Evaluation Methods of Energy Performances in Buildings

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Abstract. Since the introduction of the buildings that targets the first energy conservation regulations in the 1970s and the increasing emphasis on the field in the late 1990s and early 2000s, a wide range of methodologies have been developed for predicting, analyzing and evaluating the energy performance of buildings. Some of these methodologies have been integrated into national or public evaluation programs of new and existing buildings, while in recent years there has been a rapid growth in the development and application of new methodologies for the evaluation and classification of energy performance. This paper presents the basic methods by which the thermal loads necessary to ensure adequate thermal comfort inside enclosed spaces can be established, taking into account the influence of factors such as the type of construction materials, indoor and outdoor air temperature, number of air changes, providing conditions of physiological comfort, location and structure of buildings. The opportunity to use each method according to the objective pursued is highlighted.

Keywords: energy performance · energy efficiency of the building · trend analysis · innovative technologies · evaluation methods

1 Introduction

Energy consumption for existing buildings (utilities, heating) represents one third of the global final energy consumption and also of the amount of CO2 emissions [1]; as such, the energy performance of buildings is a field that has become increasingly important worldwide. The International Energy Agency describes energy efficiency as the “first fuel” [2], which is more important than any technology, and studies have shown that the greatest potential for energy efficiency lies in the building sector [3]. However, as the built environment becomes more complex, with multiple uses, larger buildings and increased demand for services such as thermal comfort and data processing [4], analysis and evaluation of building performance becomes an important issue.

The analysis starts from the principle according to which certain factors affect the energy consumption in buildings: Climate; Building envelope; Construction systems; Operations and maintenance; Occupant behavior; Indoor environmental conditions. The energy performance of buildings, regardless of their type and destination, is determined on the basis of energy consumption according to the heat demand for heating, hot water

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preparation, ventilation, air conditioning and technology. The standard does not apply to buildings equipped with air conditioning systems that cool the spaces during the heating season.

Energy requirements for heating a building generally include: heating, domestic hot water (DHW/DHW), ventilation, air conditioning and lighting [5]. Lately, more and more attempts have been made to solve priority problems related to construction energy, such as:

- reduction of energy consumption in old buildings;
- adopting measures for new constructions.

For the quantitative appreciation of the heat and mass transfer phenomena through the construction elements that are part of the structures that delimit the rooms of the buildings, it is necessary to know the thermal and hygro-thermal properties of the homogeneous construction materials.

2 Methods for Assessing the Heat Demand for Heating

The heat demand for static heating can be determined by:

- The method of thermal characteristic of the building;
- Calculation method on the exterior contour of the building;
- Method according to Standard SR1907-1/1997;
- The method of global thermal insulation coefficients "G";
- Method of the number of degrees days.

2.1 The Thermal Characteristic Method of the Building

Considering a stationary regime, this method is based on the following relation:

$$Q_i = x_i \times Ve \times (\theta_i - \theta_e) \times a[W] \quad (1)$$

where:

Q_i- heat flux lost through infiltrations
qi – indoor temperature (°C)
qe – outdoor temperature (°C)
x_i- thermal characteristic (coefficient) of the building ($W/m^3 \times ° C$)
Ve- built external volume (m^3)
a - coefficient depending on the outside temperature qe (°C)

The values of the parameters from the calculation relations are obtained from the literature and the specialized norms.

Example shown in Table 1.

Table 1. The thermal coefficient of the building

Crt.	The kind of building	$V_e 10^3 \left[m^3\right]$	x_i	
			$\left[W/m^{3*}\,°C\right]$	$\left[kcal/m^{2*}grd\right]$
1.	Buildings: residential, socio-cultural and administration	1 1…5 5…10 10…25 >25	0,58…0,765	0,5…0,65
2.	Workshops	5…20 20…200	0,53…0,58	0,46…0,5
3.	Garages	5…10	0,75…1,33	0,65…1,15

