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MODELLING OF IMPROVEMENT IN THERMAL TECHNICAL CHARACTERISTICS OF BUILDINGS

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Abstract

This paper deals with modelling of projects improving the thermal technical characteristics of buildings. The basic method for evaluation of economic convenience is compilation of all corresponding cash flows and their expression in time through discounting on the real construction. The solution to the problem is finding at least one economically efficient option. The output of the article is economic comparison of individual investment options and their evaluation. Potential investment options can be found on the basis of the modelled options. The aim of the paper is to prove or disprove existence of optimal investment option.

Key words

Thermal technical characteristics of buildings; energy performance of buildings; energy efficiency; modelling

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1 INTRODUCTION

One of the requirements put on future constructions and especially on reconstructions of the already realized ones is the requirement for their sufficient thermal technical protection. In case of maintenance work or the reconstruction, interventions into the building shells are common for which it is necessary to evaluate their already existing technical and especially thermal technical characteristics as early as in the pre-investment period. Investments into improvement of thermal and technical characteristics of buildings are caused by not only insufficient technical condition of the above mentioned constructions but also by the need to reduce operating costs especially the ones for heating.

The important aspect for the investment decision is the economic evaluation of partial measurements. Planned investment has to take into account these requirements as well. Every investment decision should be based on the study of investment possibilities from which investor can choose the one which is technically, technologically and economically optimal. One of the solutions of this problem is looking for cost optimal option through modelling. The aim of the paper is to prove or disprove existence of optimal investment option through modelling.

2 THEORETICAL BASIS OF THE SOLVED ISSUE

The starting point for the design of the modelling of measures improving the thermal technical characteristics of buildings are national legislation, regulations and technical standards in force. Their tightening is according to [1] one of the conditions for the increase in the energetic efficiency in the global scale. Already existing regulations of the Czech Republic result from the European regulations and fully respect them.

The effectual document of the European Union in the field of the thermal technical protection of buildings is the Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings adapted and recast by the Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010. The Directive among others states the common framework for the calculation methods of the energy performance of buildings. Minimal requirements on the energy performance of buildings while maintaining cost-optimal level are defined [2] [developed in detail in 3 below].

The choice of the measurement improving the thermal technical characteristics of buildings is not only restricted by legislation and technical requirements but also by the subsequent technical restrictions resulting from the selection and combination of the suitable technological processes and insulating materials.

Modelled variants have to meet all restricting criteria. The chosen investment option is then the option which is the most cost-efficient under given conditions. In the scope of modelling it is necessary to take into account experience and requirements of the residents of the buildings, summarised in [4]. Before initiation of the modelling task it is necessary to check whether the tested building corresponds with the basic principles for designing the building in the terms of energy performance and optimize the main financial ratios defined as following [5]:

- Ratio of building surface to building volume.
- Ratio of total window area to total wall area.
- Ratio of total window area to indoor space volume.
- Ratio of total window area to total floor area.

3 METHODOLOGICAL PROCESS OF THE SOLVED ISSUE

The phases of model creating and looking for the potential investment possibilities can be summarised in the following points:

- Determining restricting criteria (legislation conditions, technical standards).
- Setting the input data (description of the building and its technical characteristic).
- Determining EPA (specific energy consumption [kWh/m^2 year] and determination of the energy efficiency band of the building.
- Decision about the technologies used and the insulation material used.
- Evaluation of the costs of chosen options and determining the life-cycle costs.

The method used is based on the assumption that in case of the existence of at least one cost-effective option, there is also an optimal option. The first level of the solution is the evaluation of the current condition of the building (the above mentioned points 1-3). The second level is looking for the cost-effective option (points 4-6). The demanded solution is the option ensuring economic efficiency.

The practical solution to this problem is the application of the above mentioned points on the chosen construction. The chosen building represents the individual residential housing of the middle of 20th century, using classic materials and technological processes. It is a building which does not meet requirements nowadays and with regard to its condition it is possible to assume that the search for the potential investment option will prove sufficiently the advantages and disadvantages of the investment into the improvement of the thermal technical characteristics of the building.

