
IDENTIFICATION OF THE REAL THERMAL CHARACTERISTICS OF EXISTING BUILDINGS

Dan CONSTANTINESCU^{*}), Horia PETRAN¹⁾

ABSTRACT

The identification of the real thermal characteristic of an existing building implies mainly the assessment of the invariants specific to that structure, namely the equivalent thermal conductivity of the materials used for the opaque external envelope of the dwelling space. The paper focuses on the problem of identifying the thermal characteristic of the opaque external envelope of the apartment buildings with central heating system and implicitly with heating units in the dwelling and commune.

The method used is of the *inverse modelling* type, based on the building global balance and on the thermal response of the heating system to random climatic conditions. The problem implies two phases as follows:

- The preliminary phase, consisting in the integration of the heat balance differential equation of the dwelling spaces;
- The final phase, based on the thermal response characteristic of the heating system in real operation conditions.

The average indoor air temperature t_{a1} used in the preliminary phase is assessed from the thermal balance equation of the heating system where the m coefficient specific to the heat flow, specific to the heating units, is a variable value. In the end it results a correlation of the value of the equivalent thermal conductivity of the heat insulating material, k_E , with value n_a , specific to each experiment. Value k_E also includes the dissipative effects of thermal bridges.

The software assisted simulation of the building dynamic thermal behaviour for a couple $\{k_E, n_a\}$ (for a certain value m_1) and the use of the measured heat flow-rate values $Q_M(\tau)$ lead to the value series $t_{a1}(\tau)$. Based on $t_{a1}(\tau)$ values, the hourly values of the outlet heat carrier temperature $t_R(\tau)$ is determined. The decision on the accuracy of values m_1 and n_a is given by the analysis of the daily average values t_R and t_{RM} as well as by the standard deviation of $t_R(\tau)$ and $t_{RM}(\tau)$ values.

Key-words: global heat transfer coefficient, thermal conductivity, mass flow-rate, exponent specific to the heating element, ventilation rate

REZUMAT

Identificarea caracteristicii termice reale a unei clădiri implică, în principal, evaluarea proprietăților termofizice invariante, respectiv conductivitatea termică echivalentă a materialelor din care este realizată anvelopa clădirilor. Articolul are drept obiectiv identificarea caracteristicilor termice ale anvelopei unei clădiri de locuit de tip condominiu, dotată cu instalație de încălzire centrală, cu corpuri statice în spațiile locuite și în cele comune. S-a utilizat metoda modelării inverse bazată pe bilanțul termic global al clădirii asociată răspunsului termic al sistemului de încălzire la solicitări climatice aleatoare.

Rezolvarea problemei implică două faze, după cum urmează:

- Faza preliminară – integrarea ecuației diferențiale de bilanț termic proprie spațiilor ocupate;
- Faza finală – răspunsul termic al sistemului de încălzire în condiții reale de funcționare.

Temperatura medie interioară t_{a1} , utilizată în faza preliminară, se determină din ecuația de bilanț termic global a sistemului de încălzire în care coeficientul m propriu corpurilor de încălzire este parametrul variabil. În final se obține o ecuație care corelează conductivitatea termică echivalentă k_E a materialului termoizolant inclus în structura anvelopei opace cu valoarea medie a ratei de ventilare n_a proprie intervalului de măsurare. Valoarea k_E include efectul punților termice.

Simularea dinamică a răspunsului clădirii pentru un cuplu $\{k_E, n_a\}$ (pentru o valoare m) și utilizarea valorilor măsurate ale fluxului termic $Q_M(t)$, conduce la determinarea funcției $t_{a1}(t)$. Pe baza valorilor $t_{a1}(t)$ se determină temperatura de retur a agentului termic $t_R(t)$. Decizia cu privire la valorile m_1 și n_a este dată de analiza valorilor medii zilnice ale $t_R(t)$ și a abaterii medii pătratice a valorilor msurate și calculate $t_R(t)$ și $t_{RM}(t)$.

