Effects analysis of building thermal rehabilitation

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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 poluted. 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. In this paper are analyzed the main effects of building thermal rehabilitation, with implications upon heating energy consumption and upon comfort of the occupants.

Key-Words: Buildings, Thermal rehabilitation, Additional insulation, Thermal bridges, Operative temperature, Balance point temperature, Energetical analysis.

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 CO₂ emitter in the EU, and is responsible for more than 40% of the EU’s total final energy use and CO₂ 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.

Retrofitting is a means of rectifying existing building deficiencies by improving the standard and the 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.

In this paper are analyzed the main effects of building thermal rehabilitation, which have implications on heating energy consumption and on comfort for building occupants.

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.

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 occurs 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 for typical apartment blocks realized with prefabricated panels. Thus, in Figures 1 – 3 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.

![Fig. 1 Joint exterior wall–first floor (a)](image1.png)

![Fig. 2 Joint exterior wall – intermediate floor (b)](image2.png)

![Fig. 3 Joint exterior wall–flat roof (c)](image3.png)

In each case, existing exterior wall thermal resistance is 1.25 m²·K/W, and after exterior rehabilitation cladding with expanded polystyrene (12 cm) becomes 2.50 m²·K/W. Also, the corresponding values of thermal resistance for the roof are 2 m²·K/W and 5 m²·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. In Figure 4 are represented 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).

![Fig. 4 Variation of minimum interior surface temperature](image4.png)

![Fig. 5 Allowable maxima of relative humidity of indoor air](image5.png)
Also, Figure 5 shows the variation in relation to $t_r$ of indoor air relative humidity to avoid the condensation on the building element interior surface in the analyzed situations.

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.

It is considered that the exterior wall, comprising a thermal bridge is part of one room with geometrical dimensions in Figure 6, 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$^2$K/W. In the room two persons are taken into account, so the required fresh air exchange rate is $n = 0.91$ h$^{-1}$.

In Figure 7 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.

Fig. 7 Variation of air exchange rate

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

<table>
<thead>
<tr>
<th>Type of room</th>
<th>Actual</th>
<th>Reabilitated</th>
<th>Actual</th>
<th>Reabilitated</th>
<th>Actual</th>
<th>Reabilitated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_c$ [kWh]</td>
<td>177</td>
<td>31</td>
<td>31</td>
<td>4.4</td>
<td>192</td>
<td>61</td>
</tr>
<tr>
<td>[%]</td>
<td>7.50</td>
<td>1.40</td>
<td>1.60</td>
<td>0.24</td>
<td>7.40</td>
<td>3.00</td>
</tr>
<tr>
<td>$t_{c,cr}$ [°C]</td>
<td>0.5</td>
<td>6</td>
<td>4</td>
<td>9</td>
<td>-8</td>
<td>3</td>
</tr>
</tbody>
</table>

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

$$t_c = \frac{\alpha_r \theta_{mr} + \alpha_i t_i}{\alpha_r + \alpha_i} \tag{1}$$
in which: $\alpha_r$ and $\alpha_c$ are the radiative and the convective heat transfer coefficient between body and environment, in W/(m$^2$⋅K).

The linearized radiative heat transfer coefficient $\alpha_r$ can be calculated by [2]:

$$\alpha_r = 4\varepsilon \sigma \frac{A_r}{A_B} \left( 273.2 + \frac{\bar{t}_c + t_c}{2} \right)^3$$  \hspace{1cm} (2)

in which: $\varepsilon$ is the average emissivity of clothing or body surface; $\sigma$ – Stefan–Boltzmann constant, 5.67·10$^{-8}$ W/(m$^2$⋅K$^4$); $A_r$ – effective radiation area of body; $A_B$ – nude body surface area [5]; $\bar{t}_c$ – average clothing temperature.

The ratio $A_r/A_B$ is 0.70 for a sitting person and 0.73 for a standing person [6].

The convective heat transfer coefficient depends on indoor air velocity:

$$\alpha_c = 8.3i^{0.6}$$  \hspace{1cm} (3)

The mean radiative temperature is given by [3]:

$$\theta_{mr} = \frac{1}{n} \sum_{i=1}^{n} \phi_i t_{Si} - 273.2$$  \hspace{1cm} (4)

where $\phi_i$ 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 calculated 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 (Fig. 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 (Fig. 8) represents a joint between the interior walls, which separates also two rooms with similar temperatures ($t_i = 20$ °C).

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

There is a single person in the room, which works on the computer ($i_M = 1.2$ met). Considering the clothing termal resistance $R_{cl} = 0.90$ clo, results a minimum operative temperature $t_c = 22$ °C.

Assuming the values $\alpha_r = 4.7$ W/(m$^2$⋅K) and $\alpha_c = 3.1$ W/(m$^2$⋅K) results the operative temperature variation (Fig. 9). 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 10.

![Fig. 8 Thermal bridge](image)

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.

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![Fig. 9 Variation of operative temperature](image)

1- actual structure
2- new windows
3- additional insulation
4- 2+3

![Fig. 10 Required temperatures of indoor air](image)

1- actual structure
2- new windows
3- additional insulation
4- 2+3

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

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. In Figure 11 is presented the variation of additional daily energy consumption $E_i$ function of $t_c$. Based on this diagram it can be determined the yearly additional energy consumption (using the specific degree–day curve). The variation of energy saving $\Delta E$ is presented in Figure 12.
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:

\[
t_{ech} = t_i - \frac{Q_{ap}}{K}
\]

(5)

in which: \( Q_{ap} \) is the 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. Using the geometrical interpolation method the degree–days curve, for Timisoara, can be approximated with a function [9]:

\[
t_e = -15 + 3.55x^{0.3835}
\]

(6)

in which \( x \) 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:

\[
N = \left( \frac{t_{ech} - t_{e0}}{3.55} \right)^{2.6}
\]

(7)

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:

\[
t_{ech}' = t_i - (t_i - t_{ech}) \frac{K}{K'}
\]

(8)

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

\[
N' = N \frac{t_i - t_{e0} - (t_i - t_{ech}) \frac{K}{K'}}{t_{ech} - t_{e0}}
\]

(9)

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 13.

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

\[
E = \frac{K}{\eta} \int_0^N (t_i - t_e)dx
\]

(10)

where \( \eta \) is the efficiency of heating system.

Taking into account of (8) – (10), the ratio of energy consumption before and after rehabilitation could be determined as follows:

\[
\frac{E'}{E} = \frac{K'}{K} \frac{N'}{N} \frac{t_i - t_{e0} - (t_i - t_{ech}) 2.566N^{0.3835}}{t_{ech} - t_{e0} - (t_i - t_{ech}) 2.566N^{0.3835}}
\]

(11)

In Figure 14 is illustrated 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.
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 (Fig. 16).

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 17, 60…80% of heating season the heat gains cover more than 50% of the heat demand.

### 3 Conclusions

In the present economic and energetical conditions the reduction of energy consumption in building sector is a problem of global interest.

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 diminished 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.

References:


