TECHNICAL AND ECONOMIC ASPECTS OF THERMAL INSULATION OF BUILDINGS

Dana Kocova, Pavel Kic
Czech University of Life Sciences Prague
kocovad@plzen.eu, kic@tf.czu.cz

Abstract. The aim of the paper is assessment of an additional thermal insulation of buildings in terms of technical and economic evaluation with a view to achieve economic savings. This topic is very important now, because of the need to reduce energy for heating. Currently, there is offered a large number of options, methods and technical solutions how to improve the thermal insulation of buildings, which, however, often differ significantly in their properties, parameters, and also in the cost of implementation. This research work is focused on the assessment of the investment costs in the terms of calculation of the unit prices with respect to the operational costs, expected energy savings and compliance with the necessary operational and hygienic parameters of comfort. On an example of construction of a smaller house typical for contemporary rural housing an analysis of different methods, structural elements and types of materials for building insulation in practice is provided. The calculations results are summarized and assessed from many points of view and thus allow the processing and generalization of the acquired knowledge for other future similar solutions.

Keywords: costs, energy savings, family house, heat balance, reconstruction.

Introduction

Energy consumption is in the interest and attention of all owners of family houses as well apartment buildings. There are many standards and recommendations for reduction of energy consumption in these houses, e.g. [1]. Several of them, transformed from the international (European) standards, are used for the ventilation, heating and air-conditioning design in the Czech Republic, e.g. [2; 3; 4]. The most important regulation used in the Czech Republic is [5], as a source of information for evaluation of buildings from the point of view of energy consumption. It is based on the legislation of the EU [6; 7].

There is a different approach in designing the method. According to the heat losses and gains a suitable heating system of the building is proposed and designed, where the capacity, efficiency and control of the whole system is the main priority. The main parameter of ventilation is the quality of indoor air. Hygienic conditions [8] must be respected during the whole year.

The research was applied in modernization of a usual family house. Some practical information and solutions for improvement of the thermal insulation are formulated in publications, e.g. [9; 10; 11]. In many cases it is very difficult to decide, which form of insulation is suitable for the reconstruction. Currently, there are many buildings of various ages improved by thermal insulation, which were designed and constructed according to the standards valid during different periods.

Table 1 summarizes the evolution of the required standard values over the years – since 1949 to 2011, always giving the crucial years in which there has been a change in the requirements. The required value of the overall heat transfer coefficient formed the basis for the required thickness of the structure. From the data in the table it can be read in which period attention was paid to energy savings and the related environmental protection. The tables were compiled from the technical standards from the archives of SYSTHERM Ltd. [12-15].

Table 1

Development and progress of the overall heat transfer coefficient

Construction	Overall heat transfer coefficient, $W\cdot m^{-2}\cdot K^{-1}$								
	1949	1954	1962	1977	1992	1994	2002	2005	2011
Peripheral walls	1.40	1.45	1.45	0.87	0.50	0.50	0.38	0.38	0.30
Roof	1.45	1.45	1.10	0.50	0.32	0.33	0.24	0.24	0.24
Ground floor	2.30	2.30	2.30	2.10	1.20	0.77	0.60	0.60	0.45
Windows	4.652	4.419	3.700	3.700	2.700	2.900	1.800	1.700	1.500

Not all family houses are insulated properly by the right technology and suitable materials. In the opinion of the Mineral Insulation Manufactures Association [16] every second house is insulated in an unprofessional manner and there are defects, which significantly reduce the quality of the building and energy savings. Many homeowners (approximately 71 % in the Czech Republic), construct the insulation of their houses by themselves.

Unfortunately, approximately half of the houses are poorly insulated and therefore suffer from a number of defects that impair the quality of housing in terms of hygiene and safety. Moisture and mold, noise and the risk of fire frequently threaten people's health. Improved thermal insulation currently has only in 20 % of houses in the Czech Republic, ie. 300 000 housing units out of the total 1.5 million. It can be assumed that a similar situation and problems exist in many other European countries. The situation in many non-European countries is even worse.

Well done insulation in addition to energy savings extends the possibility of the use of the house for 30 years or more. For this reason, the article is focused on the evaluation of the thermal insulation improvement of typical family houses from the technical, economical and functional points of view.

Materials and methods

As a model object a typical family house with the ground plan dimensions 11.2 x 11.2 m was chosen. This building has a partial basement, the living rooms are located on the 1st and 2nd floor; the attic is uninsulated. A simplified general view of the house is given in Fig. 1.

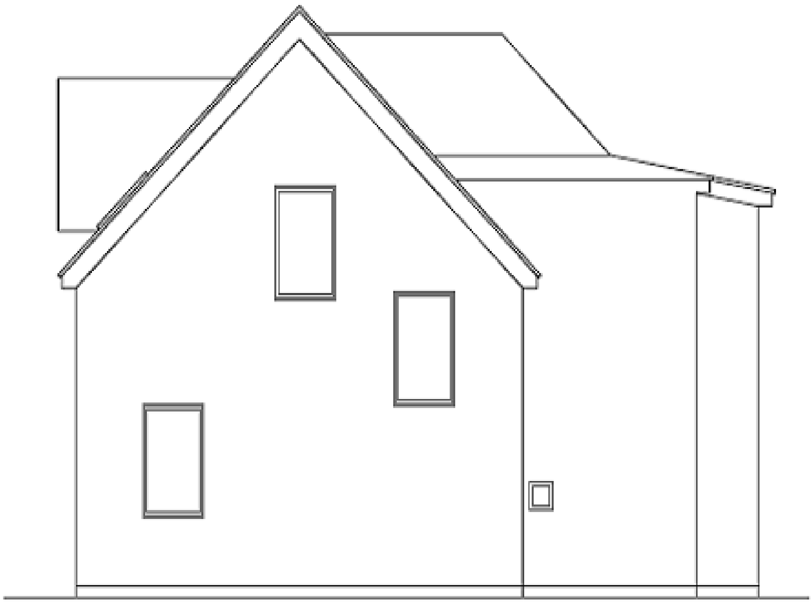

Fig. 1. **Schematic drawing of the experimental house**

The use of mineral wool was considered for thermal insulation in all cases. The experimental building was evaluated in terms of the overall heat transfer coefficient and in terms of the requirements of the annual balance of water vapour.

Heat losses are calculated for the investigated house just for the years of the main standard changes, in which the modernized house could be built according to the standards valid in that period. The individual construction parts of the house are divided in the following groups: peripheral walls, the roof, ground floor on terrain and windows including the balcony door. The calculations compare the insulation of the house by three different technologies.

In the first case, the material used for contact external insulation is mineral wool with the trade name FRONTROCK E MAX. In the second case it is internal insulation with the material Rockwool Airrock LD and in the third case it is heat insulation with the material Knauf Insulation TP 116 with a ventilated facade.

The thermal-technical calculations that were used in this work are performed by software tools PROTECH spol. Ltd. TOP version 15.5.1, the license no. 006600 – SYSTHERM Ltd. – Pilsen. Determination of the investment costs for insulation of the building is processed by a detailed calculation of the budget works. The budgets of the investment costs for individual assessment of insulation systems were performed using software tools for implementation of the construction budgets KROS – license SYSTHERM Ltd. – Pilsen. This software tool is used for calculation of the budgets, using for costs of the construction works the calculation system CS URS [17]. It is a comprehensive system of information, methodological manuals and procedures for determining the price of constructions.

Calculation of the suitable thermal insulation, fulfillment of the standard requirements for heat resistance of individual insulation technologies has been evaluated simultaneously with the fulfillment of the standard requirement for the annual balance of condensed water vapor.

Results and discussion

The thermal-technical calculations were performed for the peripheral construction of the house constructed from materials commonly used in the years when the houses were built. The results of calculations according to the requirements of the Czech standards [2] are shown in Tables 2-5. Table 2 shows the share of heat loss through the parts of the house structure before insulation. The big shares on the heat losses in all cases of constructed houses have walls (from 39.5 to 53.5 %) and windows together with the balcony doors (from 16.0 to 32.4 %).

The improvement of the house quality by external contact insulation (Table 3) in a required thickness (Table 6) reduces the overall heat transfer loss to the level of the needed standard requirements for heat transmission, and also the requirements for protection against moisture condensation are achieved.

