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EFFECTS ANALYSIS OF ADDITIONAL THERMAL PROTECTION FOR RETROFITTED BUILDINGS

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ABSTRACT

One of main research direction on the construction field is the reduction of the energy consumption, which supposes materials, technology and conception of buildings with lower specific energy need on one hand and equipment with high performances on the other hand. Proper thermal rehabilitation of a building will lead to a significant reduction of heating energy demand offering a higher degree of comfort, and better condition for hygiene. At the same time the environment is less polluted. The energy saving depends on the initial building characteristics and the thermal rehabilitation level on one hand, and on the proper adjustment and control of the heating system on the other hand. This paper analyzed the main effects of building thermal rehabilitation, with implications upon heating energy consumption and upon comfort of the occupants. Thus, it is developed a computational model of optimum additional insulation thickness, taking into account the investment cost to improve thermal resistance of building envelope and operational costs as heating energy consumption.

Keywords: buildings, additional insulation, thermal bridges, air exchange rate, operative temperature, balance point temperature, thermal energy consumption, optimum insulation thickness, energy saving.

1. INTRODUCTION

Buildings are an important part of European culture and heritage, and they play an important role in the energy policy of Europe. Economical strategy of a sustainable development imposes certainly to promote efficiency and a rational energy use in buildings as the major energy consumer in Romania and the other member states of the European Union (EU). Studies have shown that saving energy is the most cost effective method to reduce green house gas emissions (GHG). It has also pointed out that buildings represent the biggest and most cost effective potential for energy savings. The reduction of 26% energy use is set as a goal for buildings by the year 2020 which corresponds to 11% of the reduction of total energy use in EU countries [1].

The buildings sector is the largest user of energy and CO_2 emitter in the EU, and is responsible for more than 40% of the EU's total final energy use and CO_2 emissions. At present heat use is responsible for almost 80% of the energy demand in houses and utility buildings for space heating and hot water generation, whereas the energy demand for cooling is growing year after year. In this context, the thermal energy performance of the building envelope is significant [2, 3].

As a consequence of the EPB Directive 2002/91/CE [4], many national legislations were adopted by the Member States introducing requirements imposed by law for energy saving for new and existing buildings [5, 6, 7]. In many cases those requirements assumed the form of stronger insulation performance for all envelope building surfaces and in particular of maxim values for the thermal transmittance of the envelope components [8].

Retrofitting is a means of rectifying existing building deficiencies by improving standard and thermal insulation of buildings and/or the replacement of old space conditioning systems by energy-efficient and environmentally sound heating and cooling systems. In terms of heat engineering, building rehabilitation involves increasing thermal resistance of building envelope and the condensation phenomenon elimination where these phenomena manifest, and ensure the thermal comfort requirements, for both winter and summer regime [9].

In this paper we analyzed the main effects of building thermal rehabilitation, which have implications on heating energy consumption and on comfort for building occupants, and is developed a computational model for optimum insulation thickness.

2. EFFECTS OF ADDITIONAL INSULATION

Additional insulation of a building directly or indirectly influences its energy balance and has many repercussions on thermal properties and thermal comfort of the building. The manner and extent to which these influences occur depends largely on thermal insulation position in the structure of exterior building element and on the joints execution. Direct and indirect effects of additional insulation are shown in Figure-1.

Exterior element thermal resistance R of buildings manufactured with prefabricated panels is much smaller than that resulting from calculations because of the insulation thermal conductivity influenced by mechanical and thermal factors or moisture during the execution process, and punctually thermal bridges.

Through an additional thermal insulation to the exterior walls thermal resistance increases, until the additional insulation reaches a certain thickness limit, over which this increase is insignificant. Corresponding to these increases in thermal resistance, heat losses through the opaque surface are reduced several times, but it occurs simultaneously with a reduction of heat losses by heat transfer in the two- and three-dimensional thermal bridges.

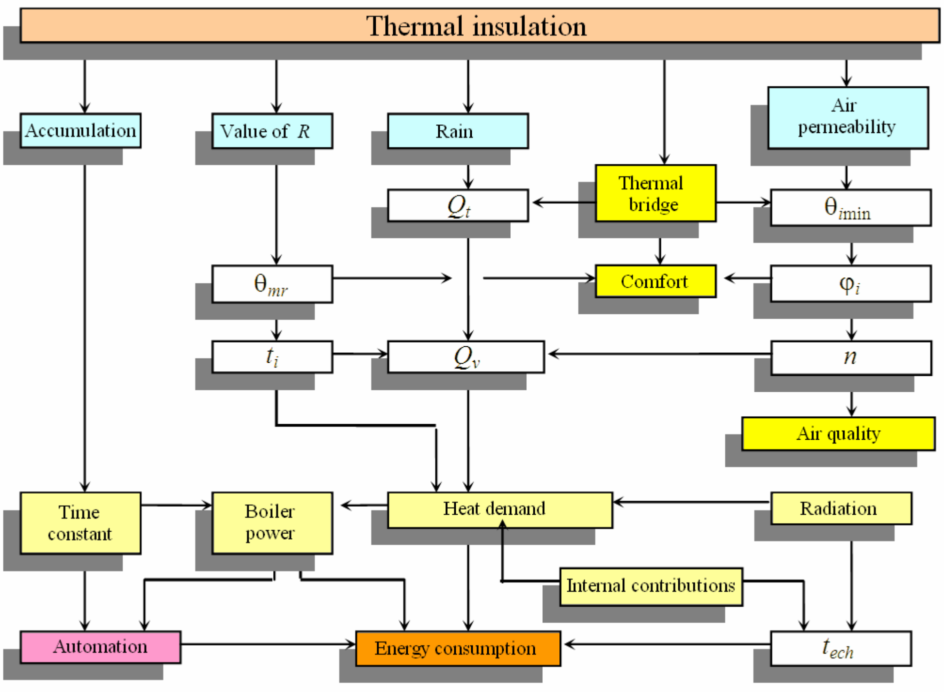

Figure-1.Effects of additional insulation.

Through an additional thermal insulation to the exterior walls thermal resistance increases, until the additional insulation reaches a certain thickness limit, over which this increase is insignificant. Corresponding to these increases in thermal resistance, heat losses through the opaque surface are reduced several times, but it occurs simultaneously with a reduction of heat losses by heat transfer in the two - and three - dimensional thermal bridges. Based on the resulting temperature field of thermal bridges at joints can be determined one factor, which is used to calculate the additional heat losses occurring in the thermal bridges. This factor is called linear thermal resistance (unidirectional) R_l, corresponding to 1 m of joint.The effect of exterior thermal insulation is varied for different types of joints: very favorable to T joints (exterior wall - interior wall, exterior wall - intermediate floor), less good in the corners, it has little influence on balconies and depends on to realization of lateral surfaces to the windows perimeter.

