New Method to Assess the Energy Efficiency and Energy Effectiveness to the Industrial End-Users

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Abstract — **The paper presents a new analysis method of the evolution of energy efficiency and the assessment of energy savings / losses resulting from the evolution of energy efficiency for industrial End-Users and a presentation of a new energy performance indicator - energy effectiveness - which allows qualitative analysis of energy utilization in the case of industrial end-users, by dividing energy consumption into productive consumption and non-productive consumption.**

Keywords- energy efficiency; energy effectiveness; energy savings; ODEX

I. Introduction

The new energy efficiency analysis method adapts the ODEX indicators method [1] to the End-Users level and complements it with a new concept - energy effectiveness - providing the opportunity to assess the energy savings/losses resulting from the evolution of energy efficiency to the industrial End-Users.

Currently, energy performance assessment is a legal obligation for the industrial End-Users. The End-Users with an energy consumption of more than 1000 TEP have the legal obligation to perform an energy audit all over the energy consumption contour once every 4 years. [2]

The purpose of setting up an energy audit is assessing energy efficiency within a contour at a given time and drawing up a medium-term action plan for increase energy efficiency.

As part of the energy audit, the energy balance sheet method is now used to establish measures and actions aimed at improving the efficiency of energy use within the contour and to estimate the effects of the measures promoted in the foreseeable future. [3]

The energy balance sheet presents the state of the consumers analyzed at one point in terms of energy efficiency. The energy balance method is therefore a very useful method of energy analysis, but it is one of a state and not of a process.

One of the major problems faced by industrial energy managers, unlike the energy auditors, is the lack of a coherent, affordable, continuous and generally applicable method of analyzing and evaluating energy performance of the industrial End-Users, as well as determining the evolution of energy savings in time, obtained after the implementation of various measures to improve energy efficiency.

This paper presents a new method of energy analysis by analyzing the evolutions of the energy efficiency and of the energy effectiveness as well as determining the energy savings/loses assessments obtained to industrial End-Users, eliminating the disadvantage of discontinuity of the energy balance sheet method, without replacing it but by completing it.

For assessing the evolution of energy efficiency, the ODEX indicator method is currently used.

"The ODEX indicator system was designed and developed by an international consortium led by the French company ENERDATA in Grenoble under the SAVE program of the European Commission and continued under the Intelligent Energy Europe Program. Directive 2006/32 / EC explicitly states that ODEX indicators will be used to develop a comprehensive reporting methodology for the implementation of Energy Efficiency Action Plans.

ODEX indicators are percentage indicators; a reference year is chosen for which the value of the given indicator is 100% and its values are calculated for other years; if those values are greater than 100% means that energy efficiency has worsened (energy consumption to achieve a given useful effect has increased); if those values are less than 100%, it means that energy efficiency has improved.

ODEX indicators do not describe the level of energy efficiency (low or high) but the evolution of energy efficiency (positive or negative trend). ODEX indicators describe the dynamics of the process and not its state at some point. They do not allow comparisons for a given year between two countries, two consumer sectors but only comparisons for different years for the same consumer sector.

The ODEX indicator is by definition the percentage value of the ratio between: consumption of energy in the year t, with which a certain quantity of goods or services has been obtained, and the energy consumption that would have been needed in the year t if the energy efficiency was the one as in year t^0 (a conventionally elected previous year). " [4]

The ODEX indicator method [1] to calculate energy savings resulting from increased energy efficiency has the disadvantage that it does not allow a qualitative analysis of how energy is used.

The new method introduces a new concept – energy effectiveness – which allows to highlight the evolution of energy performance of industrial end-users by dividing energy consumption into productive consumptions and unproductive consumptions.

Energy efficiency is a new qualitative indicator of energy performance that shows how energy is used by industrial consumers.

The Energy Analysis according to the presented method is applied at the level of an Energy Analysis Centre and is done monthly, quarterly, semester and annually, comprising an analysis period of two consecutive years.

