sciendo
Slovak Journal of Civil Engineering
Vol. 30, 2022, No. 3, 33 – 42
DOI: 10.2478/sjce-2022-0019

FEASIBILITY OF USING ENERGY PERFORMANCE CONTRACTING FOR THE RETROFIT OF APARTMENT BUILDINGS IN SLOVAKIA

Veronika GOMBOŠOVÁ[1], Michal KRAJČÍK[1*], Ondřej ŠIKULA[2]

Abstract

This study is focused on the feasibility of using energy performance contracting (EPC) for the retrofit of two apartment buildings constructed using precast concrete technologies in Slovakia decades ago. The retrofit packages were defined, and their suitability for EPC was evaluated through discounted payback. The uncertainties in the profitability calculations were covered by designing five possible economic developments and defining input ranges instead of just single inputs. The measures in the technical systems were shown to be more feasible than the retrofit of the building envelopes. The potential to finance the selected measures for technical systems through EPC was further evaluated. It was shown that, for at least one of the two buildings studied, the EPC was recommended only for the economic developments with a notable increase in energy prices compared to the baseline that referred to the situation before the Covid-19 pandemic. In the best case, the payback was four years for one building and seven years for the other; thus, both were potentially suitable for EPC. However, for a complex retrofit, the EPC must be combined with a different funding source to also finance other retrofit measures.

Address

[1] Faculty of Civil Engineering, Slovak University of Technology, Bratislava, Slovak Republic

[2] Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic

* ***Corresponding author:*** michal.krajcik@stuba.sk

Key words

- Apartment building,
- Energy performance contracting (EPC),
- Profitability,
- Building retrofit.

1 INTRODUCTION

The reduction of fossil fuel consumption is one of the most urgent challenges worldwide due to the need to mitigate impending climatic changes. Furthermore, for many countries, phasing out fossil fuels is vital for decreasing their dependence on the import of energy carriers. This triggers various incentives for the reduction of energy consumption and the decarbonisation of economies. For example, just recently, the European Commission adopted a set of proposals to make the European Union's (EU) climate, energy, transport, and tax policies capable of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels (European Commission, 2022 a). Retrofitting old buildings is an important means of reducing energy consumption and decarbonising building stock (Życzyńska et al., 2020; Vargová and Ingeli, 2021; Cholewa et al., 2022). One of the potentially feasible methods to fund and execute a retrofit is the use of energy performance contracting (EPC), which is an energy service with guaranteed energy savings provided under a contract concluded between an energy service provider and a recipient of the energy service (Act No. 321/2014 Coll.).

The EPC is provided by an energy service company (ESCO). Funding a retrofit project through EPC means that if the project does not provide returns on the investment, the ESCO is responsible for paying the difference, thus assuring their clients of any energy and cost savings. Therefore, ESCOs accept some degree of risk to achieve improved energy efficiency in a user facility and receive their payments based on the achievement of those energy efficiency improvements (European Commission, 2022 b). The risk-free nature of the service provided by ESCOs offers a convincing incentive for their clients to invest. The result is a verifiable, measurable, or estimable energy savings that improves energy efficiency and allows for a financial or material advantage for all parties involved due to more energy-efficient technology or activity (Act No. 321/2014 Coll.). Another important advantage of the EPC is the significant potential to retrofit public buildings without the need for public funds.

Apartment buildings are an essential component of the building sector. In Slovakia, most apartment buildings were built several decades ago in an era of massive prefabrication. Most of these buildings have only been partially renovated or are almost entirely in their original condition. The majority of the apartment buildings, where a large part of the population in Slovakia lives, are in private ownership (European Commission, 2017; MDV SR, 2020). In addition, apartment buildings can also be owned by governmental bodies and municipalities and used, for example, as social housing, care centres for the elderly, and dormitories. Due to the risk-free nature of EPC and the lack of a need of funding, EPC could be a feasible method to retrofit these apartment buildings. The advantage is that an ESCO could guarantee energy savings without the need for the building owner to look for funding. Apartment buildings owned by the government and municipalities could especially be retrofitted without the need for public funds.

Currently, there are several potential barriers to the use of EPC for building retrofits, which do not apply only to apartment buildings. First, research on the use of EPC for retrofitting is scarce, while studies on the use of EPC for retrofitting apartment buildings are entirely lacking. Research on the use of EPC for building retrofits includes Bizzarri and Morini (2006), who focused on the environmental benefits achievable in hospitals in Ferrara, Italy, through a shift from conventional systems to various hybrid plants. The high costs of the energy sources there represented an insurmountable market barrier. More recently, Principi et al. (2016) presented an analysis of the suitability of EPC for three acute care hospitals and two community clinics in Italy. The best renovation activities included improving the control and regulation of existing subsystems without the replacement or with the partial replacement of subsystems and the integration of renewables. For such low-cost actions, the savings were at least 35 to 40%, and payback was 9 to 11 years, which could be potentially suitable for EPC.

Furthermore, as concluded by Labanca et al. (2015) and based on a literature search and questionnaire survey, "*despite the substantial economic energy saving potential in the building sector of the European Union (EU), the energy efficiency service market is not correspondingly developed. Especially in the residential sector, the energy service market is much less developed in this market segment than in other demand sectors such as, for example, the industry or the public/service sector*". The use of EPC for retrofitting buildings is also hampered by the fact that a complex renovation increases investment costs. For a complex retrofit, the retrofit packages should also include unprofitable measures that are not suitable for financing through EPC. In addition, a significant risk for ESCOs using EPC is an erroneous estimate of the energy-saving potential and profitability of the project. This may lead to economic losses for an ESCO, which has to balance any discrepancies between the contract and the real energy savings. Therefore, it is critical to accurately estimate the energy savings and financial developments.

