	3,78
a2)	By purge [Q_{apr}]	332,80	0,78
a3)	Prin nearse mecanice [Q_{nm}]	1,01	0,00
a4)	Through slag [Q_{zg}]	31,65	0,07
a5)	By radiation and convection [Q_{rc}]	2776,19	6,47
b)	On the generator group [P_{PGG}]	1780,06	4,15
c)	Pe transformatorul de evacuare [P_{PTE}]	47,54	0,11
d)	On pipes [P_{PCD}]	488,00	1,14
2.3.	Returned from the trial [P_{CD}]	6013,70	14,01
3.	Technological own consumption [P_{CPT}]	435,46	1,01
4.	Total out + CPT [$\sum P_{IS} + P_{CPT}$]	44311,98	103,24
5.	Closing error [$\Delta P = \sum P_I - (\sum P_{IS} + P_{CPT})$]	-1398,39	-3,26

Table 5. Actual BEC results of energies for S-CGE [November average]

	Characteristic quantities	[kW]	[%]
1.	Input power [$\sum P_I$]	1078,45	100,00
a)	By fuel [Q_c]	881,69	81,75
b)	Through the water [Q_{ap}], din care	177,71	16,48
b1)	In the boiler [Q_{apcz}]	143,75	13,33
b2)	In SRR[Q_{apSRR}]	33,97	3,15
c)	Through ventilation air [Q_{ae}]	6,75	0,63
d)	Electric power for SP [P_{IE}]	12,33	1,14
2.	Out power [$\sum P_{IS}$]	1016,64	94,27
2.1.	Useful power [$\sum P_U$] from which	776,18	71,97
a)	thermal [Q_{CT}]	660,98	61,29
b)	Electric [P_{EU}]	115,20	10,68
2.2.	Power losses [$\sum P_P$] from which	113,66	10,54
a)	Associated with the boiler [Q_{pcz}], from which	74,83	6,94
a1)	Through combustion gases and incomplete chemical combustion of fuel [Q_{gai}]	40,03	3,71
a2)	By purge [Q_{apr}]	8,44	0,78
a3)	Prin nearse mecanice [Q_{nm}]	0,02	0,00
a4)	Through slag [Q_{zg}]	0,78	0,07
a5)	By radiation and convection [Q_{rc}]	25,54	2,37
b)	On the generator group [P_{PGG}]	18,59	1,72
c)	Pe transformatorul de evacuare [P_{PTE}]	1,04	0,10
d)	On pipes [P_{PCD}]	19,20	1,78
2.3.	Returned from the trial [P_{CD}]	126,80	11,76
3.	Technological own consumption [P_{CPT}]	12,33	1,14
4.	Total out + CPT [$\sum P_{IS} + P_{CPT}$]	1028,97	95,41
5.	Closing error [$\Delta P = \sum P_I - (\sum P_{IS} + P_{CPT})$]	49,48	4,59
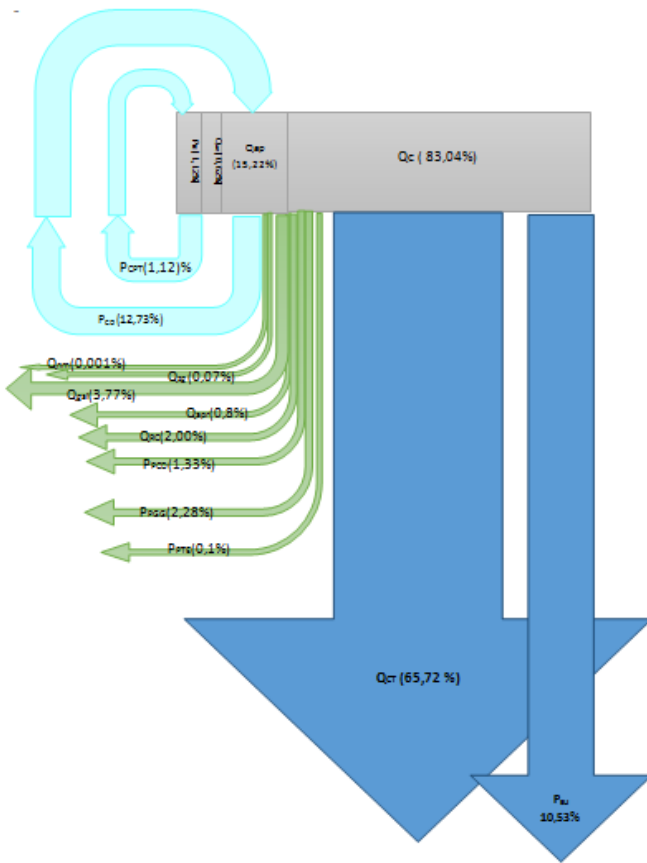
Fig. 8. Sankey diagram of real BEC for contour of S-CGE [certain load]

Table 6 summarizes the values of energy performance indicators of S-CGE analyzed for typical regimes.