The Energy Analysis Centre is defined as that energy balance contour of an Organization where it generates, monitors, centralizes and accounts for both Production Values and related Energy Consumption. It is created by business/production areas, zonal/functional/organizational differentiation, or cost allocation criteria. Examples of Energy Analysis Centers could be: equipment, plant, line or technological process, final energy consumption process, department or production unit, the whole or part of the Organization.

II. The ODEX Energy Efficiency Analysis and the Energy Savings Assessment by Improving the Energy Efficiency for the Industrial End-Users

The new ODEX method of energy analyses, presented below, adapts the ODEX indicators method [1] to the End-Users level allows to highlight both the evolution of the Energy Efficiency (monthly, quarterly, semester or annually) and the value of the Energy Savings obtained in the 2nd year of analysis compared to the year 1 (the reference year chosen) resulting from the evolution of the Energy Efficiency.

$$EC_1^i = VP_1^i \div C_1^i \tag{1}$$

C_1^i = The Energy Consumption in the month i of the year 1, (*i* = 1 ... 12);
VP_1^i= the Value of Production achieved in the year 1, in the month *i*;
EC_1^i= the Energy Efficiency related to the Energy Consumption C_1^i in the year 1, the month *i*;

$$EC_2^i = VP_2^i \div C_2^i \tag{2}$$

C_2^i = the Energy Consumption in the month i of the year 2, (*i* = 1 ... 12);
VP_2^i = the Value of Production achieved in the year 2, in the month *i*;
EC_2^i= the Energy Efficiency related to the Energy Consumption C_2^i in the year 2, the month *i*;

$$C_{2:1}^i = VP_2^i \div EC_1^i \tag{3}$$

$C_{2:1}^i$ = the Energy Consumption that would have been necessary in the year 2 month *i*, if the Energy Efficiency in the year 2 month *i* would have been equal to that achieved in the year 1 (*the reference year chosen*) month i:

$$ODEX_{2:1}^i = C_2^i \div C_{2:1}^i = EC_1^i \div EC_2^i \tag{4}$$

$ODEX_{2:1}^i$ = the ODEX indicator corresponding to the same month i of those two consecutive years for which the Energy Efficiency analysis is made.

$$EE_{2:1}^i = C_{2:1}^i - C_2^i \tag{5}$$

$EE_{2:1}^i$ = The Energy Savings through Energy Efficiency in the month *i* of the year 2 compared to the same month *i* of the year 1, obtained by the evolution of the Energy Efficiency from EC_1 to EC_2;

Because:

$$EC_2^i \times C_2^i = EC_1^i \times C_{2:1}^i \tag{6}$$

Result:

$$\left(C_{2:1}^i - C_2^i\right) \div C_2^i = \left(EC_2^i - EC_1^i\right) \div EC_1^i \tag{7}$$

Or:

$$EE_{2:1}^i \div C_2^i = \left(EC_2^i - EC_1^i\right) \div EC_1^i \tag{8}$$

Result:

$$EE_{2:1}^i = C_2^i \times \left[\left(EC_2^i - EC_2^i\right) \div EC_1^i\right] \tag{9}$$

Or:

$$EE_{2:1}^i = C_2^i \times \left(EC_2^i \div EC_1^i - 1\right) \tag{10}$$

Result:

$$EE_{2:1}^i = C_2^i \times \left(1 \div ODEX_{2:1}^i - 1\right) \tag{11}$$

$$R_{2:1}^i = \left(1 \div ODEX_{2:1}^i\right) - 1 \tag{12}$$

$R_{2:1}^i$ = the Energy Efficiency Growth Rate in the year 2 month i compared with the year 1 month *i*:

Result:

$$EE_{2:1}^i = R_{2:1}^i \times C_2^i \tag{13}$$

Applying the same algorithm can be determined the value of the Energy Savings through Energy Efficiency ($EE_{2:1}^i$)

obtained in the 2nd year of analysis compared to the year 1, resulting from the evolution of the Energy Efficiency from EC_1 to EC_2, by applying the ODEX method of energy analysis:

$$EE_{2:1} = C_2 \times (1 \div ODEX_{2:1} - 1) = R_{2:1} \times C_2 \quad (14)$$

$$ODEX_{2:1} = C_2 \div C_{2:1} = EC_1 \div EC_2 \quad (15)$$

$$EC_1 = VP_1 \div C_1 \quad (16)$$

$$EC_2 = VP_2 \div C_2 \quad (17)$$

Where:

C_1 = The Energy Consumption in the year 1 (*considered as the reference year*);

VP_1 = The Value of Production achieved in the year 1;

EC_1 = The Energy Efficiency in the year 1;

C_2 = The Energy Consumption in the year 2;

VP_2 = The Value of Production achieved in the year 2;

EC_2 = The Energy Efficiency in the year **2**;

$C_{2:1}$ = The Energy Consumption that would have been necessary in the year 2 if the Energy Efficiency in the year 2 would have been equal to the Energy Efficiency achieved in year 1;

$ODEX_{2:1}$ = The ODEX indicator corresponding to those two consecutive years for which the Energy Efficiency analysis is made.

III. The Energy Effectiveness Analysis for the Industrial End-Users

Unlike the energy efficiency, which is a quantitative indicator of the energy performance, showing the energy efficiency of energy consumptions, the energy effectiveness is a qualitative indicator of energy performance, showing the efficiency of the energy use to industrial consumers.

Starting from the same primary statistical data as in the case of the Energy Efficiency analysis, below is presented a method of analysis of the Energy Effectiveness, also made for the same two consecutive years. As a result of this analysis, both the evolution of Energy Effectiveness and the Productive/ Unproductive Consumption can be determined. Energy efficiency is thus a new indicator of how to use energy for industrial consumers.

The Energy Effectiveness has the meaning of an energy consumption utilization for the analysis period, characterizing how energy is used. It will be symbolized with the letter H of the Greek alphabet, similar to the symbol η - used for energy yields. It is determined as the percentage value of the ratio between the Productive Energy Consumption and the Energy Consumption for the analyzed period.

The Productive Energy Consumption is that part of the Energy Consumption used for the deployment of the production process. The part of the Energy Consumption that is directly used to production process together with that part of the Energy Consumption that contributes indirectly to the deployment of the production process

The Unproductive Energy Consumption is that part of the Energy Consumption that is independent of the deployment of the production process.

The Productive Energy Consumption in the year 1 (C_1^{pr}), is defined as the ratio between the Value of Production in the year 1 (VP_1) and the Maximum Value of the Monthly Energy Efficiency registered in the year 1 (EC_1^{max}):

$$C_1^{pr} = VP_1 \div EC_1^{max} \quad (18)$$

For every month *i* of the year 1, after the end of the year, can be determined the Productive Energy Consumption

$$C_1^{pr,i} = VP_1^i \div EC_1^{max} \quad (19)$$

The Unproductive Energy Consumption in the year 1 (C_1^{npr}), is defined as the difference between the Energy Consumption in the year 1 (C_1) and the Productive Energy Consumption in the year 1 (C_1^{pr}):

$$C_1^{npr} = C_1 - C_1^{pr} \quad (20)$$

For every month *i* of the year 1, after the end of the year, can be determined the Unproductive Energy Consumption

$$C_1^{npr,i} = C_1^i - C_1^{pr,i} \quad (21)$$

The Energy Effectiveness for the year 1 (HC_1), is defined as the percentage value of the ratio between the Productive Energy Consumption in the year 1 (C_1^{pr}) and the Energy Consumption in the year 1 (C_1):

$$HC_1 = C_1^{pr} \div C_1 = EC_1 \div EC_1^{max} \quad (22)$$

For every month *i* of the year 1, after the end of the year, can be determined:

$$HC_1^i = C_1^{pr,i} \div C_1^i = EC_1^i \div EC_1^{max} \quad (23)$$

HC_1^i = The Energy Effectiveness for the month *i* of the year 1, is determined as the percentage value of the ratio between the Productive Energy Consumption in the month *i* of the year 1

($C_1^{pr,i}$) and the Energy Consumption in the same month i of the year 1 (C_1^i).