For a given exterior building element it can be defined the equivalent thermal resistance R_e, numerically equal to the heat flow that crosses a unit area per unit time at a temperature difference of 1 K, taking into account the additional heat losses caused by thermal bridges:

$$\frac{1}{R_e} = \frac{1}{R} + \frac{1}{A} \sum_{j=1}^{N} \frac{l_j}{R_{l\,j}} \qquad (1)$$

where:

R is the thermal resistance for building element, in m^2 K/W

A – the element area, in m^2

l_j – j type joints length, in m

R_{lj} – linear thermal resistance for j joint type, in m·K/W.

For buildings thermal rehabilitation is interesting to follow the ratio variation for the equivalent resistances of exterior elements before and after additional thermal insulation.

2.1 Interrelation between thermal bridges and air exchange rate

Locking elements are non homogeneous elements, with thermal bridge. Due to two - and three-dimensional heat transfer in the joints occures more intense heat transfer, having as effect the appearance at interior surface of a much lower temperature than the temperature of the interior surface in element open field. These low temperatures can determine the appearance of capillary condensation on those surfaces.

It considers three types of thermal bridges [10] for typical apartment blocks realized with prefabricated panels.

Thus, in Figures 2-4 are presented: a joint between the exterior wall and the floor, which separates a room from a garage; a joint between the exterior wall and the floor, which separates two rooms; a joint between the exterior wall and the flat roof. The indoor air temperature in all rooms is of 20°C and in garage of 15°C.

In each case, existing exterior wall thermal resistance is 1.25 m^2·K/W, and after exterior rehabilitation cladding with expanded polystyrene (12 cm) becomes 2.50 m^2·K/W. Also, the corresponding values of thermal resistance for the roof are 2 m^2·K/W and 5 m^2·K/W. Calculations are based on a steady state heat transfer, corresponding for the heating season, outdoor air temperature ranging from –15 °C to +12 °C.

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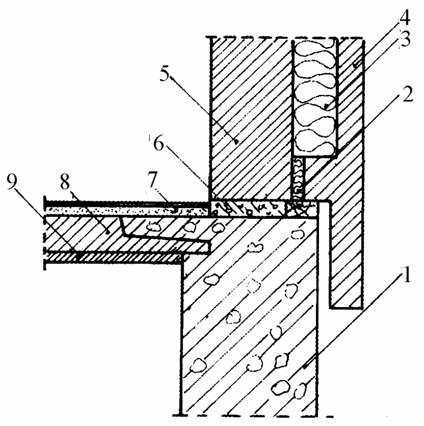

Figure-2. Joint external wall-first floor (*a*)
1-concrete foundation (30 cm); **2**-mineral wool (2 cm); **3**-mineral wool (8 cm); **4**-rein-forced concrete (7 cm); **5**-reinforced concrete (15 cm); **6**-concrete (15 cm); **7**-concrete (2.5 cm); **8**-reinforced concrete (14 cm); **9**-rendering (3 cm).

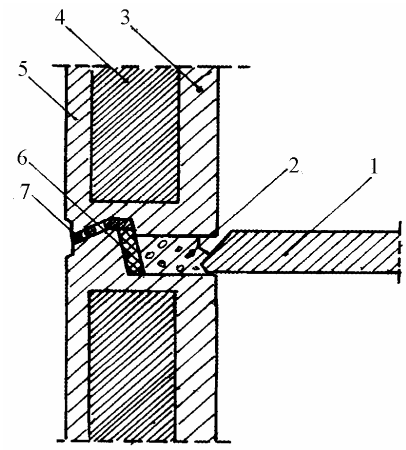

Figure-3. Joint external wall - intermediate floor (*b*)
1-steel concrete (12 cm); **2**-concrete (12 cm); **3**-steel concrete (6 cm); **4**-slag concrete 15 cm); **5**-steel con-crete (4 cm); **6**-expan-ded polystyrene (2 cm); **7**-bitumastic sealing (8 cm).

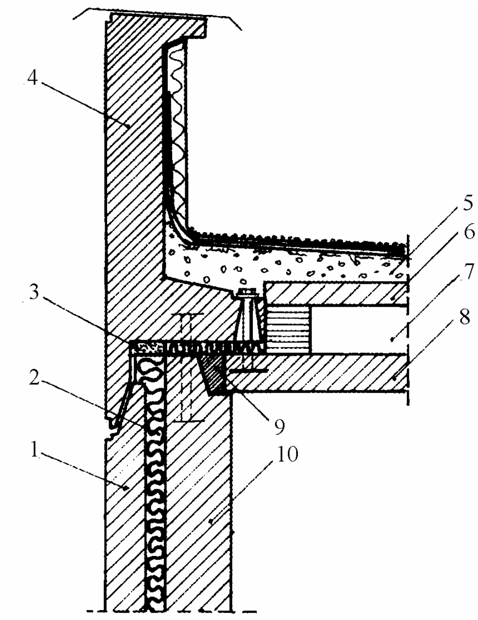

Figure-4. Joint external wall-flat roof (*c*)
1-reinforced concrete (9 cm); **2**-mineral wool (2 cm); **3**-bitumastic sealing (3 cm); **4**-steel concrete (12 cm); **5**- slag concrete (14 cm); **6**-concrete plaque (5 cm); **7**-air (10 cm); **8**- reinforced concrete (14 cm); **9**-concrete (5 cm); **10**-reinforced concrete (15 cm).

Figure-5 represents the variation curves, in relation to outdoor air temperature t_e, of minimum temperature t_m on the interior surface of condensed building element for the three types of thermal bridges, before and after exterior cladding with expanded polystyrene (12 cm for walls and 20 cm for roof).

Also, Figure-6 shows the variation in relation to t_e of indoor air relative humidity to avoid the condensation on the building element interior surface in the analyzed situations.

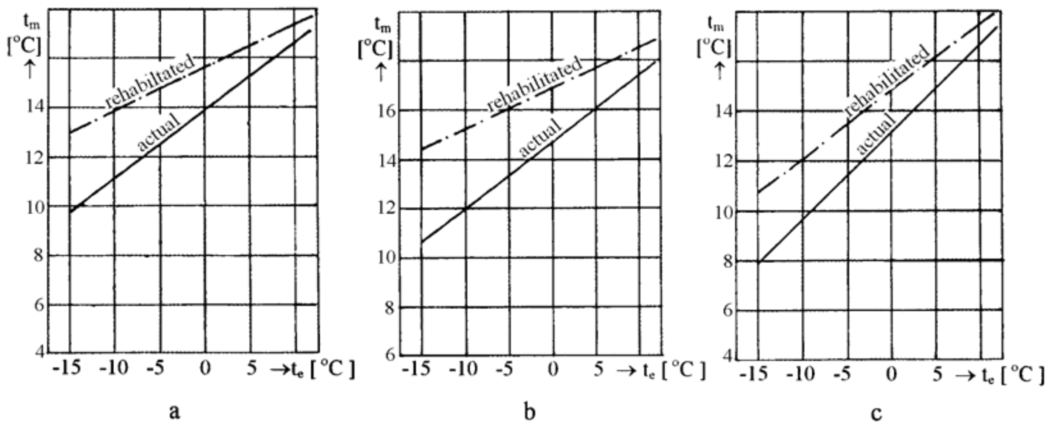

Figure-5. Variation of minimum interior surface temperature.