Various studies have been aimed at estimating the energy savings potential of apartment buildings and the profitability of their retrofit (e.g., Kuusk et al., 2014; Kuusk and Kalamees, 2015; Patiño-Cambeiro et al., 2016). However, as Giretti et al. (2018) stated, "*gathering comprehensive and reliable technical information is a time-consuming and expensive process that must be carried out within the submission deadline. In these conditions, the standard approach to energy performance forecasting which uses detailed simulation is practically unfeasible*." This is one of the reasons why energy simulations are not widely used for energy audits of building in practice; on the other hand, professionals tend to use simpler calculation tools such as commercial software or custom Excel spreadsheets. This also can lead to erroneous estimations due to, for example, the lack of precision and lack of capability to fully take into account some components of the energy balance. These factors prevent reliable estimations of the energy-saving potential and profitability of retrofitting. For these reasons, part of these investigations aims to develop simplified procedures to reliably estimate savings and reduce the uncertainty of the calculations (Faggianelli et al., 2017; Giretti et al., 2018; Lee et al., 2018; Ramos et al., 2019). An alternative approach is to generate many predefined combinations of energy efficiency measures in various climates that can be used to select suitable retrofit scenarios (Gustafsson et al., 2017; Dipasquale et al., 2019).

Based on the above discussion, several conclusions can be drawn: research on the use of EPC for the retrofit of apartment buildings is scarce, and suitable combinations of retrofit measures for financing through EPC must be determined; to this end, reliable and affordable methods to estimate the calculations precisely are needed. EPC often needs to be combined with other sources of financing for the retrofit to be successful, while also being profitable for the ESCO. This study focuses on the possibilities of using EPC for typical old apartment buildings in Slovakia. Potentially feasible retrofit packages were defined, and their suitability for EPC was evaluated through discounted payback (PB). The uncertainties in the energy and economic calculations were covered by devising several possible scenarios of economic development and defining input ranges instead of just single inputs. The present study contributes the very limited body of research on the use of EPC for the retrofit of apartment buildings. It defines retrofit measures that are potentially suitable for apartment buildings and shows the feasibility of financing the retrofit measures through EPC under several possible economic developments. Although this study refers to apartment buildings in Slovakia, the results can also be applied internationally, especially in countries with a similar climate and building construction technologies.

2 MATERIALS AND METHODS

2.1 Description of the buildings

Two apartment buildings are presented here as representatives of the old building stock. The buildings were constructed using precast concrete technologies in the 1980s. In this sense, the two buildings are similar to many other apartment buildings built with precast concrete technologies several decades ago that currently represent a substantial part of the housing stock in Slovakia. The schematic geometry of the apartment buildings is shown in Fig. 1. Both buildings are located in Bratislava, Slovakia.

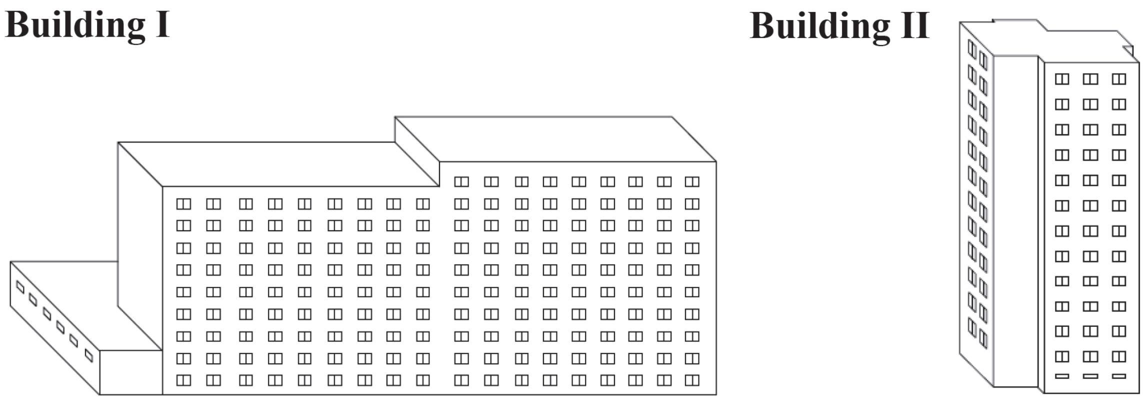

Fig. 1 *Geometry of the apartment buildings (not to scale)*

2.1.1 Building I

Building I is a 10-story apartment building with an outbuilding located on the left side of the building. The floor plan of the building is a simple rectangle with external dimensions of 13.5 x 88 m and each floor has an average construction height of 2.8 m. The heated volume is 32,992 m^3. The peripheral walls mainly consist of 300 mm-thick walls made of reinforced concrete panels with thermal insulation in between them. Some of the walls consists of bricks made of aerated concrete (300 m). The walls of the outbuilding are made of reinforced concrete (300 mm) insulated with expanded polystyrene (120 mm). The original roof structure is flat and made of reinforced concrete and perlite concrete. It is insulated with 70 mm-thick expanded polystyrene and has waterproofing made of asphalt strips. The original insulation is in poor condition. The roof of the outbuilding is made of reinforced concrete, perlite concrete, 200 mm-thick expanded polystyrene, and waterproofing. The opening structures were previously renovated and are made of triple glazing with an insulated plastic frame. The heat emission elements are plate radiators and fitted with thermostatic heads. The space heating and DHW distribution pipes are in their original condition and partially insulated with original insulation. The heat for the space heating and domestic hot water (DHW) is supplied from a district system, which is connected to a heat exchange station located outside of the building. The heat consumption is measured at the entrance to the building. The thermal gradient is 90/70°C. The lighting system has undergone a partial renovation. The building is equipped with linear fluorescent lamps with a classic ballast, LED lamps, or lamps with a classical incandescent bulb.

