Energy and financial evaluation of envelope retrofit measures for an apartment block in Slovakia

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This study analyses the energy effectiveness and financial viability of some energy retrofit measures for a selected apartment block in Slovakia.

Introduction

As the residential sector in the EU is responsible for about 40% of the total energy consumption and up to 36% of the total carbon dioxide emissions, the residential building stock offers high potential for energy savings [1]. Among the energy efficiency targets, the existing building stock and its energy performance improvements play a crucial role, because energy use in buildings has steadily increased.

While new buildings should be designed as intelligent low or zero-energy buildings, refurbishment of the existing building stock may present even a greater challenge, when in particular financing of the necessary investments to energy saving measures poses the biggest barrier. Improving the energy performance of buildings is a cost-effective way of fighting against climate change and improving energy security [1].

A case study of a selected apartment block located in Slovakia is presented, for which the cost-optimal levels of energy performance are determined in terms of life-cycle costs of the building. Although the housing stock in Slovakia belongs to youngest in Europe, the residential buildings built by mass forms of construction have been in use for several decades and the limitations associated with the excess of the planned lifetime of the building structures and services are becoming apparent. Based on the current building features, the building model was implemented in dynamic simulation software EnergyPlus and retrofit measures were simulated and evaluated by applying the cost-optimal methodology that allows the promotion of sustainable buildings with low energy consumption and cost effectiveness [2].

The case study

The main objective of the study was to design energy effective and financially viable retrofit measures for retrofit apartment blocks in Slovakia.

The chosen apartment block is a typical representative of the old building stock in Slovakia consisting mainly of buildings made from prefabricated ferroconcrete panels. It belongs to the largest group of existing building stock built before year 1983 that account for 46% of total net area of old building stock. [3] It was built in 1978, has 13 above ground floors, no basement and 48 dwelling units.

The apartment block is located in the capital city Bratislava, in the one of the housing estates. Slovakia is located in the northern moderate climatic zone with average heating period comprises 3,500 heating degree-days a year. Outdoor design temperature for Bratislava is −11°C with 202 heating days. Building envelope before retrofit presented a traditional construction system based on prefabricated ferroconcrete panels. The roof is mode of reinforced concrete panel, porous concrete panel and covered with waterproofing. There is just poor insulation in the external wall about 80 mm and about 70 mm in the roof construction. The windows in residential part used to have a single glass with windows frames made of wood. In original condition, about 1/2 of the original windows have been replaced by new windows with plastic frames and double glazing. In the space of stairs and elevator, the windows were made with steel frame and also single glazing.

Building constructions of the apartment building are mostly in original condition, except for the roof construction where a new hydroisolation was made in 2003. The **Table 1** shows thermal properties of the building elements.

Table 1. Thermal properties of the building elements.

Building element	Thermal transmittance (W/(m².K))		
	Before renovation	After renovation	
		Second level (year 2016)	Third level (year 2021)
U_{wall}	1.33	0.22	0.15
U_{roof}	0.86	0.10	0.10
U_{floor}	1.03	1.03	1.03
$U_{window\text{-}replaced}$	1.30 (plastic frame)	1.30	1.30
$U_{window\text{-}original}$	5.20 (steel frame) 2.70 (wooden frame)	1.00	0.60

Figure 1. View of apartment building before renovation and after the renovation.

The source of heat for the apartment block is the heat exchange station, which is in original condition, located in the neighbourhood. Heat is supplied to the building by underground distribution. The system has been hydraulically balanced since 2001. Temperature gradient of 90/70°C. The insulation of the heating distribution pipes does not fulfil the current requirements on thermal insulation. Domestic hot water (DHW) is supplied from accumulation tanks located within the technical room with the exchange station. The distribution efficiency and transformation factor of district heating is 0.84.

The apartment building does not have a mechanical ventilation system and there is no cooling system installed. There are no renovations in technical systems in this part of a research.

Energy simulation assumptions

Energy analysis was carried out for the apartment building through energy simulation by dynamic software, EnergyPlus. Weather statistic data for Bratislava were used as input data, obtained from [4].

