SOLUTIONS OF ENERGY-RELATED UPGRADING OF THE EXISTING BUILDING CONNECTED TO THE COGENERATION HEATING SYSTEM IN ROMANIA

Prof. Dan Constantinescu, Dr. eng.
Rodica Mitrofan, eng.
Tudor-Dan Constantinescu, stud.

INCERC - National Building Research Institute
266, Pantelimon Sos., Sect. 2
Bucharest, Romania
Fax. 00401-3128062

Abstract

The energy rehabilitation of district heating system requires a proper expert survey of secondary loop including thermal substation, heat carrier distribution network and buildings of residences. This paper present the theoretical fundamentals as well as the measurements specific to the procedure used in assesing the thermal characteristics of the heat exchangers, network and buildings of residences. The results obtained were used in the diagnosis activity supported by the "SIMPATIC" software.

The paper also introduces the present energy efficiency of the PT 1" Uverturii" thermal substation as well the efficiency values that may be reached as a result of the rehabilitation of the entire system.

INTRODUCTION

The energy-related rehabilitation of the cogeneration heating system is a most important concern of the experts in the field, covering the whole range from energy production to its use by consumers.

This paper is focused on the methodological support of the energy related expertise and diagnosis of the secondary heating loop in the apartments connected to the urban cogeneration heating system. The numerical examples refer to the operation of several thermal substation in Bucharest; but the theoretical and experimental analysis methods are general and therefore may be applied to any cogeneration heating system.

Taking into account that ab. 40% of the heat demand of the apartments in Romania is presently covered by the cogeneration heating system, the proper operation of this system is of the utmost importance it should ensure the comfort parameters necessary for a decent living standard. Moreover, comfort ensuring should involve a rational energy comsumption, therefore an efficient operation of the whole system. At present these targets are only partly fulfilled because of the unacceptable level of the apartments indoor temperatures during the cold season. Of course, by reducing the thermodynamic potential specific to the consumers, energy consumption is reduced, but the main function is eluded.

It may be stated that most of the apartments supplied by the cogeneration heating system are affected by the "sick building" syndrom. The low level of the indoor temperatures (14 ^{0}C – 17 ^{0}C) in the cold season on the hand and the insufficient ventilation of the dwelling spaces as well as the use of totally improper auxiliary heat sources ("free uncovered flame") on the other hand favour the occurrence of the above- mentioned syndrom. Moreover, only in Bucharest, ab. 200,000 apartments are affected by condensation in more or less serious forms. The lack of any intervention in order to improve this situation leads to negative social effects such as serious illnesses affecting the occupants and the damaging of the apartments structure. Therefore the energy related upgrading of the system is a problem of the utmost urgency and in our opinion involves two distinct phases of the analysis:

- to conclude the minimal technical solution that may ensure, in the existing heat supply conditions, an acceptable microclimate in the buildings. The technical solution refers to the heat carrier distribution network, thermal substations equipping, apartments heating systems and additional thermal protection:

- to conclude the optimal solution for reducing the apartments heat consumption - this is mainly an energy management issue and represents a phase subsequent to the ensurance of normal habitat conditions.

Any upgrading solution implies two working stages as follows:

- technical expertise of the system components and of the system as a whole;
- energy related diagnosis and technical rehabilitation solutions.

This report focuses on the secondary loop of the cogeneration heating system, including the indoor heating equipment. It presents the technical expertise procedures in the case of the thermal substations, secondary heat carrier network and buildings, both theoretically and in the form of measurements performed in the period 1994 - 1996 in several thermal substations in Bucharest. The report also presents the possible technical upgrading on the "SIMPATIC" diagnosis software worked out by the authors.

The economic analysis of the solutions described in the paper is not included.

CHARACTERISTICS OF THE APARTMENTS COGENERATION HEAT SUPPLY SYSTEM IN BUCHAREST

The main characteristics of the cogeneration heat supply system as well as those of the thermal protection of the apartments in Bucharest are further briefly presented.

The measurements performed in the period 1994 - 1996 in several representative thermal substations in Bucharest (fig.1) prove that of the annual heat demand of 19,500 TJ, only 13.620 TJ (69%) have been supplied for the heating of the ab. 570,000 apartments connected to the cogeneration heating system, resulting in an average indoor temperature of 16.5 ^{0}C [1].

In the present conditions of the apartments heat supply, the buildings thermal protection cannot ensure the indoor temperature required by the comfort standards.

A solution focused on new production capacities may seem proper for improving the existing situation, but it would perpetuate the risk of an important heat wastage at the level of the apartments. Is enough to remind you that in the case of the Romania buildings the annual average heat consumption is of 800 MJ/m^{2}year [1].

A further important aspect is represented by the improper operation of the entire heat distribution system between the substations and the consumers. The heat distribution system specific to the cogeneration district heating system used in Romania (as well as in the other former socialist countries) includes - in the secondary loop-high capacity thermal substations with values ranging form 2.3 MW to 14 MW. The heat carriers are distributed from the substations through a four pipe system (two for space heating and two for domestic hot water); more than 93% of these pipes are placed in inaccessible thermal channels and in the

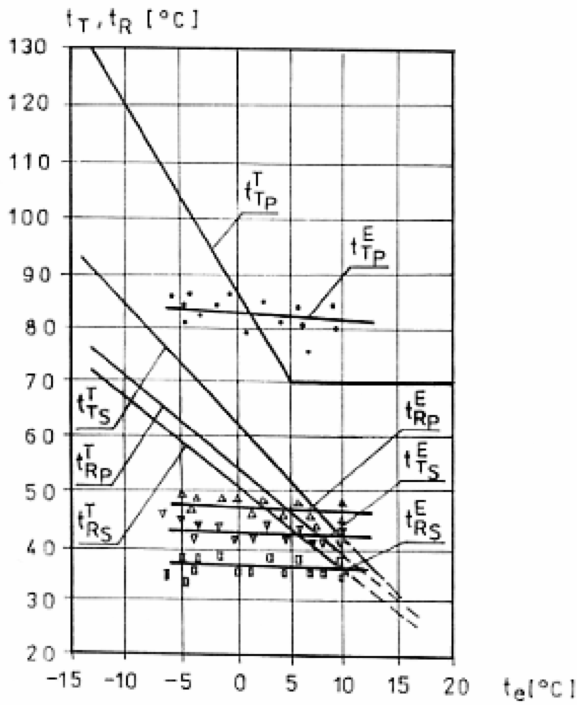

FIG. 1

Heat carrier temperature variation

acording to the outdoor temperature:

T – theoretical

E – experimental

basements of the apartment buildings. The age of the system (more than 30 years), the technical solutions adopted (in line with the technologies used in the 60s) as well as the dramatic lack of the system maintenance funds generated its damaging and therefore a serious energy efficiency reduction [2], [3]. May we emphasize that this critical situation has been worsened by the artificial preservation of the thermal energy cost at an extremely low cost. The energy management elements are represented by an extremely small number of heat meters in the substations and in a few blocks or block staircases. The legislation in force on energy management has very vague stipulations, frequently contradictory, which hinders the installations of heat meters in the system.