2.1.2 Building II

Building II has a pointed shape and thirteen above-ground storeys. The floor plan is irregular in shape, and the construction height of each storey is 2.8 m. The heated volume is 13,649 m^3. There is a gas boiler room, auxiliary rooms, and storage areas on the first floor. On the second storey, there is the main entrance to the building, a gatehouse, living quarters, rented premises, a cleaning room, and auxiliary and storage spaces. The third storey contains apartments, offices, and auxiliary premises. There are apartments on the fourth to the thirteenth stories. The peripheral walls are 290 mm-thick sandwich panels made of reinforced concrete panels with thermal insulation in between them. The roof is flat and uninsulated. The opening structures are mostly made of double glazing and a plastic frame. The radiators are cast iron with steel plates and thermostatic heads for individual control. The pipes for the space heating and DHW systems are newly insulated in the boiler room but are in their original condition otherwise. The heat source is a gas boiler room located on the first storey, with seven gas condensing boilers with a total heat output of 400 kW and an expected efficiency of 86%. The thermal gradient is 90/70°C. The DHW is centrally prepared using two storage heaters with a volume of 750 litres each. The lighting system has undergone a partial renovation. It consists of luminaires with linear fluorescent lamps and classic and electronic ballasts, LED bulbs, or old luminaires with classical incandescent bulbs, and one halogen light.

2.2 Calculation methodology

The calculation procedures regarding the energy needs for the heating, thermal losses and auxiliary energy for the heating system, the auxiliary energy, and losses for the DHW system, the energy balance of the solar thermal system, and the entire economic calculation procedure were custom programmed in MS Excel.

2.2.1 Energy calculations

The energy calculations for the space heating system follow the latest European standards. These included the energy need for heating (EN ISO 52016-1), heat losses from emission (EN 15316-2), distribution (EN 15316-3), storage (EN 15316-5) and generation systems, including electricity for circulating pumps (EN 15316-3). The calculations of the DHW system involved thermal losses of the distribution system, including electricity for circulating pumps (EN 15316-3), storage losses (EN 15316-5), and generation losses. The energy balance of the solar thermal system was calculated as defined in EN 15316-4-3. The EN standards provide calculation procedures with a seasonal, monthly, and hourly calculation step. In the present work, the monthly calculation step was used compared with the seasonal step, which was considered too inexact for the purpose. The calculation procedure was programmed into a customized MS Excel tool that was easy to modify and suited for practical calculations. In addition, it permitted calculations of emission, distribution, storage, and generation losses from space heating and DHW systems.

The values calculated were compared with the invoiced data measured. Furthermore, to obtain realistic results, data on the physical condition of the buildings were carefully collected through a study of the project documentation, detailed inspection of the buildings, and interviews with the caretakers responsible for the buildings and their energy systems. The invoiced data was used to adjust the calculation inputs. However, the invoiced data provided information on the total energy consumption. This overall value was divided between space heating and DHW. First, the energy budget for the space heating system was determined, and the rest was attributed to the DHW, making sure that the values were realistic. After determining the energy needs and losses, the energy delivered was divided among the energy carriers. In the end, the calculated and measured values were 1355 MWh versus 1322 MWh for Building I and 905 MWh versus 934 MWh for Building II.

The energy balance of the photovoltaic system was calculated using a verified online calculation tool (European Commission, 2022 c). The modernization of the lighting system was based on an evaluation of the individual types of luminaires and their current state and wattage. As the electricity consumption for the lighting was not measured separately, it was necessary to approximate it according to the number of hours of lighting, which was determined based on the operating characteristics for this type of building. Electricity consumption was determined for each luminaire separately as the product of the total number of hours of lighting per year and the total wattage of the given type of luminaire. This consumption was further increased by 15% for obsolete lamps with a classic magnetic ballast. This value is routinely used by energy auditors in practice.

2.2.2 Economic calculations

Net present value (NPV) is the present value of future cash flows generated by a retrofit measure or a project; it also includes the initial investment. Using the terminology and notation defined in EN 15459-1, it can be expressed as follows:

$$NPV = \sum_{t=1}^{n} CF_t \cdot \left(\frac{1}{1+RAT_{\text{disc}}}\right)^t - CO_{INIT} + CO_{INIT,ref} \quad (€) \quad (1)$$

where CF_t is the difference in cash flows between the optional case and the reference case in year t; n is the lifetime or calculation period; RAT_{disc} is the discount rate; CO_{INIT} are the initial investment costs; and $CO_{\text{INIT,ref}}$ are the initial investment costs for the reference case (0 is for the option of doing nothing).

For an ESCO that guarantees the value of energy savings for a certain period, knowing the payback is critical. Therefore, the discounted payback (PB) is an important profitability indicator for an ESCO that needs to be sure that the investment will pay for itself before the contract is terminated. PB is the time when the NPV equals zero. It is calculated as follows (EN 15459-1):

$$PB = \sum_{t=1}^{TPB} CF_t \cdot \left(\frac{1}{1+RAT_{\text{disc}}}\right)^t - CO_{INIT} + CO_{INITref} = 0 \quad (a) \quad (2)$$

where TPB is the last year for the payback period (the time when the sum is stopped because the formula becomes negative or equal to 0).

The discounted payback was used to evaluate the suitability of retrofit measures for EPC in the present study. The reason was that in EPC projects, it is crucial to assure that the investment in the retrofit measures returns before a certain interval, typically 10 to 15 years. For this reason, from the point of view of suitability for EPC, the discounted payback is considered to be the single most important indicator.

