

## **MODEL FOR TECHNIC AND ENVIRONMENT ANALYSIS OF A DISTRICT HEATING SYSTEM**

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*Model for technic and environment analysis of a district heating system represents a module from a program for technic, economic and environment analysis of a district heating system.*

*The model is based on algorithm for calculation of technic indicators. These indicators together with economic and legislative aspects are the basis for conclusions regarding actual situation and future evolution of a district heating system.*

*The algorithm is based on the principle ``from simple to complex`` begining with the analysis of each type of source, continued with the ensemble of each type of sources and finally with the ensemble of all heat sources.*

**Keywords:** district heating system, cogeneration plant, thermal plant, efficiency.

### **1. Introduction**

Analysis of a DH system from technic and environment point of view is a first stage of a heating strategy of a city. Its results are essential for decisions regarding modernization and development the analysed DH system.

### **2. Assumptions**

Mathematic model has the following characteristics:

- from the point of view of heat source type can be applied for CHP, TP and/or LTP;
- from the point of view of technology of heat production, can be applied for ST, GT, CCGT, MAI and for HWB;
- from the point of view of primary resources used for heat production, can be applied for all types of resources (classic resources and renewables);
- is designed for DH systems which supply heat for heating and hot tap water to urban consumers and those from services sector;
- from the point of view of TDS type, can be applied to DH systems with TDS composed from TN-S/TM-DSN and for DH systems composed from LTP and DSN.

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### **3. Principles of mathematic model**

The algorithm is based on the principle ``from symple to complex`` begining with the analysis of each type of source, continued with the ensemble of each type of sources and finally with the ensemble of all heat sources of DH system- see Fig. 1. Mathematic model for technic and environment analysis of a DH system has 4 principal steps described in chapters 3.1 ... 3.4.

#### **3.1 Analysis of technical situation of components of DH system: equipment from heat sources (STB, ST, GT, CCGT, MAI, HWB), elements of TDS**

Analysis of technical situation of components of DH system has the scope of determining remanent life duration of equipment to establish their availability in the future. This is determined through processing statistical data regarding periods of operation from PIF and from last OH.

Analysis of technical situation of TDS is based on constructive aspects such as: year of PIF, length of circuit, placing (underground, aerial), type of pipes (classic or pre-insulated pipes), replacements of pipes from PIF.

#### **3.2 Analysis of technical performances of heat sources of DH system**

Analysis of technical performances is based on statistical data from operation activity as input data. Output data are technical indicators of DH system. Chapters no. 3.2.1...3.2.6 describe calculation of performance indicators for heat sources both for each source and for ensemble of sources of DH system.

