THERMAL REHABILITATION OF BUILDINGS – A DEEPER TECHNICAL AND ECONOMIC ANALYSIS

— research paper —

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Abstract: this paper presents a deeper economic analysis of the influence of the insulation thickness from additional insulation thermosystems for external walls of buildings on the annual energy savings achieved and on the duration of simple recovery of the investment costs. It is a continuation of earlier works which are technical and economic analyses, respectively, of the phenomenon, trying to optimize the thickness of the insulation for several wall structures and for different climatic zones. In the present paper this analysis goes more in depth, taking into account the life duration of investment as a variable. Several conclusions and recommendations are highlighted.

Keywords: thermal rehabilitation of buildings, thermal insulation optimization, heat losses

INTRODUCTION

The additional thermal insulation of external buildings walls is generally well known and correctly applied by the constructors. In our opinion, the main problem is the right choice of the thickness of the insulation in the thermosystem, which varies from 5 cm (insufficient) to 30 cm (recommended for „passive houses", but too large in our opinion).

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In order to clarify this problem, we realized a technical and economic analysis concerning the influence of thermal insulation thickness on the thermal losses flow, on the annual energy savings and on the simple recovery duration of the investment costs, respectively.
In a previous paper (Reff et al., 2009), the technical analysis was presented based on a conventional external wall, considering three structure variants, the most commonly encountered in practice, namely:
a) PE1 - full brick, having a thickness of 25 cm, with inside and outside plaster of lime/cement.
b) PE2 - efficient brick, with vertical hollows, having a thickness of 25 cm, with inside and outside plaster of lime/cement.
c) PE3 - BCA blocks, having a thickness of 25 cm, with inside and outside plaster of lime/cement.

In order to make clearer the correlation with the economic analysis, below we present briefly, the main findings of the technical analysis:

1. Temperature distribution in the external wall and the minimum thickness of insulation for removing the frost off the wall itself (in insulation, see figure1).

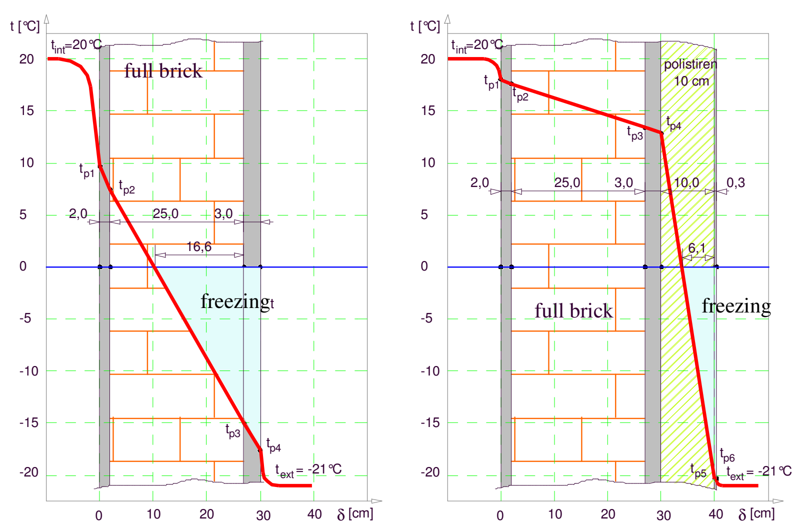

Figure 1. Temperature distribution in the structure of type a) for climatic zone IV.

It was determined that the thickness of expanded polystyrene insulation required for removing the frost outside wall increases as the thermal resistance of the wall is higher and as the outside temperature drops.