When calculating the investment in an EPC energy efficiency measure, it is necessary to consider the additional costs of financing through EPC by increasing the investment in the measure. The existing legislative framework requires that additional costs related to risk, management, insurance, or repairs be reflected in the investment costs. These additional costs were expressed as a percentage of the initial investment per measure as follows: EPC project financing 20%, EPC project management 2%, repair costs for building structures 1%, repair costs for technical systems 2%, and insurance 1%.

Tab. 1 *Retrofit measures and subpackages considered*

System	Retrofit measure	Subpackage
Building structures	Replacement of opening structures	*EEM0*
	Insulation of perimeter walls	
	Insulation of roof	
	Insulation of floor above basement	
	Insulation of attic floor	
Space heating	Replacement of heat source	*EEM1*
	Insulation of piping	
	Hydraulic regulation and temperature control	
	Adjustment of temperature gradient (supply/return)	
	Renovation of measurement and control system	
Domestic hot water (DHW)	Insulation of piping	*EEM2*
	Replacement of circulating pump	
Indoor lighting	Renovation of lighting system	*EEM3*
Renewable energy sources (RES)	Solar thermal system	*EEM4*
	Photovoltaics	*EEM5*
Energy management	Energy management system (EMS)	*EEM6*

2.3 Retrofit measures considered

The retrofit measures are divided into two categories, i.e., measures for building structures and measures for technical equipment. Table 1 shows the combinations of retrofit measures considered. At the beginning, several retrofit measures were selected to allow for the creation of various combinations of measures (packages). This set of measures was created based on the scanning of the buildings and the experience from previous energy audits. The retrofit measures were divided into subpackages, because some of the measures were implemented meaningfully or typically together. Another reason is that, in some cases, it may be difficult to determine the energy savings of an individual measure, and it makes sense to determine the savings together for a group of measures. Two combinations of retrofit measures were created. Combination 1 only included the retrofit of the building envelope. These measures are part of the EEM0 subpackage (Table 1). An energy management system (EMS) was also included because it is mandatory in EPC projects (EEM6). Combination 2 involved retrofit measures on technical equipment (subpackages EEM1 to EEM6). Combinations of measures were selected so as to achieve paybacks that indicate the suitability of the project for EPC.

3 RESULTS

The formulation of the results included two phases. First, retrofit measures that could potentially be suitable for financing through EPC were selected. Subsequently, the suitability of the chosen retrofit package for financing through EPC under various possible economic developments was discussed, based on the detailed energy and economic calculations.

3.1 Selection of retrofit measures

One of the retrofit packages contained measures regarding the insulation of the building envelope, whereas the other focused on the retrofit of the technical systems. The measures on the envelope and technical systems were treated separately because they tend to have very different initial investments and profitability.

3.1.1 Retrofit package 1

The retrofit measures regarding the building structures were primarily aimed at the reduction of heat transmission losses. For each structure, the proposed level of thermal insulation was based on the requirements defined in the national standard STN 73 0540-2+Z1+Z2 (Table 2). The corresponding EEM0 subpackage included measures such as insulation of the roof structure, insulation of the walls, and replacement of the opening structures. The measures were selected separately for each building according to its renovation needs. For Building I, Combination 1 included insulation of the perimeter walls, replacement of the opening structures, and the installation of EMS. For Building II, the measures included insulation of the perimeter walls, insulation of the roof, and the installation of EMS. For both buildings, the payback calculations showed the measures on the building envelope to be relatively unfeasible and thus not suitable for EPC. These results referred to the use of mineral wool as thermal insulation.

Tab. 2 *Requirements for the thermal insulation of building structures of retrofitted buildings as defined in STN 73 0540-2+Z1+Z2*

Building structure	Indicator	Requirement
External wall and slope roof above inhabited space (slope > 45°)	U, W/(m^2.K)	0.22
Flat or slope roof (slope ≤ 45°)	U, W/(m^2.K)	0.15
Ceiling above outdoor environment	U, W/(m^2.K)	0.15
Ceiling beneath unheated space	U, W/(m^2.K)	0.20
Windows, doors in external wall	U, W/(m^2.K)	0.85
Floor above unheated space (Difference in air temperature between spaces of up to 15 K)	U, W/(m^2.K)	0.60
Floor of heated space on the ground	R, (m^2.K)/W	2.50

Explanation: U – heat transfer coefficient, R – thermal resistance

3.1.2 Retrofit package 2

The assessment of the suitability of the measures was based on the terms of the EPC signed between the provider and the beneficiary. In our case they were ESCO and the owner of the buildings in question. It was assumed that the contract could be signed for a maximum duration of 15 years, which is typical of EPC projects. For this reason, appropriate measures were selected so that the payback of the combination did not exceed a payback period of 15 years. The retrofit sub-packages proposed for each building are summarized in Table 3. The measures considered for the EPC are marked by a cross. An overview of the calculation inputs and outputs is shown in Table 4. The costs of the heat and electricity used in the calculations were based on invoices. The difference in the cost of the heat between Building I and Building II was caused by different heat sources, that is, the district heating plant versus the boiler room located in the building.

