IDENTIFICATION OF THE THERMO-PHYSICAL CHARACTERISTICS OF THE REAL BUILDING MEMBERS

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ABSTRACT

The energy-related upgrading of the existing buildings involves the upgrading of the opaque perimetric building members. Any technical upgrading solution is based on the knowledge of the heat transfer characteristics of the building in its present condition. If the values of the λ_i heat transfer coefficients as well as of the ρ_i and c_i thermodynamic parameters, corresponding to materials with high stability in time (e.g. concrete) are not modified even in a long time, the same parameters, corresponding to the heat insulating material layers are in time subjected to important modifications (e.g. qualitative damage effect because dampness of walls or condensation occurrence in the structure). On the other hand, even during the building erection stage, it is possible for the design and real values λ_i of the materials in the structure not to coincide, or, of course, it is possible not to know any value (lack of building technical documentation); these are reasons requiring, in certain cases, the identification of the real values of the coefficients of thermal conductivity λ_i, density ρ_i and specific heat c_i which will be used in the calculation of simulating the energy behaviour of the building under upgrading.

Key words: thermal conductivity, thermodynamic parameters, standard deviation, predictor-corrector method, dynamic simulation

REZUMAT

Modernizarea energetică a clădirilor existente implică modernizarea elementelor opace de anvelopă. Orice soluție de modernizare energetică se bazează pe cunoaşterea caracteristicii termice reale a anvelopei în starea sa actuală. În timp ce proprietățile termofizice ale materialelor cu mare stabilitate în timp (spre exemplu betonul) nu se modifică, aceiaşi parametri corespunzători materialelor termoizolante suferă modificări importante în timp (spre exemplu: ca urmare a infiltrațiilor de apă sau a condensului din structură). Pe de altă parte, chiar în procesul de realizare a clădirilor este posibil ca valorile reale ale materialelor utilizate să nu coincidă cu cele din proiect sau să nu se cunoască nici măcar valorile de proiect din cauza lipsei documentației tehnice a clădirii. Toate acestea sunt motive care impun, în anumite cazuri, identificarea valorilor reale ale proprietăților termofizice ale materialelor, utile în activitatea de simulare a răspunsului termic al clădirii şi a comportamentului energetic al acesteia, în funcție de soluțiile de modernizare preconizate.

Cuvinte cheie: Conductivitate termică, parametri termodinamici, abaterea medie pătratică, metoda predictor-corector, simulare în regim nestaționar

1. Introduction

This paper introduces two methods of identifying the thermo-physical characteristics of the materials acting as heat insulation, included in the structure of the existing buildings.

The first method refers to the so-called field zone of the envelope structural and non-structural members. This method allows the assessment of the real value of the thermal conductivity of the materials acting as heat insulation in one-layer and multi-layer structures. Based on the real values of the thermal conductivity and of the mass specific heat together with the material density, the assessment of the real thermal response of the structure may be approached in terms of the natural outdoor environment stresses and of the restrictions imposed by the thermal comfort condition specific to the building, taking into account the characteristics modifications, a consequence of the thermal bridges effect which amplifies the heat flow dissipated through the opaque envelope components. If it is difficult to identify the detailed structure of the opaque envelope components, the use of an advanced method of the "inverse modelling" type is proposed for the identification of the above mentioned thermodynamic and transport parameters. In this case the paper presents solutions of the type with three and four variable parameters, based on calculation algorithms of the predictor –

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corrector type. Both methods resort to the measurement of several parameters specific to the thermal response function of the envelope components, together with the parameters specific to the heating systems reflecting the indoor microclimate condition. Case studies are presented for each method; they are at the same time studies validating the proposed methods. These methods are scientific news in the field and will be presented within the CA2 (Concerted Action 2) European project at the session which will be organized in Prague at the end of the year 2008. The practical application of the methods is facilitated by the measured data and processing procedures, including those of selection of the useful data, as well by the methodological indications accompanying the case studies that are presented.

2. Identification of the thermo-physical characteristics of the real building members in the field zone

The energy-related upgrading of the existing buildings also involves the upgrading of the opaque perimetric building members. The aim of the existing buildings energy-related up-grading is to reduce the heat / cold consumption and at the same time to ensure thermal and physiological comfort in the dwelled / occupied spaces. Any technical upgrading solution is based on the knowledge of the heat transfer characte-ristics of the building in its present condition. If the values of the λ_i heat transfer coefficients as well as of the ρ_i and c_i thermodynamic parameters, corresponding to materials with high stability in time (e.g. concrete) are not modified even in a long time, the same parameters, corresponding to the heat insulating material layers are in time subjected to important modifications (e.g. qualitative damage effect because dampness of walls or condensation occurrence in the structure).

On the other hand, even during the building erection stage, it is possible for the design and real values λ_i of the materials in the structure not to coincide, or, of course, it is possible not to know any value (lack of building technical documentation); these are reasons requiring, in certain cases, the identification of the real values of the coefficients of thermal conductivity λ_i, density ρ_i and specific heat c_i which will be used in the calculation of simulating the energy behaviour of the building under upgrading. The RTU (Unitary Thermal Response) method associated with the measurement of the temperatures and thermal flows allows the assessment of the values of the previously mentioned parameters [24]. The measurements refer to the temperatures of the flat building member surfaces, *in the field zone*, as well as to the density of the heat flow specific to the limit adjoining the occupied space, $q_{Pi}(\tau)$. Three sets of values result therefore:

$$\{t_{Pi}(\tau)\},\ \{t_{Pe}(\tau)\},\ \{q_{Pi}(\tau)\}$$

The thermal response of the analyzed structure is obtained using the INVAR software (or by the RTU method), where in order to achieve the limit conditions imposed by the experiment, namely Dirichlet limit conditions, the wind velocity $w = \infty$ is required, which leads to value $\alpha_e = \infty$ and, similarly, $\alpha_i = \infty$ is imposed at the two limits ("boundary") adjoining the outdoor, indoor respectively environment. The two transformations lead to the use of the measured values $t_{Pe}(\tau)$ instead of values $t_E(\tau)$ specific to the outdoor climate on one hand, and of values $t_{Pi}(\tau)$ instead of the indoor temperature, on the other hand. The unknown values of the identification problem are the thermal conductivity λ_i of the heat insulating material layer, in the field zone, and product $(\rho c)_i$ specific to the same insulating material.

The two parameters mentioned above both individually (λ_i), and in a group $(\rho c)_i$ are independent parameters and therefore may be associated without any restriction. The software is used in the variant "variable thermal conditions" and provides the temperature variation on the inside area of the flat building member $t_{Pi}(\tau)$, as well as the variation of the heat flow dissipated through the building member, $q_{Pi}(\tau)$, consequent to the known thermal boundary condition, $t_{Pe}(\tau)$ (measured values).

Values $q_{Pi}(\tau)$ are requested by the software as input data, and the output parameter $t_i(\tau)$ is identical with variation $t_{Pi}(\tau)$ consequent to the use of value $\alpha_i \cong \infty$. The software operation is conditioned by the input of an indoor temperature initialization value. The influence of this (random) value is removed by introducing a long enough "initialization" working time and the display of the results only during the measurement period (T).

In order to consider accurate the result obtained by the numerical test, the fulfillment of two conditions is necessary:

– *the necessary condition,* involving the equality of the *daily average values* of the temperatures calculated and measured at the limit $x = 0$ of the structure;

– *the sufficient condition,* which involves the criterion of the minimum standard deviation between the two rows of values, t_{Pim} (τ) şi t_{Pi} (τ), where the index m means measured values.

The analysis involves the use of a pair of values $\{\lambda_{ij}, (\rho c)_{ij}\}$, where j means the sequence number and assessment, for each j value, of the temperature row of values $t_{ij}(\tau) \equiv t_{Pij}(\tau)$. The average temperature of values $t_{Pim}(\tau)$ is generated as well as the average temperature of the values calculated, $t_{Pij}(\tau)$, respectively:

$$\overline{t_{Pim}} = \frac{1}{T} \cdot \sum_{0}^{T} t_{Pim}(\tau) \tag{1}$$

$$\overline{t_{Pij}} = \frac{1}{T} \cdot \sum_{0}^{T} t_{Pij}(\tau) \tag{2}$$

The values obtained lead to a finite number of pairs $\{\lambda_{ij}, (\rho c)_{ij}\}$ which fulfill the necessity condition (fig. 1).

Of all the $\sigma\left\{\overset{*}{t}_{Pij}\right\}$ values is determined the minimum value corresponding to a pair of values $\{\dot{\lambda}_i, (\dot{\rho} c)_i\}$, representing the values identified as

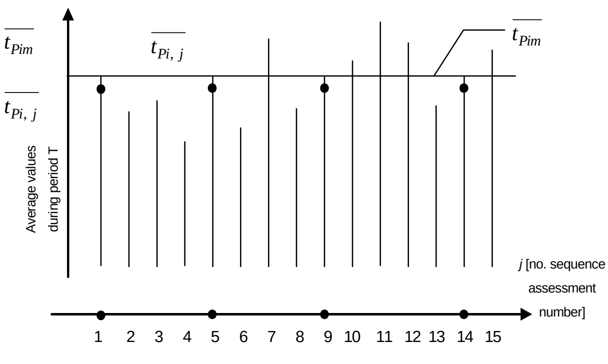


Fig. 1. Necessity condition for the thermal identification of a structure (field zone)

belonging to the structure analyzed in the "field" zone (not perturbed by thermal bridges).

Case study – synthesis

The experimental testing of the previously presented method was performed on the INCERC – Bucharest pilot building in the year 2004. Complementary experiments were performed on an outside wall; the properties of the wall material – BCA (autoclaved lightweight concrete) were determined (and checked). The tests were performed in the following rooms:

– SW room, S wall, period 19.01-20.01.2004 (19 h);

– SW room, S wall, period 20.01-23.01.2004 (65 h).