In a similar manner, for the year 2, is determined:

C_2^{pr} = the Productive Energy Consumption in the year 2, is defined as the ratio between the Value of Production in the year 2 (VP_2) and the Maximum Value of Monthly Energy Efficiency registered in year 2 (EC_2^{max}):

$$C_2^{pr} = VP_2 \div EC_2^{max} \quad (24)$$

For every month *i* of the year 2, after the end of the year, can be determined:

$$C_2^{pr,i} = VP_2^i \div EC_2^{max} \quad (25)$$

$C_2^{pr,i}$ = the Productive Energy Consumption in the month *i* of the year 2, is determined as the ratio between the Value of Production in the month *i* of the year 2 (VP_2^i) and the Maximum Value of the Monthly Energy Efficiency registered in the year 2 (EC_2^{max}).

C_2^{npr} = the Unproductive Energy Consumption in the year 2, is defined as the difference between the Energy Consumption in the year 2 (C_2) and the Productive Energy Consumption in the year 2 (C_2^{pr}):

$$C_2^{npr} = C_2 - C_2^{pr} \quad (26)$$

For every month i of the year 2, after the end of the year, can be determined:

$$C_1^{npr,i} = C_2^i - C_2^{pr,i} \quad (27)$$

$C_2^{npr,i}$ = the Unproductive Energy Consumption in the month *i* of the year 2 and it is determined as the difference between the Energy Consumption in the month *i* of the year 2 (C_2^i) and the Productive Energy Consumption in the same month *i* of the year 2 ($C_2^{pr,i}$).

The Energy Effectiveness for the year 2 (HC_2), is defined as the percentage value of the ratio between the Productive Consumption in the year 2 (C_2^{pr}) and the Energy Consumption in the year 2 (C_2):

$$HC_2 = C_2^{pr} \div C_2 = EC_2 \div EC_2^{max} \quad (28)$$

For every month *i* of the year 2, after the end of the year, can be determined:

$$HC_2^i = C_2^{pr,i} \div C_2^i = EC_2^i \div EC_2^{max} \quad (29)$$

HC_2^i = the Energy Effectiveness for the month *i* of the year 2, is determined as the percentage value of the ratio between the Productive Consumption in the month *i* of the year 2 ($C_2^{pr,i}$) and the Energy Consumption in the same month i of the year 2 (C_2^i).

IV. Practical Example of Applying the New Energy Analysis Method

It is presented the application of the new energy analysis method in case of an industrial End-User with an energy consumption of over 1000 TEP/year, having as a profile the casting of non-ferrous metals.

Energy analysis is carried both for electricity and natural gas consumptions, at the level of the entire organization.

The graphical analysis is based on the monthly statistical data - energy consumptions and production values - recorded in the two consecutive years of analysis.

The specific field of productive activity for the analyzed consumer has the specificity that the share of natural gas consumption in the production process is higher than the share of electricity consumption, Fig. 1.

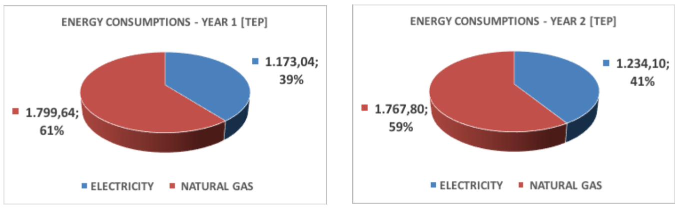

Figure 1. Energy consumptions for two consecutive years

The new method of energy analysis is based on the monthly statistical data of the electricity and natural gas consumptions (Fig.2) and of the production values (Fig.3), recorded in the two consecutive years for which analysis is performed.

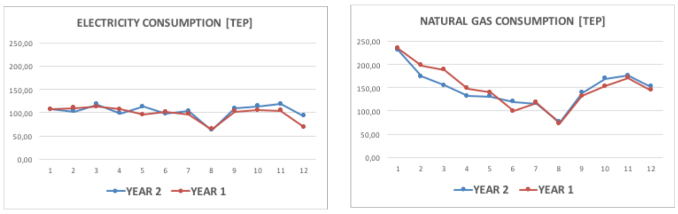

Figure 2. Monthly evolution of the energy consumptions

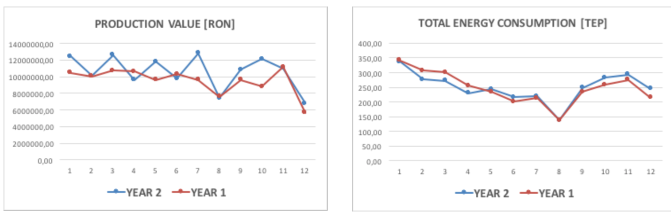

Figure 3. Monthly evolution of the production values

By the qualitative separation of energy consumption into productive consumption and unproductive consumption, energy effectiveness can be highlighted.