Cuvinte cheie: coeficient global de transfer de căldură, conductivitate termică, debit masic, coeficientul corpului de încălzire, rata de ventilare

^{*})Corresponding author: D. Constantinescu, e-mail: dan_const_home@yahoo.com

¹⁾National Institute for Research and Development in Construction, Urban Planning and Sustainable Spatial Development "URBAN-INCERC", INCERC Bucharest Branch, Romania

1. INTRODUCTION

The energy modernization of the existing buildings implies two determinate phases for the adoption of the technical solutions. We refer to the thermal survey and the energy audit. The thermal survey phase includes the energy diagnosis step, which, for the thermal processes, is based on the global heat balance of the building and of the corresponding systems [1]. The heat balance equations as well as the heat demand and consumption indicators are themselves based on the thermo physical properties of the opaque and transparent building elements. In the case of the existing buildings, according to the technological execution and the type of materials used, the value of the thermal resistance of the building elements are subjected to essential modifications compared to the values used in the design phase, based on laboratory values of the thermal conductivity and on the design constructive layout. Beside the aggressive action of the objective climatic factors, the aggressive action of anthropic factors interferes as well.

The energy auditing activity is based on the accurate evaluation of the energy potential of the upgrading solutions, which depends on the heat transfer properties of the envelope elements in the present and post-upgrading condition. Therefore, it results that the use of accurate values of the thermal characteristics of the existing buildings is determinant in adopting the energy upgrading solutions. In the case of old detached buildings (built before 1945) the constructive solutions used were rather simple, with homogeneous materials and stable properties in time (e.g. brick). In the case of multi-apartment buildings that are predominant in the Romanian urban landscape, the constructive solutions are characterized by the use of composite materials of the multi-layer type that contain both heat insulating materials and thermal bridges. The lack of a quality system related to buildings thermal protection rendered probable the use in execution of materials with a higher thermal conductivity than that indicated in the design solution. Moreover, the building elements of the large panels with mineral wool underwent considerable modifications of the thermal resistance because of settling and/or humidification of the heat insulating material. The thermal conditions in the dwellings, deficient in the '80s, caused structure condensation and further deterioration of the thermal (but also structural) resistance of many buildings. In these conditions, the values of the heat consumption indicators of 200-250 kWh / m²year for heating attest

the strongly dissipative nature, from in terms of energy use, of the existing buildings, with all the social and environment protection consequences.

In general the real value of the thermal characteristic of an existing building is expected to be higher than its design value, because of the actual execution and the structural discontinuities (thermal bridges, occasional lack of heat insulation or its settling etc.). Mingsheng and Claridge [6] show that the design value of the building thermal characteristic can be often higher than the real one. Other thermal characteristics established by various identification procedures are presented by Reeves [7] and Fischer [8], Judkoff [9] and others, resulting in values of the ratio $(UA)_p / (UA)_M$ ranging between 1.10 and 5.12. Therefore, the use of building thermal characteristic "depreciation" indices compared to the design value is in this sense not only an approximate procedure but also a possible blunder from the technical point of view, leading to erroneous results in the estimation of the efficiency of the buildings energy upgrading operations. The literature presents a few methods of thermal identification of a building, the most known being the Penman model [10] and the Co-Heating Method [11], [12], the latest based on the use of electric heating sources with a view to preserve the indoor temperature during the night at a constant value. Thus, the building thermal characteristic is determined as the ratio between power consumption and the difference between the inside and outside temperature during one night, when the temperature has not significant variations. The Co-Heating Method ignores the thermal flow released over night because of heat storage in the interior building elements during the day, from the solar radiation or the occupants' domestic activities and so the resulting value of the thermal characteristic will be higher than the real (UA) value.

This paper presents a method of the *inverse modelling* type for establishing the real thermal characteristics of the opaque envelope elements as well as the infiltrations indices of the doors and windows mobile joints (gaps), based on the minimum necessary measurements, without altering the structure or the occupants' activity.

2. NOMENCLATUR

- L joint (gap) length of the mobile closing elements (door, window) (m)
- A area (m²)
- V volume (m³)

a	internal gains (human activity) (W / m ²)
q	heat flow released by a heating unit element (W / elem.)
Q	heat flow (W)
h	specific heat transfer coefficient (W / m ² K)
R	thermal resistance (m ² K / W)
I	infiltration coefficient of mobile joints (gaps) of windows and doors (W / mK (m / s) ^{4/3})
r	reduction coefficient of thermal resistance in current field
U	global heat transfer coefficient (W / m ² K)
k	thermal conductivity (W / mK)
t	temperature (°C)
G	mass flow-rate (kg/s)
M	mass (kg)
c	specific heat (J / kgK)
n_a	ventilation rate (s ⁻¹)
$\bar{F}$	view factor (-)
m	exponent specific to the heating element