The first period of 19 h represents the identification period, and the second, the validation period.

As concerns the identification period, the variation of function R_t was assessed in terms of the $(\rho c)_i$ values where R_t is provided by the following relation:

$$R_t = \frac{\sigma\left\{\overset{*}{t}_{Pij}\right\}}{\overline{t_{Pim}}}$$

The thermal conductivity value $\lambda_{BCA(id)} \cong 0{,}16\,\mathrm{W/mK}$ for all the tested cases. The resulting curve has the following expression:

$$R_t = 0{,}0159 \cdot x^4 - 0{,}0321 \cdot x^3 +$$
$$+ 0{,}0292 \cdot x^2 - 0{,}0096 \cdot x + 0{,}002$$

where $x \equiv (\rho c)_i$.

The minimization necessary condition $\frac{\mathrm{d}R_t}{\mathrm{d}(\rho c)_i} = 0$ provides the real solution:

$$(\dot{\rho} c)_i = 0{,}251\,\mathrm{GJ/m^3K}$$

(Value $\frac{\mathrm{d}^2 R_t}{\mathrm{d}(\rho c)_i^2}$ where $(\dot{\rho} c)_i = 0{,}251$ is 0.022063, therefore $\frac{\mathrm{d}^2 R_t}{\mathrm{d}(\rho c)_i^2} > 0$, which attests the fulfillment of the sufficiency condition by the existence of a minimum of the function $R_t = f((\rho c)_i)$.)

Therefore, the thermo-physical characteris-tics of the examined material are the following:

$$\begin{cases} \lambda_{BCA} = 0{,}16 \text{ W/mK} \\ (\rho c)_{BCA} = 0{,}251 \text{ GJ/m}^3\text{K} \end{cases}$$

The measurements specific to the validation period ($\bar{t}_{Pi} = 19{,}01°\text{C}$; $\bar{t}_{Pe} = 2{,}49°\text{C}$; $\bar{q}_{Pi} = 5{,}25 \text{ W/m}^2$) lead to value $\lambda_{BCA} = 0{,}165$ W / mK, associated to $(\rho c)_{BCA} = 0{,}238$ GJ/m^{3}K. The error of 3,13% corresponding to value λ_{BCA} is perfectly acceptable and therefore the above-mentioned values are admitted as specific to the BCA (autoclaved lightweight concrete) structure. If the values indicated in code C 107 / 3 – 2005 have been used, where for BCA masonry with thin joints are indicated the following values: $\lambda = 0{,}27$ W / mK (GBN 35) and $\lambda = 0{,}30$ W / mK (GBN 50), the calculation errors would have been very important and would have influenced the building thermal protection solution (much more severe) in the case of the energy upgrading or the energy-related mark in the case of the Energy Performance Certificate granting.

An algorithm for assessing the thermo-physical characteristics of the materials (one layer) in the field zone of the multi-layer flat structures

A. Measurements in real conditions
(in situ) (cloudy days)

1. The temperature variation on building member the outside area $t_{Pe}(\tau)$ is measured. The measurements will last for at least 24 consecutive hours.

2. The temperature variation on the building member inside area, $t_{Pi}(\tau)$, is measured. The measurement period is the same with that specific to temperature $t_{Pe}(\tau)$.

3. The variation of the heat flow density at the limit represented by the inside surface of the building member, $q_{Pi}(\tau)$ is measured. The measurement period is the same with that of the two temperatures, $t_{Pi}(\tau)$ and $t_{Pe}(\tau)$.

B. Numerical analysis by simulation

1. The software (INVAR) uses the following outdoor climatic data:
– $t_{Pe}(\tau)$ as an outdoor temperatures function;
– I_T, $I_d = 0$;
– wind velocity $w > 500$ m / s.

2. For the layers of material with stable thermo-physical characteristics (concrete, brick etc.) the values λ, ρ and c are taken from the values catalogues.

3. For the layer of material subjected to identification, random values are given (of the physically possible range of values!) for λ_i and $(\rho c)_i$.

4. For the heat transfer surface coefficients specific to closed spaces, the values provided are the following:

$$\alpha_{cv} \cong \infty \qquad \alpha_r = 0$$

5. The software is initialized with a period of time necessary for the extinction of the structure initializing temperature effect, $\tau_i \geq 96$ h.

6. The display time of the result equal to the measurement time, T, is set.

7. The software is run and the following set of values results: $t_{Pi}(\tau)$, where $\tau \in [1, T]$.

8. $\bar{t}_{Pi}$ is assessed using the relation (2) and it is compared to $\bar{t}_{Pim}$ determined using relation (1).

9. As a result of the necessity condition, the pairs of values λ_i and $(\rho c)_I$ are preserved, where:

$$\bar{t}_{Pi} \cong \bar{t}_{Pim}$$

(actually the error may range within 0,10°C).

10. For the pairs of values fulfilling the necessity condition, the value of the square average deflection between the calculated values $t_{Pi}(\tau)$ and the measured values $t_{Pim}(\tau)$, is calculated.

11. The minimum value of $\sigma\{t_{Pi}\}$ belongs to the pair of values $\left\{\overset{*}{\lambda}_i, \overset{*}{(\rho c)}_i\right\}$, representing the solution of the identification procedure.

12. In order to validate the result, the procedure is resumed for the same structure, but based on measurements performed in a different period of time.

3. Thermal identification of the existing buildings for their energy-related upgrading – inverse modeling method

3.1. Target and object of the buildings thermal identification

The thermal identification is a component of the technical expert analysis activity and means the assessment of the real characteristics of a system or / and of its components. Based on these characteristics, it is possible to create a mathematical model describing the behaviour of the system, which could be used in diagnosing activities and activities of issuing technical energy upgrading solutions. The thermal identification involves the experimental data processing according to mathematical models that approximate as accurately as possible the analyzed phenomenon.

The necessity and at the same time the opportunity of approaching the issue of the existing buildings thermal identification is supported by the following:

1. The thermal balance of a building is fundamentally influenced by the values of the characteristics specific to the envelope compo-nents (areas, thermo-dynamic potential, material thermo-physical characteristics etc.);

2. Achievement of the thermal and physiological comfort determined by the characteristic of the real operation of the thermal systems, by the thermal capacity of the building members and by the quality of the mobile closing components of the building envelope;

3. The hygro-thermal dimensioning charac-teristics (laboratory thermo-physical characte-ristics) are either not observed in the activity of buildings erection or they are subjected in time to alterations (mechanical deformations, environment aggressiveness – moisture, settling etc.);

4. The knowledge of the real hygro-thermal characteristics provides the possibility to exa-mine the energy-related energy upgrading of the existing buildings;

5. The use of the theoretical assessment of the thermal resistance according to the local package of codes involves, beside a laborious calculation, the use of certain values of the material thermo-physical characteristics specific to the laboratory tests; and therefore, in many cases, the value of the calculated thermal resistance may be sensibly different from the real values.

Taking into account the above-mentioned elements, the result is that the accurate use of the local package of codes is strictly limited to issues related to the construction physics in the phase of design. The upgrading of the existing built stock is still a major priority both in terms of the rate of the buildings and in terms of the remaining lifetime – about 40 years for most of the residential and public buildings.

The experimental procedure which may provide a partially correct response consists in the assessment of the global thermal resistance by "in vitro" measurements; there are such test facilities in Romania at INCERC – Iasi. There are objective limitations related to the use of this method in this case too, as it is actually impos-sible to transport the envelope in a laboratory type cell, even in the case of panel type members which apparently are thermally individualized compared to the other structural / non-structural components.

6. Taking into account the above-mentioned elements it results as follows:

- It is opportune and useful to use the calculation procedure specific to the heat transfer steady-state conditions, providing the definitions of the criteria that make possible the practical use of this procedure;
- It is necessary to impose the issuing of techniques of identifying the heat transfer characteristics of the existing buildings by using

"in situ" measurements and their processing according to a specific analysis model;

- It is possible to use the thermo-physical parameters laboratory values of the materials stable from the thermo-technical point of view and not subjected to severe influences from the environment (e.g. concrete or inside homogeneous structures);

- The mathematical models describing the characteristic balance should be as close as possible to the physical phenomenon.

Therefore the identification of the real thermo-physical characteristics of the existing buildings envelope components is a necessary activity and its final target is the energy-related upgrading of the existing buildings. Beside the detailed presentation of the methodological structure, it is necessary to emphasize the wrong putting into practice of certain analysis proce-dures, theoretical or experimental, presented in the literature as variants of existing buildings thermal identification. We emphasize that, unfor-tunately, Romania paid a minimum attention to the procedures of identifying the characteristics of existing and real objects; the calculation techniques and the measurement techniques were strictly limited to the issuing of new solutions. If in the sector of building service, and especially of the equipments in the systems, measurements may be also performed in laboratory conditions by the use of proper procedures, *no identification method has been issued concerning the envelope.*

The procedure which form the object of this paper is an absolute "premiere", at least at the level of the local literature and is among the very few procedures developed in the world. From this last point of view, this procedure falls into the "*inverse modeling*" class. The specific of this method resides in using the effects as a measure of the transfer function. The effects are due to the use of an quantifiable excitation (heat flows, temperatures, etc.) and their size, both as a model and as variable functions in time is determined by the transfer function specific to the building system – thermal plant. In the line of the above mentioned elements and taking into account the target of identifying the thermal characteristic of the existing buildings, specific analysis models are presented as well as the use of the results obtained in applying the energy upgrading of the existing buildings.