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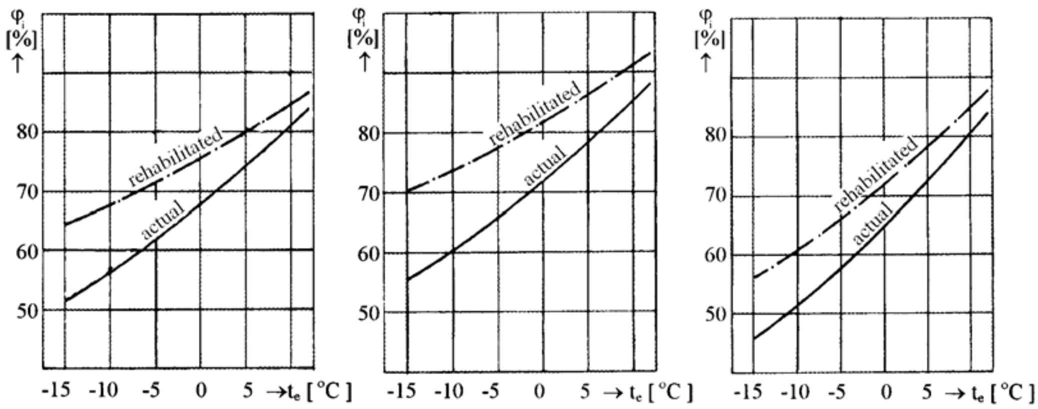

Figure-6. Allowable maxima of relative humidity of indoor air.

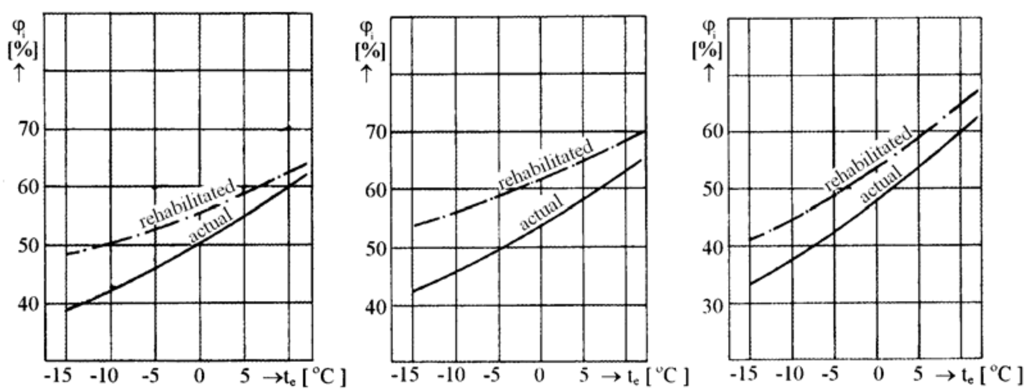

Figure-7. Relative humidity of indoor air for avoiding capillary condensation.

Based on the values of the charts presented in Figures 5 and 6 which results the variation curves for relative humidity φ_i of indoor air for avoiding capillary condensation in the two examined cases (Figure-7). Rehabilitation of thermal protection leads to reduction of thermal bridges negative influence, with beneficial effect on temperature distribution on the interior surfaces of exterior building elements. With this decreases significantly the possibility of condensation, respectively the structural damages. Indirectly, it affects the energy consumption because if the temperatures are higher in joints where the relative humidity of indoor air can be larger, it may be reduced the air exchange rate and with this, the heat losses through spaces ventilation.

It is considered that the exterior wall, comprising a thermal bridge is part of one room with geometrical dimensions in Figure-8, all located on the first level (thermal bridge type *a*) at an intermediate level (thermal bridge type *b*) or the last level (thermal bridge type *c*) and avoiding capillary condensation in such spaces is achieved by increasing the fresh air exchange rate. The double glazed window surface represents 28% from the total surface of exterior wall and its thermal resistance is of 0.4 $m^2 \cdot K/W$. In the room two persons are taken into account, so the required fresh air exchange rate is $n = 0.91\ h^{-1}$.

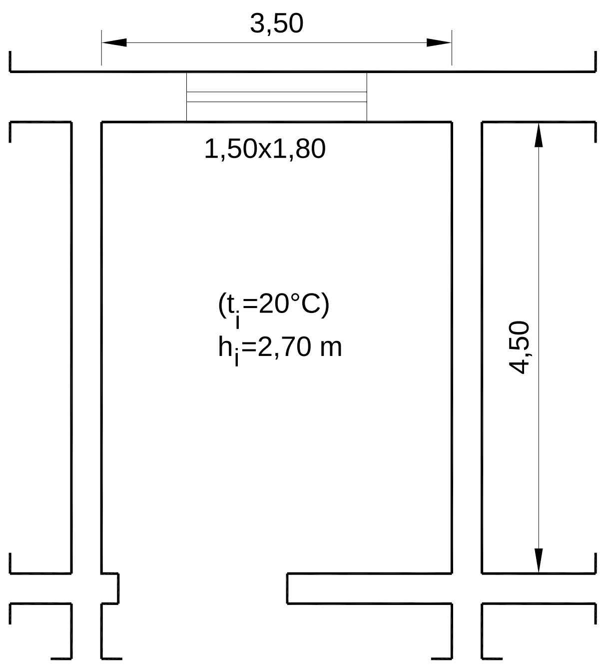

Figure-8. Geometrical characteristics of room.

In Figure-9, those air exchange rate values are shown in function of outdoor air temperature which is required to avoid the capillary condensation, for the three types of rooms. It is noted that at a given outdoor air temperature (critical temperature), the air exchange rate increases sharply, exceeding the minimum required value.
That means is introducing a cold air flow rate into the room more than planned. In this case, or is not provided an appropriate thermal comfort for occupants, or ad-ditional air flow rate must be heated to indoor air temperature, when the heating energy is no longer considered to coincide with the designed one.

Table-1 shows the values of additional fresh air heating energy Q_c to avoid capillary condensation during the heating season and the values of outdoor air critical temperature $t_{e,cr}$, for the three types of analyzed rooms.

One of the three types of thermal bridges least demanding in terms of capillary condensation is the (*b*) type, followed by (*a*) and (*c*) types. For the latter one results substantial amounts of additional heat to be introduced into the room to avoid capillary condensation. By the thermal rehabilitation is not avoided the additional consumption of energy, but due the increase of the interior surface temperature of exterior building elements results a reduction of additional air flow rate, respectively is obtaining an increase for critical outdoor air temperature, so a reduction of the time period where there exist additional energy consumption.