The energy model of the building was created in order to assess the energy consumptions for space heating, domestic hot water (DHW) production, lighting and equipment. The model is divided into four different thermal zones (**Figure 2**); the first one is unconditioned. Heating set point temperature is set equal to 20°C. The heating period is from September to May. The use of manually controlled internal blinds is expected in each apartment. Energy consumption of the building is also influenced by internal gains-people, lights, various equipment. As internal gains were used: People-3 persons/apartment, Lighting-10.6 W/m², Electric equipment-3.9 W/m². The number of occupants was based on a questionnaire, the interior lighting was based on the market analysis and the electric consumption was based on the statistical data from SIEA (Slovak Innovation and Energy Agency).

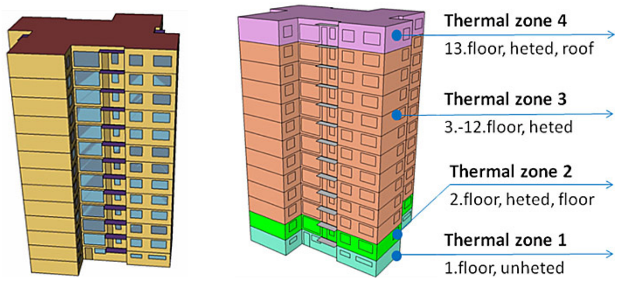

Figure 2. Model of apartment building with thermal zones.

Energy retrofit measures

A series of variants were developed to apply to the building constructions in terms of energy saving and costs. First, some single retrofit measures were defined and then the combination of measures into retrofit packages were developed.

Each measure has different level of thermal insulation of building constructions, based on the requirements on thermal protection as defined in the Slovak standards [5], which is mandatory standard for Slovakian buildings. It divides the time to year 2020 into the three periods: 2012-2015, 2016-2020 and after year 2021 with exact U-values requirements. **Table 2** shows those single measures characteristics and U-values requirements and **Table 2** shows the variants of retrofits with insulations features.

Life cycle costs analysis (LCCA)

Life cycle costing (LCC) is used to evaluate the cost performance of a building throughout its life cycle, including acquisition, development, operation, management, repair, disposal and decommissioning. It allows comparisons of cost among different investment scenarios, designs, and specifications. Standard ISO 15686, part 5 specifies procedures for performing life-cycle cost analyses of buildings and their parts. This assessment typically includes a comparison between options or an estimate of future costs at portfolio, project or component level [6]. Compared to other products, buildings are more difficult to evaluate for the following reasons: they are large in scale, complex in materials and function and temporally dynamic due to limited service life of building components and changing user requirements. [7]

The task of LCCA is to determine the economic effect of different variants of building retrofit and to quantify these effects and express them in financial amounts. Life cycle costs for building and its elements were calculated by summing different types of costs and applied to these the discount rate using a discount factor to express all feature costs to present. Following the Commission delegated regulation (EU) No 244/2012, the formula for calculating global LCC is:

$$LCC = C_O + O + M\&R + C_D - C_{RV}\ (€) \qquad (1)$$

Where: C_O - investments to saving measures, O - operation costs, $M\&R$ - costs of repairs and maintenance, C_D - demolition costs, C_{RV} - residual value at the end of the study life.

The period of 30 years from implementation of the retrofit was considered, which represents the predicted economic lifetime of measures on the building envelope. Costs are relevant when they are different for one

Table 2. Variants of building construction renovation.

Variants of renovation	Additional insulation characteristics		Replacement of windows
	External wall	Roof construction	
W1AR1A	EPS 14 cm; U = 0.22	EPS 30 cm; U = 0.10	–
W1AR1B	EPS 14 cm; U = 0.22	MW 34 cm; U = 0.10	–
W1BR1A	MW 12 cm; U = 0.22	EPS 30 cm; U = 0.10	–
W1BR1B	MW 12 cm; U = 0.22	MW 34 cm; U = 0.10	–
W1AR1AG1	EPS 14 cm; U = 0.22	EPS 30 cm; U = 0.10	double glazing; U =1.0
W1AR1BG1	EPS 14 cm; U = 0.22	MW 34 cm; U = 0.10	double glazing; U =1.0
W1BR1AG1	MW 12 cm; U = 0.22	EPS 30 cm; U = 0.10	double glazing; U =1.0
W1BR1BG1	MW 12 cm; U = 0.22	MW 34 cm; U = 0.10	double glazing; U =1.0
W2AR1A	EPS 20 cm; U = 0.15	EPS 30 cm; U = 0.10	–
W2AR1B	EPS 20 cm; U = 0.15	MW 34 cm; U = 0.10	–
W2BR1A	MW 20 cm; U = 0.15	EPS 30 cm; U = 0.10	–
W2BR1B	MW 20 cm; U = 0.15	MW 34 cm; U = 0.10	–
W2AR1AG2	EPS 20 cm; U = 0.15	EPS 30 cm; U = 0.10	triple glazing; U =0.6
W2AR1BG2	EPS 20 cm; U = 0.15	MW 34 cm; U = 0.10	triple glazing; U =0.6
W2BR1AG2	MW 20 cm; U = 0.15	EPS 30 cm; U = 0.10	triple glazing; U =0.6
W2BR1BG2	MW 20 cm; U = 0.15	MW 34 cm; U = 0.10	triple glazing; U =0.6
W1AR1AG2	EPS 14 cm; U = 0.22	EPS 30 cm; U = 0.10	triple glazing; U =0.6
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W2BR1BG1	MW 20 cm; U = 0.15	MW 34 cm; U = 0.10	double glazing; U =1.0