Greek Letters

α	hourly rate of mobile elements opening (windows, doors)
σ	standard deviation
ε	admissible error
δ	material layer thickness (m)
ρ	density (kg / m ³)
τ	time

Subscripts

0	nominal value
T	inlet
R	outlet
a	indoor air
S	heat source
L	free heat
EX	outdoor
P	inside element
IR	indoor, resultant
ev	outdoor, virtual
E	equivalent
p	constant pressure
F	windows, doors
Loc	useful (area) of heated space floor
r	by radiation

cv	by convection
w	wall
IZ	heat insulating material
M	measured value
j	measurement index for external building elements
k	measurement index for building elements between the dwelling space and the secondary zone
n	measurement index for external walls with distinct structures

3. IDENTIFICATION OF THE REAL THERMAL CHARACTERISTIC OF EXISTING BUILDINGS – THEORETICAL SUBSTANTIATION

The method this study focuses on is based on the heat balance equations of the apartment building type structure as well as on the thermal response of the heating system, in real operational conditions. The problem implies two phases, as follows:

1. The preliminary phase consisting in the integration of the differential equation of the space within the thermodynamic outline of the dwelling spaces and is based on the variation of the virtual outdoor temperature of the closing elements $t_{ev}(\tau)$ and on the variation of the reference outdoor temperature including solar radiation influence. The virtual outdoor temperature $t_{ev}(\tau)$ [2] is the intensive thermodynamic parameter characteristic to the environment against which, at any moment τ , the heat transfer through the opaque homogeneous or composite walls can be written in steady-state conditions. In these conditions, the association of values $t_{ev}(\tau)$ with the thermal resistance value R_j of a building unit j is justified and correct. We emphasize that the $t_{ev}(\tau)$ variation is not influenced by the resultant indoor temperature value $t_{IR}(\tau)$.

The calculation model is of bi-zonal type. The central zone subjected to analysis is formed of the dwelled spaces while the secondary zone is that of the jointly shared spaces. Between the two zones there is a heat transfer whose intensity is imposed by the specific average resultant indoor temperatures. The bi-zonal character of the calculation model is a qualitative feature of the model that is used. The secondary spaces are also distinctive according to position and purpose (e.g. staircase, unheated basement, drying room etc.). The result of the

preliminary phase consists in establishing a correlation between the thermal resistance of the opaque building elements and the average number of air changes n_a between the inside and the outside.

2. The final phase represents in fact the procedure of identifying the equivalent value of the thermal conductivity of the heat insulating material in the structure of the opaque vertical outside walls, k_E and the thermal response real function of the heating system. The equivalent thermal conductivity k_E includes the effect of linear and punctual thermal bridges and is a value used in the one-dimensional model of heat transfer through the analysed building elements. The relation used to determine the heat flow released by the heating units in the dwelling spaces represents the real thermal response of the heating system:

$$q = q_0 \cdot \dot{A} \cdot \left(\frac{t_T - t_R}{\ln \frac{t_T - t_a}{t_R - t_a}} \right)^{(m+1)} \quad (1)$$

where $\dot{A}$ is a function depending on the logarithmic mean temperature difference specific to the testing room altered by the m_0 exponent specific to the previously mentioned conditions. In real operational conditions of the heating system, the m indicator differs from the one in the testing room and varies according to the real thermal conditions in the heated space. Actually relation (1) represents a semi empirical relation and the m indicator transfers to the volume average air temperature in the space, t_a , the

quality of thermodynamic parameter associated to the convective and radiation heat transfer from the heating units surface to the immediately neighbouring thermal boundary layer and to the heated space closing elements. The final phase uses heat transfer modelling in non-steady-state conditions, specific to the room (unique for the whole building) that is heated, in the assessment of the outlet temperature of the heat carrier $t_R(\tau)$ and the comparison to the same parameter noted $t_{RM}(\tau)$, generated by processing the real operational parameters of the heating system at the level of the connection to the heating source (district heating system). In the end, following the statistical analysis of the two sets of values $t_R(\tau)$ and $t_{RM}(\tau)$, an option is made for the real values k_E, n_a, m specific to the building in the measurement period. The procedure is applied in a few rather approached periods of time resulting in sets of values $\{k_E\}, \{n_a\}, \{m\}$. The unique value k_E is assessed based on the meeting of a usual statistical criteria represented by the upper limiting of the ratio between the values standard deviation and their mean. The logical pattern of the identification procedure is presented in fig. 1.