3.2. Thermal identification procedure of an existing building (model with three variables)

Introduction

The thermal balance of the outdoor perimetric components forming a building is focused on the thermodynamic outline defined by the indoor areas of the building members.

The method referred to in this chapter is based on the thermal balance equations of the building and on the heating system thermal response, in real operational conditions. The issue involves two phases, as follows:

• **The preliminary phase**, consisting of the integration of the equation of the space, which is closed in the thermodynamic outline delimiting the dwelled enclosures and is based on the variation of the virtual outdoor temperature of the closing elements t_{ev} (τ) and on the reference outdoor temperature variation including the solar radiation. In these conditions, the association of values t_{evj} (τ) to the R_j thermal resistance value of a building member *j* is justified by the value of the resulting indoor temperature, t_{iR} (τ). The calculation model is of bi-zonal type: the central zone subjected to the analysis is formed by the dwelled enclosures and the peripheral zone is that of the joint spaces. Between the two zones there is a heat transfer, its intensity being imposed by the indoor temperatures resulting as specific environments. The bi-zonal nature of the calculation model is a quality treat of the used model. The peripheral spaces are also individualized according to their position and use (e.g. staircase, technical basement, drying room etc.). The result of the preliminary phase is the settling of a correlation between the thermal resistance of the opaque building members and the average number of air exchanges, n_a, between the inside and the outside.

• **The final phase** represents, in fact, the identification procedure for the equivalent thermal conductivity of the insulating material in the vertical outside opaque walls, λ_E and of the real thermal response of the central heating thermal response. The equivalent thermal conductivity, λ_E includes the effect of the linear and punctual thermal bridges and is a value used in the mono-dimensional model of heat transfer through the analyzed building members. The real thermal response function of the heating system is represented by the assessment relation of the heat flow released to the heating spaces in the dwelled spaces:

$$q = q_0 \cdot \mathring{A} \cdot \left(\frac{t_T - t_R}{\ln \dfrac{t_T - t_a}{t_R - t_a}} \right)^{1+m} \qquad (4)$$

where $\mathring{A}$ is a function depending on the temperature logarithmic average difference specific to the laboratory conditions (Thermal cell) influenced by the m_0 index, specific to the above-mentioned conditions. In real heating system operation conditions, the index m is different from the one in the laboratory and varies according to the real thermal conditions in the heated enclosure.

Actually, the relation above represents a semi-empiric relation and the m index transfers to the enclosure air volume average temperature, t_a, the quality of a thermodynamic parameter associated with the convective and radiative heat transfer from the heating units surface to the thermal limit layer close to it and to the very close closing members of the heated enclosure.

The final phase uses the heat transfer modeling in unsteady-state conditions specific to the heated enclosure (single in the building) in assessing the heat carrier outlet temperature variation $t_R(\tau)$ and the comparison with the same noted parameter $t_{RM}(\tau)$, assessed by processing the real operational parameters of the heating system at the level of the building heating systems connection. In the end, following the statistic analysis of the two rows of values, $t_R(\tau)$ and $t_{RM}(\tau)$, the real values λ_E, n_a, m are chosen, specific to the building in the measurement period. The procedure is used in several rather close time periods, and the result is represented by rows of values, $\{\lambda_E\}$, $\{n_a\}$, $\{m\}$. The single value λ_E is assessed by the fulfillment of a usual statistic criterion, represented by the upper limitation of the ratio between the square average deflection of the values and their average. The logical scheme of the identification procedure is presented in fig. 2.

The values mentioned above may be rather easily estimated if there is expertise in monitoring the operation of heating systems in collective dwellings and if the building technical book exists. As concerns the dwelling blocks in Romania, the building members with stable characteristics are the walls between the dwelling spaces and the peripheral spaces, windows, in terms of the glazing thermal resistance and the terraces, representing the outside horizontal closing member. Most of the blocks are erected according to typified designs, and the terrace structure, with a few exceptions, is an invariant, leading to a known value of the thermal resistance. This advantage derives from the low thermal insulation achieved with stable materials, but characterized by rather high thermal conductivity values. On the other hand, the rate of thermal bridges at the level of the terrace is not significant, so that the adoption of a sub-unit coefficient r = 0,93...0,95 to correct the field thermal resistance is absolutely sufficient for the realistic evaluation of the terrace thermal resistance. In the case of the other closing components to the peripheral spaces, the catalogue values of the thermal conductivity of the materials used will be used (the reinforced concrete prevails, with λ_b = 1,74 W/mK).

Preliminary phase of the identification of the existing buildings real thermal characteristics

The thermal balance equation at the level of the thermodynamic outline delimitating the dwelling spaces has the following form:

$$Q_S(\tau) + Q_L(\tau) = \sum_j \left(\frac{S}{R}\right)_j \cdot [t_{i_R}(\tau) - t_{ev_j}(\tau)] + n_a(\tau) \cdot V \cdot \rho_a \cdot c_{pa} \cdot [t_a(\tau) - t_e(\tau)] + Mc_i \cdot \frac{\mathrm{d}t_p(\tau)}{\mathrm{d}\tau} \qquad (5)$$

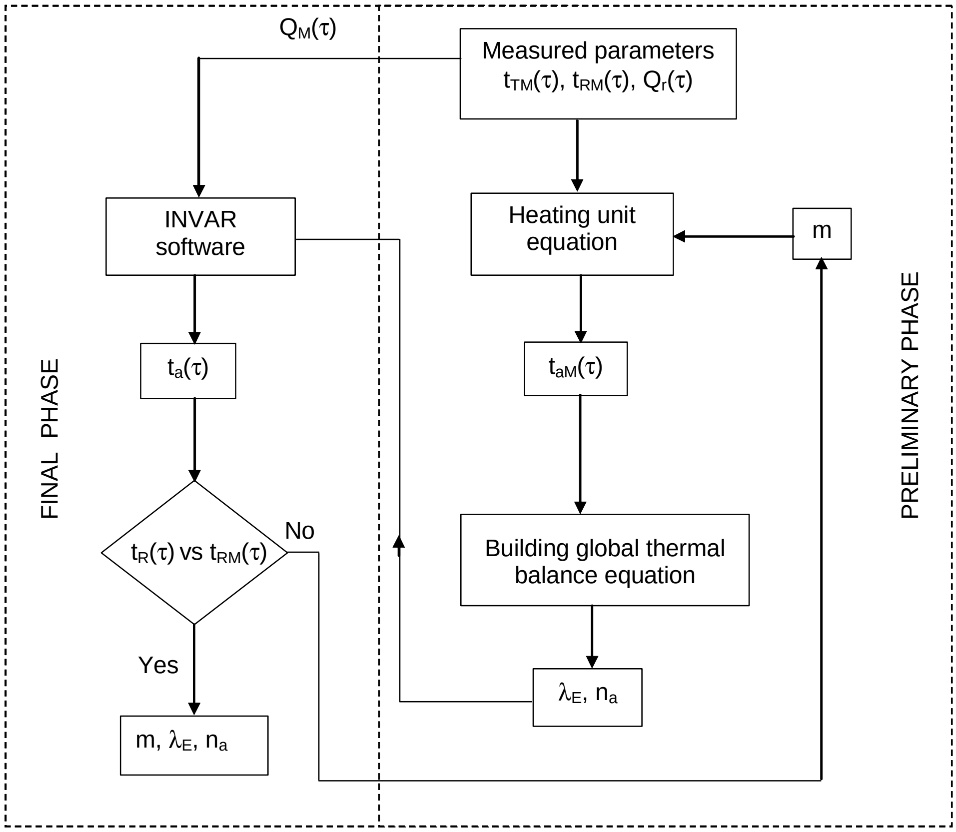


Fig. 2. Logical scheme of the building thermal identification procedure – three variable model

The average number of air exchanges may be determined by the following relation:

$$n_a(\tau) = C_1 \cdot [t_a(\tau) - t_e(\tau)]^{0,30} + C_2 \qquad (6)$$

where:

$$C_1 = 28{,}75 \cdot \alpha \cdot \frac{S_F}{V \cdot \rho_a \cdot c_{p_a}} \cdot dt \qquad (7)$$

$$C_2 = 1{,}25\, \frac{i \cdot w^{4/3}}{V \cdot \rho_a \cdot c_{p_a}} \cdot [(1-\alpha) \cdot L_{(1-\alpha)} \cdot dt + L \cdot (1 - dt)] \qquad (8)$$

Relation (6) takes into account the dt average period of windows opening in terms of the integration pace (in this case 1 h), the average length of the joints of the windows which do not open, $L_{(1-\alpha)}$ and the windows opening rate, $\alpha \le 1$. Values dt, $L_{(1-\alpha)}$ and α are estimated based on tests by cooperation with the occupants of the dwelled spaces.

The heat input generated by the tenants may be estimated by the following relation:

$$Q_L(\tau) = a(\tau) \cdot S_{Loc} \qquad (9)$$

The heat flow provided by the heating system in the dwelled spaces is expressed by the following relation:

$$Q_S(\tau) = (1 - \varepsilon_1) \cdot (1 - \varepsilon_2) \cdot Q_{SM}(\tau) \qquad (10)$$

Coefficients ε_1 and ε_2 depend on the condition of the basement distribution pipes and on the rate of the thermally equivalent area of the heating units meant for the dwelling spaces heating, of the total area of the building under expertise.