Nevertheless, a few recent resolutions of the new Government concerning the transformation of the "regies" in commercial companies on the one hand and the adopting of the real value of the energy price on the other hand require urgent measures for the upgrading or / and modernization of the Romania's district heating system. In the line of the previous statements the optimum technical solutions may be reached only based on the accurate knowledge of the actual characteristics of the system in its present condition. Two of the logical phases of the upgrading activity should be the system expertise and diagnosis. The technical expertise implies the working out of several procedures based both on "in situ" measurements and on the knowledge of the thermal and hydraulic processes specific to the entire system. The enormous dimensions (e. g. Bucharest has 625 thermal substations supplying heat to 570,000 apartments through ab. 700 km of network which form the secondary loops of the system), as well as the complete absence of the monitoring equipment induce to the technical expertise a number of features which render it different from certain procedures used in the assessment of the "in vitro" type characteristics [4], [5].

This report briefly presents three important procedures which are necessary in the assessment of the real thermal characteristics of the substations equipment, of the secondary heat carrier distribution network and of the buildings in general.

The heat engineering characteristics and the " SIMPATIC" complex software are used in the assessment of the real energy-related efficiency and in the study of the effects in terms of energy of the application of several upgrading solutions; the real energy potential specific to each technical solution which may be applied is also evaluated.

The following results are obtained if the expertise procedures described in this report are correctly applied:

- the real thermal characteristic of the heat exchangers (one or several) in the substation;
- the global thermal characteristic of the secondary heat carrier distribution network;
- the real thermal characteristic of the existing buildings.

• The real heat exchanger thermal characteristic is expressed either by the global heat transfer characteristic $(UA)_{SCH}$, as an average value, or as a complex function related to the heat carrier temperatures and to their mass flow-rates. Both results are useful in practice:

- the average value compared to the design value shows the global reduction of the heat transfer capacity;
- the characteristic in the form of a thermal and hydraulic parameters function is expressed by a mathematical relation included in the mathematical model specific to the "SIMPATIC" software. The numerical coefficients of the mathematical relation leaded to the assessment both of the real heat transfer area, and of the real thermal resistance of the organic and inorganic deposits inside the heat exchangers.

- The real thermal characteristic of the secondary heat carrier distribution network is mainly represented by the real average thermal resistance of the thermal protection and in the second place by the heat carrier losses which cause important energy losses in the system.
- The real thermal characteristic of the buildings in general consists in the real value $(UA)_C$, different form the design one, considered in terms of the components specific to the opaque building units $(UA)_P$ and to the transparent ones (including the air exchanges with the environment), $(UA)_F$. These values are reference figures in the evaluation of the energy-related effects produced by the application of a number of additional thermal protection solution on the existing buildings. Allow us to emphasize that the use of the traditional methods in assessing the overall heat transfer coefficient of the structures generates specific results that may not constitute the global thermal characteristic of a building as a whole. The real values $(UA)_C$ are used in the structure of the "SIMPATIC" software as they are necessary in the assessment of the heated rooms thermal response.

The assessment of the real thermal characteristics of the system and of its components demands short-time but relevant and useful experiments.

This report introduces the theoretical support of the thermal identification procedures necessary in the expertise, diagnosis and upgrading of the system. The report also includes the results obtained by the application of the analysis method in the case of a high capacity (8.3 MW) substation in Bucharest.

Our opinion is that the methods presented in this report are instruments indispensable in any activity related to the upgrading of the district heating system in the Central and Eastern Europe countries.

PROCEDURES USED IN THE THERMAL IDENTIFICATION OF THE THERMAL SUBSTATIONS. SECONDARY HEAT CARRIER NETWORK AND BUILDINGS

The thermal identification is a component of the technical expertise and consists in the identification of the real characteristics of a system or/and of its components. These characteristics will be used in a mathematical model describing the behaviour of the system as well as in the diagnosis and finally in concluding the energy related rehabilitation solutions.

The thermal identification involves the processing of experimental data according to mathematical models that estimate as accurately as possible the phenomenon that is analyzed. The paper further introduces the theoretical fundamentals of several types of thermal identification that are absolutely necessary in an energy related diagnosis.

Heat exchangers thermal identification

The equation specific to the thermal substation heat exchangers is the following:

$$Q_{SCH} = (UA)_{SCH} \cdot \Delta t_{log} \tag{1}$$

The thermal identification consists in the assessment of the real thermal characteristics $(UA)_{SCH}$ which is different from the design theoretical characteristic. The measurements that are performed refer to the following values: t_{Tp_j}, t_{Rp_j}, t_{Ts_j}, t_{Rs_j}, $G_{P_j}^{PT}$ and $G_{S_j}^{PT}$ where index "j" means the experiment number. Equation (1) provides:

$$(UA)_{SCHj} = \frac{G_{Sj}^{PT} \cdot c}{R_{Tj} - 1} \cdot \ln\left(R_{Tj}^{1}\right) \tag{2}$$

where:

$$R_{Tj} = \frac{t_{TPj} - t_{RPj}}{t_{TSj} - t_{RSj}} \; ; \qquad R_{Tj}^{1} = \frac{t_{TPj} - t_{TSj}}{t_{RPj} - t_{RSj}}$$

The practical law of assessing the "U" heat transfer global factor is assimilated for the flat-plate wall law:

$$U_{SCH} = \left(\frac{1}{\alpha_p} + \frac{1}{\alpha_s} + R_d\right)^{-1}$$

Therefore the global thermal characteristic may be written as follows:

$$(UA)_{SCH} = \left(\frac{1}{\dot{\alpha}_p} + \frac{1}{\dot{\alpha}_s} + \dot{R}_d\right)^{-1} \tag{3}$$

where:

$$\dot{\alpha}_s = \alpha_s \cdot A_{SCH} \; ; \quad \dot{\alpha}_p = \alpha_p \cdot A_{SCH} \; ; \quad \dot{R}_d = \frac{R_d}{A_{SCH}} \; ;$$

$$\dot{\alpha}_s = \left(a_s + b_s \cdot \bar{t}_s + c_s \cdot \bar{t}_s^2\right) \cdot G_s' \; ; \quad \text{where } \; \overline{t_s} = 0.5 \cdot \left(t_{TS} + t_{RS}\right)$$

$$\dot{\alpha}_p = \left(a_p + b_p \cdot \bar{t}_p + c_p \cdot \bar{t}_p^2\right) \cdot G_p' \; ; \text{where } \; \overline{t_p} = 0.5 \cdot \left(t_{TP} + t_{RP}\right)$$