The application of the procedure referred to in this paper does not exclude the estimation of numerical coefficients or of certain values of thermal conductivity or / and of the thermal resistance of certain stable materials and / or structures with known and stable composition.

The above mentioned values can be easily estimated based on the existing expertise in monitoring the operation of heating system in multi-dwellings buildings and if the building technical documentation is available. As concerns the apartment buildings in Romania, the building elements with stable properties are the walls between the dwelling space and the secondary spaces, the windows, in terms of glazing thermal resistance and the terraces that represent the external horizontal element. Most of the blocks are built based on a standard design, and the terraces structure, with few exceptions, is an invariant, leading to a known value of the thermal resistance. This advantage derives from the poor heat insulation formed of stable materials but with rather high thermal conductivity. Moreover, the rate of thermal bridges at the terrace level is insignificant so that the adoption of a subunit coefficient $r = 0.93$ to correct the field thermal resistance is absolutely sufficient for a realistic evaluation of the terrace thermal resistance. In the case of the other indoor closing elements near the secondary spaces, the catalogue values of the materials thermal conductivity will be used (reinforced concrete prevails, with $k_b = 1.74 \text{ W / mK}$).

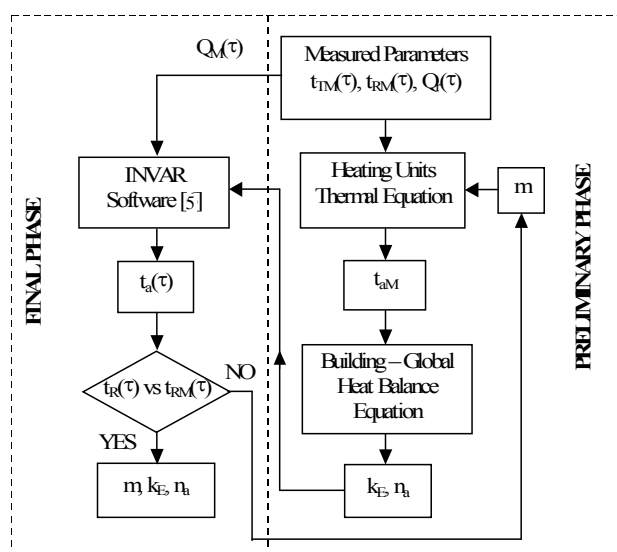


Fig. 1. Logical pattern of the identification procedure

3.1. Preliminary phase in the identification of the real thermal characteristic of existing buildings

The thermal balance equation at the level of the thermodynamic outline delimiting the dwelled spaces has the following form:

$$Q_S(\tau) + Q_L(\tau) = \sum_j \left(\frac{A}{R} \right)_j \cdot [t_{i_R}(\tau) - t_{ev_j}(\tau)] + n_a(\tau) \cdot V \cdot \rho_a \cdot c_{p_a} \cdot [t_a(\tau) - t_e(\tau)] + M C_i \cdot \frac{dt_P(\tau)}{d\tau} \quad (2)$$

The average number of air changes can be determined using relation [3]:

$$n_a(\tau) = C_1 \cdot [t_a(\tau) - t_e(\tau)]^{0.25} + C_2 \quad (3)$$

where:

$$C_1 = 28.75 \cdot \alpha \cdot \frac{A_F}{V \cdot \rho_a \cdot c_{p_a}} \cdot d\dot{\tau} \quad (4)$$

$$C_2 = 1.25 \cdot \frac{i \cdot W^{4/3}}{V \cdot \rho_a \cdot c_{p_a}} \cdot (1 - \alpha) \cdot L_{(1-\alpha)} \cdot d\dot{\tau} + L \cdot (1 - d\dot{\tau}) \quad (5)$$

Relation (3) takes into account the windows opening average duration against the integration step (in this case 1h), the average length of the joints of the windows that are not opened $L_{(1-\alpha)}$ and the windows opening rate $\alpha \leq 1$. Values $d\dot{\tau}$, $L_{(1-\alpha)}$ and α are estimated based on tests in cooperation with the occupants.