variant compared with another; in this case, the calculation of LCC includes the following costs:

- *Investments to saving measures* – all investments associated with the retrofit, particularly the costs of material and installation costs, based on prices from company catalogues and bids made by companies.
- *Operation costs* – depends on the heat demand for heating and DHW and on the efficiency of heating and DHW systems (determined by a calculation). The price of heat was based on annual reports of the Office for regulation of network industries, which regulates the price heat in Slovakia.
- *Costs of repairs and maintenance* – include costs of regular repairs of facade, roof, windows; based on the expected time of failure of the construction and expected repair interval.

Results discussion

Building retrofit is proposed with two different levels of thermal protection of building constructions. External walls are insulated with a contact insulation system in variant A made of expanded polystyrene to the height of 22,4 m (8th floor) and of mineral wool from 9th to 13th floor, in variant B made of mineral wool. The roof has the thermal insulation made of expanded polystyrene (variant A) and made of mineral wool (variant B).

Primary energy conversion factor for gas is 1.36 (regulation No 364/2012). The results of energy consumption simulation show that the most of primary energy belongs to space heating. Indeed, space heating consumes about 60% of total energy consumption than it is domestic hot water that consumes about 20% and lighting and electric equipment with 11% and 9% (**Figure 3** - left). Monthly distribution of energy consumption is showed in **Figure 3** - right. The highest energy consumption is in January and December, due to high energy consumption for heating.

The results show that the whole opaque retrofit is more efficient than the single retrofit actions (**Figure 4**). Glazing retrofit is not useful as a single measure, but the combination with wall and roof retrofit, can reduce primary energy consumption by about 32% (Variant W2BR1BG2) to reach 87 kWh/m².a.

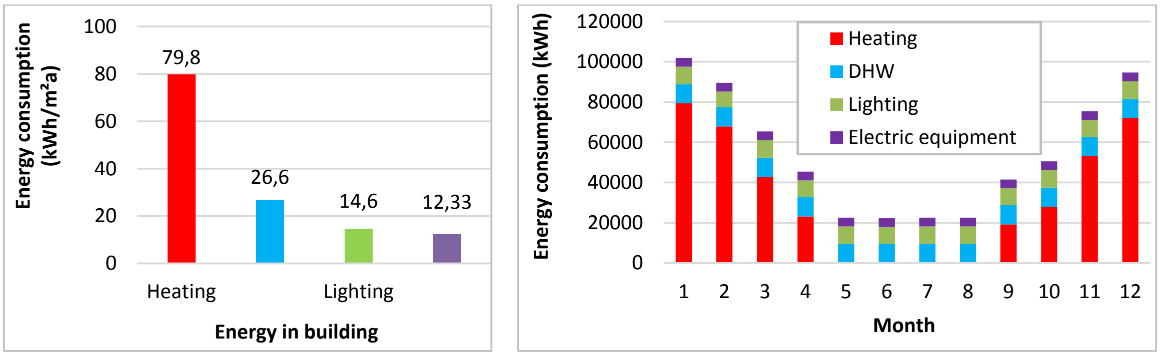

Figure 3. Left -Distribution of energy consumption of apartment building in original, Right - Monthly energy consumption of apartment building in original.