Equation (3) may be written as:

$$\frac{G_{Sj}^{PT} \cdot c}{R_{Tj} - 1} \cdot \ln\left(R_{Tj}^{1}\right) = \left(\frac{1}{\dot{\alpha}_{pj}} + \frac{1}{\dot{\alpha}_{sj}} + \dot{R}_d\right)^{-1} \tag{4}$$

including seven unknown values a_s , a_p , b_s , b_p , c_s , c_p and R_d . If "n" measurements are performed, C_n^7 equations system of equation (4) type are generated, each of them leading to the assessment of a set of unknown values. The final values are assessed from the analysis $\left(\sigma a/\bar{a}\right)$, therefore:

$$\sigma a/\bar{a} \le \varepsilon \tag{5}$$

With the average values $\bar{a}_p$ ..... $\bar{R}_4$ thus assessed, the mathematical model describing the thermal behaviour of the heat exchangers is given by relation (3).

The real characteristic (3) may be used in comparisons with the theoretical characteristic, emphasizing the deficiencies of the existing heat exchangers.

The method of using the convection correlations in assessing the variation of the convection heat transfer coefficient α cannot be applied in the case of the heat exchangers and especially in that of the old devices in the substations. Taking into account the fact that the convection correlations allowing the assessment of the Nu dimensionless number established by various researchers (Dittus - Boelther [6], Sieder and Tate [7], Colburn [8] etc.) are valid for smooth circular tubes and for fully developed thermal flow, their use in the assessment of the heat exchangers global thermal characteristic would be a mistake. Moreover, the object of [9] is a comprehensive discussion on the validity of the convection correlations and supports the previous statements. The fact has to be emphasized that most of the heat exchangers still in operation in Romania are of the shell - and - tube type and made of steel. The malfunctions occur mainly because of the tubes breaking and cannot be easily avoided by the replacement of the tubes, therefore the damaged tubes are frequently blocked . From the thermal point of view, the consequence is the reduction of the heat transfer area. The main result provided by the method is the establishment of the accurate thermal characteristic relation $(UA)_{SCH}$ which further is the instrument used in analyzing the thermal response of the heat exchangers in the substations under examination.

May we further present an application of the method used in the assessment of the heat exchangers real thermal characteristic, referring to a shell - and - tube device of the class B850L, existing in most of substation in Romania. Two types of experiments were performed:

1. On the INCERC testing stand - a new device.
2. In the "PT1 Uverturii" substation in Bucharest - a device whose age was more than 10 years, currently in operation (in the season 1995 - 1996).

Nine experiments were performed in each case, which were further used in establishing the relations that define the global thermal characteristic of the devices that were tested. Two experiments of each type been selected for this report and the theoretical results have been compared to those provided by measurements. Table 1 present the synthesis of the result.

The application of the identification procedure produced the following relations and calculation values (the device was tested in "in vitro" conditions):

$$\dot{\alpha}_S = \left[6.94 \cdot 10^3 + 89.24 \cdot \bar{t}_S - 0.1735 \cdot (\bar{t}_S)^2\right] \cdot G_S^{0.78};$$
$$\dot{\alpha}_P = \left[1.75 \cdot 10^4 + 224.99 \cdot \bar{t}_P - 0.4372 \cdot (\bar{t}_P)^2\right] \cdot G_P^{0.78};$$
$$\dot{R}_p = 3.81 \cdot 10^{-7};$$

In the case of the currently operated device, the results were the following:

$$\dot{\alpha}_S = \left[9.105 \cdot 10^3 + 117.06 \cdot \bar{t}_S - 0.228 \cdot (\bar{t}_S)^2\right] \cdot G_S^{0.60};$$
$$\dot{\alpha}_P = \left[1.742 \cdot 10^4 + 223.98 \cdot \bar{t}_P - 0.435 \cdot (\bar{t}_P)^2\right] \cdot G_P^{0.60};$$
$$\dot{R}_p = 1.498 \cdot 10^{-5}.$$

Table 1.

Cond.	IN VITRO		IN SITU		
Exp. / Param	1	2	1	2	U.M.
G_P	33.0	33.0	33.0	23.1	t/h
t_{TP}	60.0	100.0	82.0	105.0	°C
t_{RP}	39.7	54.3	54.9	56.9	°C
$\bar{t}_P$	49.8	77.2	68.5	81.0	°C
Q_P	0.78	1.75	1.04	1.29	MW
G_S	115.52	115.52	115.52	115.52	t/h
t_{TS}	45.2	66.4	47.2	51.4	°C
t_{RS}	39.5	54.0	39.8	42.0	°C
$\bar{t}_S$	42.3	60.2	43.5	46.7	°C
Q_S	0.76	1.67	0.99	1.25	MW
Q_P/Q_S	1.02	1.05	1.05	1.03	–
$(UA)_E$	194.3	226.3	43.9	42.9	kW/K
$(UA)_T$	201.0	239.0	43.2	42.2	kW/K
$(UA)_E/(UA)_T$	0.97	0.95	1.02	1.02	–

The results confirm the accuracy of the method proposed by this report. The measured data processing method is included in the IDSCAL software worked out by the authors [10].

As concerns the data in table 1., a reduction by ab. 80% of the real thermal characteristic is obvious, which is reflected by a reduction by ab. 30% of the heat transfer capacity in the operating heat exchanger compared to a new device [11].

Taking into account that the heat transfer area of the tested device, according to the production norms is of 125.40 m^2, the conclusion is that the value of the heat transfer global coefficient specific to the new device varies - in the two experiments described - between 1,550 W/m^2K and 1,800 W/m^2K, which are normal values for this type of device. The global heat transfer coefficient of the device operating in the substation varies between 350 W/m^2K and 335 W/m^2K, values which attest a completely defective operation. The diminishing of value U in the case of the second experiment is consequent to the diminishing of the primary heat carrier by 30% as against the normal situation. A comparison of values $\dot{R}_P$ proves a spectacular increase in the case of the substation device as against the new one. According to the assumption that the heat transfer area has not altered, this increase of value $\dot{R}_P$ is accounted for by the organic and inorganic deposits, equivalent to a thickness of 0.0021 m, for λ_p=1.16 W/mK. Based on the relations $\dot{\alpha}_P = \dot{\alpha}_P(\bar{t}_P, G_P)$, and $\dot{\alpha}_S = \dot{\alpha}_S(\bar{t}_S, G_S)$ the thermal response of the heat exchangers in the PT1 Uverturii substation was analyzed, in various operational situation.

In fact, the conclusion resulting from this case is that the only proper measure to be adopted is to replace the existing heat exchangers of PT1 "Uverturii" by new compact devices, with a higher efficiency.

Thermal identification of the secondary heat carrier distribution network

The secondary heat carrier distribution network is characterized by energy loss to the environment as well as by the energy loss caused by the top-up water introduced in the thermal substation so as to compensate the network water losses. The mathematical model describing the variation of the heat carrier temperature is the classical model specific to the steady-state heat transfer:

$$\frac{t_{x,j} - t_{CT}}{t_{x=0,j} - t_{CT}} = \exp\left(- \frac{U_j \cdot P_j}{G_j \cdot c} \cdot X_j \right) \tag{6}$$

where the average air temperature in the thermal channels or/and in the basements of the buildings depends on the geometrical and physical characteristics of the environment. Relation (6) facilitates the assessment of the energy loss by the heat flow transfer from the fluid to the environment. The second type of energy losses is represented by the heat flow necessary for the top-up water heating. This volume of water can be measured directly or estimated indirectly. The assessment of the heat exchangers thermal response is based both on the inlet temperature of the primary heat carrier and on the network thermal response, including the network fluid losses.

In terms of the energy losses by transfer to the environment, the flow-rates dispersion is not relevant for the thermal response of the heat exchangers. The top-up water rate, whose calculation is based on the secondary heat carrier mass flow-rate influences values t_{R_p}, t_{T_s} and t_{R_s} of the heat carrier temperatures at the level of the heat exchangers. The identifying of the calculated values t_{R_p}, t_{T_s}, t_{R_s} with the measured values leads to the assessment of value G_{ad}/G_S^{PT} and implicitly of the energy losses to the environment as well as those caused by the top-up water heating. The identification of the thermal characteristics of a secondary heat carrier distribution network consists in fact in an implicit procedure as, in the conditions of the total absence of any operation monitoring equipment it involves punctual temperature measurements in the thermal substation and in a few blocks as well as data on the real distribution of the heat carrier flow-rates in the network. Such measurements are rather simple and support the working out of the hydraulic configuration of the system, which is to be included in the "SIMPATIC" software. If the heat carrier inlet temperature in the substation is an input data, the remaining temperatures in the system are outlet values and compared to the measured ones. The identification of the network condition mainly consists in the assessment of the average thermal resistance of the thermal protection, as well as of the top-up average flow-rate introduced in the system. The values obtained are compared to the design ones ($R_{iz} \cong$ 1.2 m^2K/W; $G_{ad} \cong 0.0025 \cdot G_S^{PT}$). These values are included in the "SIMPATIC" software which provides the network energy losses rate in the heat quantity supplied by the substation.

Apartment buildings thermal identification

The thermal identification of a building is the most difficult activity as it involves long-term measurements that are subjected to objective and subjective random factors. The variation of the outdoor climatic parameters (temperature, solar radiation intensity, wind velocity) are considered, as well as the occupants' behaviour - they interfere by using various local heat sources attempting to improve the indoor microclimate. The heat flow dissipated by these sources cannot be directly assessed, as a special analysis procedure is necessary. The goal of the buildings thermal identification is to assess the real global thermal characteristic $(UA)_c$ which is different from the design one as well as the real thermal characteristics of the glazed part-including the fresh air inlets $(UA)_F$ and of the opaque part $(UA)_P$. Taking into account the variation in time of the outdoor climatic parameters, the heat balance is valid for periods of time exceeding 3 ÷5 days.

This period of time mainly depends on the buildings thermal capacity and may be improved according to the deviation of the results as against those specific to the above-mentioned period of reference.

The heat balance of a building in these conditions is provided by relation (7):

$$Q_R + Q_L = (UA)_c \cdot (\bar{t}_i - \bar{t}_e) \tag{7}$$

Value Q_L of the left component of equation (7) is not a constant value specific to the usual calculation norms [12]. Value Q_L varies both with the outdoor climate conditions and with the indoor microclimate conditions. The theoretical statement may be made that values Q_L depend on the temperature difference $(\bar{t}_i - \bar{t}_e)$ values. Values Q_L decrease simultaneously with the increase of values $(\bar{t}_i - \bar{t}_e)$ up to a minimum that represents a normal dwelling condition associate with the providing by the heating system of an acceptable thermal comfort. Because of the operational deficiencies of Romania's urban cogeneration district heating system, when the outdoor temperature decreases, an acceptable level of comfort is no longer provided and the occupants start using "local" systems so as to improve the dwelling conditions. Such interventions generate the increase of value Q_L up to a maximum value imposed by the reduced capacity of microclimate improvement or by the additional costs (in the case of the electric heating devices). Therefore the zone of the important temperature differences $(\bar{t}_i - \bar{t}_e)$ is characterized by actually constant Q_L values regardless of value $(\bar{t}_i - \bar{t}_e)$.

If reference is made again to equation (7), it may be written as follows:

$$Q_R = (UA)_c \cdot (\bar{t}_i - \bar{t}_e) - \Psi(\bar{t}_i - \bar{t}_e) \tag{8}$$

Where:

$$Q_L = \Psi(\bar{t}_i - \bar{t}_e)$$

The variation of the heat flow supplied by the heating system as against the temperature difference $(\bar{t}_i - \bar{t}_e)$ leads to relation (9):

$$\frac{dQ_R}{d(\bar{t}_i - \bar{t}_e)} = (UA)_c - \frac{d\Psi(\bar{t}_i - \bar{t}_e)}{d(\bar{t}_i - \bar{t}_e)} \tag{9}$$

In terms of the high values limit $\left(\bar{t}_i - \bar{t}_e\right)$ and taking into account what has been previously mentioned in connection with Q_L:

$$\lim_{\left(\bar{t}_i - \bar{t}_e\right) \to \infty} \frac{dQ_R}{d\left(\bar{t}_i - \bar{t}_e\right)} = (UA)_c \qquad (10)$$

Therefore, the graphic expression of function $Q_R = Q_R\left(\bar{t}_i - \bar{t}_e\right)$ helps in the identification of the building global thermal characteristic by the assessment of the curve tangent angular coefficient for important values of the $\left(\bar{t}_i - \bar{t}_e\right)$ temperature difference. The above-mentioned function can be established only based on the processing of the data supplied by a heat meter equipment with a data collection system.