The heat contribution from the occupants' activities can be estimated using the following relation:

$$Q_L(\tau) = a(\tau) \cdot A_{Loc} \quad (6)$$

The heat flow released by the heating system into the dwelled spaces is expressed by:

$$Q_S(\tau) = (1 - \varepsilon_1) \cdot (1 - \varepsilon_2) \cdot Q_{SM}(\tau) \quad (7)$$

The ε_1 and ε_2 coefficients depend on the condition of the distribution pipes in the basement as well as on the rate of the thermal equivalent area of the heating units in dwelled space against the whole area of the block heating system.

The integration of equation (2) in a period of time T leads to the following equation:

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

$$+ \rho_a \cdot c_{p_a} \cdot \bar{n}_a \cdot V \cdot (\bar{t}_a - \bar{t}_e) + M C_i \cdot \frac{dt_P(\tau)}{d\tau} \quad (8)$$

Equation (8) is valid as for normal conditions of dwelled spaces ventilation the following identity can be admitted with an error lower than 0.70 %:

$$T \cdot \int_0^T n_a(\tau) \cdot [t_a(\tau) - t_e(\tau)] \cdot d\tau = \int_0^T n_a(\tau) \cdot d\tau \cdot \int_0^T [t_a(\tau) - t_e(\tau)] \cdot d\tau \quad (9)$$

Equation (8) marks the *first condition* of performing the physical experiment, namely the selection of periods with steady-state thermal conditions in the dwelled spaces. The meeting of this condition transforms equation (8) as:

$$\bar{Q}_S + \bar{Q}_L = \sum_j \left(\frac{A}{R} \right)_j \cdot (\bar{t}_{i_R} - \bar{t}_{ev_j}) + \rho_a \cdot c_{p_a} \cdot \bar{n}_a \cdot V \cdot (\bar{t}_a - \bar{t}_e) \quad (10)$$

For $T > 120$ h it can be demonstrated [4] that the relation of thermal balance in steady-state conditions for outdoor closing elements can be used. Therefore:

$$\bar{t}_{ev_j} = \bar{t}_{E_j} \quad (11)$$

Equality (11) marks the *second condition* of performing the physical experiment, namely the selection of days with no direct solar radiation so as to make possible the use of relation (11) in the form:

$$\bar{t}_{ev_j} \approx \bar{t}_e \quad (12)$$

In these conditions equation (10) is written as:

$$Q_S = A_{EX} \cdot \left[\sum_j \frac{\beta_j}{R_j} \cdot (t_{i_R} - t_e) - \sum_k \frac{\beta_k}{R_k} \cdot (t_{i_k} - t_e) \right] + \rho_a \cdot c_{p_a} \cdot n_a \cdot V \cdot (t_{a_M} - t_e) - a \cdot A_{Loc}$$

with $\beta_j = \frac{A_j}{A_{EX}}$ and $\beta_k = \frac{A_k}{A_{EX}}$ (13)

where the symbol of mean has been dropped.

Relation (13) can be written in a short form as:

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

where

$$D_1 = \left(A_E - \frac{Q_S + a \cdot A_{Loc}}{t_{a_M} - t_e} \cdot A_1 \right) \cdot \rho_a \cdot c_{p_a} \cdot V \quad (15)$$

$$D_2 = \left(A_2 + \frac{Q_S + a \cdot A_{Loc}}{t_{aM} - t_e} \right) \cdot \rho_a \cdot c_{p_a} \cdot V \quad (16)$$

and

$$A_1 = \frac{h_r \cdot \bar{F}}{h_{cv} \cdot h_i} ; \quad A_2 = \sum_k \frac{A_k}{R_k} \cdot \frac{t_{ev_k} - t_e}{t_{aM} - t_e} \quad (17)$$

The overall transfer coefficient h_i is established with relation [4]:

$$h_i = h_{cv} + h_r \cdot \bar{F} \cdot \frac{A_T}{A_{EX}} \quad (18)$$

where the average view factor $\bar{F}$ is established according to the geometry of the room representative for the dwelled space.

