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Optimal technical and economic strategy for retrofitting residential buildings in Romania

Mihail-Bogdan CĂRUȚAȘIU
University Politehnica of Bucharest, Bucharest, Romania
carutasiu@gmail.com

Constantin IONESCU
University Politehnica of Bucharest, Bucharest, Romania

Horia NECULA
University Politehnica of Bucharest, Bucharest, Romania

Abstract. *The European Legislation is very strict regarding the importance of reducing the energy consumption in buildings sector. The importance of achieving nearly zero energy consumption levels for both new and existing buildings is also highlighted in each Members' national legislation. Moreover, the high percentage of existing buildings across European Union, indicates that they need to be adequately approached in order to achieve the ambitious energy efficiency goals. This implies creating the optimal technical and financial retrofit strategies regarding minimizing the energy consumption without lowering the interior comfort levels. In Romania, there is no unitary strategy aiming to maximize the energy efficiency in buildings which also takes into consideration the financial part of the process. Moreover, there are no known national guidelines and strategies for buildings retrofit which takes into consideration a wide range of equipment. The Romanian Energy Efficiency Strategy presents few possibilities resulted from integrating renewable energy sources within typical Romanian buildings, while the Buildings Performance Institute Europe conducted a research regarding the potential of nearly Zero Energy Buildings implementation across Romanian territory. Both studies refer only to typical buildings and do not present a large perspective for retrofitting action, while the financial study is not properly presented. Thus, this paper develops a comprehensive financial study which could be used as guideline by stakeholders, in order to find the best technical solution for decreasing the final energy consumption in Romanian residential buildings. Using the RETScreen software and its economical features, there were developed several energy efficiency solutions, and by analyzing the financial benefits implied, the best solution was chosen. By adopting the solutions presented within this feasibility study, the energy consumption of buildings should be significantly reduced.*

Keywords: zero energy buildings, retrofitting, feasibility study, energy efficiency, RETScreen.

Introduction

The European Union (EU) energetic strategy aims drastic reduction of greenhouse gas emission across its territory, by reducing the energy consumption in key sectors. The latest surveys estimated that the buildings sector is responsible for a major share of emissions (35%), due to the fact that is the largest end-use energy consumer in Europe, with a total share of 40% (B. Anastasiu et al, 2011). Moreover, the fact that this sector is continuously growing, determined the European Parliament to introduce "the nearly Zero Energy Buildings" (nZEB) principle as cornerstone for new and retrofit buildings starting from 2018 onwards (Directive 2010/31/EU). In the EU, there are approximately 75% residential buildings, from which, only about 17% were built between 1991 and 2010, thus a

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substantial share of this sector is older than 50 years (more than 40% were built before 1960s) (BPIE, 2011). Due to these facts, the EU's Energy Plan from 2011 stated that *"the sectors that deserves the highest attention are residential, tertiary and transport"*, among which, the residential sector has the highest technical potential for increasing the energy efficiency, estimated at 30% (BPIE, 2011).

In Romania, according to the census from 2011, there are slightly over 5.1 million buildings, totaling approximately 0.5 billion m^2 of useful area, from which, more than 85% is represented by dwellings (BPIE, 2012). The Romanian buildings are responsible for more than 44% of final energy consumption, while more than a half of the existing buildings were built before 1970, and more than 90% before 1989, thus the energy performances are low. A typical building in Romania has an energy performance level ranging from 150 to 400 kWh/m^2/year, from which, more than 55% is required for heating the interior space (EEA, 2011). According to the latest Romanian Energetic Strategy, these statistics implies great efficiency potential for this sector, estimated at 35-50% for dwellings and 13-19% for tertiary buildings. To achieve these daring energy efficiency goals, it is necessary apply different methods for decreasing the energy intensity for both old and new buildings. While for new buildings there are a number of standards to be applied in order to achieve an increased efficiency (e.g. passive-house standard), the most difficult part is to find the optimal strategy to retrofit the existing buildings. This is a very difficult task for Governments, due to the complexity of the given problem: specific climate, efficiency potential, numerical evaluation criteria, available technology and budget, and last but not least, cultural, psychological and aesthetics aspects. Moreover, the importance of renovating the buildings constructed prior to any energy performance requirements, is highlighted in the Energy Efficiency Directive (Directive 2012/27/EU), which required Member States to establish long-term strategies for mobilizing investment in the renovation on national buildings stocks.