The heat flow supplied by the heating system, $Q_R(\tau)$ is further processed as average daily values which afterwards are processed as average values for periods of 3÷5 consecutive days.

The average indoor value of the heated space is assessed according to the thermal and hydraulic characteristics of the heating system. The calculation relation which allows the assessment of the indoor temperature variation is provided by the heating units thermal balance equation:

$$G_R \cdot c \cdot \left(t_T - t_R\right) = S_R \cdot U_R \cdot \Delta t_{log} \qquad (11)$$

Considering the design and real characteristics of the system,

$$t_i = \frac{E \cdot t_R - t_T}{E - 1} \qquad (12)$$

where:

$$E = \exp\left[\left(\bar{\beta}/\bar{\alpha}\right)^{\frac{1}{1-m}} \cdot \ln\frac{t_{T_0} - t_{i_0}}{t_{R_0} - t_{i_0}} \cdot \left(\frac{t_T - t_R}{t_{T_0} - t_{R_0}}\right)^{\frac{m}{1-m}}\right]$$

and:

$$\bar{\alpha} = G_R/G_{R_0}; \bar{\beta} = S_R/S_{R_0}$$

Figure 2 presents the variation of values Q_R and Q_L according to the $\left(\bar{t}_i - \bar{t}_e\right)$ temperature difference, in the case of a 44 apartment block connected to the district heating network of the PT1 "Uverturii" substation. The block is of the ground-floor plus ten floors type and was built in 1974. Values Q_R were assessed by means of an experimental system placed in the basement and equipped with thermal and hydraulic monitoring devices as well as heat meters. Values Q_L are assessed based on equation (8); the global characteristic is known:

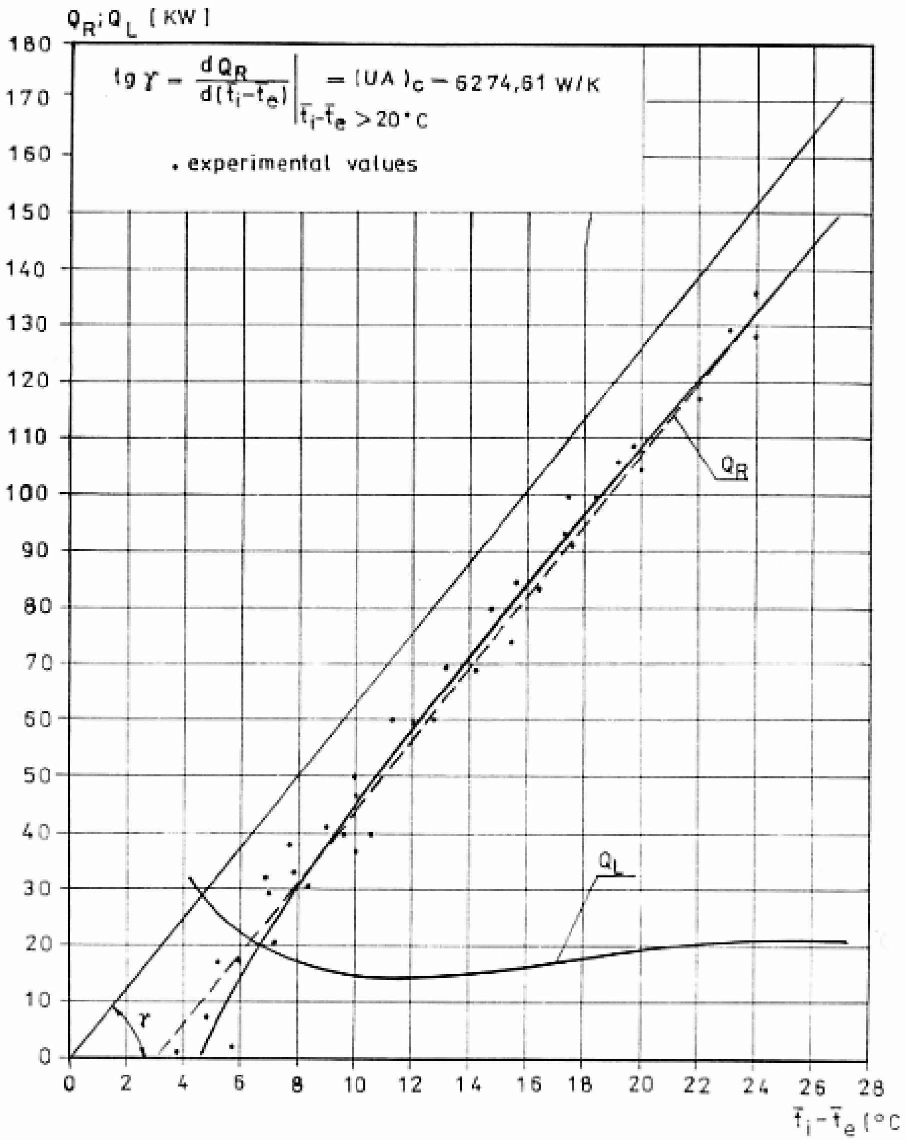

FIG 2 Global thermal characteristic of block M 28

$(UA)_C$ = 6,274.61 W/K (the procedure is described in Fig. 2). As concerns values Q_L, they range between 5.3 W/m^2 and 8 W/m^2 for $\bar{t}_i - \bar{t}_e > 12°C$. The values, which are high exceed by ab. 18% the normal ones (ab. 6W/m^2) and are consequent to the occupants' intervention meant to improve the indoor microclimate.

May we emphasize that the value of the global thermal characteristic $(UA)_C$ is not constant. Moreover, the rather important dispersion of the measured values, Q_R confirm the previous statement. The variation of value $(UA)_C$ is mainly explained by the effect of wind velocity on the overall heat transfer coefficient (windows) and by the number of inside-outside air exchanges. An important remark is that the decrease of the outdoor temperature and implicitly of the indoor temperature because of the heating system operational malfunctions is accompanied by a diminishing of the dwelling space ventilation. Actually value $(UA)_C$ inferred according to the procedure that has been described represents the significant value for the period characterized by negative outdoor temperatures. Theoretically, the value of the global thermal characteristic is assessed as follows:

$$(UA)_C = (UA)_P + (UA)_F \qquad (13)$$

where:

$$(UA)_F = (UA)_V + n_a \cdot V \cdot \rho \cdot c_p \qquad (14)$$

Relations (13) and (14) include two actually invariable terms, $(UA)_P$ and $(UA)_V$ and a variable one which depends on the alteration of the air exchange number, "n_a". The variation of value n_a from 0.7 h^{-1} and 0.3 h^{-1} causes the variation of $(UA)_C$ by 8.7% for the building in question, between the maximum and the minimum value. It is the reason why the aim of this report is to separately identify the components of the global value $(UA)_C$; the proposed upgrading solutions will focus on each and every component.