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

$$t_{aM} = t_e + (\dot{t}_{aM} - t_e) \cdot [0.99761 \cdot (t_{TM} - t_e) - 0.0005] \quad (19)$$

where temperature $\dot{t}_{aM}$ is assessed according to the operational characteristics of the indoor heating system:

$$\dot{t}_{aM} = \frac{t_{RM} \cdot E_S - t_{TM}}{E_S - 1} \quad (20)$$

Function E_S is established according to the average coefficient m specific to the heating units, to the heat carrier measured temperatures, to the heat carrier mass flow-rate, G , and the nominal heat load Q_0 :

$$E_S = \exp \left[\left(0.003921 \cdot \frac{Q_0}{G \cdot c} \right)^{\frac{1}{1+m}} \cdot (t_{TM} - t_{RM})^{\frac{m}{1+m}} \right] \quad (21)$$

The average thermal resistance of the outdoor opaque building elements is established using relation (14) in the form:

$$\bar{R}_{Opaque} = \bar{R} \cdot \beta_{Opaque} \cdot \frac{D_2 - n_a}{E_1 - E_2 \cdot n_a} \quad (22)$$

$$\beta_{Opaque} = \frac{A_{Opaque}}{A_E}$$

where E_1 and E_2 are determined according to the geometric layout of the building and to the thermal

resistance values, actually known, of the building elements separating the dwelled spaces from the secondary spaces, as well as to the glazing area.

Taking into account the previously mentioned procedure of evaluation of the terrace thermal resistance, it results as follows:

$$\bar{R}_w = \frac{A_w}{\frac{A_{Opaque}}{R_{Opaque}} - \frac{A_T}{R_T}} \quad (23)$$

The building units forming the opaque external walls, regardless of their structure, contain the same heat insulating material, so that the final equation of the preliminary phase has the following form:

$$\sum_{n=1}^N \frac{k_E \cdot A_{w_n}}{\delta_{IZ_n} + b_n \cdot k_E} = \frac{\sum_{n=1}^N A_{w_n}}{R_w} \quad (24)$$

where b_n represents the thermal resistance of the n building unit without heat insulation. We mention that between the volume average air temperature, t_a , and the resultant indoor temperature exists a linear correlation with the following form:

$$t_a = F_1 \cdot t_{iR} + (1 - F_1) \cdot t_{ev} \quad (25)$$

where F_1 is a function of the average thermal resistance of the building elements.

Relation (24), together with relations (23) and (22), establishes a correlation between the equivalent thermal conductivity k_E of the insulating material and the average number of air changes n_a . We mention that the value t_{aM} established according to relation (19) uses the average values of the measured thermodynamic parameters namely t_{TM} , t_{RM} and G in a period of time T .

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

Based on relation (24) two sets of values are generated, $\{k_E\}$ and $\{n_a\}$ whose terms are in bi-univocal correspondence. The sets of values are inferiorly and superiorly limited so that:

$$\min \{k_E\} \geq k_{E_{IZ}}$$

$$\max \{k_E\} \leq k_{Max}$$

where $k_{E_{IZ}}$ represents the minimum catalogue value of the building materials that were used (e.g.

concrete). We emphasize that the two rows of values are associated to a transfer function of the heating units actually represented by coefficient m . Therefore to an m_1 value of coefficient m correspond the rows of values $\{k_E\}_1$ and $\{n_a\}_1$ as well as the average value of temperature t_{aM1} . The objective elements of the measurement are $t_{TM}(\tau)$, $t_{RM}(\tau)$ and G and therefore the heat flow released by the system $Q_M(\tau)$. The non-steady-state thermal building simulation software INVAR [5] is used, in the variable heat flow inlet values $Q_M(\tau)$ variant. The INVAR software, worked out by the INCERC experts in 1992, is based on the Unitary Thermal Response (R.T.U.) and operates both for establishing the heat demand in order to reach thermal comfort in the cold season and in hot season and the variation of the resultant and air indoor temperatures in natural random climatic conditions. The calculation algorithm was tested at INCERC (Solar House CS3 Bucharest) and on buildings in Bucharest and Cluj-Napoca in the period 1983-1996. The tests focused both on the cold and hot season. The synthetic climatic parameter used in the software is the equivalent outdoor temperature established according to measured values of the outdoor temperature, of overall solar radiation and of the diffuse component of the solar radiation. Wind velocity is measured as well. The calculation step is 1h, but can be modified if requested by the type of the analysis.