2.2 Variation of operative temperature

The subjective sensation of thermal comfort is decisively determined by the following parameters [11]: indoor air temperature (t_i); mean radiant temperature (t_{mr}) of bordering surfaces; relative humidity of air (φ_i); partial water vapours pressure (p_a); air velocity (v_i); thermal resistance of clothing (R_{cl} or R_h), and their influence on the vaporization.

In order to evaluate the sensation of thermal comfort we use the thermal sensation scale with seven levels [12]: +3 (hot); +2 (warm); +1 (slightly warm); 0 (neutral); −1 (slightly cool); –2 (cool); –3 (cold).

Numerical prediction of thermal comfort in a room is performed by using the PMV – PPD model [13].

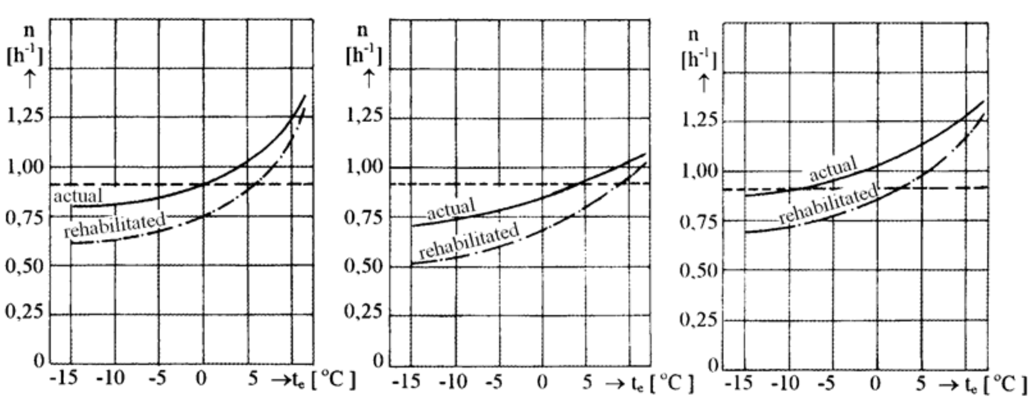

Figure-9. Variation of air exchange rate.

Table-1. Additional fresh air heating energy and outdoor air critical temperature.

Data		Type of room					
		(*a*)		(*b*)		(*c*)	
		Actual	**Reabilitated**	**Actual**	**Reabilitated**	**Actual**	**Reabilitated**
Q_c	[kWh]	177	31	31	4.4	192	61
	[%]	7.50	1.40	1.60	0.24	7.40	3.00
$t_{e,cr}$ [°C]		0.5	6	4	9	-8	3

The operative (comfort) temperature t_c may be defined as the average of the mean radiative temperature θ_{mr} and indoor air temperature t_i weighted by their respective heat transfer coefficients:

$$t_c = \frac{\alpha_r \theta_{mr} + \alpha_c t_i}{\alpha_r + \alpha_c} \qquad (2)$$

where:

α_r and α_c are the radiative and the convective heat transfer coefficient between body and environment, in W/(m^2·K).

Figure-10 represented the values of operative comfort temperature t_c (corresponding to index PMV = 0), correlated to thermal resistance of clothing (R_{cl} and R_h), metabolic rate i_M and metabolic heat production M.

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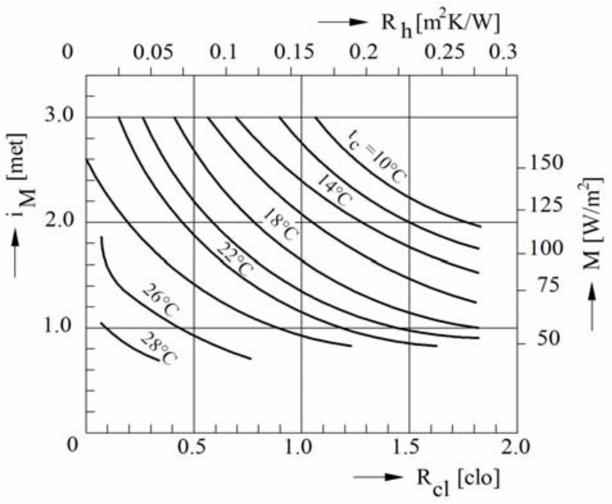

Figure-10. Operative temperature function of clothing and activity

The linearized radiative heat transfer coefficient α_r can be calculated by [12]:

$$\alpha_r = 4\,\varepsilon\,\sigma\frac{A_r}{A_D}\left(273.2+\frac{\bar{t}_{cl}+t_c}{2}\right)^3 \qquad (3)$$

where:

ε = the average emissivity of clothing or body surface
σ = Stefan-Boltzmann constant, $5.67\cdot10^{-8}$ W/ ($m^2\cdot K^4$)
A_r = effective radiation area of body
A_D = nude body surface area [14]
$\bar{t}_{cl}$ = average clothing temperature

The ratio A_r/A_D is 0.70 for a sitting person and 0.73 for a standing person [15].

The convective heat transfer coefficient depends on indoor air velocity:

$$\alpha_c = 8.3 v_i^{0.6} \qquad (4)$$

The mean radiative temperature is given by [16]:

$$\theta_{mr} = \sqrt[4]{\sum_{i=1}^{n}\varphi_i t_{Si}} - 273.2 \qquad (5)$$

where φ_i is the angle factor between body and surrounding surface S_i with temperature t_{Si}.

Considering a room in a block of flats, situated on intermediate level, with geometrical characteristics presented in Figure-8, one can calculate the variation of operative temperature depending on the outdoor air temperature. The calculus is performed taking into account a stationary heat transfer regime.

Two thermal bridges are analyzed, which appears especially in buildings from Romania built in 70's. The first type (Figure-3) represent a joint between the exterior wall and floor which separates two rooms with t_i = 20°C. The second type of thermal bridge (Figure-11) represents a joint between the interior walls, which separates also two rooms with similar temperatures (t_i = 20°C).

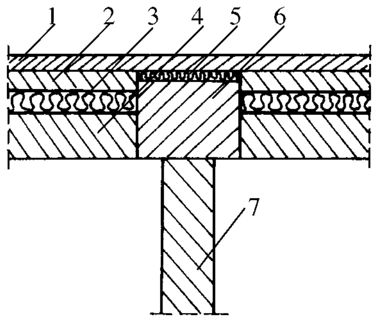

Figure-11. Thermal bridge
1-rendering (3cm); **2**-steel concrete (5cm); **3**-mineral wool (5cm); **4**-steel concrete (15cm); **5**-mineral wool (2cm); **6**-steel concrete (23cm); 7-steel concrete.

Thermal resistance of initially structure was 0.935 $m^2\cdot K/W$. Considering an additional thermal insulation of 12 cm expanded polystyrene, the thermal resistance increases to 2.5 $m^2\cdot K/W$. The double glazed window surface represents 28% from the total surface of exterior wall and its thermal resistance increases from 0.33 $m^2\cdot K/W$ to 0.80 $m^2\cdot K/W$.