Another invariable element of the building is its thermal capacity, Mc. This value is useful in the assessment of the glazed area thermal characteristic $(UA)_F$. Value Mc is assessed based on the time constant value $Mc/(UA)_c$ of the building. The time constant value may be experimentally assessed based on the variation of the average indoor temperature of the building in the process of the dwelling space natural cooling. The experiment is performed during the night so as to reduce the effect of the free heat on the one hand and the dwelling space discomfort on the other hand. In fact the building heat supply is cut off and the indoor system water is re-circulated by means of the pump in the basement. After about 3h the water average temperature is in fact equal to the indoor temperature. An additional condition imposed by the experiment is that the outdoor temperature should not be subjected to important oscillations, the amplitude being inferior to the value of 2 °C. In Bucharest such days are specific to the first twenty days of November.

Fig. 3 introduces the results of an experiment performed in November 1996 on the pilot block M 28 (44 apartments). The heat carrier inlet and outlet temperatures were recorded - which were obtained by the re-circulating the water in the system - as well as the indoor temperature in apartment 35 and the indoor temperature assessed by relation (12). The assessment of the time constant value was performed in relation with the time interval between 1^{00} h and 7^{00} h. Heat supply was cut off between 21^{00} h and 7^{00} h.

The approximate balance equation is the following:

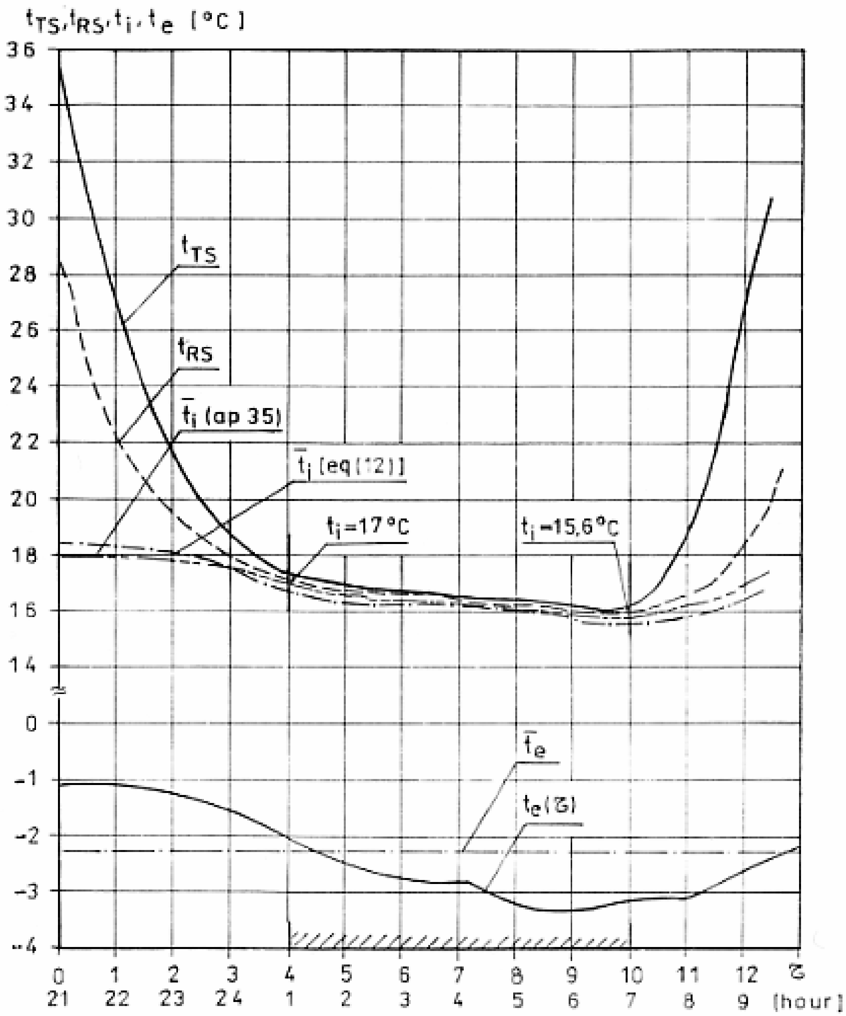

FIG 3 Time constant analysis (Block M 28)

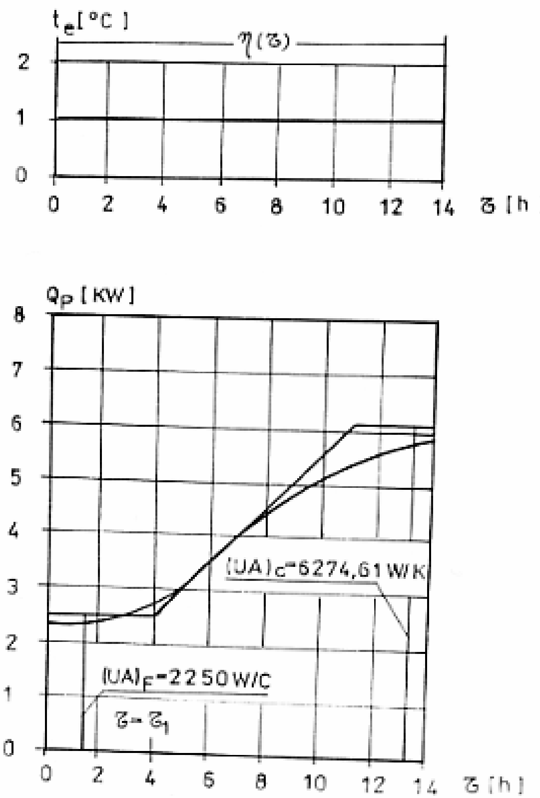

FIG. 4

The thermal response of blok M 28
to a step type thermal load
(theoretical analysis)