In the case of electricity (Fig. 4 and Fig. 5), the shares of the productive and the unproductive consumptions remained almost unchanged, recording an improvement of only 1% in the 2nd year.

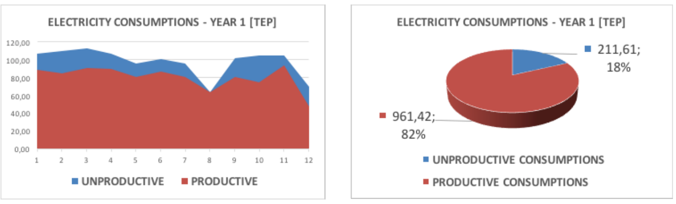

Figure 4. The productive and unproductive electricity consumptions: year 1

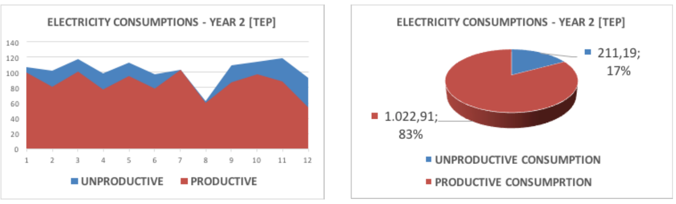

Figure 5. The productive and unproductive electricity consumptions: year 2

Compared to electricity consumption, in the case of natural gas consumption (Fig. 6 and Fig.7), there is a 4% increase in the share of productive consumption. This has emerged as a result of greater focus on improving the efficiency of using natural gas.

Noteworthy higher weights of unproductive natural gas consumption during the cold period, effect of extra consumption for space heating. The fact that natural gas consumption doubles in that period of the year shows that significant energy savings can be achieved by recovering heat from technological installations.

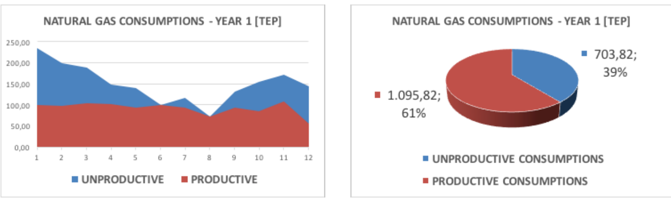

Figure 6. The productive and unproductive natural gas consumptions: year 1

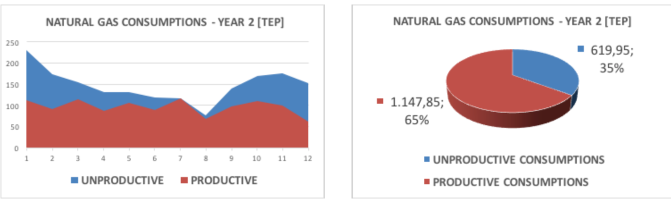

Figure 7. The productive and unproductive natural gas consumptions: year 2

The energy efficiency of the electricity consumption increased by only 1% (Fig. 8), which shows that no attention was paid to the implementation of new measures to improve energy efficiency.

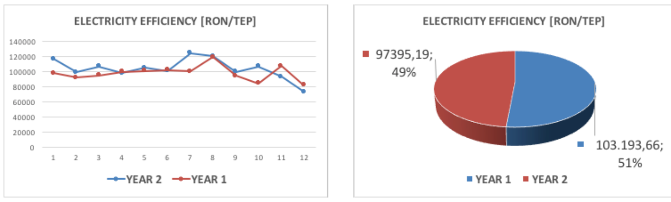

Figure 8. The evolution of the efficiency of the electricity consumptions

In the case of natural gas (Fig. 9), there is an increase of the energy efficiency of 6%, thus showing, unlike electricity consumption, the increased interest in this type of consumption.