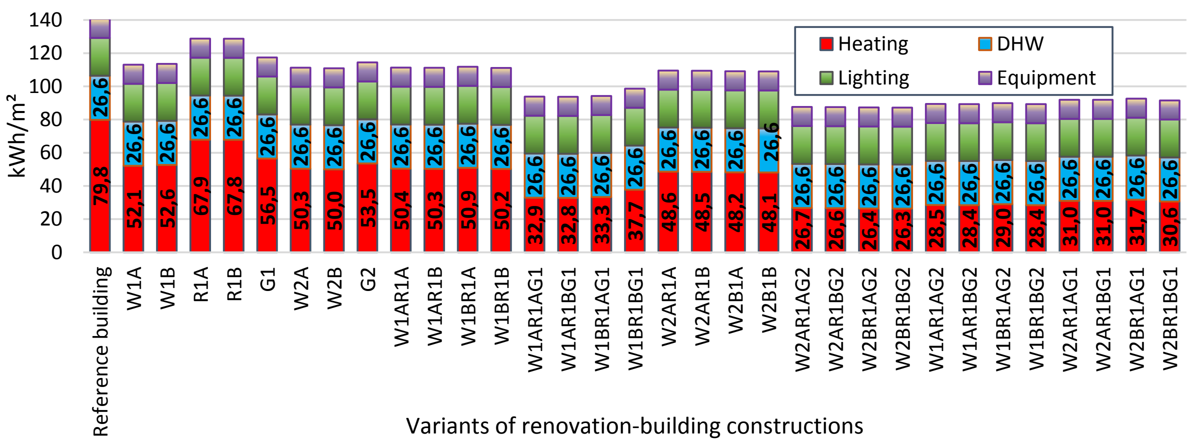

Figure 4. Energy consumption of the Apartment building with retrofit variants.

Different costs for each variant of retrofit are shown in the **Table 3**. The related costs of combined variants of retrofits are calculated. Energy costs are calculated for 30 years period based on the prices from last 10 years and predicted increase. For the calculations the 3% discount rate was applied, which can be considered suitable for the long-term life cycle calculations [8]. This relatively low rate reflects the benefits that investments in energy efficiency brings to users of the building throughout the life cycle.

The building in original has approximately 327 €/m² LCC. Variant W1AR1AG2 with 172 €/m² LCC is the one with the lowest LCC during 30-year period and can provide about 48% LCC reduction during this period. The graph in the **Figure 5** shows the LCC of different variants of retrofit during the 30-year period.

The analysis showed that, if is just energy consumption considered, most profitable variant of retrofit seems to be Variant W2BR1BG2. To obtain more comprehensive results, the operation costs during the defined life-cycle period must be counted with the discount rate using a discount factor to express all feature costs to present. The LCC calculation showed, that the most convenient variant of retrofit during the 30-year period is Variant W1AR1AG2. It is the variant with the opaque retrofit that meet the requirements of second level insulation valid from year 2016; insulation of facade with EPS thickness of 14 cm, insulation of roof with EPS thickness of 30 cm. The original windows are replaced by the windows with high efficient triple glazing and U value = 0.6 W/m²K, that are requirements valid from year 2021. The façade insulation with mineral wool is not a suitable because of the high investment costs. Currently, the materials that meet the most stringent requirements valid after year 2021, are expensive, that cause the variants designed for this requirement have high investment costs. We can predict, that the research of new materials in following years will go forward and the price will be more suitable, so it could change the rank of Variants in feature.

Table 3. Costs of building in original and different variants of renovation during 30 year life cycle.

Variants of renovation	Investment costs (€)	Operation costs (€)	Maintenance costs (€)	Total cost (€)	Cost per area (€/m²)
Original	0	1163386	240568	1403954	327
W1AR1A	163842	733926	88587	986355	230
W1AR1B	175120	733623	88587	997330	233
W1BR1A	192313	741357	88587	1022257	238
W1BR1B	203591	732178	88587	1024356	239
W1AR1AG1	221302	478578	88587	788467	184
W1AR1BG1	232580	478344	88587	799511	186
W1BR1AG1	249773	485711	88587	824071	192
W1BR1BG1	261051	476924	88587	826562	193
W2AR1A	194795	707763	88587	991145	231
W2AR1B	206073	707422	88587	1002082	234
W2BR1A	250266	702487	88587	1041340	243
W2BR1B	261544	702140	88587	1052271	245
W2AR1AG2	267032	389504	88587	745123	174
W2AR1BG2	278310	389270	88587	756167	176
W2BR1AG2	322503	384208	88587	795298	185
W2BR1BG2	333781	383980	88587	806348	188
W1AR1AG2	236079	414901	88587	739567	172
W1AR1BG2	247357	414667	88587	750611	175
W1BR1AG2	264550	421905	88587	775042	181
W1BR1BG2	275828	413266	88587	777681	181
W2AR1AG1	252255	452873	88587	793715	185
W2AR1BG1	263533	452633	88587	804753	188
W2BR1AG1	307726	447549	88587	843862	197
W2BR1BG1	319004	447291	88587	854882	199