Tab. 3 *Proposed retrofit measures on the technical systems*

	EEM1	EEM2	EEM3	EEM4	EEM5	EEM6
Building I	x	x	x		x	x
Building II	x	x	x	x		x

Tab. 4 *Inputs and profitability indicators for Buildings I and II – retrofit package 2*

	Building I	Building II
Discount rate (RAT_{disc})	1%	1%
Investment (€)	249,906	115,981
Investment with EPC (€)	299,887	139,178
Inflation rate (%)	3%	3%
Price of heat (€/kWh)	0.1500	0.0450
Price of electricity (€/kWh)	0.1496	0.1496
Energy saving – heat (MWh/a)	183.6	38.3
Energy saving – electricity (MWh/a)	136.9	82.2
Financial saving (€/a)	43,828	14,019
Discounted payback (a)	6.8	14.4

3.2 Suitability for EPC under various economic developments

Here, we evaluate in detail the suitability of the retrofit measures selected in the previous section (retrofit package 2) for EPC. The effect of the input parameters on profitability is also discussed. The economic calculations are performed for several possible economic developments. The EPC project is based on the Energy Saving Performance Contract, which defines the basic terms, the subject of the contract, the obligations of the provider and the client, payments for the EPC, the financing and insurance of the project, sanctions, and the termination of the contract. The duration of the contract should be at least eight years, and it is defined in the contract. A typical duration is 10 years, but contracts for up to 15 years are not uncommon. One of the most important criteria for the suitability of retrofit measures for EPC is the payback of the EPC project compared to the duration of the contract. The payback must be lower than the duration of the contract, even when uncertainties are taken into account.

3.2.1 Definition of possible economic developments

Unfortunately, it is not possible to precisely characterize the current situation because it is constantly changing. For example, most of the calculation inputs were prepared and the calculations performed during a relatively stable economic situation. Recently, the economic situation has become turbulent. The cost of building materials has been increasing, as has the energy costs. It is not clear how the situation will develop in the future. In addition, there is always uncertainty in energy savings due to simplification of the calculation models and input data. The uncertainty in inputs includes the insulation level of building structures, the geometry, the internal and solar heat gains, the indoor temperature and air change rate, etc. To cover this uncertainty at least partially, five economic developments have been devised to cover the range of possible developments of investment and energy costs (Table 5). However, the rate of increase is not the same for the investments and energy. Investments tend to rise at a lower rate relative to the baseline, whereas energy prices can double or even triple. The economic developments are briefly described as follows:

- **INV -10%, EP -10%** – Favourable development of the economy i.e., materials are abundant and cheaper compared to the baseline. In addition, energy costs are relatively favourable for consumers. Investments (INV) and energy prices (EP) are 10% lower than the baseline. This development is unlikely to occur but is included for purposes of comparison.
- **Baseline (INV 0%, EP 0%)** – This is a basic scenario that assumes a realistic input based on the searches and documents available in the input preparation phase. It reflects the situation just before the Covid-19 pandemics before costs began to increase sharply. It serves as a reference.
- **INV +30%, EP +50%** – Investments (INV) are 30% higher and the energy prices (EP) are 50% higher than the baseline. In the current situation, this development is more realistic than the baseline.
- **INV +50%, EP +100%** – It represents unfavourable economic developments. It assumes that the investments (INV) are 50% higher and energy prices (EP) are 100% higher than the baseline.
- **INV +100%, EP +150%** – Least favourable of all the economic developments. It assumes that investments (INV) will double and that energy costs (EP) will increase by as much as 150%.

For each economic development, the middle, upper, and lower values were calculated. The middle values represent the estimated parameters that were input. The upper and lower values represent the estimated ranges of the parameters that were input to assess the uncertainty of the calculations. The ranges of the parameters input were chosen so as to be realistic, i.e., not too narrow to account for the errors in the calculation, but not too wide so that the calculated payback is specific enough to allow drawing conclusions. The values that were input represented the initial calculation values. The average inflation in the energy costs during the calculation period was assumed to be 3%. The discount rate (RAT_{disc}) was selected as 3%. The zero discount was also considered to represent a situation with a stronger intent to retrofit without considering the discounting of the money. The uncertainty in the investment was ±10%; the uncertainty in the energy costs was ±20%; and the uncertainty in the energy savings was also ±20%. The upper and lower limits were obtained by combining the parameters that were input in the most unfavourable way possible to determine the maximum overestimation and underestimation of the payback.

Tab. 5 *Definition of the economic developments*

Economic development	Value	Change in inputs relative to the reference (Baseline - middle)		
		Investment	Energy costs	Energy savings
1 INV -10%, EP -10%	lower	-20%	10%	20%
	middle	-10%	-10%	0%
	upper	0%	-30%	-20%
2 **Baseline** (INV 0%, EP 0%)	lower	-10%	20%	20%
	middle	**0%**	**0%**	**0%**
	upper	10%	-20%	-20%
3 INV +30%, EP +50%	lower	20%	70%	20%
	middle	30%	50%	0%
	upper	40%	30%	-20%
4 INV +50%, EP +100%	lower	40%	120%	20%
	middle	50%	100%	0%
	upper	60%	80%	-20%
5 INV +100%, EP +150%	lower	90%	170%	20%
	middle	100%	150%	0%
	upper	110%	130%	-20%

Explanation: INV – investment, EP – energy costs

3.2.2 Suitability for EPC – Building I

The values that were input and results for Building I are shown in Table 6 and visualized in Fig. 2. In general, the payback is favourable for the EPC. This was because only profitable retrofit measures on technical systems were selected for the EPC project and the systems were mostly in the original condition. For a complex retrofit, the EPC would probably need to be combined with a different funding scheme. It can be seen that any deterioration in the economic conditions did not negatively affect the profitability of the retrofit. This was caused by the fact that, with the increase in the initial investment, the energy costs also increased. This can be considered realistic because, percentage-wise, energy costs are likely to increase more rapidly than the investment costs in time of crisis. The outcome would be different if the investment increased much more dramatically than the energy costs.

The payback for the favourable economic development (INV -10%, EP -10%) was almost identical to that for the baseline scenario. However, in the current situation, neither of these two developments is likely to happen in the foreseeable future. The more pessimistic developments are more likely to occur. It is seen that with any negative developments in the economy, that is, with the increase of the investments but mainly of the energy costs, the payback decreased down to five years. Regardless of the economic developments considered, the payback was reasonably low, indicating potential suitability for EPC.