The diagrams from Figure-12 presents the minimum interior surface temperature t_{Smin} at considered joints, depending on outdoor air temperature t_e.The effect of thermal bridge is perceptible on 0.6 m band from the edge.

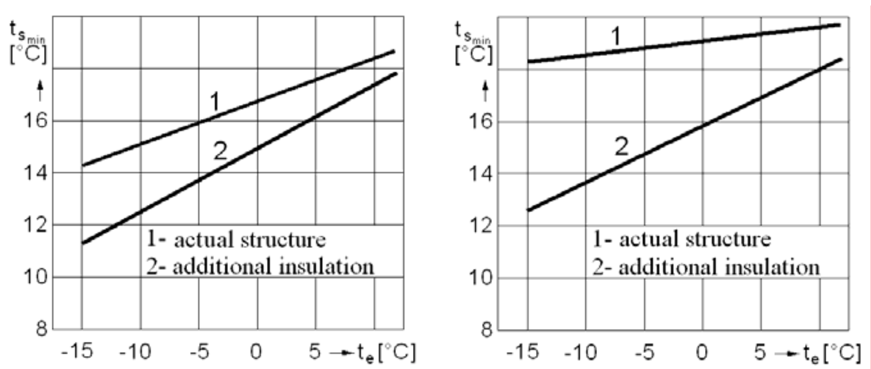

Figure-12. Minima of interior surface temperature for the two joints.

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There is a single person in the room, which works on the computer (i_M =1.2 met). Considering the clothing thermal resistance R_{cl} = 0.90 clo, results a minimum operative temperature t_c = 22°C (Figure-10). If the interior wall temperature is not influenced by thermal bridges and is equal with indoor air temperature (t_i = 20°C) results the variation curves of mean radiant temperature presented in Figure-13. It can observe that the value decrease with the outdoor temperature.

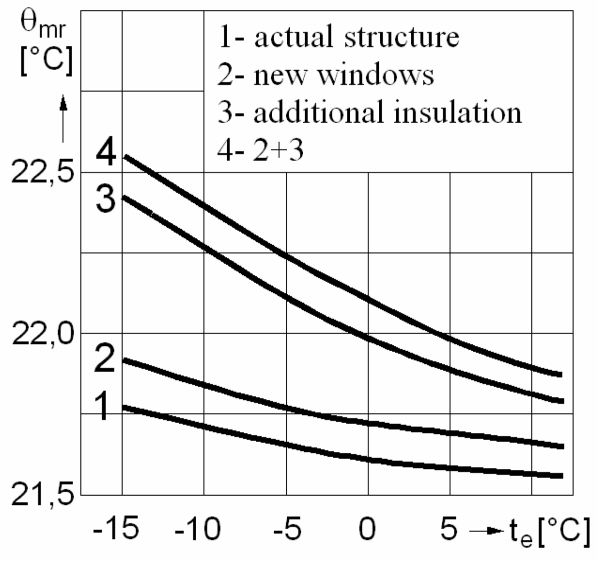

Figure-13. Mean radiant temperature.

Assuming the values α_r = 4.7 W/ (m^2·K) and α_c = 3.1 W/ (m^2·K) results the operative temperature variation (Figure-14). These values are lower than the optimal required value of 22°C. To obtain the optimal value the indoor air should be heated up supplementary. The required values of indoor air temperature are shown in Figure-15.

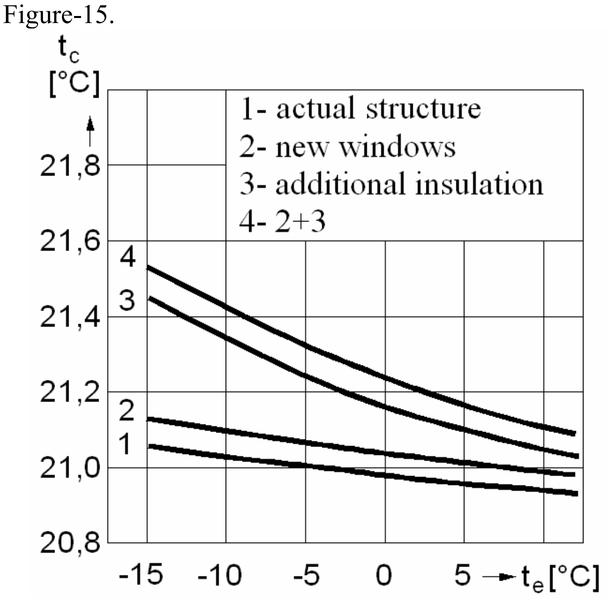

Figure-14. Variation of operative temperature.

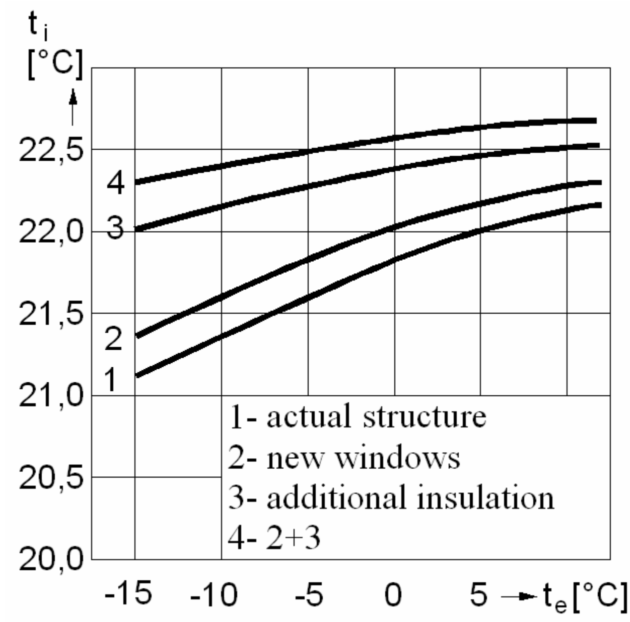

Figure-15. Required temperatures of indoor air.

It can be observed that increasing the thermal performance of exterior building elements (walls, windows) increases the operative temperature.

Assuming an air exchange rate n = 0.8 h^{-1} results a fresh airflow rate of 32.02 m^3/h. This airflow rate should be heated up to the new value of indoor air temperature to assure the required comfort parameters.

Figure-16 presents the variation of additional daily energy consumption E_s function of t_e. Based on this diagram it can determine the yearly additional energy consumption (using the specific degree -day curve). The variation of energy saving ΔE is presented in Figure-17.