The integration of equation (5) in a time period [0, T] and its rating to value T leads to the following integral equation:

$$\overline{Q}_S + \overline{Q}_L = \sum_j \left(\frac{S}{R}\right)_j \cdot \left(\overline{t}_{i_R} - \overline{t}_{ev_j}\right) + \rho_a \cdot c_{p_a} \cdot \overline{n}_a \cdot V \cdot \left(\overline{t}_a - \overline{t}_e\right) + Mc_i \frac{\Delta t_P}{T} \qquad (11)$$

Equation (11) is valid as in normal ventilation conditions of the dwelling spaces, it is possible to admit an error under 0.70% the following equality:

$$T \cdot \int_0^T n_a(\tau) \cdot [t_a(\tau) - t_e(\tau)] \mathrm{d}\tau =$$

$$= \int_0^T n_a(\tau) \mathrm{d}\tau \cdot \int_0^T [t_a(\tau) - t_e(\tau)] \mathrm{d}\tau \qquad (12)$$

Equation (11) settles the *first condition* of the physical experiment, namely the selection of a period with stable thermal conditions in the dwelling space. The fulfillment of this condition changes the equation (11) as:

$$\overline{Q}_S + \overline{Q}_L = \sum_j \left(\frac{S}{R} \right)_j \cdot \left(\bar{t}_{i_R} - \bar{t}_{ev_j} \right) +$$

$$+ \rho_a \cdot c_{p_a} \cdot \bar{n}_a \cdot V \cdot \left(\bar{t}_a - \bar{t}_e \right) \qquad (13)$$

where:

$$\bar{t}_{evj} = \bar{t}_e + \frac{\left(\frac{S_{cs}}{R_{cs}} + \frac{S_{sb}}{R_{sb}} \right) \cdot \left(\bar{t}_{en} - \bar{t}_e \right)}{\frac{S_E}{\overline{R}}} = \bar{t}_{ev} \qquad (13_1)$$

$$\bar{t}_{en} = \frac{\frac{S_{cs}}{R_{cs}} \cdot \bar{t}_{cs} + \frac{S_{sb}}{R_{sbs}} \cdot \bar{t}_{sb}}{\left(\frac{S_{cs}}{R_{cs}} + \frac{S_{sb}}{R_{sb}} \right)} \qquad (13_2)$$

For $T > T_0$ ($T_0 > 144$ h) may be used the thermal balance relation in steady-state conditions for closing members adjoining the outdoor environment. In these conditions, equations (13) lead to the following solution:

$$\overline{R} = \frac{D_1 + A_1 \cdot n_a}{D_2 - n_a} \qquad (14)$$

where:

$$D_1 = \left(S_E - \frac{Q_S + a \cdot S_{Loc}}{t_{a_M} - t_e} \cdot A_1 \right) \cdot (\rho_a \cdot c_{p_a} \cdot V)^{-1} \qquad (15)$$

$$D_2 = \left(A_2 + \frac{Q_S + a \cdot S_{Loc}}{t_{a_M} - t_e} \right) \cdot (\rho_a \cdot c_{p_a} \cdot V)^{-1} \qquad (16)$$

and

$$A_1 = \frac{\alpha_r \cdot \overline{F_R}}{\alpha_{cv} \cdot \alpha_i}; \quad A_2 = \sum_n \frac{S_n}{R_n} \cdot \frac{t_{ev_{nk}} - t_e}{t_{a_M} - t_e} \qquad (17)$$

The values of the heat transfer coefficients through α_r radiation and through α_{cv} convection actually are constant and easy to assess. The global heat transfer coefficient, α_i, is assessed by the relation:

$$\alpha_i = \alpha_{cv} + \alpha_r \cdot \overline{F}_R \cdot \frac{S_T}{S_E} \qquad (18)$$

where the environment form factor $\overline{F}_R$ is assessed according to the geometry of the representative enclosure for the dwelling space.

The air volume average temperature in all the precincts of the dwelling space is assessed based on the heat transfer equation specific to the heating units.

$$t_{aM} = \frac{t_{R_M} \cdot \overline{E}_S - t_{T_M}}{\overline{E}_S - 1} \qquad (19)$$

The function $\overline{E}_S$ is determined according to the *m* average coefficient specific to the heating units, to the heat carrier measured temperatures, to the heat carrier average mass flow-rate, $\overline{G}$, and the installed thermal power, Q_0:

$$\overline{E}_S = \exp\left[\left(0{,}0045 \cdot \frac{Q_0}{\overline{G} \cdot c} \right)^{\frac{1}{1+m}} \cdot (t_{T_M} - t_{R_M})^{\frac{m}{1+m}} \right] \qquad (20)$$

The average thermal resistance of the outdoor opaque building members is assessed by the relation (14) as follows:

$$\overline{R}_{OPAC} = \left[\frac{D_2 - n_a}{D_1 + A_1 \cdot n_a} - \frac{\sum_k \left(\frac{S}{R} \right)_k}{S_E} \right]^{-1} \qquad (21)$$

where $\sum_k \left(\frac{S}{R}\right)_k$ is assessed according to the geometric outline of the building and of the thermal resistance values, actually known, of the building members separating the dwelling spaces from the peripheral spaces and of the glazed building members.

Taking into account the terrace thermal resistance evaluation procedure, previously mentioned, the value of the thermal resistance of the opaque closing members of the overland walls, adjoining the outdoor environment, is a value that results:

$$\overline{R}_w = \frac{S_w}{\frac{S_{OPAC}}{\overline{R}_{OPAC}} - \frac{S_T}{R_T}} \qquad (22)$$

The building members that form opaque outside walls, regardless their structure, embed the same heat insulating material so that the final equation of the preliminary phase has the following form:

$$\sum_{n=1}^{N} \frac{\lambda_E \cdot S_{wn}}{\delta_{IZn} + b_n \cdot \lambda_E} = \frac{\sum_{n=1}^{N} S_{wn}}{\overline{R}_w} \qquad (23)$$

where b_n represents the thermal resistance of the n building member, without heat insulation.

Relation (23), together with relations (22) and (21), settle a correlation between the equivalent thermal conductivity λ_E of the heat insulating material and the average number of air exchanges, n_a.

The variation of the equivalent thermal conductivity in terms of the air exchange number, n_a, for a value of coefficient m, is presented in qualitative terms in fig. 3.

We mention the fact that the t_{aM}, necessary in setting the $\lambda_E = f(n_a)$ correlation is assessed according to the relation (19) and uses the average value of the measured thermodynamic parameters, namely t_{TM}, t_{RM} and G. It is also mentioned that the parameter specific to the m heating units is selected as an independent variable, as it is one of the unknown values of the identification issues. Therefore, the above-mentioned correlation function will be $\lambda_E = f(n_a, m)$, where each curve of the form

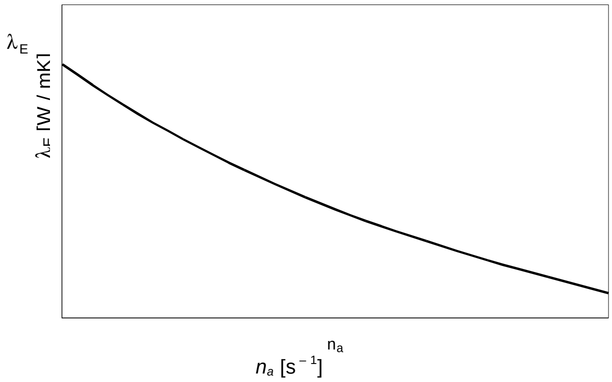


Fig. 3. Variation of the equivalent thermal conductivity, λ_E, according to the number of air exchanges, n_a

$\lambda_E = f(n_a)$ is specific to an m value of the set selected for the analysis. On the other hand, the $t_{RM}(\tau)$ temperature hourly average values are considered, to be compared to the values obtained by the use of the procedure specific to the second, final phase.

Final phase in the identification of the existing buildings real thermal characteristics

Based on relation (23), two rows of values are generated, $\{\lambda_E\}$ and $\{n_a\}$ the terms of which are in direct correspondence. The rows of values are limited inferiorly and superiorly so that:

$$\min\{\lambda_E\} \geq \lambda_{EIZ} \qquad (24_1)$$

$$\max\{\lambda_E\} \leq \lambda_{max} \qquad (24_2)$$

where $\lambda_{E\,IZ}$ represents the minimum catalogue value of thermal conductivity of the insulating material and λ_{max} the maximum thermal conductivity of the used building materials (e.g. concrete). We emphasize that the two rows of values are associated to a heating units transfer function used as the m coefficient value. Therefore, to a value m_1 of the m coefficient correspond the rows of values $\{\lambda_E\}_1$ şi $\{n_a\}_1$, as well as the hourly values of temperature $t_{aM1}(\tau)$. The objective elements of the measurement are $t_{TM}(\tau)$, $t_{RM}(\tau)$, G generating the heat flow conveyed by the system, $Q_M(\tau)$.

The simulation software of the unsteady-state conditions of a building is used, INVAR in variable conditions, with $Q_M(\tau)$ input values for assessing $Q_M(\tau)$ input values, for assessing the $t_a(\tau)$ air theoretical volume average tempera-tures, while the λ_E and n_a known pairs of values resulted from the preliminary identification phase. The INVAR software, issued by INCERC experts in 1993, is based on the Unitary Thermal Response (RTU) method and operates both for the achievement of thermal comfort – by assessing the heat demand – in the cold season and for the assessment of the variation of the resulting indoor temperature and of the air in natural conditions of random climatic heat. The calculation algorithm was tested by experiments performed at INCERC (Solar House CS3 Bucharest, 1982-1992) as well as on buildings in Bucharest and Cluj-Napoca, in the period 1983-1996.The tests were focused both on the hot and on the cold season.