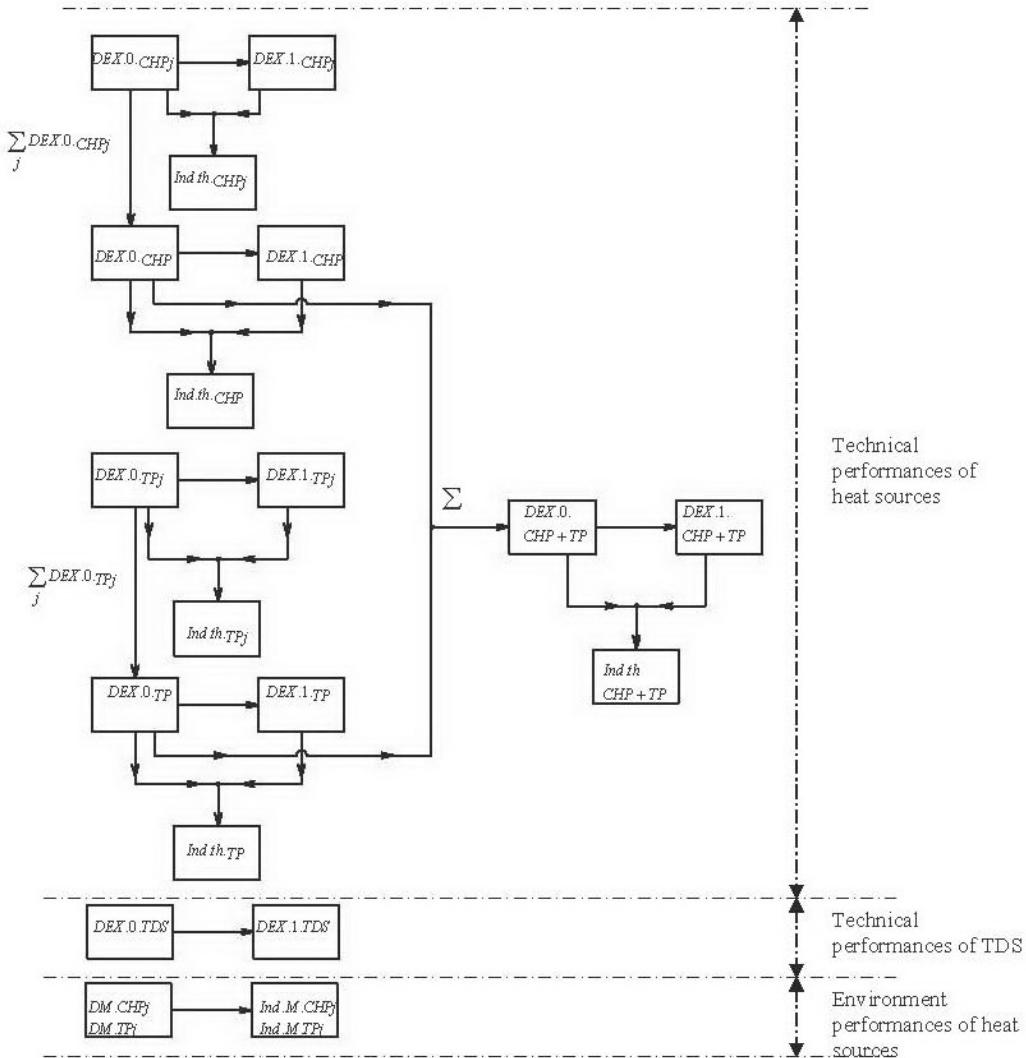


Fig. 1 – Principle of mathematic model “from simple to complex”

Legend for fig. 1:  $DEX.0.CHP_j$ ,  $DEX.0.TP_j$  – input data from operation for each CHP/TP;  $DEX.1.CHP_j$ ,  $DEX.1.TP_j$  – calculated data using DEX.0 for each source;  $DEX.0.CHP$ ,  $DEX.1.TP$  – input data for ensemble of CHP, respective TP;  $DEX.1.CHP$ ,  $DEX.1.TP$  – calculated data using for ensemble of CHP, respective TP using  $DEX.0.CHP$ ,  $DEX.0.TP$ ;  $Ind.th$  – technical indicators for each source ( $CHP_j$ ,  $TP_j$ ) and for ensemble;  $DM.CHP_j$ ,  $DM.TP_j$  – environment data for each source;  $Ind.M.CHP_j$ ,  $Ind.M.TP_j$  – environment indicators for each source.

### 3.2.1 Technical indicators for CHP [1], [2]:

- Gross overall efficiency,  $\eta_{gl.CHP}^{gr}$ :

$$\eta_{gl.CHP}^{gr} = \frac{QP.CHP + EP.CHP}{F.CHP} \quad [\%] \quad (1)$$

- Net overall efficiency,  $\eta_{gl.CHP}^{net}$ :

$$\eta_{gl.CHP}^{net} = \frac{QL.CHP + EL.CHP}{F.CHP} \cdot 100 \quad [\%] \quad (2)$$

- gross value of structure factor of energy production,  $y_{SP}^{gr}$ :

$$y_{CHP}^{gr} = \frac{EP.CHP}{QP.CHP} \quad [\text{kWhe/kWht}] \quad (3)$$

- net value of structure factor of energy production,  $y_{SP}^{net}$ :

$$y_{CHP}^{net} = \frac{EL.CHP}{QL.CHP} \quad [\text{kWhe/kWht}] \quad (4)$$

- gross value of average annual cogeneration factor of CHP, YCG:

$$YCG = \frac{EP.CG}{QP.CG} \quad [\text{kWhe/kWht}] \quad (5)$$

- gross value of degree of cogeneration of CHP, XCG:

$$XCG = \frac{EP.CG}{EP.CHP} \cdot 100 \quad [\%] \quad (6)$$

- share of noncogeneration electricity, XNCG:

$$XNCG = \frac{EP.NCG}{EP.CHP} \cdot 100 \quad [\%] \quad (7)$$

- annual value of cogeneration coefficients for :

- hot water production,  $\alpha_{cg.hw}^{an}$ :

$$\alpha_{cg.hw}^{an} = \frac{QP.HW.CG}{QP.HW.CHP} \quad (8)$$

- steam production,  $\alpha_{cg.st}^{an}$ :

$$\alpha_{cg.st}^{an} = \frac{QP.ST.CG}{QP.ST.CHP} \quad (9)$$

- total heat production of CHP,  $\alpha_{cg.CHP}^{an}$ :

$$\alpha_{cg.CHP}^{an} = \frac{QP.CG}{QP.CHP} \quad (10)$$

- specific consumption of electricity for pumping in TN:

$$cs_{pp} = \frac{E_{pp}.CHP}{QL.HW.CHP} \quad [\text{kWhe/MWt}] \quad (11)$$

- specific consumption of make-up water for TN:

$$cs_{mkw} = \frac{C.MKW.CHP}{QL.HW.CHP} \quad [\text{m}^3/\text{MWt}] \quad (12)$$

- annual average load of capacities for electricity production from CHP,  $pmd.CHP$ :

$$pmd.CHP = \frac{(EP.CHP / TAUAN.CHP)}{Pi.CHP} \cdot 100 \quad [\%] \quad (13)$$

- annual average load of capacities for heat production from CHP,  $qmd.CHP$ :

$$qmd.CHP = \frac{(QL.CHP / TAUAN.CHP)}{Qi.CHP} \cdot 100 \quad [\%] \quad (14)$$

### 3.2.2 Technical indicators for ensemble of CHP sources of DH system

Technical indicators for ensemble of CHP are calculated in the same mode with chapter 3.2.1 using quantities of heat, electricity, fuel, make-up water obtained through sum for all CHP – see Fig. 1 (DEX.0.CHP, respective DEX.1.CHP).