Table 2. Conventional indoor calculation temperatures

Nr. crt.	Destination of rooms	Conventional temperature calculation, [°C]
1.	Living rooms and hallways	20
2.	Lobbies in apartments	18
3.	Bathrooms, showers	22
4.	Kitchens	18
5.	Closets in the apartment	18
6.	Toilets outside the apartment	15
7.	Stairs and corridors outside the apartment	10
8.	Windfangs	12
9.	Laundries and ironers	15
10.	Dryers in apartment buildings	25
11.	Garages under houses	10

Table 3. Coefficient "a" depending on the outside temperature θe

$\theta_{e,}\left[°C\right]$	-12	-15	-18	-21
a	1,35	1,29	1,21	-

The calculation of the heat demand for heating according to the method of the thermal characteristic of the building requires the determination of the additional need for heating the infiltrated air due to leaks.

$$Qvm = f \times Qi[W] \tag{2}$$

Table 4. Correction coefficient "f" depending on the outside temperature θe

$\theta_{e,}[°C]$	> 0	-5…-10	-10…-15	-15…-20
f	0,15…0,2	0,1…0,15	0,07…0,1	0,05…0,07

where:

Qνm - average heat loss through glazed surfaces, heat required (W) to heat infiltrated air through ventilation
f - correction coefficient depending on the outside temperature qe (°C)
Qi - the useful heat input resulting from living in the building, corresponding to a m^3 of heated volume ($kWh/m^3 \times$ an) (Table 4)

2.2 Calculation Method on the Exterior Contour of the Building

It involves performing an approximate heat transfer calculation on the outer contour of a building, regardless of its purpose. The total heat demand is:

$$Q = 1,2 \times Q + Q[\mathrm{W}] \tag{3}$$

$$Q = S_\mathrm{p} \times (\theta\mathrm{i} - \theta\mathrm{e}) \times \mathrm{k_p} \tag{4}$$

$$Q = S_v \times (\theta\mathrm{i} - \theta\mathrm{e}) \times k_v \tag{5}$$

where:

Q_i - the useful heat input resulting from living in the building, corresponding to a m3 of heated volume ($kWh/m^3 \times$ an)
Q_p - heat loss through opaque surfaces (solid, walled) (W)
Q_v - heat loss through glazed surfaces, heat required for heating infiltrated air through ventilation (W)
S_p - opaque surfaces (solid, built) through which heat transfer is performed (m^2)
S_v - glazed surfaces, through which heat transfer is performed (m^2)
$\mathrm{k_p}$ - global heat transfer coefficients through flat surfaces
k_v - global heat transfer coefficients through glazed surfaces

The global heat transfer coefficients through solid surfaces, kp, respectively glazed, kv, are dependent on the external meteorological conditions (Table 5).

Considering that the exterior surface of the building is:

$$S_E = Sp + Sv\left[\mathrm{m}^2\right] \tag{6}$$

S_E - the outer surface of the building

Table 5. Global heat transfer coefficients depending on the weather

k	No wind	Wind + rain	According to local Regulations
k_p, $\left[W/m^2 * grd\right]$	0,79	1,7	1,5…1,98
kv, $\left[W/m^2 * grd\right]$	3,82	8,26	3,25…5,23

The contribution of solid surfaces Sp will be appreciated, compared to the glazed ones Sv, as follows:

- for industrial halls Sv = (0,1…0,3)SE;
- for housing Sv = (0,1…0,2)SE;
- for socio-cultural and administrative buildings Sv = (0,2…0,4)SE;

2.3 The Method According to the Norm SR 1907-1/1997

This calculation method involves several steps, namely:

1. It is noted on the plan of the building, in a circle drawn in each room, the room number and the internal calculation temperature (Table 2). According to SR 1907-2/1997;
2. Enter in the calculation form the geometric and thermotechnical characteristics of the construction elements through which the room loses heat: dimensions, thermal resistance, temperature differences;
3. Calculate the heat loss by transmission, QT, based on which the average specific thermal resistance is calculated:

$$Q_T = \sum C_{Mm} \times Ax\frac{\theta i - \theta e}{R'} + Q_S[\mathrm{W}] \tag{7}$$

where:

Q_T - heat loss through transmission
C_{Mm} - correction coefficient of the required heat calculation depending on the specific mass of the construction
A - the surface area of each construction element; the area of the building envelope; total area of glazed element “n” (m^2)
Q_S - heat flux released through the ground (W).
R’ - the corrected specific thermal resistance of the considered construction element, determined according to STAS 6472/3 ($m^2 \times K/W$)

a. The calculation of the thermal mass coefficient is performed using the following calculation relation:

$$\mathrm{m} = 1,225 - 0,05 \times \mathrm{D} \tag{8}$$

where: m- coefficient of thermal mass of the external construction elements

D - the index of thermal inertia of the construction element

$$D = \sum_{j=l}^{n} R_{\mathrm{stj}} \times S_{\mathrm{mj}} \tag{9}$$

where: n- number of rooms in the building

j = 1 − the number of rooms in the house
Rst, j - specific thermal permeability resistance of layer "j" ($m^2 \times K/W$)
Smj - thermal assimilation coefficient of the material of the layer "j" ($W/m^2 \times K$)

b. The heat flow yielded through the ground, Qs is calculated as follows:

$$Q_s = A_p \frac{\theta i - \theta p}{Rp} + C_M \times \frac{ms}{ns} \times \frac{\theta i - \theta e}{Rbc} \times A_{bc} + \frac{1}{ns} x \frac{\theta i - \theta ej}{Rbc} \times A_{bcj} \tag{10}$$

where:

Ap - the cumulative area of the floor and walls below ground level (m^2)
qp - temperature, either in the soil at a depth of 7 m from the level of the systematized land, in case of non-existence of the groundwater layer, or of the groundwater layer (°C)
Rp - the cumulative specific thermal resistance of the floor and the soil layer between the floor and the depth of 7 m from the level of the systematized land, or of the groundwater layer ($m^2 \times K/W$)
CM - correction coefficient of the required heat calculation depending on the specific mass of the construction
ms - coefficient of thermal mass of the soil, determined according to the depth of the groundwater layer, H and the depth of burial of the floor, h
ns - correction coefficient that takes into account the thermal conductivity of the soil
Rbc - the specific thermal resistance of the contour strip when heat passes through the floor and floor to the outside air ($m^2 \times °C/W$)
Abc - the area of a 1 m wide strip located along the outer contour of the surface A (m^2)
Abcj - the area of a 1 m wide strip located along the contour corresponding to the adjacent space having the temperature qi (m^2)
qe,j - conventional computing indoor temperature for adjoining rooms (°C)
Rbc - the specific thermal resistance of the contour strip when heat passes through the floor and floor to the outside air ($m^2 \times °C/W$)

$$A_p = A_{pl} + p \times h \tag{11}$$

where:

A_{pl} - the area of the floor slab or the bottom plate of the heated basement (m^2)
h - the elevation of the floor below ground level (m)

p - the length of the contour of the walls in contact with the ground (m)

$$R_p = \frac{1}{\alpha i} + \Sigma \frac{\delta}{\lambda} \quad (12)$$

where:

Ai - surface heat transfer coefficient inside ($W/m^2 \times K$)
δ - layer thickness (m)
λ - the coefficient of the point thermal bridges of the construction element

The thermal load is determined for heating from the ambient temperature to the interior temperature of the air infiltrated by leaks of doors and windows, as well as of the air penetrated at their opening Qi, as the maximum value between the thermal loads *Qi1* and *Qi2*

$$Q_{i1} = \left[n_{ao} \cdot C_M \cdot V \cdot \rho \cdot c_p \cdot (\theta_i - \theta_e) + Q_u\right] \cdot \left(1 + \frac{A_c}{100}\right) \quad (13)$$

where:

n_{ao} - the number of air changes required in the room for conditions of physiological comfort (h−1)
V - average volume flow of fresh air (m^3/h)
P - density (kg/m^3)
Qu - the heat required to heat the air entering opening the exterior doors (W)
Ac - the addition to compensate for the effect of cold surfaces (%)

$$Qi2 = \left\{CM \cdot \left[E \cdot \sum i \cdot L \cdot v^{4/3} \cdot (\theta_i - \theta_e)\right] + Qu\right\} \cdot \left(1 + \frac{A_c}{100}\right) \quad (14)$$

where:

E - construction element
L - ventilated air flow (m^3/h)
i - coefficient of air infiltration through the joints
Qu - the heat required to heat the air entering opening the exterior doors (W)

$$Qu = U \cdot Au \cdot n \cdot (\theta i - \theta e) \cdot c_M \quad (15)$$

where:

U - specific heat loss when opening an exterior door ($J/m^2 \times °C$)
Au - the area of the opening exterior doors (m^2)

CM - correction coefficient of the required heat calculation depending on the specific mass of the construction

It is the most used method because the values of the parameters necessary for the calculations are obtained from the SR 1907-1/1997 norm.

2.4 The Method of Global Thermal Insulation Coefficients "G"

The calculation method takes into account the climatic conditions of the site, but also the internal and solar (passive) heat inputs that can be used to determine by calculation the annual heat demand for both new and existing buildings (rehabilitation or non-rehabilitation) [6].

For one m3 of interior volume of the building, the annual heat demand is determined as follows:

$$\mathrm{Q} = \frac{24}{1000} \times \mathrm{C} \times N_{12}^{\theta_i} \times \mathrm{G} - (\mathrm{Q_i} + \mathrm{Q_s}) \tag{16}$$

C - the internal thermal capacity of the building (Wh/K)
G - the overall thermal insulation coefficient of the building (W/m^3 $\times$ *K)*
$N_{12}^{\theta_i}$ - the annual number of degrees-days of calculation, corresponding to the locality where the building is located, calculated for the indoor temperature average during the heating period θi and for the outside temperature daily average marking the start and stop of the heating θe0 (K × days)
Qs - heat flux released through the ground (W)

$$\mathrm{Q_s} = 0,40 \times \sum\nolimits_{ij} I_{\mathrm{Gj}} \times \mathrm{g_i} \times \frac{A_{F_{ij}}}{V} \left[\mathrm{KW} \times \mathrm{h}/\left(\mathrm{m}^3 \times \mathrm{an}\right)\right] \tag{17}$$

where:

I_{Gj} - available global solar radiation corresponding to a cardinal orientation "j" (kW·h/m^2·an)
AFij - the area of the exterior carpentry provided with clear windows of type "i" and arranged according to the cardinal orientation "j", (m^2)

And where gi, the degree of energy penetration on the windows "i" of the exterior carpentry takes the values 0.75 - for single windows, or a double insulating glass; 0.65 - for three single glazing, or a single glazing + a double insulating glazing, or a triple insulating glazing; 0.50 - double insulated glass; 0.45 - for triple glazing; 0.40 - for triple insulating glass.

The annual number of degrees of calculation $N_c^{\theta_i}$ is determined as follows:

$$N_c^{\theta_i} = N_{\theta_{eo}}^{20} - (20 - \theta_i) \times D_{\theta_{eo}} \tag{18}$$

where:

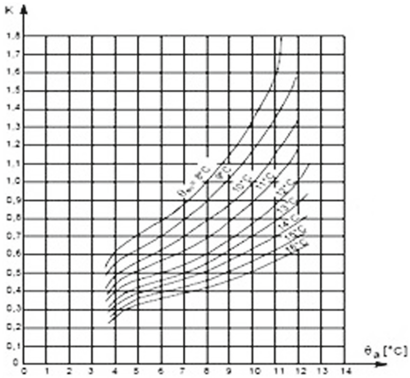

Fig. 1. Diagram of variation of the climate correlation coefficient K, according to the average annual temperature θa