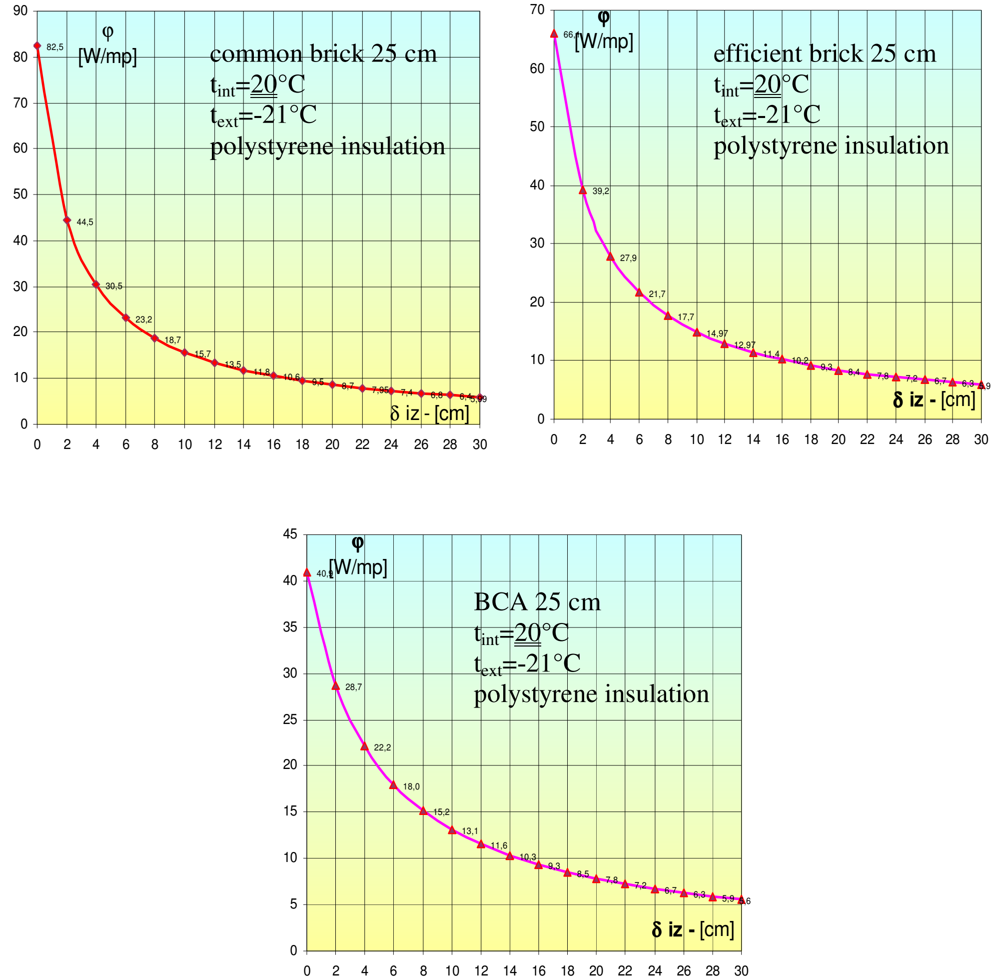

Figure 2. Heat losses flow density depending on the thickness of additional insulation in analyzed structures for climate zone IV

2. The effect of additional thermal insulation on the thermal flow density crossing the wall.

Figure2 presents the variation of heat losses flow density, depending on the additional insulation thickness in the three structures, for the worst climate zone - IV.

Conclusions resulting from technical analysis: in terms of heat losses, the effect of an additional insulation of the walls is essential if the insulation thickness at the thermosystem is between 0 and 5 cm, significant between 5 and 15 cm and insignificant when the thickness is over 20 cm.

ECONOMIC ANALYSIS

Preconditions for economic calculation.

There have been assumed and calculated, the following elements:

- The average cost for 1 MWh heat produced by a conventional standard source is considered to be 40 €;
- The specific investment costs for the additional thermal insulation of external walls with thicknesses between 2 and 30 cm are the average costs at current market prices in Sibiu, for blocks of flats with 5 levels, starting from 25 € / m^2 for a 10 cm thermosystem thickness.

To simplify the analysis with many variables, a fixed cost part of the thermosystem was considered, $c_{inv,fix}$, the same in all types of insulation thicknesses (costs for materials, labor, scaffolding, indirect costs, benefits, etc. - less polystyrene) and a variable part proportional with the thickness of the polystyrene.

The comparison term used in this analysis was „Simple recovery duration of investment costs”, N_R, calculated as follow:

$$N_R = \frac{c_{INV}}{\Delta e \cdot c_{en}} \quad \text{(years)}$$

where:

c_{inv} – specific investment cost of energy rehabilitation works, [€/m^2]

Δe – specific energy saving achieved by applying additional insulation solutions, [kWh/ m$^2 \cdot$year]

c_{en} – specific cost of thermal energy, at the consumer [€/kWh]

As shown in figure3, it can be concluded that the optimal thickness of the insulation, from the point of view of „Simple recovery duration of investment costs" is 10 cm of expanded polystyrene. The life duration of the thermosystem (25 years) and the specific investment costs were considered as invariable.