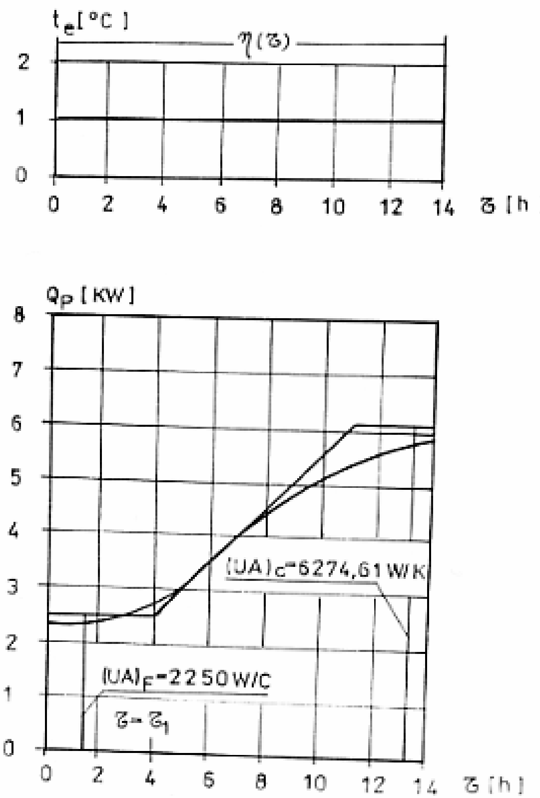

FIG. 4

The thermal response of blok M 28
to a step type thermal load
(theoretical analysis)

$$Q_K(\tau_k) - Q_K(\tau_j) = (UA)_F \Delta[t_i(\tau_k) - t_e(\tau_k)] + Mc\frac{d}{d\tau}[\Delta t_i(\tau_k)] \tag{19}$$

where:

$$\Delta t_i(\tau_k) = t_i(\tau_k) - t_i(\tau_j)$$

and

$$\Delta t_e(\tau_k) = t_e(\tau_k) - t_e(\tau_j).$$

Equation (19) is further used in the assessment of the glazed area thermal characteristic $(UA)_F$ while the other values are measurable.

The $(UA)_P$ characteristic of the opaque surface is provided by the following equation:

$$(UA)_P = (UA)_C - (UA)_F \tag{20}$$

Therefore the thermal identification of the building is completed.

The analysis of value $(UA)_F$ facilitates the approximate assessment of the average fresh air rate inlet into the dwelling space, a value which may characterize together with the indoor temperature the thermal comfort condition.

The analysis focused on the 44 apartment block provides an average value $(UA)_F$ = 2.250 W/K. Based on the fact that the 560 m^2 windows are double-glazed and the corresponding overall heat transfer coefficient is U_V = 2.5 W/m^2K, the typical value n_a = 0.35 $m^3/h/m^3$ (V= 7,260 m^3) results which is lower than the ones stated by the physiological comfort norms.

Several experiments performed in the period 1994 - 1996 on the other blocks in Bucharest lead to a conclusion which is important in terms of the energy-related upgrading solutions: there is a quasi-constant ratio between the value of the real thermal characteristic $(UA)_C$ and the design value $(UA)_0$, namely:

$$(UA)_C/(UA)_0 \cong 0.70$$

The design value is obtained according to the design thermal load specific to the building, which is assessed based on the technical norms in force in Romania [13]:

$$(UA)_0 = Q_0/(t_{i_0} - t_{e_0}) \tag{21}$$

For the construction in question, Q_0 = 320.93 kW, $t_{i_0} = 20^0C$ and $t_{e_0} = -15^0C$. Therefore, $(UA)_0$ = 9,169 W/K and $(UA)_C/(UA)_0 = 0.69$, a value which is close to the one in relation (21).

SYSTEM ENERGY RELATED DIAGNOSIS-ENERGY RELATED UPGRADING TECHNICAL SOLUTIONS

The "SIMPATIC" software is based on the heat balance equations specific to the thermal substation-buildings system which uses the components characteristics generated by the thermal identification [14].

This software can be used in the analysis of various rehabilitation solutions in terms of energy related effects. May we further briefly present an analysis based on the SIMPATIC software and focused on the building complex connected to the PT1 "Uverturii" thermal substation with a useful capacity of 8.3 MW. The following significant values have been obtained by the application of the expertise procedures:

$(UA)_{SCH}$ = 106,845 W/K as against the design value: $(UA)^{0}_{SCH}$ = 384,779 W/K mainly because of a 40% reduction of the primary heat carrier as well as of the organic and inorganic deposits inside the existing heat exchangers;

$(UA)_{C}$ Bl 28 = 6,274.61 W/K of which $(UA)_{F}$ = 2,250 W/K emphasizing the present value of air exchanges number , $\overline{n}_a$ = 0.35 m³/h/m³ which is insufficient in terms of the normal living standard;

$\overline{Q}_L$ Bl 28 = 15,000 W, a value by ab. 18% higher than the normal value stated by literature;

G_{ad}/G_S^{PT} = 0.035 leading to a value of G_{ad} = 3.37 kg/s.

Block M28 with 44 apartments of the type GF+10 floors has been selected for the analysis concerning the energy related upgrading solution.

The following cases have been analysed:

1. Present situation: average winter conditions with the outdoor temperature $t_e = 2\ ^0C$ and $t_{TP} = 82\ ^0C$, G_P^{PT} = 18.05 kg/s ($G_P^{PT} = 0.60 \cdot G_{P0}^{PT}$). The result is:

t_{iBl28} = 16.5 ^0C, t_{RP} = 48.6 °C; t_{TS} = 42.3 ^0C and t_{RS}=36 ^0C, which are very close to the measured values.

Q_{PT} = 2523 kW; Q_{UTIL} = 1907 kW (75.49%); Q_{P1} = 124 kW (4.91%); Q_{P2} = 494 kW (19.6%).

May we notice the very important energy losses in the distribution network (24.51%).

2. Average winter conditions (t_e = 2^{0}C) and t_{Tp} = 70 ^0C, upgraded network, $G_{ad}/G_S^{PT} = 0.002$ proper thermal insulation of the pre-insulated pipes, efficient heat exchangers. Result: t_{iBl28} = 21.6 ^0C (improved thermal insulation and alteration of the indoor heating equipment).

t_{R_P} = 45.70 ^0C; t_{T_S} = 50.74 ^0C; t_{R_S} = 43.82 ^0C;

Q_{PT} = 2780 kW; Q_{UTIL} = 2694 kW (96.55%); Q_{P1} = 61.18 kW (1.26%);

Q_{P2} = 96.3 kW (3.45%).

May we conclude that the rehabilitation measures lead to the achievement of thermal comfort. The energy potential of ab. 20% caused by the energy losses of the existing system is efficiently used.