The potential suitability for EPC is retained even if we take into consideration the uncertainty ranges, which are indicated by the error bars in Fig. 2. In the figure, the points represent the middle values, and the error bars represent the lower and upper values from Table 5. The lower and upper uncertainty ranges are not symmetrical, and the upper uncertainty range is wider than the lower range. For the EPC project, the upper uncertainty range is relevant because it signifies the risk that the payback will exceed the duration of the contract. The uncertainty decreases with the deterioration of the economic situation. Increases in investments and energy prices are likely to occur. In such a case, the upper uncertainty range is 2-3 years. In the two developments with the highest prices (INV +50%, EP +100% and INV +100%, EP+150%), the expected payback was up to seven years, also taking the uncertainty into account. This suggests the suitability of the retrofit project for EPC.

3.2.3 Suitability for EPC – Building II

The results for Building II were somewhat similar to those for Building I (Table 7). The optimistic economic developments (INV -10%, EP -10% and Baseline) were not suitable for EPC, whereas the developments that involved cost increases were po-

Tab. 6 *Inputs and discounted payback for the various economic developments for Building I*

Economic development	Value	Investment (€)	Inputs varied			RAT_{disc}	PB	RAT_{disc}	PB
			Electricity costs	**Heat costs**	**Energy savings**				
			(€/MWh)		**(kWh/a)**	**(%)**	**(a)**	**(%)**	**(a)**
1 INV -10%, EP -10%	lower	239,910	165	165	384,620	3	4	0	4
	middle	269,899	135	135	320,517	3	7	0	6
	upper	299,887	105	105	256,414	3	12	0	10
2 **Baseline** (INV 0%, EP 0%)	lower	269,899	180	180	384,620	3	4	0	4
	middle	**299,887**	**150**	**150**	**320,517**	**3**	**7**	**0**	**6**
	upper	329,876	120	120	256,414	3	11	0	10
3 INV +30%, EP +50%	lower	359,865	254	255	384,620	3	4	0	3
	middle	389,853	224	225	320,517	3	6	0	5
	upper	419,842	194	195	256,414	3	9	0	8
4 INV +50%, EP +100%	lower	419,842	329	330	384,620	3	3	0	3
	middle	449,831	299	300	320,517	3	5	0	4
	upper	479,820	269	270	256,414	3	7	0	6
5 INV +100%, EP +150%	lower	246,346	404	122	384,620	3	3	0	3
	middle	259,312	374	113	320,517	3	5	0	4
	upper	272,277	344	104	256,414	3	7	0	6

Explanation: INV – investment, EP – energy costs

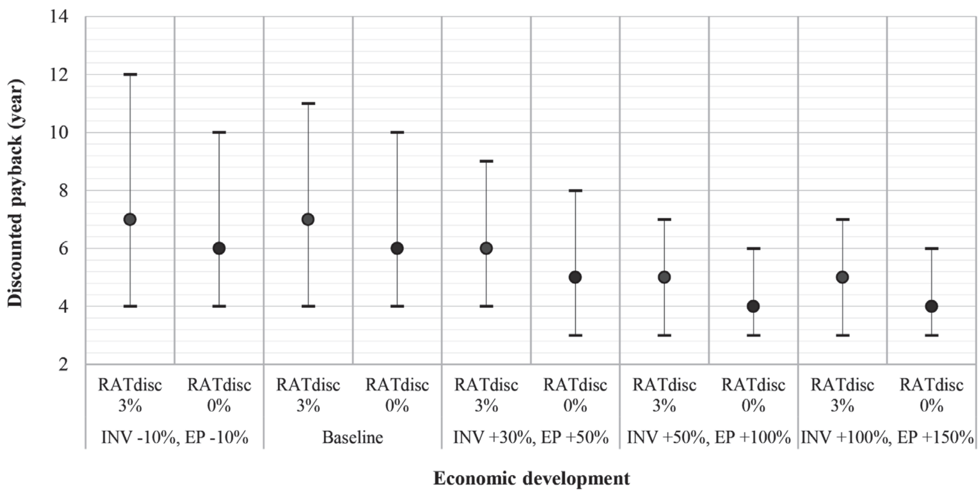

Fig. 2 *Discounted paybacks for various economic developments for Building I*

tentially suitable, especially the two most pessimistic ones (INV +50%, EP +100% and INV +100%, EP+150%). However, Fig. 3 shows that unlike Building I, in this case, the upper uncertainty level in the favourable developments (INV -10%, EP -10% and Baseline) exceeded 20 years, thus indicating a risk of exceeding the maximum contract duration of 15 years. The middle payback for these developments was eight to nine years, and the upper calculation of uncertainty was 12 years. The difference in payback, and, therefore, suitability for EPC, between the buildings, was partially caused by the difference in the cost of heat. This was because in Building II, the heat sources were gas boilers installed in the buildings; therefore the heating costs were lower. Lower heating costs mean less financial savings.

4 CONCLUSIONS

The present study has summarized the potential of various retrofit measures that can be applied to apartment buildings constructed several decades ago using old technologies. The measures were assembled into retrofit packages, and their suitability for financing through EPC was studied. The specifics of EPC are that it needs to generate enough revenue for the provider within a relatively short time frame and also cover the uncertainties in profitability calculations. Therefore, a suitable retrofit must be selected for the EPC project to achieve a reasonable payback. Research on this topic is scarce, even on the international level. Furthermore, existing studies did not consider using EPC to finance the retrofit of apartment buildings. The present research adds to the existing knowledge in this regard. The results refer to selected apartment buildings in Slovakia but are also applicable in other countries with a similar climate and building construction technologies.