Table 6. The values of energy performance indicators of S-CGE in typical regimes

Load mode \ indicator	Min.	Average	Max.	Nov. 2017
$\eta_b[\%]$	72,7	71,4	82,7	73,1
$\eta_n[\%]$	71,7	70,2	81,5	72
$c_b[\%]$	117,35	121,4	102,9	115,2
$c_n[\%]$	115,93	119,7	101,4	113,6
$c_C[t/tep]$	1,67	1,72	1,46	1,64
y_{CE}	0,205	0,186	0,128	0,17
g_{ICZ}	0,63	0,66	0,72	0,69
g_{IGG}	0,13	0,106	0,1	0,1

6. CONCLUSIONS

The analyzed thermal power (TP) and electric energy (EE) is relatively modern in that: it is in cogeneration, it is equipped with a monitoring system, it has relatively high performance equipment, the environmental impact through GHG is within the limits admitted according to current regulations. The overall S-CGE overall performance analyzed for all typical regimes exceeds the minimum threshold (70%) set in Romania for such plants but does not reach the projected and (80-85%) expected level in the EU and Romania for plant the same type, but with state-of-the-art equipment and technology.

Based on the existing data, a good boiler efficiency ([85 ÷ 92]%) and a very good generator yield ([97 ÷ 98,5]%) are found on the basis of existing data. Obviously, the valuesof these yields are affected by errors caused mainly by two factors:

- Measurement and evaluation errors of MS and additional tools used;
- Differentiated inertia of measurement processes and instruments induces unpredictability, deflation between sizes.

Taking into account the results obtained from the beneficiary's BD, for large intervals, we consider that the values obtained for the S-CGE global yield are credible. We give a higher level of confidence to the values btained for average load yield. Considering the level of effectiveness found for the S-CGE, we believe that it corresponds economically and economically to the purpose for which it was achieved and in which it is used, not recommending the replacement of equipment or major interventions in the process.

Within the AEC, the following issues have been identified that can stimulate improvement measures:

- Condensate outlet temperature at the evaporator (factory) is high (122 ° C). At a flow rate of about 12.5 kg / s, the condensate has a high energy potential. On the other hand, the issue of heating the company holding the S-CGE is not solved.
- The flue gases evacuated through the chimney have a significant energy potential, highlighted by the value of the losses (Qgai), by the temperature (187,3 ° C), the equivalent excess air ratio (1,38) and the gas content.
- Your own service transformer is oversized (2000kVA) in relation to CPT (Smax = 655kVA).
- In view of the above findings, the following measures have been formulated to improve the (energy and economic) efficiency of S-CGE:
- Recovering some of the energy potential of condensation and use for heating purposes.
- Recovering part of the combustion gas heat by preheating the addition water (extracted water from the well).
- Improvement of combustion by adjusting the speed of movement of the grate and the flow of air introduced into the boiler.
- Replacement of the TSP with the nominal power of 2000kVA, with one having Sn = 1000 kVA.

The analysis made and reproduced in [21] has led to the conclusion that these measures are economically feasible.

REFERENCES

[1]. Carabogdan Gh. s.a., *Bilanţuri energetice. Probleme şi aplicaţii pentru ingineri*. Editura Tehnică Bucureşti, 1986
[2]. Athanasovici, V., ş.a., 2010, Tratat de inginerie termică,

alimentări cu căldură, cogenerare, Editura AGIR, Bucureşti.

[3]. Diţscu, C., Ilie, I., 2002, Avantajele producerii energiei termice în sistem centralizat, comparativ cu încăzirea de la centrale de cartier, de bloc sau de apartament. FOREN, Neptun, iunie 2002

[4]. Macinoeskos K., ş.a. Cogeneration termofication and microturbines, Energetika 54(2), pg. 70 – 78, Lithuania, 2018

[5]. Moţiu, C., 1977, Centrale termo şi hidroelectrice, Editura Didacticăşi Pedagogică Bucureşti

[6]. *** Strategia de Dezvoltare Durabilă a UE, www.europa.eu

[7]. *** Directiva UE/27/2012 privind eficienţa energetică www.europa.eu

[8]. *** Legea nr. 121/2014 privind eficienţa energetică, www.anre.ro

[9]. *** H.G. Planul Naţional de Acţiune în Domeniul Eficienţei Energetice, www.minind.ro

[10]. *** H.G. nr. 1069/2007 pentru aprobarea Strategiei Energetice a României 2007-2020, actualizată pentru perioada 2011-2020, www.minind.ro

[11]. Carine Sebi and Bruno Lapillonne – Overall trends in energy efficiency in the EU, February 2017, www.odyssee-mure.eu

[12]. ***Combined Heat and Power , SIEMENS – Products and Services, www.siemens.com

[13]. ***Bilanţ termoenergetic al unei instalaţii de cogenerare cu biomasă solidă www.termo.utcluj.ro

[14]. Ciobanca A. I., Studii şi cercetări privind fiabilitatea şi eficienţa energetică a sistemelor de alimentare centralizată cu energie termică, Univesitatea din Oradea, 2014

[15]. ***Cartea tehnică a CET – Fabrica de Zahăr Oradea, format electronic, FZO, 2014

[16]. Berinde T. şi Berinde M, *Bilanţuri energetice în procese industriale*. Editura Tehnică Bucureşti, 1985.

[18]. Carabulea A., Carabogdan I. Gh, *Modele de bilanţuri energetice reali şi optime*. Editura Academiei R.S.R., Bucureşti, 1982.

[19]. ***"*Ghidul de elaborare şi analiza a bilanţurilor energetice*" în conformitate cu ordinul ARCE Nr. 245

[20]. ***PE 902/1986 (reeditare), *Normativ privind întocmirea si analiza bilanturilor energetice*, ICEMENERG, 1995.

[21]. Felea I., *Bilanţuri electroenergetice*. Note de curs, Editura Universităţii Oradea, Facultatea de Energetică, 2007

[22]. Felea I. , ş.a. Bilanţul Energetic Complex a CET-ZO, FZO, 2017