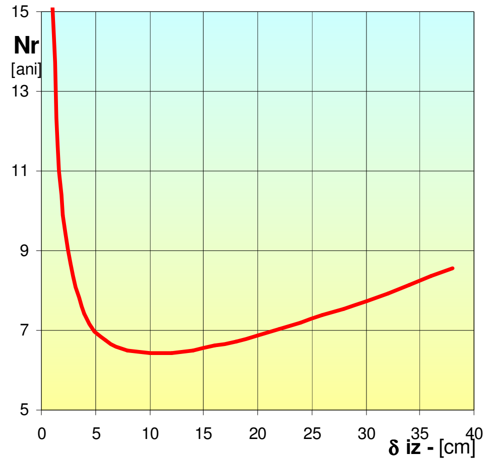

Figure 3. Recovery duration of the investment costs depending on the insulation thickness, in the climate conditions of Sibiu, life duration of thermosystem – 25 years, fix costs of the investment costs - 21.2 €/m^2.

This analysis can be extended by taking into account other variables, using the classical mathematical minimum of a function, namely the total annual unit cost (per 1 m^2 insulated wall).

Considering the following notations:

c_{en} - specific cost of thermal energy, the consumer [€/kWh]

N_s - life duration of the investment [years]

$c_{iz,1}$ - cost of a cubic meter of insulation [€/m^3]

δ_{iz} - insulation thickness [m]

c_{si} - energy consumption reduction coefficient due to internal and external sources (input of occupants, artificial lighting and solar radiation)

D_{12} - the annual duration of heating [days/year]

t_i - internal temperature [°C]

t_{em} - average outdoor temperature during heating period [°C]

α_i - inside surface heat transfer coefficient [W/m^{2}K]

α_e - outside surface heat transfer coefficient [W/m^{2}K]

δ_i - material thickness [m]

λ_i - thermal conductivity of the material [W/mK]

λ_{iz} - thermal conductivity of the insulation [W/mK],

the optimal thickness of the insulation can be determined as:

$$\delta_{iz,opt} = \lambda_{iz}\sqrt{\frac{N_s \frac{c_{en}\cdot 24}{1000} c_{si} D_{12}(t_i - t_{em})}{c_{iz,1}\lambda_{iz}}} - \lambda_{iz}\left(\frac{1}{\alpha_i} + \frac{1}{\alpha_e} + \sum_{i=1}^{n}\frac{\delta_i}{\lambda_i}\right) \text{ [m]}$$

(Reff et al., 2009)

and the optimal thermal flow as:

$$\varphi_{opt} = \frac{t_i - t_{em}}{\frac{1}{\alpha_i} + \frac{1}{\alpha_e} + \sum_{i=1}^{n}\frac{\delta_i}{\lambda_i} + \frac{\delta_{iz,opt}}{\lambda_{iz}}} \quad \text{[W/m}^2\text{]}$$

(Vonica et al., 2009)

The total annual unit costs of investment and for the heating energy, considering an optimal insulation thickness, will be minimal:

$$c_{an,\min} = \frac{c_{inv,fix}}{N_s} + \frac{c_{iz,1}\cdot\delta_{iz}}{N_s} + \frac{c_{en}\cdot 24}{1000} c_{si} D_{12} \frac{t_i - t_{em}}{\frac{1}{\alpha_i} + \frac{1}{\alpha_e} + \sum_{i=1}^{n}\frac{\delta_i}{\lambda_i} + \frac{\delta_{iz,opt}}{\lambda_{iz}}} \quad \text{[€/m}^2\cdot\text{year]}$$

(Mc 001, 2006)

Figure 4 shows the annual total costs with energy depending on the thickness of insulation, for several specific investment costs, for a brick wall of 30 cm with polystyrene insulation, in the climatic conditions of Sibiu, given a life duration of the investment of 25 years and energy costs of 0.04 €/kWh.