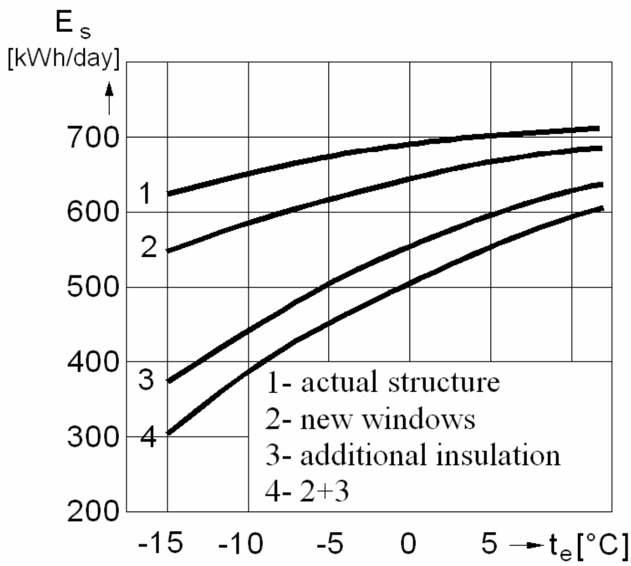

Figure-16. Daily variation of energy consumption.

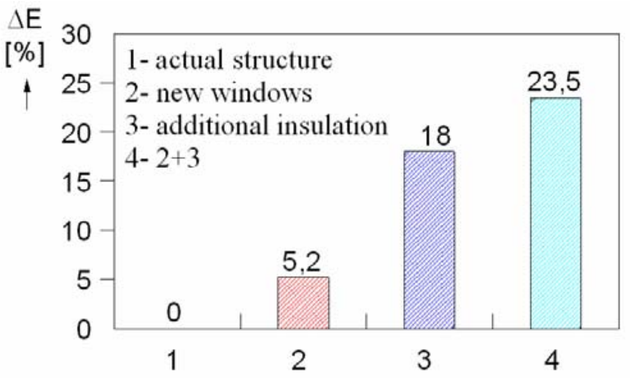

Figure-17. Energy savings.

In present, most buildings are not assured the comfort parameters, or there is additional energy consumption. Thus, considering a building with three levels, with 10 rooms/level, the yearly additional energy consumption to assure the required operative temperature is about 5MWh. Depending on the insulation level it can obtain a reduction with 15…23% of this consumption, at the same time, the heating energy with 40…60%.

2.3 Variation of balance point temperature

The heat to be delivered by heating system depends on the climatic conditions and the internal set point temperature. The balance point temperature t_{ech} is the outdoor temperature when heat gains are equal to heat losses:

$$t_{ech} = t_i - \frac{Q_{ap}}{K} \tag{6}$$

where:

Q_{ap} = heat gains of building
K = heat loss coefficient of building

Using the balance point temperature and the specific degree – day curve the length of a heating season could be determined (Figure-18).

Using the geometrical interpolation method, the degree –day curve can be approximated with a function [11]:

$$t_e = -15 + 3.55x^{0.3835} \tag{7}$$

where

x is the number of days with the same average outdoor temperature t_e.

In this equation if the outdoor temperature is equal to the balance point temperature the day number in a heating season could be obtained:

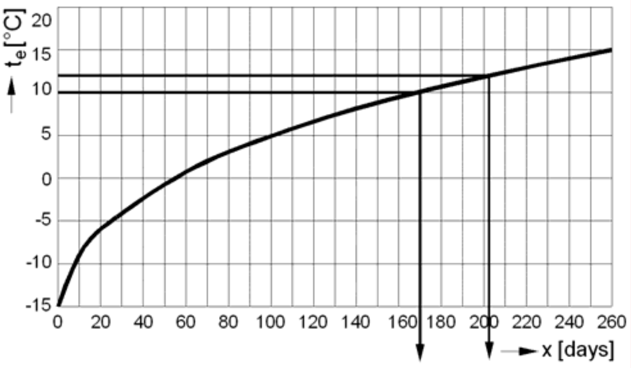

Figure-18. Determination of day number in heating season

$$N = \left(\frac{t_{ech} - t_{e0}}{3.55}\right)^{2.6} \tag{8}$$

where t_{e0} is the outdoor design temperature.

After building rehabilitation the heat loss coefficient K' will decrease considerable whereas the heat gains remain the same. Thus, the new value of balance point temperature could be calculated with following relation:

$$t'_{ech} = t_i - (t_i - t_{ech})\frac{K}{K'} \tag{9}$$

Having the value of the balance point temperature after thermal rehabilitation the number of days in the new shorter heating season is:

$$N' = N\left[\frac{t_i - t_{e0} - (t_i - t_{ech})\frac{K}{K'}}{t_{ech} - t_{e0}}\right] \tag{10}$$

The variation of balance point temperature and number of days in the new heating season in function of the rehabilitation level when the original value of balance point temperature is of 12°C is presented in Figure-19.

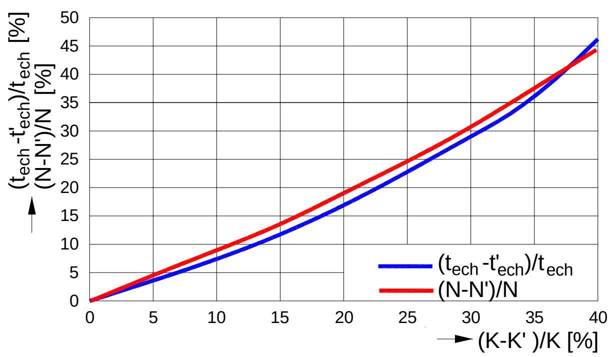

Figure-19. Day number in a heating season and balance point temperature.

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The heating energy demand for a building could be written as:

$$E = \frac{K}{\eta}\int_0^N (t_i - t_e)\,dx \qquad (11)$$

where η is the efficiency of heating system.

Taking into account of equation (9) to (11), the ratio of energy consumption before and after rehabilitation could be determined as follows:

$$\frac{E'}{E} = \frac{K'}{K}\cdot\frac{N'}{N}\cdot\frac{(t_i - t_{e0}) - 2.566N'^{0.3835}}{(t_i - t_{e0}) - 2.566N^{0.3835}} \qquad (12)$$

Figure-20 illustrates the variation of heating load ratio *Q*'/*Q* and variation of energy consumption *E*'/*E* depending on thermal rehabilitation level, for t_{ech}=12°C.

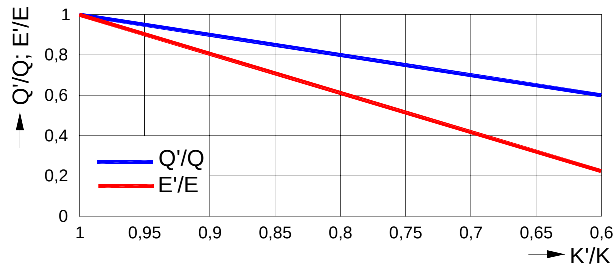

Figure-20. Variation of heat load and energy demand

The length of the heating season depends also the thermal properties of building envelope. Assuming that before thermal rehabilitation, for a building, the balance point temperature was 12°C, in Figure-21 the variation of heat demand is presented during the heating season. After thermal rehabilitation the heat demand ratio is the same but as it could be seen the heating season will be shorter taking into account the heat gains (Figure-22).