$N_{\theta_{co}}^{20}$ - the number of degrees – days of calculation
$D_{\theta_{eo}}$ - conventional duration of the heating period (days)

The annual number of degrees-days of calculation is established as follows:

- the average annual temperature is determined for the respective locality

$$\theta_a = \theta_{a0} - 0,005 \times h \tag{19}$$

where: θao - average annual outdoor temperature corrected for sea level, for that locality

- the value of the climate correlation coefficient K is determined according to $\theta\alpha$ and θeo, according to the diagram (Fig. 1);
- the locality falls into one of the two correlation zones (k, $N_{\theta_{co}}^{20}$), (Fig. 1) depending on its geographical position

The values of the annual number of degrees - days of calculation, $N_{\theta_{co}}^{20}$, are taken from one of the diagrams depending on the value of the climate correlation coefficient, K and the correlation area.

The conventional duration of the heating period, $D_{\theta_{co}}$, is also determined from the diagram according to the value of the coefficient K. For periods shorter than a heating season the calculation of the number of degrees-days is made using the Eq. 18.

2.5 The Method of the Number of Degrees-Days

This can be used to determine the annual energy consumption for heating.

The optimal design of a building, in order to minimize the costs during its lifetime, requires an evaluation/estimation of the annual *Qan* energy consumption, which represents the integral in time of the instantaneous consumption during the heating or cooling period. Instantaneous consumption is the instantaneous load divided by the efficiency of the equipment.

The degree-day number method is an appropriate calculation solution for annual energy consumption, if the use of the building as well as the efficiency of the equipment can be considered constant. For situations where they vary significantly with the outside temperature, the consumption can be calculated for certain values of the outside temperature and it is multiplied by the number of hours in the year, corresponding to intervals centered around these values; annual consumption results from summing the consumption associated with each outdoor temperature range.

The geographical location of the application and the meteorological data of the location are very important for determining the necessary thermal energy to ensure a proper air conditioning of the buildings throughout a year.

The day-degree concept assumes that:

- the average temperature inside a building has a desired average value of 21.1 °C;
- 2.8 °C of this value are provided by internal heat resources such as, lighting, various equipment and the human factor;
- the calculation basis of the degree-days is 18.33 °C.

If the number of degrees-days N is known from the climatic data and the characteristics of the building, the annual consumption for heating can be determined as follows:

$$Q_{\hat{I}nc} = \frac{1}{\eta_{\hat{I}nc}} \int Q_{tot} d\tau = \frac{G \times V}{\eta_{\hat{I}nc}} \times \sum\nolimits_{zile/an} \left(T_i^{cor} - T_e^{cor}\right) \times zi = \frac{G \times V_{clad}}{\eta_{\hat{I}nc}} \times N [J/an] \tag{20}$$

where:

G - the overall thermal insulation coefficient of the building ($W/m^3 \cdot K$)
Vclad - the interior, heated volume of the building
η înc - annual fuel efficiency
Qtot - total thermal load (W)
T_i - T_e - corresponding indoor and outdoor temperature (°C)

The global thermal insulation coefficient of building G represents the sum of heat losses achieved by direct transmission through the area of the building envelope, for a temperature difference between inside and outside of 1K, relative to the volume of the building, to which are added heat losses related to indoor air cooling., as well as those due to additional infiltrations of cold air and are determined as follows [6, 9, 10]:

$$G = \frac{1}{V_{clad}} \times \left(\sum \frac{A}{R'_m}\right) + 0,34 \times n \quad \left[W/\left(m^3 K\right)\right] \tag{21}$$

The average corrected thermal resistance of the building envelope is determined as follows:

$$R'_m = \frac{A}{\Sigma \frac{A_{j \times \tau_j}}{R'_j}} \quad \left[m^2 \times K/W\right] \tag{22}$$

where:

R'_m - corrected, average thermal resistance of the building envelope ($m^2 \cdot K/W$)
R'_j - corrected thermal resistance, average throughout the building, of perimeter construction elements ($m^2 \cdot K/W$)
Aj - the total areas, on the building, of the construction elements; area area "j" (m^2)
τj - number of hours in the heating period j, corresponding to the heating regime (h)

The level of global thermal insulation is appropriate if the condition is met:

$$G \leq GN \tag{23}$$

The value of the number of degrees-days is used to estimate and analyze the heat demand of buildings. The number of degrees-days is a characteristic of the climate-microclimate correlation for constructions, depending on their specificity and the climatic and geographical area in which they are located.

The number of degrees-days corresponding to a certain heating period, N is calculated using the following equations:

$$N = \sum_{X=1}^{\times=z} \left(\theta_{e,\times} - \theta_{e,\times}\right); N = (\theta_i - \theta_e) \times z; \theta_{i,x} = \frac{\sum_{j=1}^{j=n} \theta_j v_j}{\sum_{j=1}^{j=n} v_j}; \theta_i = \frac{\sum_{X=1}^{\times=z} \theta_{i,\times}}{z}; \theta_e = \frac{\sum_{X=1}^{\times=z} \theta_{e,x}}{z} \tag{24}$$

z - number of days in the period considered
θ_j - the average daily indoor temperature of each of the rooms of the building (°C)
V_j - the volume of each of the construction rooms (m^3)
$\theta_{i,x}$ - the average daily interior temperature of the room or building during the period considered (°C)
$\theta_{e,x}$ - average daily outside temperature during the period considered (°C)

According to the nature of the indoor and outdoor temperatures considered in the calculation of the number of degrees-days, there are two categories of degrees-days [8, 9]:

- degrees-days of calculation, established with the values of the conventional interior temperature of calculation, according to SR 1907-2/97 and with the values of the average daily outside temperature, corresponding to the period considered, (Table 3), the degrees-days of calculation serve to evaluate the necessary the heat;
- actual degrees-days, calculated with the actual values of indoor and outdoor temperatures; the actual degree-days are used to post-calculate the heat consumption.

The annual number of degrees-days of calculation ($N_c^{\theta_i}$) for a certain locality is determined for the period in which the average daily outdoor temperatures do not exceed a given value, θ_{eo} which marks the moment of starting, respectively stopping the heating.

The value θ_{eo} is 12 °C, except for the following types of constructions:

- hospitals, nurseries, kindergartens with heating with stoves or with their own central heating installations, for which $\theta_{eo} = 14$ °C;

Fig. 2. Map of correlation areas

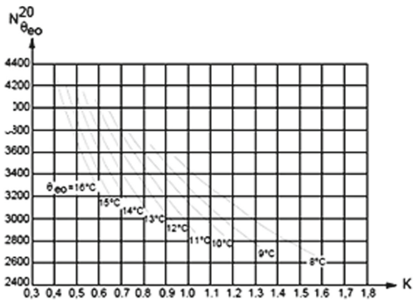

Fig. 3. Diagram for determination $N^{20}_{\theta_{eo}}$ value in area I

- industrial production rooms with their own central heating, for which the value of θ_{eo} is 8 °C below the value of the conventional indoor temperature of calculation, in the case of halls and workshops where activities are performed with specific light and medium work, respectively with 4 °C below the value of this temperature, in the case of hard work halls.

The annual number of degrees of calculation $N_c^{\theta_i}$ is established as follows:

$$N_c^{\theta_i} = N^{20}_{\theta_{eo}} - (20 - \theta_i) \times D_{\theta_{eo}} \tag{25}$$

The values of the annual number of degrees - calculation days, $N^{20}_{\theta_{eo}}$, are taken from the diagrams, according to Fig. 3, Fig. 4 or Fig. 5, depending on the value of the climate correlation coefficient, K and the correlation area (Fig. 2).

The conventional duration of the heating period, $D_{\theta_{eo}}$ is taken from the diagram, Fig. 6, depending on the value of the coefficient K.