4 CASE STUDY

4.1 Description of the building, current condition from the thermal technical point of view

It is a detached house with two floors and without a cellar (Fig. 1). Supporting structure is made of solid fired brick laid in lime mortar. The ceiling construction is a simple wooden fireboard beamed ceiling with plank roof decking. The ceiling construction over the 2nd floor is in addition covered by cob 30-50 cm thick.

Fig.1: Residential building (south-east view)

Fig. 2: Residential building (north-east view)

The floor on the first floor is concrete screed of unknown thickness. Interior plasterwork represents lime plaster and outer plasterwork cement plaster. The construction of frame is wooden collar beam one without collets. The roofing is formed by Eternit tiles nailed to full-area plank decking. Window openings are fitted by double casement windows in the sash. Heating is provided by the local stove using solid fuel. The minimal life cycle of the building is planned for 30 years Parameters entering the thermal technical calculations are summarised in Tab. 1 and Tab. 2. The calculation was done based on the provided project documentation [6-11].

Tab. 1: Recapitulation of specific heat flux through surface H_T [W/K] according to [6, 7, 8]

Construction	Name	Area	The thermal transmittance			Heat flux
		A	U[6]	b[6]	$U_{ekv} = U \times b$	$H_T = A / U_{ekv}$
		[m^2]	[W/m^{2}K]	coefficient	[W/m^{2}K]	[W/K]
SS1	**Supporting wall 1st floor**	87.41	1.11	1.00	1.11	97.02
WW	Wooden window (total area)	9.26	2.70	1.00	2.70	33.98
DE1	Front door	2.00	4.50	1.00	4.50	9.00
zone 3	Heatless vestibule	8.06	1.11	0.89	0.99	796
SS2	**Supporting wall 2nd floor**	94.60	1.30	1.00	1.30	122.57
WW	Wooden window (total area)	10.22	2.70	1.00	2.70	27.58
DB1	Balcony door	1.95	4.50	1.00	4.50	8.78
DB2	Balcony door	1.80	4.50	1.00	4.50	8.10
FLO1	**Floor on the earth**	74.40	0.64	0.55	0.35	26.00
CEI1	**Ceiling above the 2nd floor**	74.40	1.44	0.83	1.19	88.79
						420.76
ΔU_{em} [6]		364.08	0.1	1		36.408
H_T total						**457.16**

Tab. 2: Specific heat capacity calculated according to [6, 7, 8]

Coefficient (description)	Mark (relation)	Unit	Calculated value
Representative			
Total area of the building shell	A	[m^2]	364.50
Built up volume of heated area	V_C [6]	[m^3]	435.80
Total interior floor area	A_{gross} [7]	[m^2]	109.42
Total annual need of heat for heating	Q_{dem} [7]	[kWh]	36,061.6
Specific heat capacity for heating	$E_A = Q_{dem} / A_{gross}$	[kWh/m^{2}year]	329.57
Requirement			**Without requirement**

4.2 Total annual specific heat capacity EPA

For the calculation of the total specific energy consumption for the chosen building, the above mentioned data was used (specific heat capacity for heating) and values from the long-term measurements during the time of the building use (electric energy consumption for hot water and lighting), which was calculated at 1,825.00 [kWh/year] with the average daily consumption at 5 kWh. For the calculation of the real provided energy, **the efficiency of the source of conversion at 85% (**η_{gen} = 0.85 [-]) [according to 7] was used, while the other parameters will not affect the calculation (the source is situated in the heated part of the building, air conditioning is not considered). Cooling, mechanical ventilation or photovoltaic panels are not situated on the building and their influence on the total energy consumption is therefore zero. The total annual specific energy consumption EPA [kWh/m2·year] is calculated as the annual provided energy EP [kWh/year] related to the total interior floor area A_{Gross} [m^2]. The summary of the total annual energy consumption EPA [kWh/m2·year] for the chosen building results from requirements [12, 13] serve for the placement of the assessed building into one of the energy bands. It is determined as a sum of annual delivered energy necessary for the building operation (energy for heating, cooling, lighting, hot water etc.). The total annual delivered energy is represented by the energy actually delivered and covering not only annual energy consumption but also loss of energy due to transmission and source efficiency (summarised in Tab. 3). [12, 13]

Tab. 3: Total specific annual energy consumption EPA [kWh/m^{2}year] of the chosen building

Coefficient (description)	Mark (relation)	Unit	Calculated value
Representative			
Annual delivered energy for heating	EPH = Q_{dem} x 1,15	[kWh/year]	41,470.80
Annual delivered energy for hot water heating	EP_W	[kWh/ year]	
Annual delivered energy for lighting	EP_L	[kWh/ year]	1,825.00
Total annual delivered energy	EP (ΣEP_X)	[kWh/ year]	43,295.80
Representative			
Total specific annual delivered energy	EPA (EP / A_{gross})	[kWh/m^2 year]	395.70

Tab. 4: Determination of the energy band of the chosen building according to [13]

Requirement according to the Annex 2 of the Regulation no. 78/2013 Coll., on Energy Performance of Buildings						
Marking the bands of the energy performance of buildings in kWh/m^2						
A	B	**C (reference)**	D	E	F	**G**
0.5 x EPA_R	0.75 x EPA_R	**EPA_R**	1.5 x EPA_R	2 x EPA_R	2.5 x EPA_R	**>2.5 x EPA_R**
46.11	69.165	**92.22**	138.33	184.44	230.55	**>230.55**
Requirement					Unmet	

The chosen building will not meet the set requirement (comparison according to [13] in Tab. 4). The total annual energy consumption is higher than the one given by the Regulation. The building is according to [13] classed in band „G“. In case of improving the thermal technical characteristics of the building, it is necessary to lower the annual energy consumption EPA [kWh/m^{2}year] to maximum of 92.22 kWh/m^2 year which represents the reference value in the context of the Regulation.

4.3 Design and choice of technological process and choice of insulators

Floor on the earth

In regards to the existence of a relatively suitable concrete floor plate and sufficient headroom, it is possible to improve the thermal technical characteristics of the floor by laying the thermal insulation and fabrication of a new stepping and weight distributing set of layers. Because of the technical demandingness (extending the openings etc.) and economic inefficiency [13] is it possible to give the adaptation out.

Exterior walls

The nature of masonry enables the use of contact insulating system (ETICS technology) according to [14]. The thermal insulation of the exterior walls is proposed from polystyrene EPS 70 F (according the Tab. 5) λ=0.037 [W/mK], alternatively from the polystyrene GreyWall or GreyWall+ (according to Tab. 5) λ=0.032 [W/mK], resp. λ=0.031 [W/mK]. The minimal expected thickness of the insulation is according to the requirements by ČSN 730540-2 with the border value U_N=0.38 [W/m^{2}K] 100 mm.

Ceiling construction above the 2nd floor

The easiest way how to improve the thermal technical characteristics of the ceiling above the 2nd floor is laying the thermal insulation freely on the attic floor. The thermal insulation will be covered with the diffusion foil. The best suitable material seems to be mineral wool ORSIK λ=0.038 [W/mK]. The minimal expected thickness of the thermal insulation is according to the requirements by ČSN 730540-2 with the border value U_N=0.30 [W/m^{2}K] 120 mm. In case of necessity or economic benefit it is possible to lay two layers of the thermal insulation.

Fill of door and window openings

The fills of openings have to meet the requirements by ČSN 730540-2, the choice of quality characteristics and the frame material is according to the suggestion of the designer in competence of the investor. Maximal tolerable value of the thermal transmittance value U [W/m^{2}K] is according to ČSN 730540-2 Uw =1.7 [W/m^{2}K]. The requirement is fulfilled by the choice of plastic or wooden windows with the insulating double glazing.

4.4 Evaluation of the costs of the chosen option

The acceptable solution is such solution which meets all above mentioned requirements. The choice of optimal investment option fully depends on the assessment of the set of requirements with the maximum emphasis on the economic efficiency. With regards to the character, technical condition and especially the age of the chosen building it is obvious that the adopted solution has to be complex and cover the whole shell of the building except for the floor on the earth.

The first step for the evaluation of the accepted investment options is the determination of the total costs for each of the possible options. Total investment costs are then (based on the thermal technical requirements of the building) compensated by the heating costs savings.

Tab. 5: Total costs of the acceptable investment options [author]

Total costs of the acceptable investment options						
Construction of the building shell	Insulation material	Insulation thickness	Area of the shell	Costs per s.u.	Other costs	Total costs
	[W/m²K]	mm	m²	CZK/m²	CZK/area	CZK
Outer wall	GreyWall λ = 0.032 [W/mK]	100	182.01	956.00	13198.00	**187,200.00**
		120		991.00		193,570.00
		140		1095.00		212,500.00
		150		1113.00		215,775.00
		160		1131.00		219,051.00
Ceiling above 2nd floor	ISOVER ORSIK λ = 0.038 [W/mK]	200	74.40	360.49	-	**268,20.00**
		210		402.30		299,31.00
		220		418.20		311,14.00
		230		430.30		320,14.00
		240		447.20		332,72.00
Openings	According to the quotation by company SULKO s. r. o. number 410885B					**124,770.00**

Note: the costs stated in the table are taken from the database of the specific prices of the company ÚRS Praha, a. s. valid in the given period.

For the chosen construction, the total investment costs of the individual investment options are determined as the sum of the costs for the adaptation of the partial sections of the building shell:

- Costs for the adaptation of the outer walls (exterior masonry),
- Costs for the adaptation of the ceiling construction above the 2nd floor,
- Costs for the changing the fill of the window and door openings.

Also the additional costs to estimated costs which are building site equipment, operational and territorial impacts and completion activity as well as costs for the project documentation, obtaining a building permit etc. and corresponding VAT.

The choice of acceptable options is listed in Tab. 5. All acceptable options are seen from the table as well as partial solutions to the individual constructions of the shell. Every listed solution corresponds to the technical, thermal technical and technological requirements. Searching for the optimal option with regards to the other economic requirement follows.

4.5 Determination of life-cycle costs

In the final phase of the evaluation of the options, it is necessary to model all the costs and savings into assumed CF and on their basis evaluate the coefficient called life-cycle costs of the building (Building Life Cycle Costs, BLCC). Optimal option should prove the lowest life-cycle costs while balancing the acquisition costs on one hand and the thermal energy savings on the other hand.

Calculation of the coefficient can be expressed by the following formula [15]: (1)

$$BLCC = \sum_{i=0}^{n} \frac{1}{(1+r)^i} \sum_{j=1}^{t} C_{ij} \qquad (1)$$

Where:

BLCC are life-cycle costs of the building in CZK, C_{ij} is j-th cost related to the technical parameters of the building in i-th year in CZK, *i* is the year, in which the cost appears, *n* is the length of the life-cycle of the building in years and *r* is a discount rate in %/100.

Model financial years represent especially the investment costs of the chosen option (-), energy savings for heating (+), interests from the loans when financed from the external capital (-), grants (+).

Total costs of the investment option

The costs of the investment option are created by the total costs of the individual constructions of the building shell. For the chosen option they are created by the costs marked in Tab. 6 in bold face (external wall, EPS GreyWall th. 100 mm: 187,200.00 CZK, ceiling above 2nd floor, Isover Orsik th. 200 mm 26,820.00 CZK and the fills of the openings according to the price offer 124,770.00 CZK). Added should be the costs for processing energy assessments, project documentation and additional costs to estimated costs which are estimated at 15% of the costs of the construction. Total investment costs of the potential investment option are 389,608.50 CZK.

Tab. 6: Determination of the costs for heating of the chosen building

Coefficient (description)	Marking (relation)	Unit	Current state	Investment option
Representative				
Annual delivered energy for heating	EP_H	[kWh/year]	41,470.79	8,423.54
Heating power of wood (beech)	-	[kWh/kg]	3.47	3.47
Need of wood to cover EPH	EP_H/heat. power	[kg/ year]	11,951.24	2,427.53
Acquisition costs of wood	PC	[CZK/kg]	2.05[1]	2.05
Costs for heating	need x PC	[CZK/ year]	**24,500.03**	**4,976.44**

The savings are expressed by the total specific annual energy consumption EPA [kWh/m^{2}year] see chapter 3.2. For the already existing situation EPA = 395.70 [kWh/m^{2}year]. When applying the above mentioned steps and calculations, the total specific annual energy consumption decreases to 83.62 [kWh/m^{2}year]. The savings could be financially expressed using the real costs per 1 kWh of delivered energy according to the source of heating used. Comparison of the cost for heating can be seen from Tab. 6. The total annual savings representing the positive financial flow is 19,523.59 CZK. The described investment will be financed from the own sources and no grant will be used.

Final evaluation of the investment option

Evaluation of the investment option can be done by the application of the relation (1) and calculation of the internal rate of return on the investment (IRR).

It is necessary to sum up the described financial flows, determining the life-cycle costs and determining the requirements for the return on investment. Financial flows of the investment option are summarised in Tab. 7. Life span of the investment according to chapter 3.1 is 30 years at minimum. The rate of return on the investment comes out of the alternative investment possibilities of the investors. Investment can be compared to the risk-free long-term bank investment; the rate of the required return can be set at 1.00-2.00%.

[1] for example the actual price list of firewood by the company Loštická lesní, s. r. o. (www.drevonatopenilevne.cz) or DŘEVOPAR, s. r. o. (www.drevopar.cz).

Tab. 7: Financial flows of the investment option

Financial flows of the investment option							
Year	1	5	10	15	20	25	30
Costs for heating	4,976.44	4,976.44	4,976.44	4,976.44	4,976.44	4,976.44	4,976.44
Savings on the heating	19,523.59	19,523.59	19,523.59	19,523.59	19,523.59	19,523.59	19,523.59
Discount value	19,330.29	18,576.02	17,674.45	16,816.63	16,000.45	15,223.88	14,485.00
Financial flows cum. dis.	19,330.29	94,756.39	184,913.90	270,695.60	352,314.00	42,9971.00	503,859.10

Return on the investment (IRR) is according to relation (2) equal to 2.90%. From that point of view the investment – within these parameters – seems to be profitable and the investment option can be accepted.

5 EVALUATION OF THE RESULTS AND DISCUSSION

As can be seen from the results according to chapter 4, the potential investment option was found and it is possible to assume the existence of the optimal investment option meeting the conditions stated [2]. The presented procedure does not take into account the possible investments by the external sources which would mean the decrease in the internal rate of return on the investment percentage.

Financing from own sources is considered realistic according to the overall investment possibilities of the investors. Possible grants are also not taken into account (for example „Nová zelená úsporám“), which would increase the internal rate of return on the investment on the other hand. The presented procedure makes the evaluation of other investment options possible. Due to the possible final number of options it would be advisable to develop computer software for these calculations. The potential of the modelling of investment options lies not only in modelling the options for the improvement of the thermal technical characteristics of buildings for individual residential housing but also for social residential housing [16] or for the estimation of the energy audit of panel constructions [17].

The presented procedure represents the insight into the wide issue and does not deal with the follow-up details. Other researched areas can be: the precise determination of investment costs according to the price offers of the building work contractors, evaluation of the technical details of the building and broadening of the technological processes etc. [18].

6 CONCLUSION

Economic rationalization of the investments to the improvement of the thermal technical characteristics of buildings can be seen from the results. With expected return of minimal 1-2%, it is possible to accept the option. The requirement for the return from investment can be derived from return from non-risk investments (commercial bank accounts, government bonds. In relation with the specification of individual costs and total investment costs, it is subsequently possible to create a model of improvement of thermal technical characteristics of buildings, while the aim of the accepted solution should be - in ideal case – balance between technical and economic aspects.

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