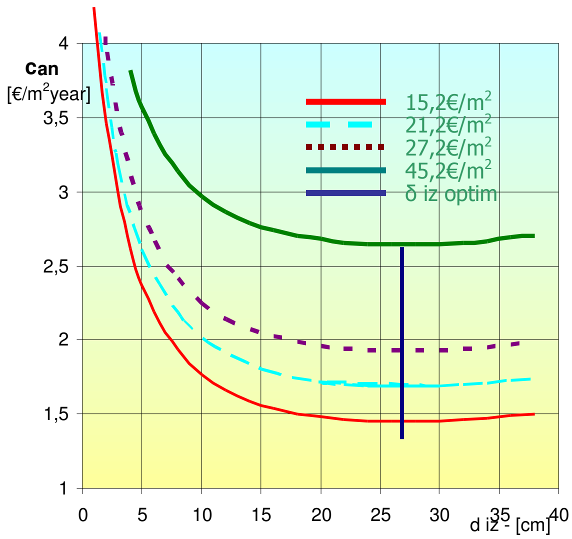

Figure 4. Annual total cost with energy, depending on the thickness of insulation, for several investment specific costs, for a brick wall of 30 cm with polystyrene insulation, in the climatic condition of Sibiu, life duration of the investment 25 years, energy costs 0.04€/kWh.

LIFE DURATION INFLUENCE

The investment's life duration is very important for the investment efficiency. For the moment, in the technologies frequently applied for the thermal insulation of the external walls of buildings, the investment's life duration is commonly considered as 25 years. In the future, for new and more performing materials, this life duration will be considerably enlarged.

In this regard, figure 5 shows the annual total costs with energy depending on the thickness of insulation, for several life durations of investment, between 20 and 50 years, for a brick wall of 30 cm with polystyrene insulation, in the climatic condition of Sibiu and for energy costs of 0.04 €/kWh.

It can be noticed that the optimal thickness of insulation, in accordance with the criterion of total annual costs with energy, increases with the life duration of investment, from 22 cm (20 years) up to 38 cm (50 years).

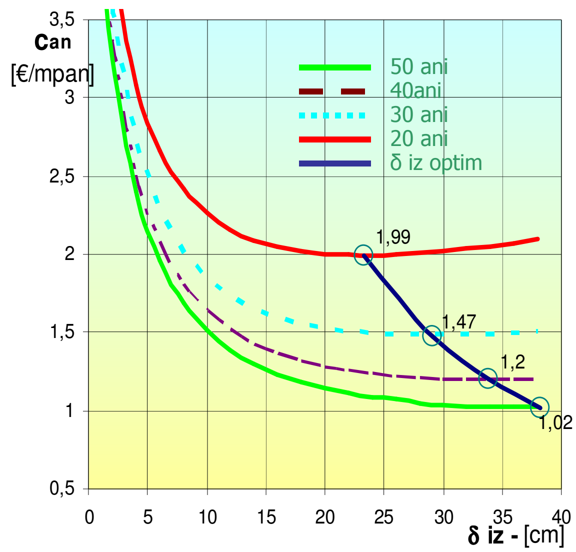

Figure 5. Annual total costs with energy depending on the thickness of insulation, for several life durations of investment, for a brick wall of 30 cm with polystyrene insulation, in the climatic condition of Sibiu, energy costs 0.04€/kWh.

The conclusion, which seems somewhat paradoxical at first sight, is explained by the fact that with an increase in the life span of the investment, the capital expenditure is allocated for a longer period. In other words, the fraction of the annual cost of c_{an} [€/m^2 year] decreases with the increase of the life span of the heat insulation, moving the optimum insulation thickness to higher values.

CONCLUSIONS

1. The optimal thickness of insulation, in accordance with the criterion of minimal annual costs with energy, decreases with the increase of energy cost and the life duration of investment, varying between 22 and 37 cm.
2. The simple recovery duration of the investment cost is very attractive for insulation thicknesses between 4 and 20 cm, acceptable up to 30 cm, and discouraging under 4 cm.
3. Life span of the investment is a parameter with great influence on annual energy costs. The use of heat insulation technologies with a life span equal with the life span of the building is a desired target.
4. The decision to start using additional insulation on walls with little thermal resistance is adopted as an economic and technical solution. This

decision has to be made after analyzing the variation curves of the annual costs for energy.

For this to happen, the technology adopted should bring a longer life span with it, the investment costs are fixed (excluding the cost of the insulating material as small) and the insulation thickness should be less than the optimal insulation thickness, but as close to it as possible, without involving architectural complications.

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