### 3.2.3 Technical indicators for each TP [1]

- gross value of efficiency of TP,  $\eta_{TP}^{gr}$ :

$$\eta_{TP}^{gr} = \frac{QP.TP}{F.TP} \cdot 100 \quad [\%] \quad (15)$$

- net value of efficiency of TP,  $\eta_{TP}^{net}$ :

$$\eta_{TP}^{net} = \frac{QL.TP}{F.TP} \cdot 100 \quad [\%] \quad (16)$$

- annual average load of capacities for heat production from TP,  $qmd.TP$ :

$$qmd.TP = \frac{(QL.TP / TAUAN.TP)}{Qi.TP} \cdot 100 \quad [\%] \quad (17)$$

- specific consumption of electricity for pumping in TN:

$$cs_{pp} = \frac{E_{pp}.TP}{QL.HW.TP} \quad [\text{kWhe/MWt}] \quad (18)$$

- specific consumption of make-up water for TN:

$$cs_{mkw} = \frac{C.MKW.TP}{QL.HW.TP} \quad [\text{m}^3/\text{MWt}] \quad (19)$$

### 3.2.4 Technical indicators for ensemble of TP sources of DH system

Technical indicators for ensemble of TP are calculated in the same mode with chapter 3.2.3 using quantities of heat, electricity, fuel, make-up water obtained through sum for all TP – see Fig. 1 (DEX.0.TP, respective DEX.1.TP).

### 3.2.5 Technical indicators for LTP [1]:

- net value of efficiency of LTP,  $\eta_{LTP}^{net}$ :

$$\eta_{LTP}^{net} = \frac{QL.LTP}{F.LTP} \cdot 100 \quad [\%] \quad (20)$$

- efficiency of PDS,  $\eta_{PDS.LTP}$ :

$$\eta_{PDS.LTP} = \frac{QV.LTP}{F.LTP} \cdot 100 \quad [\%] \quad (21)$$

### 3.2.6 Technical indicators for ensemble of LTP:

Technical indicators for ensemble of LTP are calculated in the same mode with chapter 3.2.5 using quantities of heat, fuel obtained through sum for all LTP.

## 3.3 Technical performances of TDS of DH system

### Input data:

QI.DH - heat supplied in TN by ensemble of CHP and TP – calculated in chapters 3.2.2 and 3.2.4 according to principle from fig. 1.

QV.DH – heat sold from DH system (heat sold from TN and from DSN) – data supplied by beneficiary.

C.MKW.TN - total quantity of make-up water supplied by heat sources.

### Output data:

- specific consumption of make-up water in TN:

$$cs_{mkw} = \frac{C.MKW.TN}{QI.DH} \quad [\text{m}^3/\text{MWht}] \quad (22)$$

$$\text{where: } C.MKW.TN = C.MKW.CHP + C.MKW.TP \quad (23)$$

$C.MKW.CHP, C.MKW.TP$  – calculated in chapters 3.2.2 and 3.2.4

- specific consumption of electricity for pumping in TN:

$$cs_{pp} = \frac{E_{pp}.TN}{QI.DH} \quad [\text{kWhe/MWt}] \quad (24)$$

$$\text{where: } E_{pp}.TN = E_{pp}.CHP + E_{pp}.TP \quad (25)$$

$E_{pp}.CHP, E_{pp}.TP$  calculated in chapters 3.2.2 and 3.2.4.

- efficiency of TDS,  $\eta_{TDS}$ :

$$\eta_{TDS} = \frac{QV.DH}{QI.DH} \cdot 100 \quad [\%] \quad (26)$$

### 3.4 Environment performances heat sources

Environment performances from the emissions level point of view is based on comparison between specific emissions of SO<sub>2</sub>, NOx, dust realized in current operation with maxim level of them approved by GD 440/2010 taking into account terms for complying with environment norms, as case.

Most of LCP from Romania exceed the limit value of emissions and have terms for complying with accepted limits of emissions. After these terms, complying with environment legislation will be compulsory for operation. For LCP which benefit by derogation from environment norms, complying with emissions level is not compulsory but their operation period until 2015 will not exceed 20000 hours. Generally, measures for complying with environment legislation for existing LCP require high investments which are conditioned by other technical characteristics of equipment: remanent life duration, efficiency, operating at partial loads due decreasing of heat demand. Thereby, in many cases, for complying with environment legislation, investments in new equipment are the most feasible solutions.

### 4. Aspects regarding implementation of mathematic model

Mathematic model is implemented in a Visual Basic programme with an Access database.

Input data are stored in simple tables of database and output data are query type tables of database. All elements of database are set in design stage of database. Interface of programme between user and database is designed in Visual Basic language and has the role of data manager: open an existing database or create a new database, enter, save, modify, delete and printing data.

Due the fact of input data are statistical data from operation and some of them are measured and other are calculated, all of them exposed to measurement errors or mistakes of operators. From this reason, programme is designed to check and alert the user about some gross errors of input data to prevent saving wrong data and

their propagation in finally results. In table 1 is presented verified errors and mistakes before saving data.

*Table 1*  
**Verified possible errors or mistakes before saving data**

Crt. no.	Name	Possible errors or mistakes
1	2	3
1	Analysis of technic situation of equipment from heat sources	Operating period from last OH is greater than operating period from PIF for same equipment.
2	Analysis of technic situation of TDS	Sum of length of underground circuit and aerial circuit is greater then total circuit length.
3	Operating data of CHP	$\eta_{gl.CHP}^{gr} \geq 1$ EP.NCG+EP.CG ≠ EP.CHP
4	Operating data of TP	$\eta_{TP}^{gr} \geq 1$
5	Operating data of LTP	$\eta_{LTP}^{net} \geq 1$ QV.LTP > QL.LTP
6	For all steps of input data	Duplicate records in tables with input data. Omission of some required input data (empty fields).