The thermal conductivity of the heat insulating material inside the opaque outdoor walls structure has the value $k_{E1,1}$ and the number of air changes has the constant value $n_{a1,1}$. The variation function $t_{a1,1}(\tau)$ is obtained and, based on relations (19) and (20), the theoretical function $t_{R1,1}(\tau)$ is obtained and is compared to the measured hourly values $t_{RM}(\tau)$. The comparison refers to the corresponding hourly values. The following conditions are imposed:

$$|\bar{t}_{R1,1} - \bar{t}_{RM}| \leq \varepsilon_1 \quad (26)$$

$$\frac{\sigma \bar{t}_{R1,1}}{\bar{t}_{RM}} \leq \varepsilon_2 \quad (27)$$

A variation step of the thermal conductivity Δk_E is admitted to which corresponds a sequence of values n_a . For m_1 are tested all the values $k_{E1,s}$ and $n_{a1,s}$ that, used together with $Q(\tau)$, generate the following values:

$$|\bar{t}_{R1,s} - \bar{t}_{RM}| = M_{1,s} \quad (28)$$

$$\frac{\sigma_{t_{R1,s}}}{\bar{t}_{RM1,s}} = M_{2,s} \quad (29)$$

which are compared to ε_1 and ε_2 respectively.

Value m_1 is modified, $m_2 = m_1 + \Delta m$ being generated and the procedure is resumed. In the end, the pair of values M_1 , M_2 is selected, which meets the best conditions (26) and (27) to which correspond the final values m , k_E and n_a . Taking into account relation (3) and the results of the test performed jointly with the occupants, the real value of air infiltrations coefficient i is assessed and compared to the catalogue value i_0 for the type of window that is used.

The analysis is completed by the application of the procedure during several distinct periods of time which have to meet the condition $T > 120$ h as well as the other conditions stated in the study.

Each stage represents an instrument that validates the previous one, in the sense that the admitted variations of conductivity k_E and of infiltration coefficient i have to range only within 5 % of the average value of all the established values.

4. EXPERIMENTAL WORK

The criteria that have to be met by an experiment are the following:

- measurements duration $T > 120$ h consecutively,
- cloudy days,
- dry terrace of the building, not covered by water or snow,
- average volume temperature of indoor air close to the value corresponding to the thermal comfort state (t_a within $[18^\circ\text{C}, 23^\circ\text{C}]$),
- outdoor air temperatures ranging within $[-3^\circ\text{C}, 5^\circ\text{C}]$,
- days characterized as not windy.

CASE STUDY

The use of the procedure of identification the thermal characteristic of a building represented a phase in the thermal survey of an apartment building of the "ground floor + 10 floors" type in Bucharest. The block has 44 apartments and the space heating system is connected to the district cogeneration heating system. The results supplied by measurements performed in the period 3-7.02.1999 are presented. The diagram in Figure 2 presents the measured values $t_{TM}(\tau)$, $t_{RM}(\tau)$, $t_e(\tau)$ and $Q_M(\tau)$.

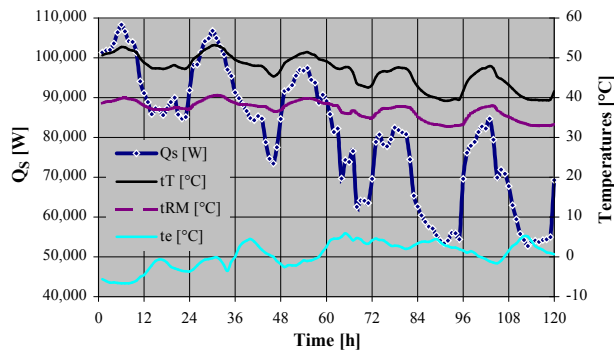


Fig. 2. Experimental values – Multi-dwelling Building, Bucharest, 3-7.02.1999

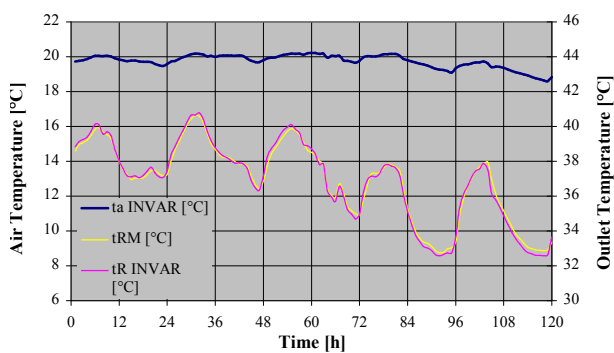


Fig. 3. Final phase of Thermal Identification of a Multi-dwelling Building, Bucharest, 3-7.02.1999

The set of values $m \in [0.10, 0.30]$ with a step $\Delta m = 0.025$ was used. Associated to the final solution $m = 0.125$ the function $t_{RM}(\tau)$ results and is represented in the diagram in Figure 3.