Therefore, for an m_1 value, the thermal conductivity of the heat insulating material in the opaque outside walls structure, of $\lambda_{E1,1}$ is selected, as well as the proper number of air exchanges with a constant value of $n_{a\,1,1}$. By the use of the INVAR software, the $t_{a\,1,1}(\tau)$ variation function is obtained and is assessed the theoretical variation of the heat carrier outlet temperature, $t_{R1}(\tau)$, which is compared to the $t_{RM1}(\tau)$ function. The comparison refers to the corresponding hourly values. The following conditions are imposed:

$$\left|\bar{t}_{R_{1,1}} - \bar{t}_{RM}\right| \le \varepsilon_1 = 0{,}10°\mathrm{C} \qquad (25)$$

$$\sigma_{\bar{t}_{R_{1,1}}} \Big/ \bar{t}_{RM_1} \le \varepsilon_2 = 0{,}08 \qquad (26)$$

together with the additional condition:

$$\left|\bar{t}_{aM} - \bar{t}_{aC}\right| \le \varepsilon_3 = 0{,}10°\mathrm{C} \qquad (26_1)$$

where $\bar{t}_{aM}$ is assessed by the relation (19).

Temperature $t_{R1}(\tau)$ is assessed by the relation:

$$t_{Rj}(\tau) = t_{aj}(\tau) + 0{,}90 \cdot \frac{Q_S(\tau)}{G(\tau)\cdot c} \cdot [E_{Rj}(\tau) - 1]^{-1} \qquad (27)$$

where:

$$E_{Rj}(\tau) = \exp\left\{0{,}90 \cdot \frac{Q_S(\tau)}{G(\tau)\cdot c} \cdot \left[\frac{Q_S(\tau)}{Q_0}\right]^{-\frac{1}{1+m_j}}\right\} \qquad (28)$$

and j is the sequence index of the m_j values and values $Q_s(\tau)$ and $G(\tau)$ are assessed experimentally.

A $\Delta\lambda_E$ thermal conductivity variation pace is admitted, to which a sequence of n_a values corresponds. For m_1, all the $\lambda_{E1,S}$ and $n_{a1,S}$ values are tested, which together with $Q(\tau)$ generate the following values:

$$\left|\bar{t}_{R_{1,s}} - \bar{t}_{RM}\right| = M_{1,s} \qquad (29)$$

$$\sigma_{\bar{t}_{R_{1,s}}} \Big/ t_{RM_{1,1}} = M_{2,s} \qquad (30)$$

compared respectively to ε_1 and ε_2.

The decision is completed with the following checking:

$$\left|\bar{t}_{aM} - \bar{t}_{ac_{1,s}}\right| = M_{3,s} \le \varepsilon_3$$

The value m_1 is modified, generating $m_2 = m_1 + \Delta m$ and the procedure is resumed. In the end, the pair of values M_1, M_2 is chosen, which mostly fulfill conditions (25) and (26) to which correspond the final values m, λ_E and n_a.

Taking into account relation (6) and in the case that following a pole performed together with the tenants, the rate of the windows opening is known as well as the average period of their opening, the real value of the i air infiltration coefficient may be assessed, which will be compared to the i_0 catalogue value for the type of window used.

We emphasize that the $\bar{t}_{aM}$ average value is known and therefore the variation $t_a(\tau)$ resulted from the use of the INVAR software should lead to the known average value.

The completion of the analysis is reached by the use of the procedure in several different periods of time which fulfill the condition $T > T_0$, as well as the other conditions specified in the paper.

Each phase represents an instrument of validating the previous one meaning that no variations of the conductivity λ_E or of the i infiltration coefficient are admitted, except for a margin representing 5% of the average value of all the assessed values.

3.3. Procedure of thermal identification with four variables (predictor-corrector method in alternate paces)

The paper further presents an alternative procedure of the existing buildings thermal identification. The difference from the procedure presented in the previous chapter is represented by the possibility of separately assessing the equivalent thermal conductivity of the heat insulation of the terrace, of the vertical opaque outside walls respectively. The logical scheme of the thermal identification procedure with four variables is presented in fig. 4.

A parameter to be continuously measured is the building heating thermal load, $Q(\tau)$. Considering that the air conditioning system may operate or not in the cold season as well, the method is subdivided into two connected sub-methods:

a. thermal load ensured by a cogeneration (central) heating system;

b. thermal load ensured by the air conditioning – ventilation system.

The central heating system is provided with static heating units

The thermal balance of the building will be written as follows:

$$\overline{Q} \cong \left(\sum_p \frac{S_{Pe_p}}{R_{Pe_p}} + \frac{S_F}{R_F} + \frac{S_T}{R_T} + B_1 \cdot V \cdot \rho \cdot c_{pa} \cdot n_a \right) \cdot \left(\bar{t}_i - \bar{t}_{ev} \right) - a \cdot S_{Loc} \quad (31)$$

where $\bar{t}_{ev}$ is determined by relation (13_1).

The corrected thermal conductivities characterize the vertical walls and the terrace and are marked by λ_{CP} and λ_{CT}. The average temperature (in the working period) of the heated spaces

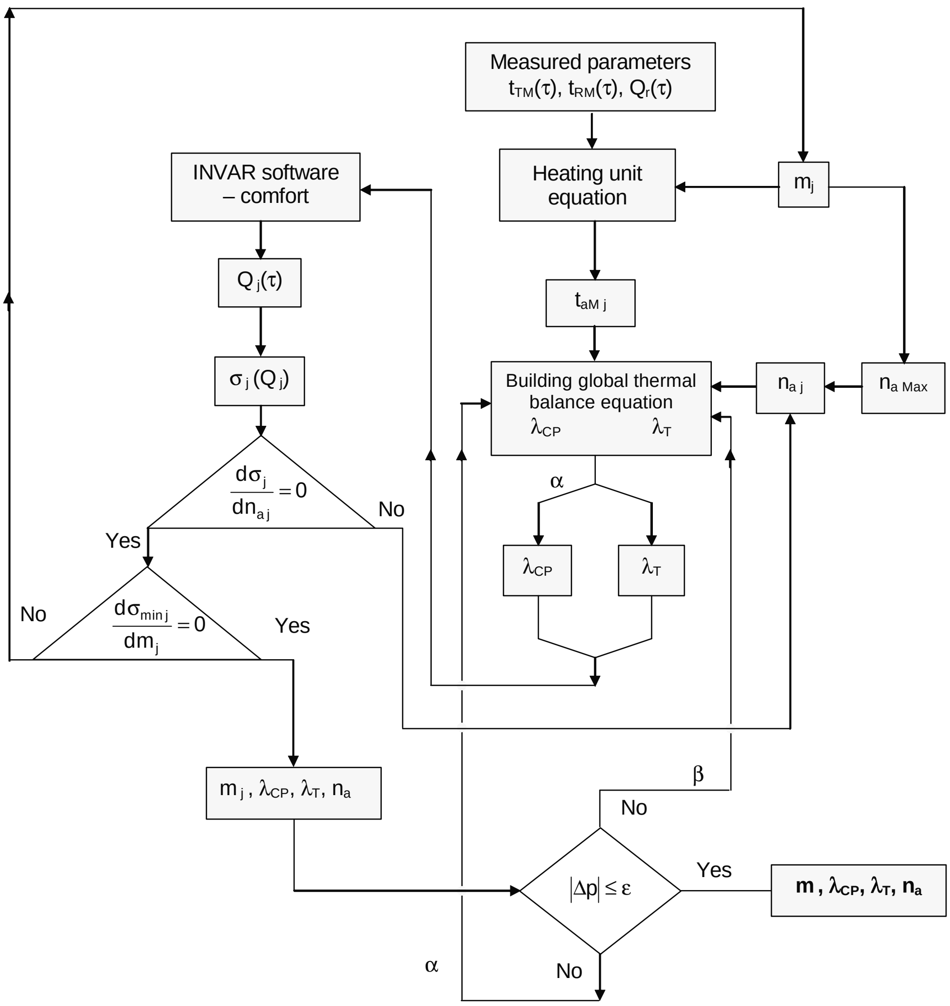


Fig. 4. Logical scheme of the thermal identification procedure – four variable models

may be accurately assessed using the following relation:

$$\bar{t}_i = \frac{\bar{t}_R \cdot \overline{E}_S - \bar{t}_T}{\overline{E}_S - 1} \qquad (32)$$

where: $\bar{t}_T$ and $\bar{t}_R$ – heat carrier average temperatures assessed from the hourly values specific to the measurement time (at least 5 consecutive days)

Index m also represents an unknown value of the thermal utilities system. In phenomenological terms, index m represents the heat transfer characteristic of the heating unit, by conduction as well as by convection, to the air in the limit layer, and by radiation to the side (lateral) areas of the heated enclosures.

The corrected thermal resistance values of the perimetric building members are assessed by the relations specific to the uni-dimensional heat transfer:

$$\begin{cases} R_{Pe_1} = \dfrac{1}{\alpha_i} + \dfrac{1}{\alpha_e} + \sum\limits_{k_1} \left(\dfrac{\delta}{\lambda} \right)_k + \dfrac{\delta_{iz_1}}{\lambda_{CP}} = A_{k_1} + \dfrac{\delta_{iz_1}}{\lambda_{CP}} \\ R_{Pe_p} = \dfrac{1}{\alpha_i} + \dfrac{1}{\alpha_e} + \sum\limits_{k_p} \left(\dfrac{\delta}{\lambda} \right)_{k_p} + \dfrac{\delta_{iz_p}}{\lambda_{CP}} = A_{k_p} + \dfrac{\delta_{iz_p}}{\lambda_{CP}} \end{cases} \qquad (33)$$

Therefore:

$$\sum_p \frac{S_{Pe_p}}{R_{Pe_p}} = \frac{S_{Pe_1}}{A_{k_1} + \dfrac{\delta_{iz_1}}{\lambda_{CP}}} + \ldots + \frac{S_{Pe_p}}{A_{k_p} + \dfrac{\delta_{iz_p}}{\lambda_{CP}}} \qquad (34)$$

or

$$\sum_p \frac{S_{Pe_p}}{R_{Pe_p}} = \lambda_{CP} \cdot \left(\frac{S_{Pe_1}}{\lambda_{CP} \cdot A_{k_1} + \dfrac{\delta_{iz_1}}{\lambda_{CP}}} + \ldots + \frac{S_{Pe_p}}{\lambda_{CP} \cdot A_{k_p} + \dfrac{\delta_{iz_p}}{\lambda_{CP}}} \right) \qquad (35)$$

$$R_T = B_T + \frac{\delta_{iz_T}}{\lambda_{CT}}; \; B_T = \frac{1}{\alpha_i} + \frac{1}{\alpha_e} + \sum_{k_T} \left(\frac{\delta}{\lambda} \right)_{k_T} \qquad (36)$$

$$\frac{S_T}{R_T} = \frac{\lambda_{CT} \cdot S_T}{\lambda_{CT} \cdot B_T + \delta_{iz_T}} \qquad (37)$$

where: P –vertical wall index; T – terrace index.