When the heating system is dimensioned the heat gains are neglected so that the system will operate at partial capacity during the whole heating season. Furthermore, as it could be seen in Figure-23, 60…80% of heating season the heat gains cover more than 50% of the heat demand.

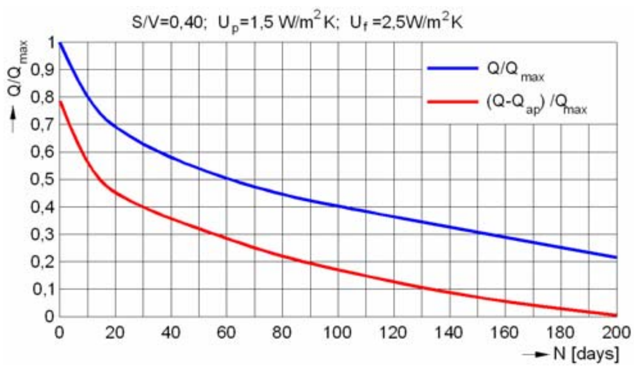

Figure-21. Heat demand variation before rehabilitation

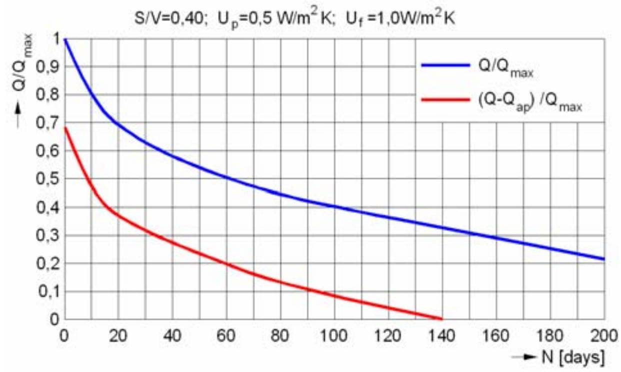

Figure-22. Heat demand variation after rehabilitation

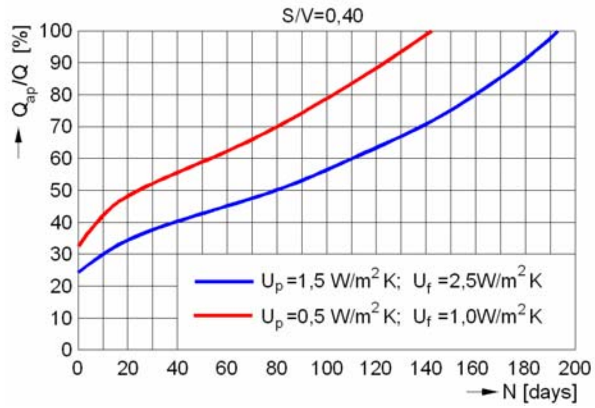

Figure-23. Heat gains ratio from total heat demand

When a building is retrofitted from energy point of view about 30% of the total energy saving is obtained due to the shorter heating season. The new balance point temperature depends on the rehabilitation level and on the original thermo-physical state of building envelope. The influence of heat gains will increase significantly after rehabilitation.

3. DETERMINATION OF OPTIMAL ADDITIONAL INSULATION THICKNESS

3.1 Investment cost

One of the most typical rehabilitation methods for exterior walls of block flats, built with industrialized technology is the thermal skin system (Thermohaut). The insulation material is expanded polystyrene. Taking into account the insulation and other necessary material price, the scaffolding and execution costs, and using the geo-metrical interpolation method [17] the specific investment cost (for 1 m^2 wall surface) can be approximated as [18]:

$$I = 15800\,\delta\frac{\left(2088.7\,p\,\delta^{0.487} + 190.3\,\delta^{0.5327} + 248ah\right)}{A_p} +$$

$$+\left(4652 + 0.48A_p\right) \qquad (13)$$

where:

δ = insulation thickness

p = building peri-meter
a = number of building corners (positive and negative)
h = height of building
A_p = area of exterior walls

3.2 Operation costs

The heat to be delivered by heating system depends on climatic conditions and internal set point temperature. The main goal is the minimization of heat load and energy consumption. From energy point of view the achievement of internal set point temperature without auxiliary heating is favorable. The heat loss coefficient of building K can be determined as [18]:

$$K = (1 + C_0)U_p \sum A_p \tag{14}$$

where:

$$C_0 = \frac{\sum A_o U_o + \sum A_f U_f + \sum l U_l + \rho_e c_e n V}{\sum A_p U_p} \tag{15}$$

where:

A_p = area of exterior walls, in m^2
U_p = thermal transmittance of exterior walls, in W/ (m^2·K)
A_o = area of other exterior opaque surfaces except walls, in m^2
U_o = thermal transmittance of exterior opaque surfaces except walls, in W/ (m^2·K)
A_f = area of glazed surfaces, in m^2
U_f = thermal transmittance of glazed surfaces, in W/ (m^2·K)

Improving the thermal resistance of exterior walls the new value of building heat loss coefficient will be:

$$K' = \left(\frac{\lambda}{\delta U_p + \lambda} + C_0\right) U_p \sum A_p \tag{16}$$

where:

λ = heat conductivity of insulation, in W/ (m·K)
δ = thickness of insulation layer, in m

Thus, the new thermal balance point temperature can be written as:

$$t'_{ech} = t_i - \frac{(1 + C_0)(t_i - t_{ech})}{\frac{\lambda}{\delta U_p + \lambda} + C_0} \tag{17}$$

where t_{ech} is the thermal balance point temperature corresponding to the initial conditions.

Taking into account the equation (7), number of days with auxiliary heating ($t_e < t_{ech}$) corresponding to the heating period in the new conditions will be:

$$N = 0.037\left[t_i - t_e - \frac{(1 + C_0)(t_i - t_{ech})}{\frac{\lambda}{\delta U_p + \lambda} + C_0}\right]^{2.6} \tag{18}$$

The energy consumption in a heating season is given by equation (11), which taking into account the previous equations becomes as:

$$E = \frac{0.024 U_p \Sigma A_p}{\eta}\left(\frac{\lambda}{\delta U_p + \lambda} + C_0\right)\left[t_i - t_e - \frac{(1 + C_0)(t_i - t_{ech})}{\frac{\lambda}{\delta U_p + \lambda} + C_0}\right]^{2.6} \times$$
$$\times \left[0.0113(t_i - t_e) + 0.0257\frac{(1 + C_0)(t_i - t_{ech})}{\frac{\lambda}{\delta U_p + \lambda} + C_0}\right] \tag{19}$$

The cost of heating energy C_t, for a heating season is given by:

$$C_t = E\,e \tag{20}$$

where e is the price of 1 kWh thermal energy.
The total cost is given by:

$$F = A_p I + T_r C_t \tag{21}$$

where T_r is the operating duration.

The optimal insulation layer thickness is obtained when the function value F is minim.