Taking into account the character of input data (mentioned above), even some gross errors and mistakes are corrected and input data are validated remains a problem regarding “degree of trust” of input data. For example, electricity and heat produced in cogeneration regime (EP.CG and QP.CG) in many cases are calculated while total electricity and heat supplied by CHP are object of commercial transactions and are measured with devices metrological verified. From this point of view, some data can be considered being “trustworthy” (example: fuel consumption, heat supplied, electricity supplied) as long as are determined through measurement with approved devices and accepted by the supplier and client, while the others keep an “uncertainty degree”. This aspect is important in analysis of performance indicators.

## 5. Example

In this example are presented results of technical and environment analysis of a DH system of a city, noted with A, composed of 8 CHP (CHP A1÷CHP A8) and 1 TP (TP A1) as heat sources and TDS composed of TN, S, MT, DSN. Fig. 2 presents RLD of equipment and environment restrictions represented by terms of complying or derogation period.

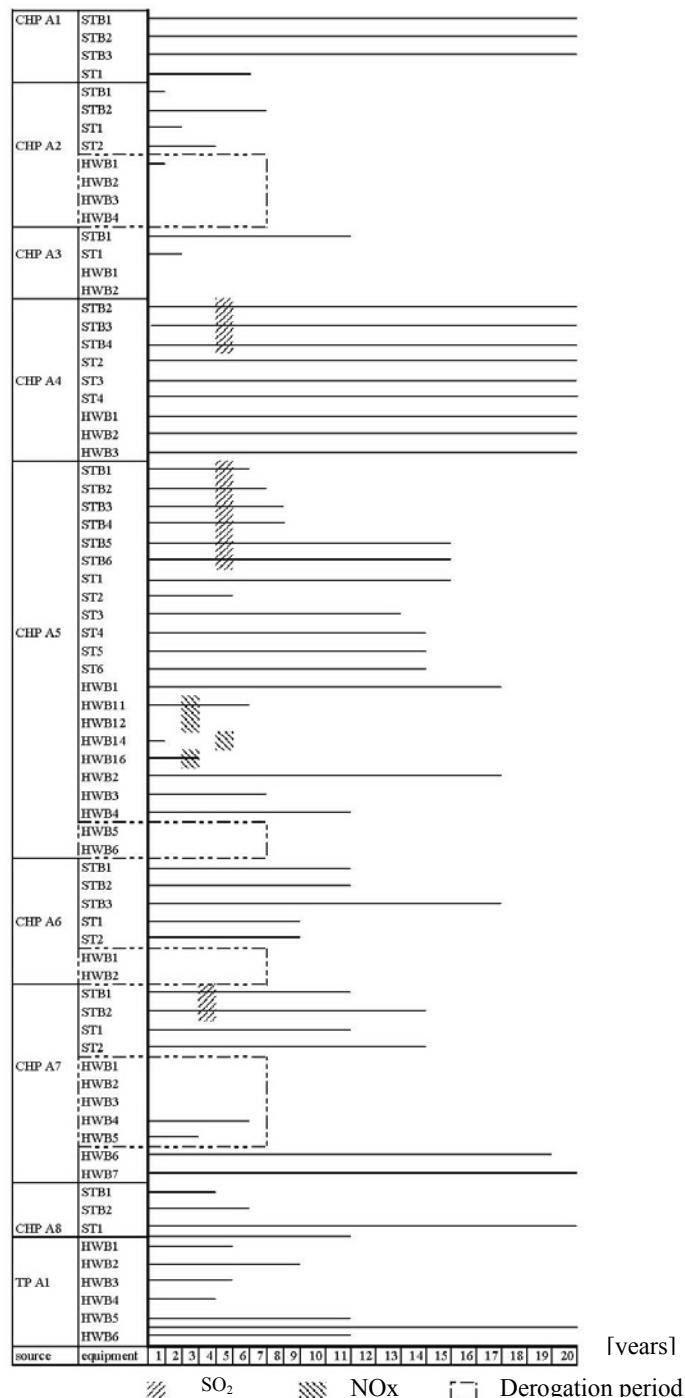


Fig. 2 – RLD of equipment and environment restrictions

For STB whose RLD is close to complying terms (see CHP A5) measures for complying with emissions level has many questions regarding to their maintaining in operation or replacing with new ones. RLD of HWB from CHP (see CHP A2, A5, A6, A7) is almost expired and this is the main reason of derogation from environment norms.

Figs. 3÷8 present value of performance indicators of heat sources.

Fig. 3 present values of gross and net efficiency of CHP and TP (3.a and 3.b) and for ensemble of CHP, TP (3.c). The difference between gross and net values is represented by own consumptions and losses.