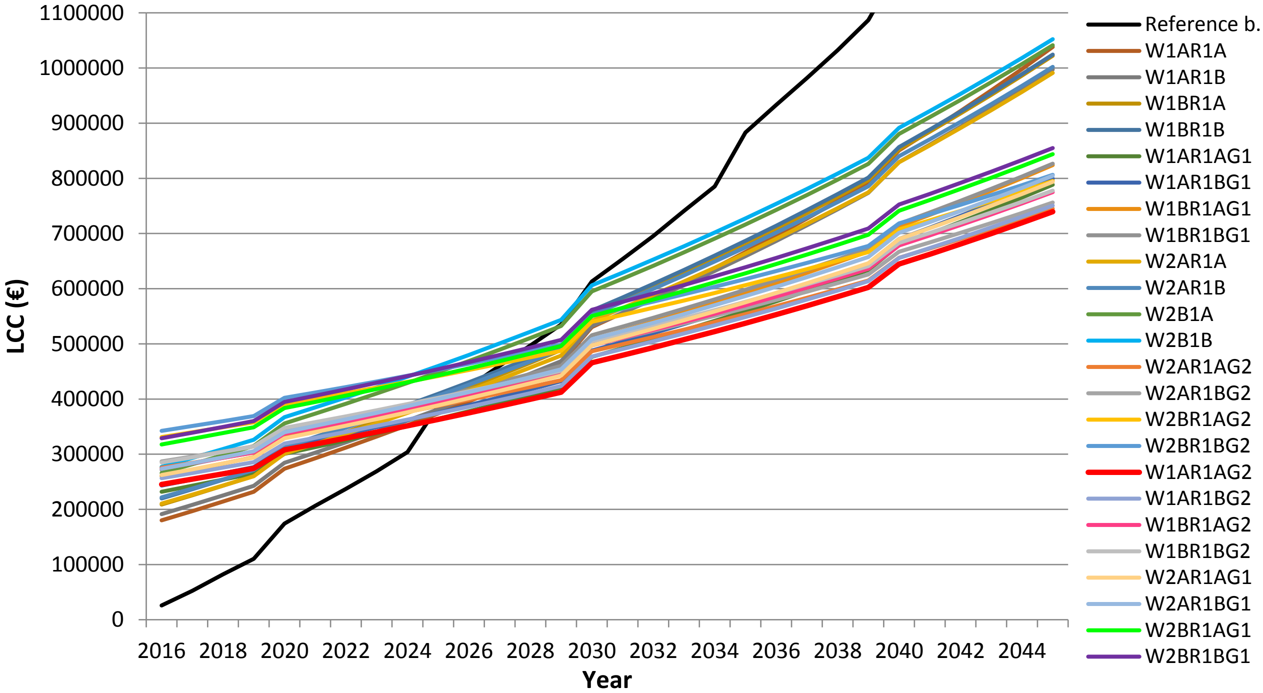

Figure 5. Time-course of total life-cycle costs during the 30 years for the apartment building in original condition and for the different variants of renovation.

Conclusions

The retrofit requirement was satisfied by using additional thermal insulation for the whole building envelope and by replacing windows. From the energy saving point of view, there is not much need to insulate the basement ceiling. The analysis showed a potential of energy consumption reduction of more than 40% by implementing the energy efficiency measures. In terms of calculations for the period of 30 years, we came to the conclusion that the most convenient combination of retrofit measures is Variant W1AR1AG2. It is the variant with the opaque retrofit made of insulation of facade with EPS thickness of 14 cm, insulation of roof with EPS thickness of 30 cm and the replaced windows with high efficient triple glazing and U value = 0.6 W/m²K. The success of the retrofit project depended mostly on the detailed design of the retrofit solutions and ability to direct the apartment owners to make the right choices. To realize the complex retrofit of apartment buildings, the financial support by retrofit funds or subsidies from the Government are needed. ■

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