3.3 Numerical application

The example considered a block of flats, built with medium size monolythic panels in ‘70s. The dimensions of building are 54×11×14 m. The exterior walls are 30 cm slag concrete with U_p = 1.5 W/ (m^2·K), the flat roof is reinforced concrete with air cavities, where the slope is provided with slag in variable thickness, U_a = 1.1 W/ (m^2·K). The U-value of windows is U_f = 2.5 W/ (m^2·K). The glazed surfaces and the corresponding average solar gains for heating season are presented in Table-2.

Table-2. Glazed surfaces and solar gains.

Orientation	Glazed surfaces [m^2]	Solar gains [W]
NE	141.66	4445.57
SE	6.75	125.02
SW	212.13	6657.06
NW	6.75	125.02
Building	367.29	11352.67

Based on above presented dates the specific solar gains for studied building are Q_s = 5.2 W/m^2, and the internal gains are Q_i = 17.8 W/m^2. The heat load and the heating energy before rehabilitation are presented in Table-3.

Specific energy consumption of existing building is 192.35 kWh/ (m^2·year). The Figures 24 and 25 illustrates the variation of balance point temperature and

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heating season length in function of insulation thickness δ and original U_p-value, for a thermal conductivity λ = 0.045 W/ (m·K).

In Figure-26 it is presented that the variation of total cost *F* depending on insulation thickness δ and heating system efficiency η for T_r = 10 years, U_p = 1.5 W/ (m^2·K), λ = 0.045 W/ (m·K).

The heat load and energy consumption after rehabilitation with an optimum insulation thickness of 12 cm are presented in Table-4. The heat load of building decreased with 29%, and specific energy consumption of retrofitted building is 11.909 kWh/ (m^2·year). The total energy saving due to the reduction of heat load and heating period is 38%.

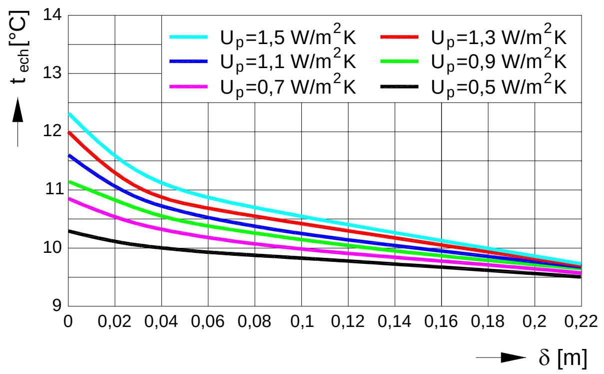

Figure-24. Variation of balance point temperature with insulation thickness.

Table-3. Heat load and energy consumption for existing building.

Floor	**Heated area** [m^2]	**Heated volume** [m^3]	**Heat load** [W]	**Specific heat load** [W/m^3]	**Energy consumption** [kWh/year]
1st floor	25632	774.08	32459.56	41.93	74448.3
Gen. floor	476.64	1285.58	35405.46	27.54	76604.0
4th floor	476.64	1285.58	56669.77	44.08	120511.9
Building	2208.32	6097.15	195345.7	32.03	424772.2

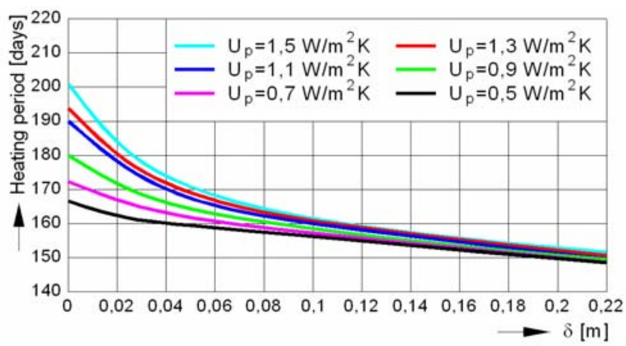

Figure-25. Variation of heating season length with insulation thickness

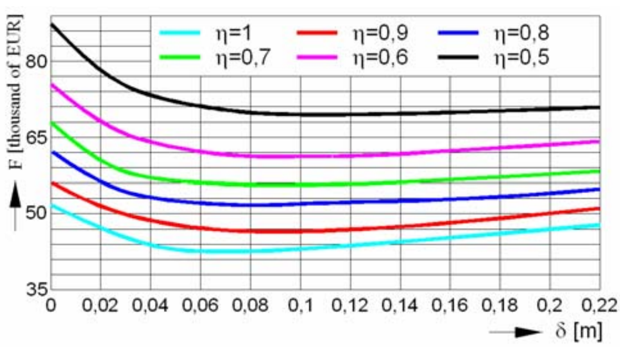

Figure-26. Variation of total cost with insulation thickness

Table-4. Heat load and energy consumption for rehabilitated building.

Floor	**Heated area** [m^2]	**Heated volume** [m^3]	**Heat load** [W]	**Specific heat load** [W/m^3]	**Energy consumption** [kWh/year]
1st floor	256.32	774.08	21830.81	28.20	42334.4
Gen. floor	476.64	1285.58	27897.79	21.70	53244.6
4th floor	476.64	1285.58	33289.73	25.89	60924.0
Building	2208.32	6097.15	138813.90	22.76	262992.5

In Figure-27 the variation of optimum insulation thickness is presented in function of heating system efficiency η for different U_p-value, an operating duration of 10 years and λ = 0.045 W/ (m·K).

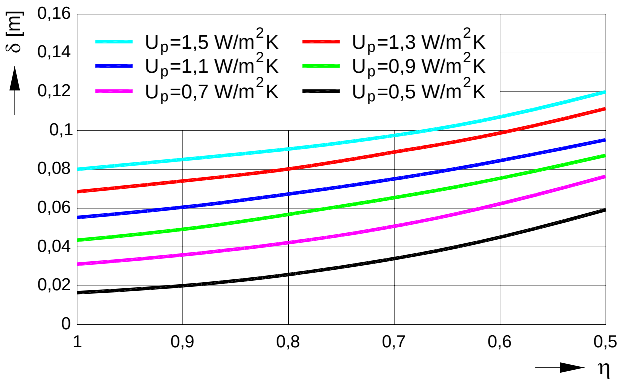

Figure-27. Variation of optimum insulation thickness with heating system efficiency.

4. CONCLUSIONS

In the present economic and energetically conditions the reduction of energy consumption in building sector is a problem of global interest. For this purpose it is imperative that the works to improve the thermal insulation of buildings should be performed as stated in the actual regulations.

Thermal rehabilitation of existing building envelope is obtained by increasing the thermal protection of structural components. This leads to a reduction of investment costs for rehabilitation/upgrading of heating systems, due to a lower building heat demand.

Thermal rehabilitation of existing buildings determines a considerable reduction of heating energy offering a higher degree of comfort, and better condition for hygiene. At the same time the environment is less polluted.

Based on a complex economic and energy analysis the optimum thickness of additional insulation can be established for each building.

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