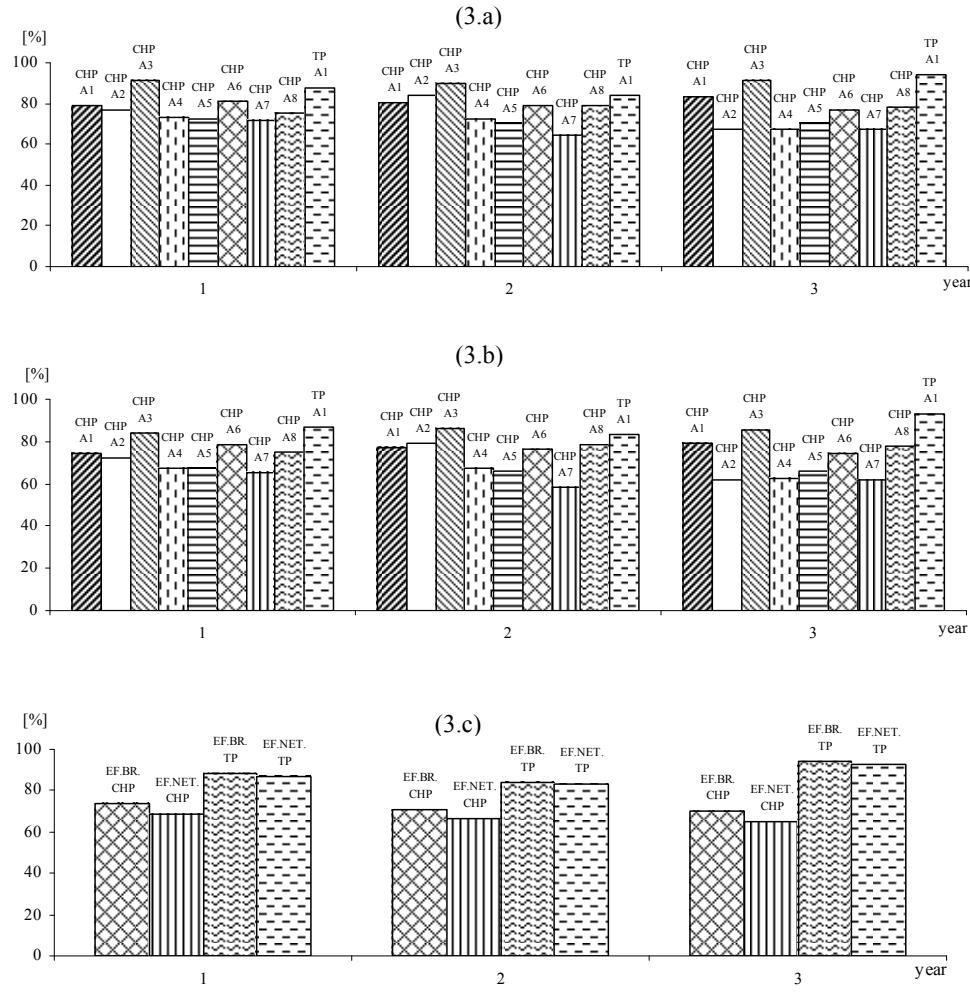


Fig. 3 - Gross and net efficiency of heat sources

3.a – gross value,  $y_{CHP/TP}^{br}$ ; 3.b – net value,  $y_{CHP/TP}^{net}$ ; 3.c – ensemble of CHP and TP

Fig. 4 present gross (4.a) and net (4.b) values of structure factor of energy production.

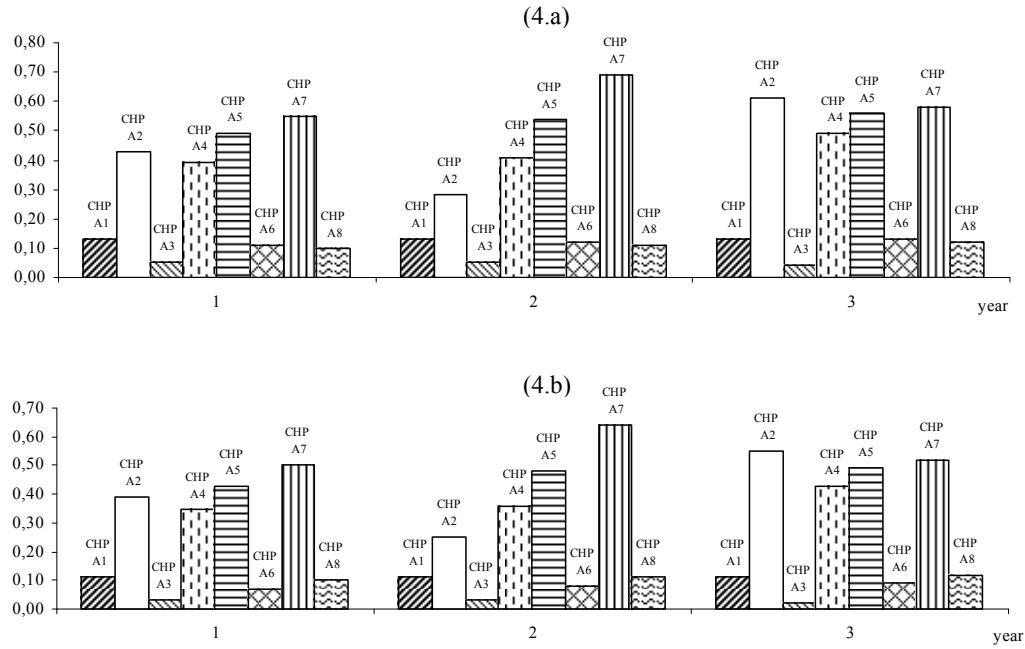


Fig. 4 - Gross and net value of structure factor of energy production

4.a - gross value  $y_{CHP}^{gr}$ ; 4.b – net value,  $y_{CHP}^{net}$

Fig. 5 present average annual values of cogeneration factor of CHP.