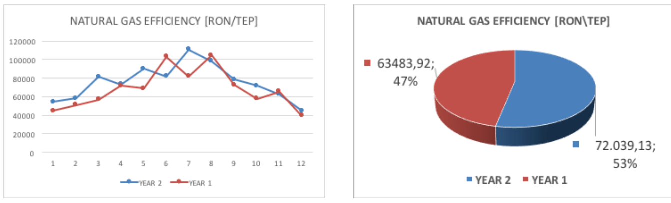

Figure 9. The evolution of the efficiency of the natural gas consumptions

Even at values below potential savings, the evolution of energy savings for both electricity and natural gas is positive (Fig. 10), the result of improving both energy efficiency and energy efficiency.

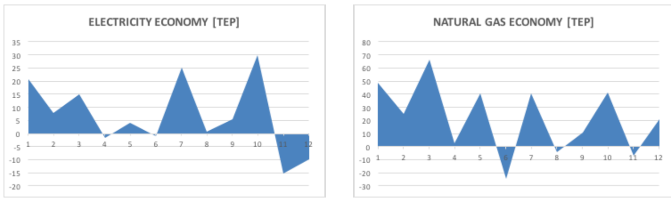

Figure 10. The evolution of the monthly evolution of the energy savings

Due to the improvement of the energy efficiency, there is an energy saving of 81.00 TEP for electric power and 260.19 TEP for natural gas. The total energy savings achieved by increasing energy efficiency is thus 341.16 TEP.

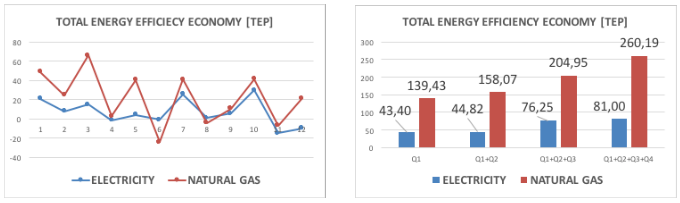

Figure 11. The evolution of the evolution of the energy savings

The effectiveness of the electricity consumption (Fig.12) is constant, which shows once again the lack of measures to improve the energy efficiency of these consumptions.

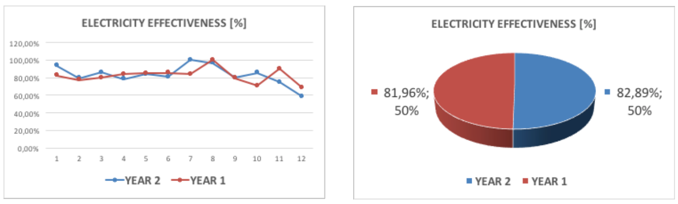

Figure 12. The evolution of the effectiveness of the electricity consumptions

The small percentage of increase in the energy efficiency of natural gas consumption (Fig. 13), as well as in case of electricity effectiveness, shows that in the absence of a method of energy analysis such as presented, it is impossible to track and optimize the evolution of energy efficiency.

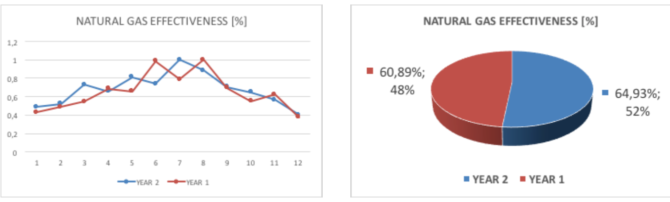

Figure 13. The evolution of the effectiveness of the natural gas consumptions

V. CONCLUSIONS

The new energy analyses method presented brings forward a solution to the need to improve and optimize the activity of any Energy Manager.

Together with the energy balance sheet, the new energy analyses method represents the most important tools at the disposal of the Energy Manager for the monitoring, analysis and optimization of energy consumptions, being also a valuable tool in the elaboration of the Energy Efficiency Improvement Plan.

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