A similar situation is in the case of insulation by external insulation with a ventilated gap (Table 5). The standard requirements for heat transmission are achieved and the requirements for protection against moisture condensation are achieved as well.

Table 2

Share of heat loss through the parts of the house structure before insulation

Year of construction	Share of heat loss, %					
	Peripheral walls	Roof	Ground floor	Ceiling	Windows and balcony doors	Exterior doors
1962	53.5	7.0	6.3	15.7	16.0	1.5
1977	50.6	4.6	8.9	10.6	23.3	2.0
1992	39.5	5.1	12.4	10.9	29.6	2.5
1994	40.0	5.6	10.9	8.3	32.4	2.8
2002	43.2	5.4	12.1	8.4	28.0	2.9

Table 3

Overall heat transfer loss of the house insulated by external contact insulation

Year of construction	Overall heat transfer loss, kW		Standard requirements for heat transmission achieved	Requirements for protection against moisture condensation achieved
	Before insulation	With improved insulation		
1962	23.793	6.097	Yes	Yes
1977	16.358	6.076	Yes	Yes
1992	9.393	5.459	Yes	Yes
1994	8.583	5.162	Yes	Yes
2002	6.625	4.945	Yes	Yes

The situation is more complicated in the case of insulation by internal contact insulation (Table 4). The standard requirements for heat transmission are achieved, but the requirements for protection against moisture condensation are not achieved, and this case of thermal insulation could cause problems for the use of the house during hard winters with low external temperatures.

Table 4

Overall heat transfer loss of the house insulated by internal contact insulation

Year of construction	Overall heat transfer loss, kW		Standard requirements for heat transmission achieved	Requirements for protection against moisture condensation achieved
	Before insulation	With improved insulation		
1962	23.793	6.122	Yes	No
1977	16.358	6.097	Yes	No
1992	9.393	5.466	Yes	No
1994	8.583	5.169	Yes	No
2002	6.625	4.945	Yes	No

Table 5

Overall heat transfer loss of the house insulated by external insulation with a ventilated gap

Year of construction	Overall heat transfer loss, kW		Standard requirements for heat transmission achieved	Requirements for protection against moisture condensation achieved
	Before insulation	With improved insulation		
1962	23.793	6.143	Yes	Yes
1977	16.358	6.119	Yes	Yes
1992	9.393	5.487	Yes	Yes
1994	8.583	5.183	Yes	Yes
2002	6.625	4.959	Yes	Yes

A very important question, which should be solved also during the decision process of choosing the suitable insulation method, is the investment costs. In all the studied cases of the houses constructed in different years external insulation with a ventilated gap would be the most expensive modernization system. The cheapest modernization would be internal contact insulation.

Table 6

Investment costs for thermal insulation

Year of construction	Thickness of thermal insulation, mm	Investment costs, EUR		
		External contact insulation	Internal contact insulation	External insulation with ventilated gap
1962	140	35 340	21 663	39 974
1977	120	33 989	21 374	39 464
1992	80	31 904	20 879	36 972
1994	80	31 904	20 879	36 972
2002	60	24 273	13 098	29 336

The costs of the house insulation implemented according to the standard requirements in the years 1992 and 1994 are identical as to meet the required coefficient of heat the structure is designed with thermal insulation of the same thickness and therefore the budget items do not differ.

The investment costs in Table 6 include all the necessary supply of materials and installation related to construction modifications (insulation claddings, the roof, ceiling above the basement, replacement of all windows and doors), with external insulation systems the costs areassociated with the construction and the need to use scaffolding and other costs on work associated with building construction. In the case of internal insulation there is no need to use external scaffolding, therefore the investment cost includes only the added cost for the necessary adjustments of the central heating pipeline and electricity wiring.