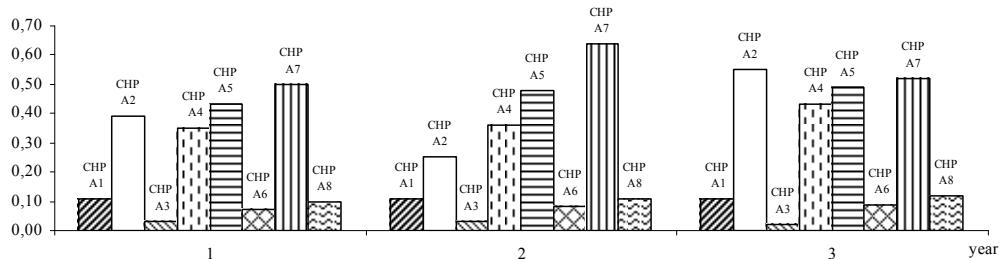


Fig. 5 - Average annual cogeneration factor of CHP, YCG

Fig. 6 presents shares of noncogeneration (6.a) and cogeneration (6.b) electricity production in total electricity production.

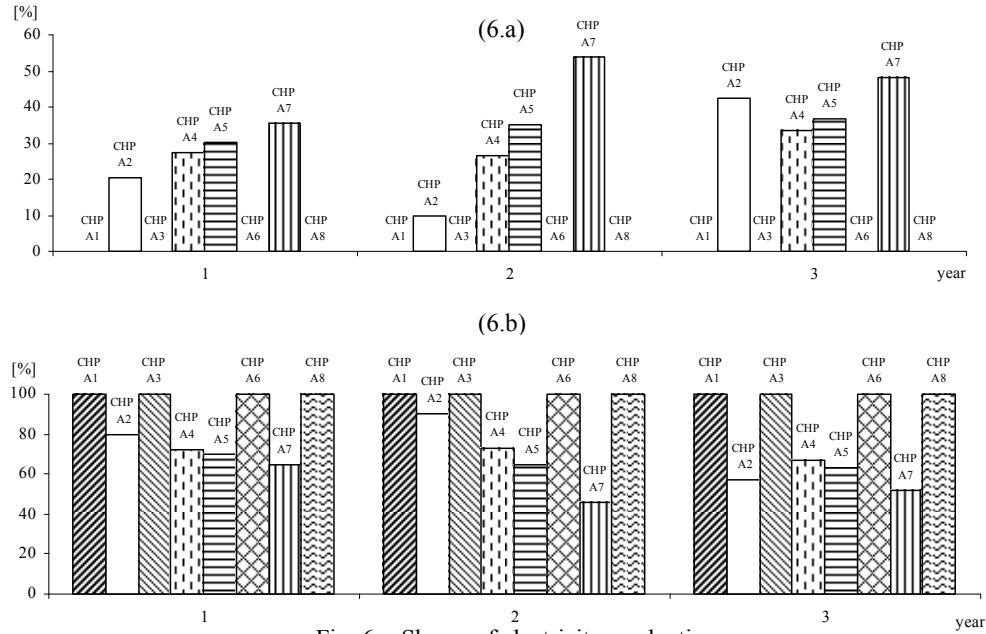


Fig. 6 - Shares of electricity production  
6.a – electricity production in noncogeneration regime, XNCG; 6.b – electricity production in cogeneration regime, XCG.

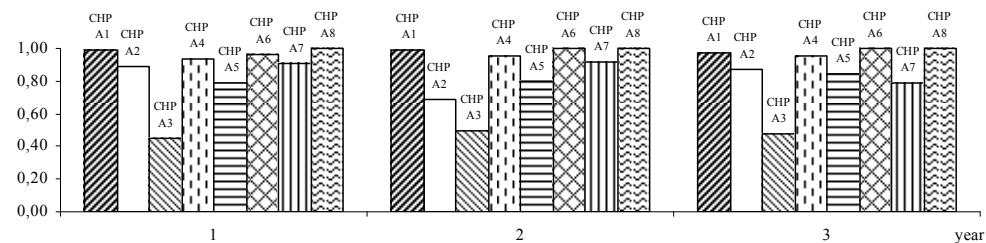
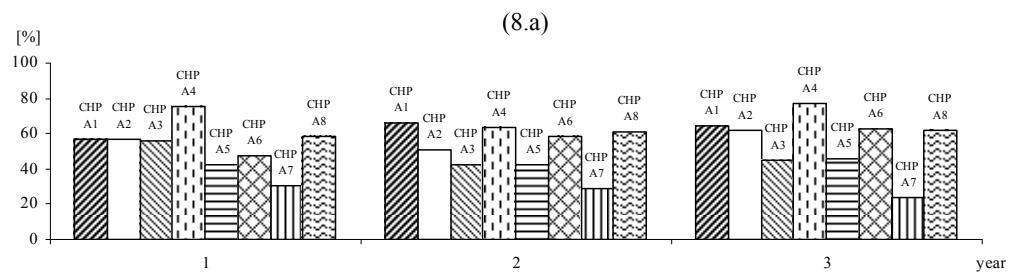


Fig. 7 - Annual values of cogeneration coefficient for heat production,  $\alpha_{cg}^{an} \cdot CHP$