The thermal balance relation (31) becomes:

$$\sum_p \lambda_{CP} \cdot \frac{S_{Pe_p}}{\lambda_{CP} \cdot A_{k_p} + \delta_{iz_p}} + \frac{\lambda_{CT} \cdot S_T}{\lambda_{CT} \cdot B_T + \delta_{izT}} = $$

$$= \frac{\overline{Q} + a \cdot S_{Loc}}{\bar{t}_i - \bar{t}_e} - \frac{S_F}{R_F} - C \cdot n_a \qquad (38)$$

where $\bar{t}_i$ is assessed using relation (32) according to the values of index m. Relation (38), λ_{CP}, λ_T, m and n_a, with a predictor function, is an equation including as unknown values λ_{CP} and λ_T, m and n_a.

The calculation is further carried out as an algorithm of the "predictor-corrector" type, alternatively.

A value $\lambda_{CT}^{(0)}$ is proposed and the λ_{CP} thermal conductivity is assessed from the following equation:

$$\lambda_{CP} \cdot \sum_p \frac{S_{Pe_p}}{\lambda_{CP} \cdot A_{k_p} + \delta_{iz_p}} =$$

$$= \frac{\overline{Q} + a \cdot S_{Loc}}{\bar{t}_i(m) - \bar{t}_e} - \frac{S_F}{R_F} - \frac{S_T}{R_T^{(0)}} - C \cdot n_a \qquad (39)$$

The following is noted:

$$\frac{\overline{Q} + a \cdot S_{Loc}}{\bar{t}_i(m) - \bar{t}_e} - \frac{S_F}{R_F} - \frac{S_T}{R_T^{(0)}} = f^{(0)}(m) \qquad (40)$$

and equation (39) becomes:

$$\lambda_{CP} \cdot \sum_p \cdot \frac{S_{Pe_p}}{\lambda_{CP} \cdot A_{k_p} + \delta_{iz_p}} =$$

$$= f^{(0)}(m) - C \cdot n_a^{(0)} = \hat{f}^{(0)}(m) \qquad (41)$$

Taking into account the physical significance of the terms of equation (40), the following condition results:

$$n_a^{(0)} < f^{(0)}(m) \cdot C^{-1} \qquad (42)$$

On the other hand, the m index cannot vary randomly, its values being controlled by the $\bar{t}_i$ value plausibility range, according to relation (32). The imposing of two limit values $\left(\bar{t}_{i\,\min}, \bar{t}_{i\,\max}\right)$ the range $m \in [m_{\min,} m_{\max}]$ results . An Dm variation pace is admitted so that the following successive values are generated:

$$m_j = m_{j-1} + \Delta m \qquad (43)$$

For an m_j value chosen from the $\{m\}$ set, value $n_{a_{\max}}^{(0)}(m_j)$ is assessed using the inequality (42). A Δn_a pace is admitted, so that successive values are generated:

$$n_{a_j} = n_{a_{j-1}} - \Delta n_a \qquad (44)$$

For each $n_{a_j}(m_j)$ value, equation (41) is solved and a λ_{CP_j} value results. Equation (41) is a non-linear algebraic equation to be solved by one of the specific methods (e.g. modified Kani). To each n_{a_j} value corresponds an λ_{CP_j} value and this bi-univocal correspondence in the sets of elements $\{\lambda_{CP}\}$ and $\{n_a\}$ leaves room to one m_j value chosen from the $\{m\}$ set of values.

We mention that any $\{\{\lambda_{CP}\},\{n_a\}\}$ combination leads to the same value of the $\overline{Q}$ heat flow and to various $\bar{t}_i\left(m_j\right)$ indoor temperature values. Using the INVAR software – thermal comfort conditions, for $\bar{t}_i\left(m_j\right)$ and $\left(\lambda_{CP}, n_a\right)$ values, together with $\lambda_{CT}^{(0)}$, $Q_{jk}(\tau)$ is assessed where k is the sequence number of the solution according to the sequence of the Δn_a paces.

The result is:

$$\int_1^{24} Q_{jk}(\tau)\,\mathrm{d}\,\tau = 24 \cdot \overline{Q} \qquad (45)$$

The square average deflection of the hourly values of $Q_{jk}(\tau)$ is assessed by INVAR and $Q(\tau)$ experimentally determined.

$$\sigma(Q_j) = 0{,}042563 \cdot \sqrt{\sum_{\tau} \left[Q_{jk}(\tau) - Q(\tau)\right]^2} \qquad (46)$$

For various $(\lambda_{CP}, n_a)_k$ values generated by the same m_j value, values of the $\sigma_{jk}^{(0)}$ square average deflection are obtained. The minimum value is retained:

$$\sigma_j^{(0)} = \min\left\{\sigma_{jk}^{(0)}\right\} \qquad (47)$$

which will be associated with the m_j value of index m. The procedure is resumed for several m_j values and the result will be represented by square average deflections associated with the m_j values, with the decision made by (47).

Of all the $\sigma_j^{(0)}$ values, the minimum value is preserved or a curve is generated:

$$\sigma_j^{(0)} = f\left(m_j\right)$$

In a polynomial form which, subjected to the minimizing procedure, leads to the $m^{(o)}$ solution. To this value is associated the pair $\left(\lambda_{CP}, n_a\right)$ which generated the minimum value of the square average deflection, or is assessed according to the procedure specific to each m_j value previously presented.

A first result of the prediction is obtained, namely: $m^{(o)}$; $\lambda_{CP}^{(0)}$; $n_a^{(0)}$ associated to the proposed value $\lambda_{CT}^{(0)}$.

The next corrective step, named corrector, supposes as real value $\lambda_{CP}^{(0)}$ and covers the same analysis line to the following solutions:

$$m^{(1)};\ \lambda_{CP}^{(0)};\ n_a^{(1)}\ \lambda_{CT}^{(1)}.$$

The analysis further develops alternative predictor – corrector steps; the prediction-correction items are the values of the thermal conductivity of the two respective materials λ_{CT}.

The calculation stops when the following inequalities are simultaneously fulfilled:

$$\begin{aligned} &\left|m^{(p)} - m^{(p-1)}\right| \le \varepsilon_1 \\ &\left|\lambda_{CP}^{(p)} - \lambda_{CP}^{(p-1)}\right| \le \varepsilon_2 \\ &\left|\lambda_{CT}^{(p)} - \lambda_{CT}^{(p-1)}\right| \le \varepsilon_3 \\ &\left|n_a^{(p)} - n_a^{(p-1)}\right| \le \varepsilon_4 \end{aligned} \qquad (48)$$

where the following are proposed:

$$\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \varepsilon_4 = 0{,}002$$

Them main result of the analysis is represented by values λ_{CP} and λ_{CT}, different from the catalogue values, and including the thermal bridge effect. If the ρ and c material characteristic values are associated, the RTU method for assessing the heat flow on the $Q_{Pe}(\tau)$, respectively $Q_T(\tau)$ building members inside may be properly used.

The heat demand is ensured by the ventilation system (air conditioning)

The difference from the previous procedure is represented by the necessity of assessing the indoor temperature by direct measurement.

Consequent to this aim, the *m* index is no longer an unknown value, as it is removed from the mathematical formalism. The working equation is equation (42) where $f^{(o)}$ is exclusively assessed by the prediction of value $\lambda_{CT}^{(0)}$ according to relation (41).

A single value $n_{a\max}$ results which is determined from the inequality:

$$n_a < f^{(0)} \cdot C^{-1} \qquad (49)$$

n_{a_j} values are further obtained, with corresponding λ_{CP_j} values. For each pair $(n_{a_j}, \lambda_{CP_j})$, value $\lambda_{CT}^{(0)}$ is assessed according to the INVAR software, $Q_j(\tau)$; the working temperature is the one experimentally known, $\bar{t}_i$. From this moment, the calculation and implicitly the decision are identical to those presented at the end of the previous item.

The values λ_{CP}, λ_{CT} are used in the calculation for the hot season, in order to assess the $Q_{CP}(\tau)$ and $Q_T(\tau)$ heat flows.

By association with the heat flows specific to the glazed areas and with that corresponding to the fresh air rate, necessary for the modification of the enthalpy, the cold demand $Q(\tau)$ will be assessed at any moment in a typical summer day, as well as, implicitly, the maximum value to be compared to Q_{inst}. The following situations are possible:

$|Q_{\max}| > Q_{inst}$ – the microclimate conditions mentioned in the project are not fulfilled

$|Q_{\max}| < Q_{inst}$ – the microclimate conditions mentioned in the project are fulfilled

The second conclusion is conditioned by the efficiency of the air conditioning system which is assessed by its expert examination.