The retrofit measures in technical systems were shown to be considerably more feasible than the retrofit of the building envelope. Therefore, the potential to finance the selected package of retrofit measures for technical systems through EPC was further evaluated. Five possible economic developments, representing different starting points in terms of investments and energy costs, were devised. It was shown that even with filtering out potentially unfeasible retrofit measures, the profitability and suitability of EPC depended significantly on economic developments. For

Tab. 7 *Inputs and discounted payback for the various economic developments for Building II*

Economic development	Value	Investment (€)	Inputs varied			RAT_{disc}	PB	RAT_{disc}	PB
			Electricity costs	**Heat costs**	**Energy savings**				
			(€/MWh)		**(kWh/a)**	**(%)**	**(a)**	**(%)**	**(a)**
1 INV -10%, EP -10%	lower	111,342	165	50	144,609	3	7	0	6
	middle	125,260	135	41	120,507	3	13	0	11
	upper	139,178	105	32	96,406	3	22	0	17
2 **Baseline**	lower	125,260	180	54	144,609	3	7	0	6
	middle	**139,178**	**150**	**45**	**120,507**	**3**	**13**	**0**	**11**
	upper	153,095	120	36	96,406	3	21	0	16
3 INV +30%, EP +50%	lower	167,013	254	77	144,609	3	6	0	6
	middle	180,931	224	68	120,507	3	10	0	9
	upper	194,849	194	59	96,406	3	15	0	13
4 INV +50%, EP +100%	lower	194,849	329	99	144,609	3	5	0	5
	middle	208,766	299	90	120,507	3	8	0	7
	upper	222,684	269	81	96,406	3	12	0	10
5 INV +100%, EP +150%	lower	264,438	404	122	144,609	3	6	0	5
	middle	278,355	374	113	120,507	3	9	0	8
	upper	292,273	344	104	96,406	3	12	0	10

Explanation: INV – investment, EP – energy costs

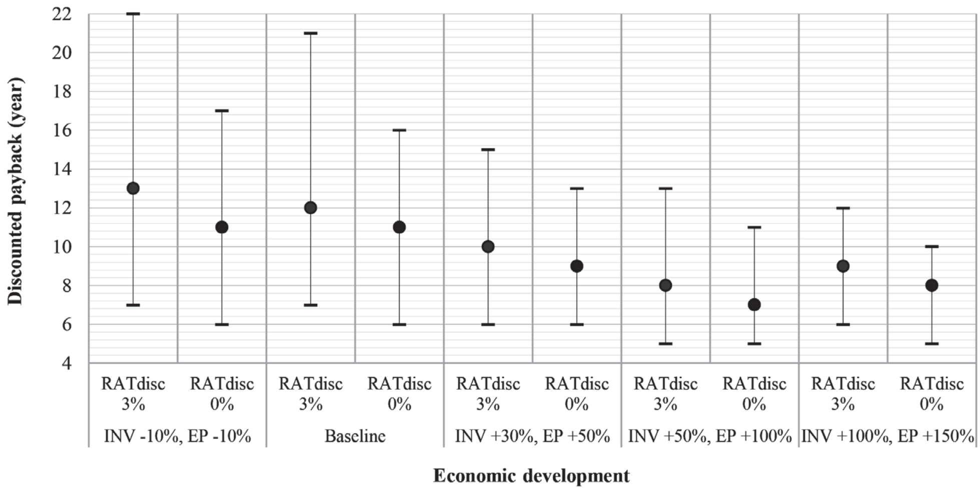

Fig. 3 *Discounted paybacks for various economic developments for Building II*

both buildings considered, financing the retrofit through EPC was realistic. However, it was shown that the use of EPC may not be preferred in a favourable economic situation involving relatively low energy costs. At least for one of the two buildings studied, the EPC was recommended only for economic developments that involved a sharp increase in energy costs.

Furthermore, the paybacks were 1-2 years shorter when assuming a discount rate of 0% instead of 3%. These findings suggested that a negative economic outlook, especially an increase in energy costs, and an incentive for energy-efficient retrofits to support the economy and reduce dependence on fuel imports (represented by the zero discount rate), help make the EPC a suitable financing method for building retrofits. However, this pertains only to the measures selected in the technical systems. For a complex retrofit, the EPC must be combined with another financing method.

Acknowledgements

This work was supported by the Ministry of Education, Science, Research and Sports of the Slovak Republic grants VEGA 1/0303/21 and 1/0304/21 and KEGA 005STU-4/2021 and Brno University of Technology project FAST-S-22-8060.

REFERENCES

National Council of the Slovak Republic (2014) Act No. 321/2014 Coll. on energy efficiency and on the amendment of certain laws.

Bizzarri, G. – Morini, G.L. (2006) *New technologies for an effective energy retrofit of hospitals*. Applied Thermal Engineering, 26, pp. 161-169. DOI: 10.1016/j.applthermaleng.2005.05.015.

Cholewa, T. – Balaras, C.A. – Kurnitski, J. – Mazzarella, L. – Siuta-Olcha, A. – Dascalaki, E. – Kosonen, R. – Lungu, C. – Todorovic, M. – Nastase, I. – Jolas, C. – Çakan, M. (2022) *Energy efficient renovation of existing buildings for HVAC professionals*, Brussels: REHVA, 2022, 103 pp. ISBN 978-2-930521-31-2.

Dahlsveen, T. – Petráš, D. – Chmúrny, I. – Smola, A. – Lulkovičová, O. – Füri, B. – Konkoľ, R. (2008) *Energetický audit a certifikácia budov (Energy audit and certification of buildings)* [in Slovak], Bratislava: Jaga Group, 2008. 163 pp. ISBN 978-80-8076-063-2.

Dipasquale, C. – Fedrizzi, R. – Bellini, A. – Gustaffson, M. – Ochs, F. – Bales, C. (2019) *Database of energy, environmental and economic indicators of renovation packages for European residential buildings*. Energy and Buildings, 203, 109427. DOI: 10.1016/j.enbuild.2019.109427.