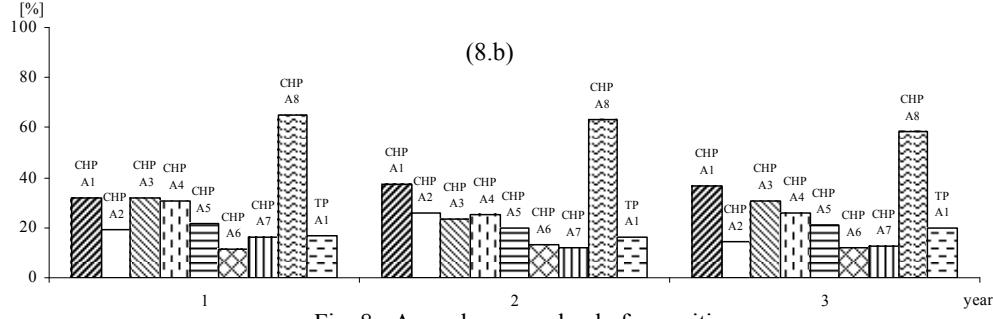


Fig. 8 - Annual average load of capacities  
 8.a – capacities for electricity production from CHP,  $pmd.CHP$ ; 8.b – capacities for heat production from CH,  $qmd.CHP$  and TP,  $qmd.TP$ .

## 6. Conclusions

### 6.1 Conclusions regarding heat sources of DH system (CHP and TP)

Correlating performance indicators resulted from technic and environment analysis from example presented in chapter 5, can be concluded the following:

- future operation of STB and HWB (as LCP) is conditioned both by RLD and compulsoriness of complying with environment legislation. In addition, decision regarding their future operation must take into account technic performances;

- gross and net efficiency of CHP A1, A3, A4, A6, A8 are higher than the others. These are equipped with backpressure ST and the operation regime is based on heat demand. CHP A2, A5, A7 are equipped condensing ST with steam extraction. Their efficiency is lower due the share of EP.NCG – see XNCG values from fig. 6.a;

- cogeneration coefficient for heat production,  $\alpha_{cg.CHP}^{an}$  - see fig. 7 - has values  $>0,8$  (except CHP A3) but analyzing together YCG, XNCG and XCG values, it turns out the following:  $YCG \leq 0,25$  for backpressure ST and  $>0,2$  until 0,6 for condensing ST with steam extraction. Usually the value of YCG for condensing ST does not exceed 0,45 depending on load and electric efficiency - subchapter 7.2.3 from [1]. Values resulting from operation exceed 0,45, which implies a share of EP.NCG – also confirmed by XNCG values from fig. 6.a. This can be explained either by an operation regime based on electrical schedule or by the necessity to avoid operation to the technical minimum load of STB taking into account low values of load equipment presented bellow;

- for all CHP, the annual weight load of equipment for electricity production did not exceed 75% for backpressure ST (see CHP A1, A3, A4, A6, A8) and 60% for condensing ST with steam extraction (see CHP A2, A5, A7);

- the annual weight load of equipment for heat production, did not exceed 40%, except CHP A8 with 65%. However, be noted that equipment for heat production from CHP also include HWB as peak units. CHP A8 is equipped only with ST without peak units;

- low values of load both for heat (qmd.CHP, qmd.TP) and electricity (pmd.CHP) production, demonstrate that equipment from all heat sources of DH system, are oversized in relation to current level of demand– see. fig. 9.a and 9.b;

Correlating performance indicators from above, result the following aspects regarding CHP equipped with condensing ST and steam extraction:

- Energy producers preferred to produce electricity in noncogeneration regime due the high price in periods with high electricity demand. Share of heat produced by peak units – resulted from  $\alpha_{cg.CHP}^{an}$  values – and low values of load of capacities for electricity production can be explained through technical condition of equipment (STB and ST) which limited loading of them. For electricity production in noncogeneration regime, these have decreased heat load of CHP units (through decreasing quantity of steam extracted), increased electricity production and covered heat demand from peak units (HWB). Option for this regime can be profitable for producer from economic point of view but not for heat consumer. This shows that operation regimes of CHP have been “independent” from the rest of DH system although the only heat consumer of CHP is DH system.

An optim operation of CHP from a DH system “must start” from heat and electricity demand profiles [3].

Also, optimal scheduling of CHP plants must be based on optimizing all economic, technic and environment factors [4], [5]. Especially, beginning with 2013 year all environment costs (externalities) will be internalized in total cost structure and determine increasing on electricity and heat price [6].

## 6.2 Conclusions regarding ensemble of DH system

Fig. 9 present a Sankey diagram of whole DH system for the third year of period of study. Diagram from Fig. 9 was realized using as many “trustworthy” data – see principles from chapter 4. Thus, it includes fuel consumption of heat sources, electricity supplied in public grid by CHP, heat supplied in TDS by CHP and TP, heat sold to the clients.

The differences between fuel consumption and both shapes of energy supplied (heat and electricity) are represented by own consumptions and losses.

From fig. 9 result that net efficiency of whole DH system  $\eta_{DH}^{net} = 54,1\%$  while efficiency of TDS of DH system  $\eta_{TDS} = 75,2\%$ .