3.4. Measurement management criteria for the thermal identification of an existing building

The assessment of the building envelope average thermal resistance, $\bar{R}$, depends on the windows permeability class, which was settled by the building visual expert examination. We have to mention that this permeability class includes subjective elements (spaces aeration) which may move the permeability class in the cold season.

Thus, on days with very low outdoor temperatures and deficit of heat flow from the heating system (situations specific to the blocks of flats supplied by the district heating system), the aeration of the dwelling space is minimum and actually the permeability class will be of the normal-tight or very tight type.

An experiment performed during the transition season, when aeration is frequent, may lead to the conclusion of using the low or very low tightening permeability class, which alters the conclusion on $\bar{R}$. Theoretically, the identification of the $\bar{R}$ value should remove the subjective perturbations and should be based on the condition of the building and of the system, assessed based on objective elements. In this line, the main perturbations are the following:

– additional heat flow – by local sources – released by the heating system (emphasized by the increase of gas and / or power consumption), which also involves additional ventilation (compared to the normal one from the physiological point of view) of the dwelling space during the human activity period;

– ventilation (aeration) beyond the normal practical activity and generating fresh air quantities which exceed the infiltrations through the outdoor mobile items joints lack of tightness (windows, doors).

The following limiting measurement conditions result:

– measurement period $T \geq 5$ consecutive days;

– cloudy days, characterized by low values of the solar radiation intensity direct component;

– dry building terrace, uncovered by snow;

– indoor air volume average temperature close to the value corresponding to the physiological comfort ($t_a \cong 22$°C);

– outdoor air temperatures, average during the measurements, within the range [– 3°C, + 5°C];

– minimum limitation of the dwelling space aeration (by the heated space occupants' acceptance) or assessment of the $\overline{\alpha}_F$ windows opening average rate, as an average hourly value, by hourly notices on the building facades.

3.5. Case study focused on the thermal identification of an existing dwelling building (three variable model)

We further present a case study concerning the use of the preliminary thermal and energy diagnosis and expert analysis procedure in the case of an apartment building connected to the Bucharest district heating system. The building which is the object of the preliminary expert analysis is presented, as well as the measurements performed in the 1998-1999 winter.

Experiment presentation

Brief presentation of the building

The building is located in sector 6 of Bucharest and is part of a group of four identical buildings designed by the "Proiect" (Design) Bucharest Institute in 1973, erected in 1974.

The structure of the building is of the cellular type, with longitudinal and transversal reinforced concrete diaphragms, with interposed reinforced concrete frames. The horizontal elements of the structure are made of 12 cm thick reinforced concrete precast plates. The building was built in 1974 and therefore does not reach a heat insulation rate corresponding to the values in the present codes.

According to the design data, the heat demand is of Q_0 = 276 000 kcal / h (320 930 W).

A statistic of the number of the radiator elements leads to the total value of 2,646 of the 600 / 2 type, with a nominal heat flow (95 / 75 / 20) of 116 kcal / h (135 W) element. The resulting installed power is of about 306,940 kcal / h (356,900 W). An excess of installed power of η = 1,112 results, a value valid for most of the apartment buildings heating systems. The heat carrier nominal flow-rate, according to the design, is G_0 = 13,800 kg/h.

The design of the indoor heating system was carried out according to the calculation norms valid in 1973, among which the most important was STAS 1907-68 on the assessment of the design heat demand; a significant difference results in terms of the radiator components/elements meant to ensure space heating. Fig. 5 presents the distribution of the total number of radiator components / elements and implicitly of the installed thermal power according to the location of the apartments in the building.

The heat carrier distribution is performed by a bi-tube system with lower-side distribution and vertical columns crossing the floors. The columns are visible and connected in the upper side of the building to the aeration vessel. In the technical basement of the building the pipes are placed for distribution in two main branches, supplying the apartments on the South, respectively North part of the building. The static units in the apartments are provided with double-adjustment valves, with no possibility of automatically adjusting the temperature in the enclosure.

The building survey led to the following values:

- outdoor walls area	SPE = 1,890.7 m^2
- windows area	SFE = 545.8 m^2
- basement area	S_{SB} = 220.1 m^2
- indoor walls area	S_{PI} = 7,940 m^2
- dwelling space volume	V_{LOC} = 6,864 m^3
- staircase space volume	V_{CS} = 750 m^3
- dwelled area	S_{LOC} = 2640 m^2
- area of walls to the staircase	S_{CS} = 934 m^2
- terrace area	S_T = 254.2 m^2
- glazing rate	R_V = 0.203

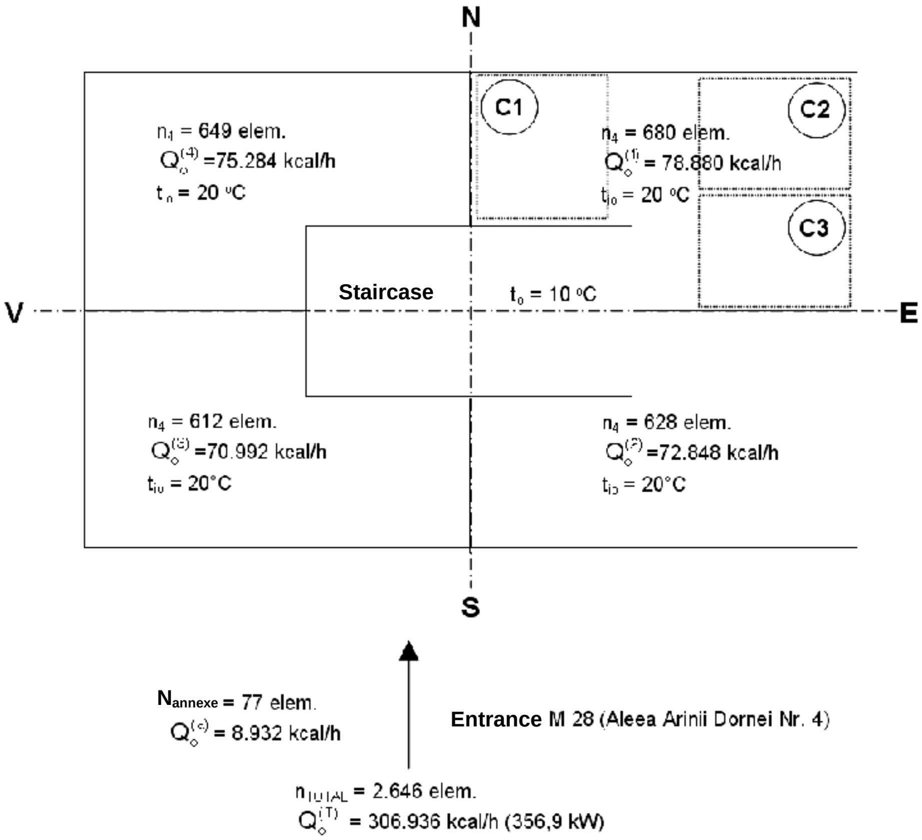


Fig. 5. Nominal thermal load distribution according to the apartments location in the building

The heat engineering characteristics of the building members forming the envelope are presented in table 1.

Description of the measurement chain used

The experiments performed in the basement of the M 28 apartment building (block) allowed the obtaining of the following values:

t_T(t) – secondary heat carrier inlet temperature [°C];

t_R(t) – secondary heat carrier outlet temperature [°C];

G_R(t) – heat carrier volume flow-rate [m^3/h];

t_e(t) – outdoor temperature [°C].

The temperature of the technical basement and of the staircase were assessed by thermal balance, according to the outdoor and indoor temperature in the dwelling spaces, and checked by tests during the measurements.

The equipment used in the measurements included the following items:

– *Aquametro* turbine flow meter, SMH Dn 50, with RM02 impulse emitter and CALEC MCP heat computer with 4 analogous outlets;

– *Sauter* EGT 342 F021 immersed temperature sounders, with Ni 200 sensors, ± 0,12 % error – for the measurement of t_T and t_R temperatures;

– *Sauter* EGT 420 indoor air temperature sounders with Pt 100 sensors, ± 0,12 % error – for t_{CS} and t_{Sb} temperatures measurement;

– *Sauter* EGT 300 sounders for the outdoor air temperature with Ni 1000 sensors, ± 0,12 % error – for t_e, temperature measurement;

– DataTaker 50 data automatic recorder with processor.

The equipments forming the measurement chain were previously calibrated in laboratory using the calibrating device method.

The values are read once in 1 min. and are mediated every 10 min. and recorded on the memory card of Data Taker 50 and then taken over in the memory of a "notebook" portable computer.

Table 1.