EN ISO 52016-1:2017 Energy performance of buildings. Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads. Part 1: Calculation procedures.

EN 15316-2:2017 Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 2: Space emission systems (heating and cooling).

EN 15316-3:2017 Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 3: Space distribution systems (DHW, heating and cooling).

EN 15316-5:2017 Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 5: Space heating and DHW storage systems (not cooling).

EN 15316-4-3:2017 Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-3: Heat generation systems, thermal solar and photovoltaic systems.

EN 15459-1:2007 Energy performance of buildings. Economic evaluation procedure for energy systems in buildings. Part 1: Calculation procedures.

European Commission (2017) *Update of the Residential and Non-residential Building Stock Renovation Strategy, Slovak Republic*. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/update_of_the_residential_and_non-residential_building_stock_renovation_strategy_slovak_republic.pdf (Accessed 3 August 2022).

European Commission (2022 a) *A European Green Deal: Striving to be the first climate-neutral continent*. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_6683 (Accessed 7 July 2022).

European Commission (2022 b) *Energy Service Companies (ESCos)*. Available at: https://e3p.jrc.ec.europa.eu/node/190 (Accessed 7 July 2022).

European Commission (2022 c) *Photovoltaic geographical information system*. Available at: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html (Accessed 7 July 2022).

Faggianelli, G.A. – Mora, L. – Merheb, R. (2017) *Uncertainty quantification for Energy Savings Performance Contracting: Application to an office building*. Energy and Buildings, 152, pp. 61-72. DOI: 10.1016/j.enbuild.2017.07.022.

Giretti, A. – Vaccarini, M. – Casals, M. – Macarulla, M. – Fuertes, A. – Jones, R.V. (2018) *Reduced-order modeling for energy performance contracting*. Energy and Buildings, 167, pp. 216-230. DOI: 10.1016/j.enbuild.2018.02.049.

Gustafsson, M. – Dipasquale, C. – Poppi, S. – Bellini, A. – Fedrizzi, R. – Bales, C. – Ochs, F. – Sié, M. – Holmberg, S. (2017) *Economic and environmental analysis of energy renovation packages for European office buildings*. Energy and Buildings, 148, pp. 155-165. DOI: 10.1016/j.enbuild.2017.04.079.

Kuusk, K. – Kalamees, T. – Maivel, M (2014) *Cost effectiveness of energy performance improvements in Estonian brick apartment buildings*. Energy and Buildings, 77, pp. 313-322. DOI: 10.1016/j.enbuild.2014.03.026.

Kuusk, K. – Kalamees, T. (2015) *Retrofit cost-effectiveness: Estonian apartment buildings*. Building Research & Information, 44, pp. 920-934. DOI: 10.1080/09613218.2016.1103117.

Labanca, N. – Suerkemper, F. – Bertoldi, P. – Irrek, W. – Duplessis, B. (2015) *Energy efficiency services for residential buildings: market situation and existing potentials in the European Union*. Journal of Cleaner Production, 109, pp. 284-295. DOI: 10.1016/j.jclepro.2015.02.077.

Lee, P. – Lam, P.T.I. – Lee, W.L. (2018) *Performance risks of lighting retrofit in Energy Performance Contracting projects*. Energy for Sustainable Development, 45, pp. 219-229. DOI: 10.1016/j.esd.2018.07.004.

Ministry of Transport and Construction of the Slovak Republic (MDV SR) (2020) *Dlhodobá stratégia obnovy fondu budov (Long-term strategy of renovation of the building stock)* [in Slovak]. Available at: https://ec.europa.eu/energy/sites/default/files/documents/sk_2020_ltrs.pdf (Accessed 3 August 2022).

Patiño-Cambeiro, F. – Armesto, J. - Patiño-Barbeito, F. – Bastos, G. (2016) *Perspectives on Near ZEB Renovation Projects for Residential Buildings: The Spanish Case*. Energies, 9, pp. 628-643. DOI: 10.3390/en9080628.

Principi, P. – Fioretti, R. – Carbonari, A. – Lemma, M. (2016) *Evaluation of energy conservation opportunities through Energy Performance Contracting: A case study in Italy*. Energy and Buildings, 128, pp. 886-899. DOI: 10.1016/j.enbuild.2016.06.068.

Ramos, J.S. – Guerrero Delgado, M. – Álvarez Dominguez, S. – Félix Molina, J.L. – Sánchez de la Flor, F. – Tenorio Rios, J.A. (2019) *Systematic Simplified Simulation Methodology for Deep Energy Retrofitting Towards Nze Targets Using Life Cycle Energy Assessment*. Energies, 12, pp. 3038-3064. DOI: 10.3390/en12163038.

STN 73 0540-2+Z1+Z2:2019 *Tepelná ochrana budov. Tepelnotechnické vlastnosti stavebných konštrukcií a budov.* Časť *2: Funkčné požiadavky*. Konsolidované znenie (*Thermal protection of buildings. Thermal performance of buildings and components. Part 2: Functional requirements*) [in Slovak].

Vargová, A. – Ingeli, R. (2021) *Assessment of the energy demands for heating in a historic building. Case study: Renewal of a functionalist building of the infectious diseases pavilion in Topoľčany, Slovakia*. Slovak Journal of Civil Engineering, 29, pp. 29-36. DOI: 10.2478/sjce-2021-0025.

Życzyńska, A. – Suchorab, Z. – Dyś, G. – Čurpek, J. – Čekon, M. (2020) *An evaluation of the structure of energy consumption in educational buildings in Poland after thermal retrofitting*. Slovak Journal of Civil Engineering, 28, pp. 29-37. DOI: 10.2478/sjce-2020-0028.