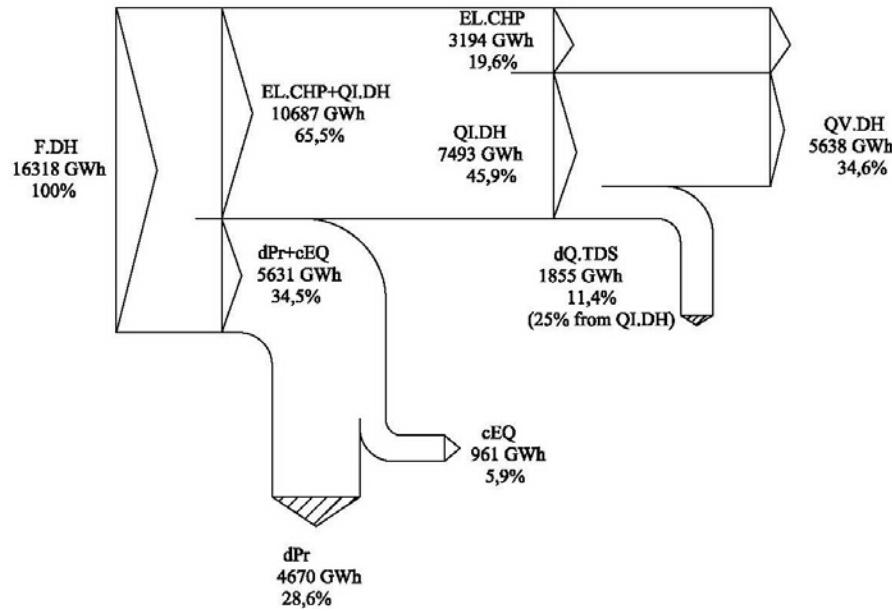


Fig. - 9 Sankey diagram of whole DH system (third year of study period)

Legend for fig. 9 : dPr – losses in production sources;  
 EQ – electricity and heat consumption (of auxiliares from sources and TDS),  
 from sources production; dQ.TDS – heat losses in TDS.

On the other hand, from characteristics of components of TDS (data supplied by beneficiary) resulted that pipes of TN and DNS are 25-30 years old. From all pipes have been replaced only 10%. All pipes of TDS are oversized in relation to current level of heat demand.

**Nomenclature:** HW – hot water; HWB – hot water boiler; CHP – cogeneration plant; TP – thermal plant; LTP – local thermal plant (thermal plant with own distribution networks for hot tap water and heating); TM – thermal module; S – substation; TN – Transmission network for HW; DSN – distribution networks for heating and hot tap water; DH – district heating system; DH.LTP – DH system composed of LTP and DSN; PDS – production and distribution system (for LTP); TDS – transmission and distribution system of heat; OH – overhaul; PIF – put in operation; STB – steam boiler; ST – steam turbine; GT – gas turbine; CCGT – combined cycle gas turbine-steam turbine; MAI – engine with internal combustion; MWe – megawatt of electricity; MWhe – megawatt hour of electricity; MWht – megawatt hour of heat; MWt – megawatt of heat; GD – Government decision; LCP – Large combustion plant, according GD 440/2010; ELV – emission level value of LCP according to GD 440/2010.

**Nomenclature for input data:** RLD - remanent life duration; F.CHP – fuel consumption of CHP, in MWht; EP.CHP – total electricity production of CHP, in MWhe; MKW.CHP – annual quantity of make up water, supplied by CHP in TN, in m<sup>3</sup>/year; MKW.TP – annual quantity of make up water, supplied by TP in TN, in m<sup>3</sup>/year; MKW.LTP – annual quantity of make up water, supplied by LTP in DSN for heating, in m<sup>3</sup>/year; EC.CHP – electricity consumption of CHP for auxiliares, in MWhe; EC.TP – electricity consumption of TP for auxiliares, in MWhe; EC.LTP – electricity consumption of LTP for auxiliares, in MWhe; EL.CHP – electricity supplied by CHP, in MWhe; EP.CG – electricity production of CHP in cogeneration regime, in MWhe; EP.NCG – electricity production of CHP in noncogeneration regime (in condensing regime–case of condensing ST with steam extraction or without heat recovery–case of GT, MAI), in MWhe. EP.CHP = EP.CG+EP.NCG; Epp.CHP – electricity consumption of CHP for hot water pumping in TN; Epp.TP – electricity consumption of TP for hot water pumping in TN; Epp.LTP – electricity consumption of LTP for pumping in DSN, in MWhe/year; Pi.CHP – installed electric power of CHP, in MWe; Qi.CHP – installed thermal power of CHP, in MWt; QL.ST.CHP – steam supplied from CHP, in MWht; QL.ST.TP – steam supplied from TP, in MWht; QL.HW.CHP – hot water supplied from CHP, in MWht; QL.HW.TP – hot water supplied from TP, in MWht; QL.TP – heat supplied from TP (steam and hot water), in MWht; QP.ST.CHP – steam produced by CHP, in MWht; QP.ST.CG – steam produced by cogeneration units, in MWht; QP.HW.CG – hot water produced by cogeneration units, in MWht; QP.HW.CHP – hot water produced by CHP, in MWht (QL.HW.CHP=QP.HW.CHP); QP.CHP – total heat produced by CHP, in MWht (QP.CHP= QP.HW.CHP+QP.ST.CHP); QP.CG – total heat produced by cogeneration units, in MWht (QP.HW.CG +QP.ST.CG =QP.CG); QP.TP – total heat produced by TP, in MWht; QP.LTP – total heat produced by LTP, in MWht; QP.NCG – heat produced by HWB from CHP), in MWht; QV.LTP – heat sold from LTP, in MWht; TAUAN.CHP – operation period of CHP, in hours/year.

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