According to the upgraded variant, $(UA)^{NEC}_{c,Bl28}$ = 5050 W/K, of which $(UA)^{NEC}_{F}$ = 2570 W/K. The new thermal characteristic was assessed at an outdoor temperature of (-10 °C) and the assumed discomfort risk was of 4%.

The discomfort risk refers to the occurrence frequency of the average daily outdoor temperature. So, in ab. 4% of all the days of the heating season, the average daily outdoor temperature is lower than -10 ^{0}C.

The fact that value $(UA)_F^{NEC}$, which is specific to the upgraded building, exceeds the value specific to the existing building is explained by the ensurance of an average rate of fresh air, $\overline{n}_a$ = 0.60 m^3/h/m^3 as against the present value of only 0.35 m^3/h/m^3.

The values previously presented outline a possible strategy of energy related upgrading which will cover the following phases:

- thermal substation upgrading;
- network upgrading by the use of pre-insulated pipes;
- improvement of buildings thermal protection.

The technical solution of reducing the heat flow dissipated through the windows is triple-glazing (the currently existing windows are double-glazed).

As concerns the opaque members of the experimental building, the average additional thermal resistance imposed by energy-related upgrading is no more than 0.42 m^{2}K/W.

May we underline that the results of item 2 refer only to the upgrading of the experimental building. The upgrading of all the 37 blocks connected to PT1 "Uverturii" could lead to an acceptable thermal comfort in the dwellings as well as to the diminishing of the supplied thermal capacity by 14% as against the present consumption (Q_{PT} = 2,170 kW).

In the present operational conditions of the heat supply system specific to the thermal substation in question (PT1 "Uverturii"), the heat consumption specific to block M 28 is of 623 MJ/m^2 year ($\bar{t}_i = 16.5°C, \bar{n}_a = 0.35$ m^3/h/m^3). If the upgrading solutions proposed in this report were applied, the specific consumption would be of 450 MJ/m^{2}year ($\bar{t}_i = 21.6°C, \bar{n}_a = 0.6$ m^3/h/m^3), which may involve a 28% heat consumption reduction in the conditions of reaching an acceptable thermal comfort level in the dwelling space. The upgrading solutions that are proposed lead at the same time at the diminishing of the heat carriers temperatures, involving beneficial effects on the cogeneration index. The diminishing of the primary heat carrier temperatures allows the adoption of modern solutions in the network upgrading by the use of pre-insulated pipes.

May we finally emphasize that if the thermal substation and the network are not upgraded, only rehabilitation of the thermal protection of block M28 leads to a value $(UA)_C^{NEC}$ = 2,.820 W/K which requires an extremely severe insulation of the opaque part of the envelope.

CONCLUSIONS

- This report presents in detail the methodologies and the procedures of thermal identification of the thermal substations heat exchangers, of the heat carrier distribution network and of the buildings connected to the cogeneration heating system.
- The characteristics that are thus assessed can be included in the SIMPATIC software which provides possibilities of energy related diagnosis concerning an entire system.
- This paper presents as an example the theoretical and experimental results obtained by the application of the thermal identification and diagnosis procedures in the case of PT1 "Uverturii" thermal substation and block M28, both in Bucharest.

Symbols

t_T - heat carrier inlet temperature [^{0}C]
t_R - heat carrier outlet temperature [^{0}C]
t_i - environment indoor temperature [^{0}C]
t_e - outdoor temperature [^{0}C]
Δt_{log} - logarithmic mean difference of heat carriers temperatures[^{0}C]
Q_{P1} - heat flow dissipated from the heat carrier to the outside [W]
Q_{P2} - heat flow demanded by top-up water heating [W]
Q_{SCH} - heat flow-rate transferred to heat exchangers [W]
Q_{po} - heat flow dissipated through the opaque parts of a building before the application of thermal perturbation [W]
Q_L - "free" heat thermal flow[W]
Q_R - installation heat flow-rate transferred to living space [W]
G - fluid mass flow-rate [kg/s]
G_R - water mass flow-rate circulated in the static heating units [kg/s]
U - overall heat transfer coefficient [W/m^{2}K]
α - convection heat transfer coefficient [W/m^{2}K]
R_d - thermal resistance caused by pipes walls and fluid impurities in heat exchangers [m^{2}K/W]
UA - global thermal characteristic [W/K]
c - mass specific heat [J/kgK]
c_p - air specific heat at constant pressure [J/kgK]
Mc - building members thermal capacity [J/K]
P - pipe perimeter [m]
X - pipe length [m]
S_R - static units heating area [m^2]
V - volume [m^3]
n_a - air changes number [h^{-1}]
τ - time [s]
ρ - air density [kg/m^3]
η - Heaviside function (unit step function)
σ - average square deviation

Indices

S - secondary
P - primary
CT - thermal channel
o - nominal
SCH - heat exchanger
C - building
F - glazed area
p - opaque area
PT - thermal substation
V - windows area
E - experimental
T - theoretical

REFERENCES

[1] * * * New technical system for the ensurance of basic energy related facilities in buildings INCERC Contract 1363 - 1996

[2] Constantinescu, D - Energy Conservation in the East European Countries. Conf. Rensselaer Polytechnic Institute, Troy, New-York, dec. 1990

[3] M.V.V. Germany - Demand Side Management for Romanian District Heating System; Contr. EBRD 1996

[4] Leca, A - Improvement of heat exchangers efficiency; Ed. Tehnica, Bucharest 1978

[5] Van Geem, M. G. - Summary of Calibrated Hot Box Test Results of Twenty-one Wall Assemblies; ASHRAE Tech. Data Bull. Vol. 2 1986, No. 5 p. 44 - 61.

[6] Dittus, F. W; Boelter, L. K. M - University Calif. Publ. Eng. Vol. 2, 1930 p. 443

[7] Sieder, E. N, Tate, G. E. - Ind. Eng. Chem. 28, 1429, 1936.

[8] Colburn, A. P. - Trans. AIChE, 29, 174 1933

[9] Kays, W. M. - Handbook of Heat Transfer Chapt. 7, Ed. McGraw-Hill, New York, 1972

[10] * * * Upgrading of Bucharest cogeneration heating system (in Romanian); INCERC Contract 1342 - 1993

[11] * * * Upgrading of the district heating system (in Romanian); INCERC Contract A55 -1994

[12] * * * A guide for the Calculation of Buildings Heat Demand (in Romanian) INCERC Contract 1128 - 1995

[13] STAS 1907 - 80 Assessment of buildings heat demand (in Romanian), Romanian Standard 1980

[14] Constantinescu, D. - Rehabilitation of District Heating System in Romania; Conf. REHVA Sinaia Romania 1995.