Diagram for determining the value in area II (altitude & lt; 650 m)

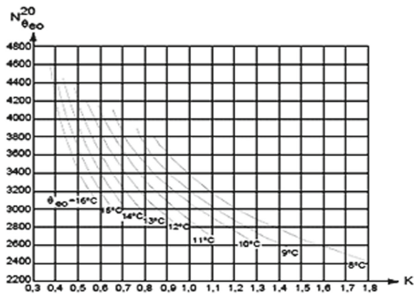

Fig. 4. Diagram for determination $N_{\theta_{eo}}^{20}$ value in area II (altitude < 650 m)

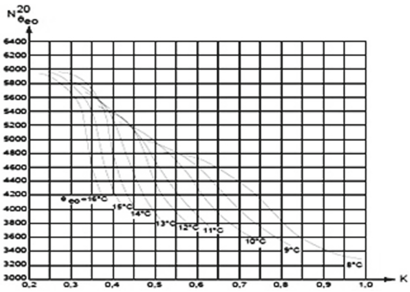

Fig. 5. Diagram for determination $N_{\theta_{eo}}^{20}$ value in area I (altitude > 650 m)

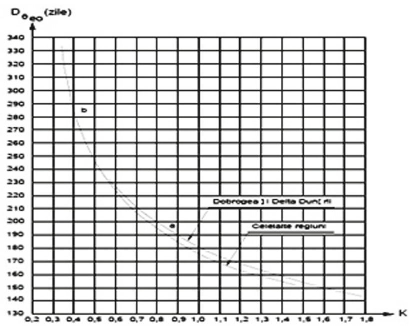

Fig. 6. Diagram for determining the conventional duration of the heating period $D_{\theta_{eo}}$ as a function of the climate correlation coefficient K

For periods shorter than a heating season the calculation of the number of degrees-days is made using the equation:

$$\mathrm{N} = (\theta_i - \theta_e) \times z \tag{26}$$

and average daily outside temperatures.

3 Conclusions

Methods for evaluating the heat demand for heating for different types of buildings have been selectively detailed: Method of thermal characteristic of the building; Calculation method on the exterior contour of the building; Method according to Standard SR1907-1/1997; The method of global thermal insulation coefficients "G"; Number of days number method.

The choice of one of the methods for assessing the heat demand is made according to the purpose of performing this calculation. Thus, if it is desired to establish the thermal power required to be installed in a thermal power plant (individual, stair, block, etc.) the first two calculation methods can be used (calculation method on the exterior contour of the building or thermal characteristic method). If it is necessary to size the heating elements to be installed in the rooms that make up the building, it is recommended to use the calculation method based on SR1907-1/1997.

The objectives of the paper are to study and develop tools for analyzing the options for energy optimization of structural components of buildings and to formulate an efficient and easily accessible framework for evaluating the decision-making process to increase the energy efficiency of buildings.

Continuation of the detailed analysis of the ways of implementing the European legislation at the level of the Member States, in order to make a constructive comparison between the European practices and those in Romania.

Continuing the development of a package of computer programs, designed to evaluate and optimize the energy performance of buildings based on the current methodology MC001/2006, made in the Visual Basic programming environment, as an efficient alternative and with low development costs, open-source, applications commercial assistants on the market.

The study of innovative measures, the presentation of concrete solutions for the realization and implementation of energy efficient building structures, aiming to increase their energy independence.

Development/implementation of an algorithm and program that allows the determination of heat fluxes/losses determined based on temperature fields resulting from the thermography of a surface.

Making comparisons on the legislative framework and regulatory issues in the field of energy efficiency in the building sector.

These objectives are particularly important, given the need to continue energy conservation measures in the construction sector, as well as the need to implement renewable energy sources that depend on the development and implementation of efficient energy conservation policies, based on analysis and models. accurate and accessible.

The energy performance of buildings should be calculated on the basis of a methodology that can be differentiated from one region to another, and which should include, in addition to thermal insulation, other factors that play an increasingly important role, such as be the heating and air conditioning installations, the use of renewable energy sources and the design of the building.

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