Heat engineering characteristics of the envelope building elements

No.	Orientation	Material	lambda [W/m.K]	Thickness [m]	Thermal resistance [m²K/W]	Area [m²]
Opaque outdoor walls:						
1	N	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	164.05
		B.C.A.	λ_{iz_E}	0.25		
		Mortar	0.930	0.03		
2	S	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	155.80
		B.C.A.	λ_{iz_E}	0.25		
		Mortar	0.930	0.03		
3	E, V	Mortar	0,930	0.02	$f(\lambda_{iz_E})$	206.62
		B.C.A.	λ_{iz_E}	0.25		
		Mortar	0.930	0.03		
4	N, S	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	656.48
		Reinforced concrete	1.744	0.20		
		B.C.A.	λ_{iz_E}	0.15		
		Mortar	0.930	0.03		
5	E	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	49.14
		Reinforced concrete	1.744	0.20		
		B.C.A.	λ_{iz_E}	0.15		
		Mortar	0.930	0.03		
6	V	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	51.48
		Reinforced concrete	1.744	0.20		
		B.C.A.	λ_{iz_E}	0,15		
		Mortar	0.930	0.03		
7	N	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	84.40
		Reinforced concrete	1.744	0.30		
		B.C.A.	λ_{iz_E}	0.15		
		Mortar	0.930	0.03		
8	S	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	80.56
		Reinforced concrete	1.744	0.30		
		B.C.A.	λ_{iz_E}	0.15		
		Mortar	0.930	0.03		
9	E, V	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	326.88
		Reinforced concrete	1.744	0.30		
		B.C.A.	λ_{iz_E}	0.15		
		Mortar	0.930	0.03		
10	E	Mortar	0.930	0.02	0.3296	43.12
		Reinforced concrete	1.744	0.20		
		Mortar	0.930	0.03		

No.	Orientation	Material	lambda [W/m.K]	Thickness [m]	Thermal resistance [m²K/W]	Area [m²]
11	V	Mortar	0.930	0.02	0.3296	41.16
		Reinforced concrete	1.744	0.20		
		Mortar	0.930	0.03		
12	V	Reinforced concrete	1.744	0.50	0.4478	30.96
Outdoor terrace:						
13	Horiz.	Mortar	0.930	0.02	$f(\lambda_{iz_E})$	254.22
		Reinforced concrete	1.744	0.19		
		B.C.A.	λ_{iz_E}	0.15		
		Mortar	0.930	0.05		
Plate over basement:						
14	Horiz.	Mortar	0.930	0.03	0.2949	220.09
		Reinforced concrete	1.744	0.12		
		Mortar	0.930	0.01		
Staircase wall:						
15	Horiz.	Mortar	0.930	0.02	0.3408	934.01
		Reinforced concrete	1,744	0,20		
		Mortar	0,930	0,02		
Outside windows:						
16	S				0.4300	119.76
17	N				0.4300	124.96
18	V				0.4300	149.68
19	E				0.4300	151.36

Measured data

The measurements were performed in the 1998-1999 winter and two periods of 5 days each were selected, which fulfilled the minimum measurement criteria (continuity in the heating system operation, a period characterized by reduced values of the direct solar radiation, dry building terrace etc.).

For the selected period (3-7.02.1999), the variation of the main operational parameters of the heating system as well as the variation of the outdoor air temperature are presented in figures 6 and 7.

The apartments power consumption values, namely the total consumption of gas in the kitchen, specific to the considered period:

V_{GN} [m³]	146
E [kWh]	693

Measured data processing

The average values specific to the considered measurement period are presented in table 2.

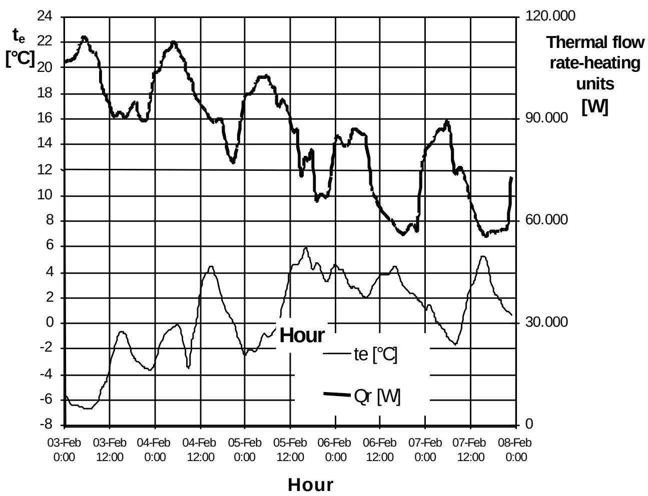


Fig. 6. Outdoor temperature and heat flow released by the heating system. Measurement period 3-7 Feb. 1999 – Block M 28

Taking into account the thermal resistance of the windows, of the building members separating the dwelling space from the staircase and from the technical basement, considered invariants, the use of the preliminary identification procedure led to the assessment of the indoor air temperature variation function in terms of the *m* coefficient, namely of the variation function of the equivalent thermal conductivity of the heat insulating material in the structure of the building envelope (BCA) and the average ventilation rate of the heated spaces.

According to the thermal identification preliminary phase, the following values resulted: $\bar{R} = 0{,}483 \text{m}^2\text{K/W}$; $\bar{R}_{OPAC} = 0{,}601 \text{m}^2\text{K/W}$ and λ_E = 0,351 W / mK as well as n_a = 0,40 h^{-1}. By using the INVAR software, the indoor air temperature variation $t_a(\tau)$ is obtained, for the pair of values λ_E, n_a. Based on the hourly values $t_a(\tau)$, the heat carrier outlet temperature variation is obtained, $t_R(\tau)$. The set of values $m \in$ [0,20...0,35] with a pace of Δm = 0,025 was used. Associated to the final solution *m* = 0,25, function $t_R(\tau)$ results, represented in the graph of fig. 8 together with the $t_{RM}(\tau)$ variation.

It results as follows:

$$M_1 = \left| \bar{t}_{RM} - \bar{t}_R \right| = 0.015$$

$$M_2 = \sigma t_R / \bar{t}_{RM} = 0.0636$$

$$M_3 = \left| \bar{t}_{aM} - \bar{t}_{aC} \right| = 0.058$$

which are compared to ε_1 = 0,10°C (25), ε_2 = 0,08 (26) and ε_1 = 0,10°C (26$_1$). Therefore, values λ_E, n_a and m correspond to the stated decision criteria.

Value λ_E = 0,351 W / mK (including the thermal bridge effect as well) is compared to the catalogue value of the autoclaved lightweight concrete catalogue value of the thermal conductivity, λ_{E0} = 0,22 W / mK, and coefficient *m* = 0.25 to the value obtained in the Thermal Cell, m_0= 0.30.

Value n_a = 0,40 h^{-1} is compared to the rational value and leads to the conclusion that the space ventilation is insufficient.

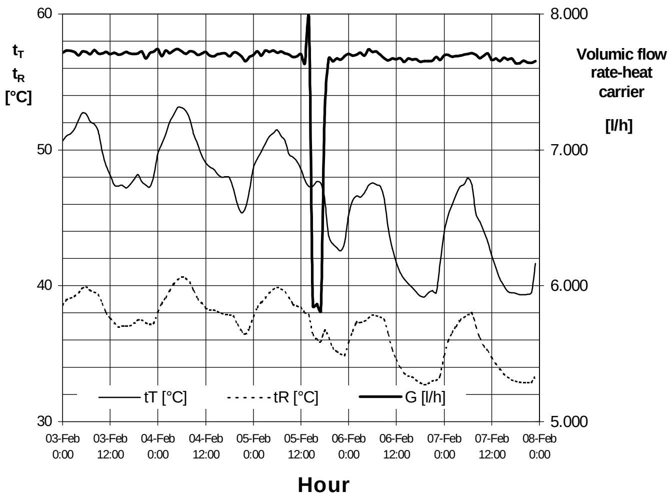
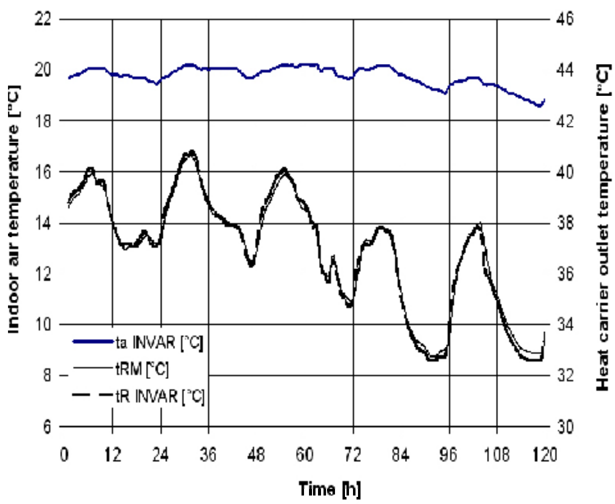


Fig. 7. Heating system operational parameters. Measurements period 3-7 Feb. 1999 – Block M28

Table 2.

Heating system operational parameters measured values

G_S [l/h]	7,647
t_T [°C]	46.60
t_R [°C]	36.93
t_e [°C]	0.48
t_{CS} [°C]	15.97
t_{Sb} [°C]	10.10
$\alpha_S = G_S / G_0$ [-]	0.55
Q_S [W]	85,050
Q_S^U [W]	80,932



Time

Fig. 8. Final phase of the building thermal identification – Measurements, Block M28, 3-7.02.1999

4. Conclusions

The two methods presented in the paper are proven useful by the case studies referring to two real buildings, of which the first is the individual experimental building at INCERC Bucharest and the second is a condominium (block M28 in the Militari district of Bucharest); their heating systems are connected to the urban district heating system.

The first experiment performed according to the method specific to the identification of the field zone of the opaque closing members led to the thermal conductivity value of the masonry consisting of small BCA blocks (BCA: autoclaved lightweight concrete) of 0.16 W / (mK), noticeably different from the catalogue values ranging between 0.27 and 0.30 W / (mK). We mention that the value proved to be real by comparing the values of the measured heat demand to the one obtained by long time dynamic simulation (monthly values).

The second experiment emphasized an average value of the heat insulation thermal conductivity (BCA plates) of 0.351 W / (mK), a value which also includes the effect of the thermal bridges specific to the envelope structural solution, associated to an average ventilation rate of 0.40 exchanges/hour. Compared to the catalogue value of the thermal conductivity, 0.22 W / (mK), the important influence of the thermal bridges emphasizes the attention that should be paid to the thermal upgrading solutions, and the value of the ventilation rate emphasizes the insufficient thermal ventilation of the main area of the building.

According to the model of the two analyses presented in detail in the paper, it is recommended to use the method of identifying the real thermal characteristics mainly in the case of old buildings with complicated structural solutions as well as in that of large buildings involving expensive upgrading works.

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