Conclusions

1. Various model solutions of thermal insulation improvement of a typical building illustrate the problems associated with renovation of older buildings and provide information about the impact of the age of the renovated building, the used technology, the costs of reconstruction and suitability in terms of the quality and durability of the building.
2. In terms of the investment costs for each type of insulation it is obvious that the cost of internal insulation is the most favorable for the investor, but the use of this technology is not suitable from the technical point of view, because the use of mineral wool inside the buildings does not meet the requirement for the annual balance of water vapor.
3. From the technical point of view the best solution would be to use ventilated facades – the external thermal insulation system with a ventilated gap. Based on the calculation of the investment costs, despite the use of a cheaper material for the surface layer of ventilated facades, this method is the most expensive for the investor. In the case of substitution of this material by another one, maybe architecturally more appropriate and interesting material, the costs will increase further.
4. From the technical and economic viewpoints the best solution for the investor is the use of external contact insulation, which meets all technical requirements and has the most acceptable cost.

References

1. Tywoniak J. Nízkoenergetické domy. (Low-energy houses) Grada Publishing. Praha, 2005. 193 p. (In Czech)
2. ČSN EN 12831 Tepelné soustavy v budovách - Výpočet tepelného výkonu. 2005. (Czech National Standard EN 12831. Heating systems in buildings - Calculation of heat power. 2005) (In Czech)
3. ČSN EN ISO 13789 Tepelné chování budov – Měrné tepelné toky prostupem tepla a větraním – Výpočtová metoda. (Czech National Standard EN 13789. Thermal performance of buildings - Specific heat flow by heat transmission and ventilation - Calculation method. 2009) (In Czech)
4. ČSN EN ISO 13790 Energetická náročnost budov – Výpočet spotřeby energie na vytápění a chlazení. (Czech National Standard EN ISO 13790. Energy performance of buildings - Calculation of energy consumption for heating and cooling. 2008, validity terminated in 2009) (In Czech)
5. Vyhláška č. 148/2007 Sb. o energetické náročnosti budov. (Decree no. 148/2007 Coll. Energy demands of buildings) (In Czech)
6. COM 2002/91/EC: Directive on the Energy Performance of Buildings
7. COM 2010/31/EC: Directive on the Energy Performance of Buildings
8. Nařízení vlády 361/2007 sb. kterým se stanovi podminky ochrany zdravi při práci. Act Government Regulation No. 361/2007 Coll. Laying down the conditions for the protection of health at work. Changes: 9/2013 Coll. 48 p. (in Czech).
9. Kic P., Kadleček B. Improvement of heat balance of family house. Proceedings of 11th International Scientific Conference “Engineering for Rural Development”, 2012, Jelgava, Latvia, pp. 134-138
10. Kic P. Hot-air heating of family houses with accumulation of energy in the floor. Agronomy Research, vol. 11, (2), 2013, pp. 329-334.
11. Kic P. Hot-air distribution in the floor heating. Agronomy Research, vol. 13, (2), 2015, pp. 494-499.
12. ČSN 1450. Výpočet tepelných ztrát budovy při navrhování ústředního vytápění, 1949, platnost ukončena 1955. (Czech National Standard 1450. Calculation of heat losses in buildings in designing the central heating. 1949, validity terminated in 1955) (In Czech)
13. ČSN 73 0020 Obytné budovy, 1955, platnost ukončena 1963. (Czech National Standard 73 0020. Residential buildings. 1955, validity terminated in 1963) (In Czech)

14. ČSN 73 0540 Navrhování stavebních konstrukcí z hlediska tepelné techniky. 1963, revize 1–6, platnost ukončena 2007. (Czech National Standard 73 0540. Design of building structures in terms of thermal engineering. 1963, revision 1-6, validity terminated in 2007) (In Czech)
15. ČSN 73 0540-2 Tepelná ochrana budov – Část 2: Požadavky. 2007, revize 2011. (Czech National Standard 73 0540-2. Thermal protection of buildings - Part 2: Requirements. 2007, revision 2011) (In Czech)
16. Anonymous. Pro zateplování se hodí jen kvalitní materiály. For thermal insulation of buildings are suitable only quality materials. Technical Weekly, vol. 64, (3), 2016, pp. 29. (In Czech)
17. Cenová soustava ÚRS (CS ÚRS) (Cost System URS CS). (In Czech) [online]. [24.02.2016]. Available at: http://www.pro-rozpocty.cz/software-a-data/cenova-soustava-urs-cs-urs-/ (In Czech)