In accordance with the preliminary phase of the thermal identification, the values $\bar{R} = 0.483 \text{ m}^2\text{K} / \text{W}$, $\bar{R}_{Opaque} = 0.601 \text{ m}^2\text{K} / \text{W}$ and $k_E = 0.351 \text{ W} / \text{mK}$ resulted together with $n_a = 0.40 \text{ h}^{-1}$. By using the INVAR software, the indoor air temperature variation function $t_a(\tau)$ is obtained for the pair of values k_E , n_a . Based on hourly values $t_a(\tau)$, the hourly values $t_R(\tau)$ are obtained (represented in the diagram in Figure 3).

The following result:

$$M_1 = |\bar{t}_{RM} - \bar{t}_R| = 0,015$$

$$M_2 = \sigma t_R / \bar{t}_{RM} = 0,0636$$

which are compared to $\varepsilon_1 = 0.20^\circ\text{C}$ and $\varepsilon_1 = 0.08$. Therefore the values k_E , n_a and m correspond to the stated decision criteria. Value $k_E = 0.351 \text{ W} / \text{mK}$ is compared to the catalogue value of the thermal conductivity of the autoclaved lightweight concrete $k_{Eo} = 0.22 \text{ W} / \text{mK}$ and exponent $m = 0.125$ to the value obtained in the testing room, $m_0 = 0.33$. Value

$n_a = 0.40 \text{ h}^{-1}$ is compared to the rational value $n_{a0} = 0.60 \text{ h}^{-1}$ and leads to the conclusion that space ventilation is not sufficient mainly because of the lack of fresh air by the opening of the windows.

5. CONCLUSION

This paper presents a method of identifying the real value of the thermal conductivity of heat insulating materials in the structure of the outdoor opaque building units of apartments buildings connected to district heating systems. The theoretical fundamentals of the method are presented in the form of two necessary phases, namely the preliminary and the final phase. The mathematical model is based on the integral equation of thermal balance of the dwelled spaces that form the central zone of the building while the other jointly used spaces form the secondary zone. A relation is established that correlated values k_E and n_a , which is valid for a value of the m coefficient specific to the heating system transfer function. Once the values k_E and n_a are determined and the values $Q(\tau)$ measured, the variation function $t_a(\tau)$ is obtained using the INVAR software. Based on hourly values $t_a(\tau)$, the hourly values of $t_R(\tau)$ are determined. Theoretically the calculated function $t_R(\tau)$ and the function resulted from the measured data processing $t_{RM}(\tau)$ have to be identical.

The study also states the statistical criteria for the validation of the resulted values. The paper is concluded by a case study which provides results that cannot be estimated theoretically or by other methods, concerning k_E and indications on the physiological outline in the dwelled spaces correlated with the heat consumption, by value n_a .

The method is useful especially in the case of expert surveys of the apartment buildings whose structures are characterized by multi-layer walls, thermal bridges and deterioration because of the anthropic and climatic factors.

The method presented has also a number of disadvantages of which we mention:

- the assuming of a unique average value of the equivalent thermal conductivity for the heat insulating material in the outdoor walls structure. This supposes the uniform distribution of the flaws and objective non-uniformities (e.g. untreated thermal bridges) on the outdoor walls sides;
- the assuming of a unique value of the i infiltration coefficient specific to the mobile closing elements joints;

- the assuming of a unique average value for the n_a air changes number although it is a strongly subjective value;

- the use of the bi-zonal calculation model which implies the reaching of very close values of the dwelled spaces indoor temperatures; in fact it is possible for the hydraulic non-uniformities specific to the operation of the district heating system to be reflected by the indoor temperatures range.

Despite all these disadvantages, representing the sum number of approximations, this method can provide quantitative information absolutely necessary in the activity of energy diagnosis and subsequently audit, its accuracy being acceptable for the entire building.

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