Even if the need of creating healthy and comfortable environment in dwellings started since ancient times, the concerns regarding the efficiency of buildings gained popularity due to the recent oil crisis and global warming menace (Ionescu et al., 2015). For Bucharest climate conditions, there have been conducted studies regarding the potential of increasing the energy efficiency of new buildings, by analyzing the behavior of the passive house concept (Carutasiu et al., 2015; Danu et al., 2015). The results showed that the energy consumption can be decreased by combining renewable energy sources with an efficient HVAC (Heating Ventilating and Air Conditioning) system, a special type of architecture, compact shape and very good insulation with minimum thermal bridges. Although the presented approach provided very good results, it does not refer to existing buildings, as it is a construction standard. Thus, this paper presents few possibilities of decreasing the energy consumption in residential buildings, by conducting a cost and technological study in order to choose the best solution.

Literature review

Retrofit strategies and approaches

In recent years, there have been developed national and local strategies focusing on increasing the energy efficiency of existing buildings, subjected to retrofit actions. For example, in a study conducted by the Building Performance Institute Europe (BIPE, 2012) regarding the implementation on nZEB (nearly Zero Energy Buildings) in Romania, the authors defined three reference buildings: detached single-family houses, multi-family houses and office buildings and used a dynamical software (TRNSYS) to simulate the energy requirement based on some assumed thermal proprieties of walls and HVAC (Heating, Ventilating and Air Conditioning) systems. Subsequently, they modify these parameters and added renewable energy systems, resulting 5 variants for nZEB for each reference building. The study was concluded with a financial analysis of the previously obtained solutions, but their approach cannot be widely used to the complexity of the simulation software and the assumptions made. The same approach can be found in the following national studies: (BIPE, 2014), and the same issues were found: the degree of difficulty of the proposed simulation method and the lack of usability among non-experts. These approaches were proved to be difficult to use and are time consuming to develop the accurate mathematical model. Moreover, the complexity of the used methods make difficult to easily integrate the financial feature. Thus, it emerged the necessity of using simpler and focused analysis tools. For this paper, the RETScreen analysis tool was used in order to develop the best retrofit scenario for a residential multi-unit building in Romanian climate conditions.

RETScreen analysis tool

In the last few years, RETScreen software gained popularity among energy efficiency experts and, with more than 200,000 downloads by 2010 become the most used simulation and analysis tool (D. Connolly et al., 2010). This Clean Energy Management Software was developed by Natural Resources Canada, in conjunction with the Canadian Government and different partners from industrial and academic fields and is a powerful tool to analyze the feasibility of renewable energy projects, helping the decision-makers to find the optimal cost-effective solution (Leng et al., 2004). Using RETScreen software, the user can analyze comprehensive projects regarding the implementation of many clean energy technologies, such as: renewable energy electricity generating technologies (wind, hydro and photovoltaic energy systems), renewable energy heating and cooling technologies (biomass, solar-air, solar-water, passive solar heating systems and ground-source heat pumps), combined heat and power (CHP) technologies, biofuels, ventilation heat recovery and efficient refrigeration systems, efficient lighting systems, tidal and wave power, buildings' efficiency measures, etc. (RETScreen Engineering & Cases Toolbox, 2005). Compared with other tools, it presents the advantage that is relatively easy to use (compared with TRNSYS or EnergyPlus), is free and can accurately evaluate both electrical and thermal systems (as compared with HOMER, energyPRO, etc.) (Lee et al., 2012). Moreover, the software has integrated features, including comprehensive databases containing climate data and technologies, as well as suggestive case studies and templates.

In recent years, due to the fact that the developers continuously extended its usability and flexibility, RETScreen gained popularity also among scientific researchers. Moreover, the current concerns about increasing buildings' energy efficiency are quantified in a series of papers which assesses the impact of different strategies over the mitigation of energy consumption in buildings. Lee et al. conducted a study to preliminary determine the optimal size for renewable energy systems to be implemented into buildings (Lee et al., 2012). Salata et al., 2012 determined the best configuration of renewable energy sources which could be used to satisfy the energy demands of some historic buildings in Rome, Italy.

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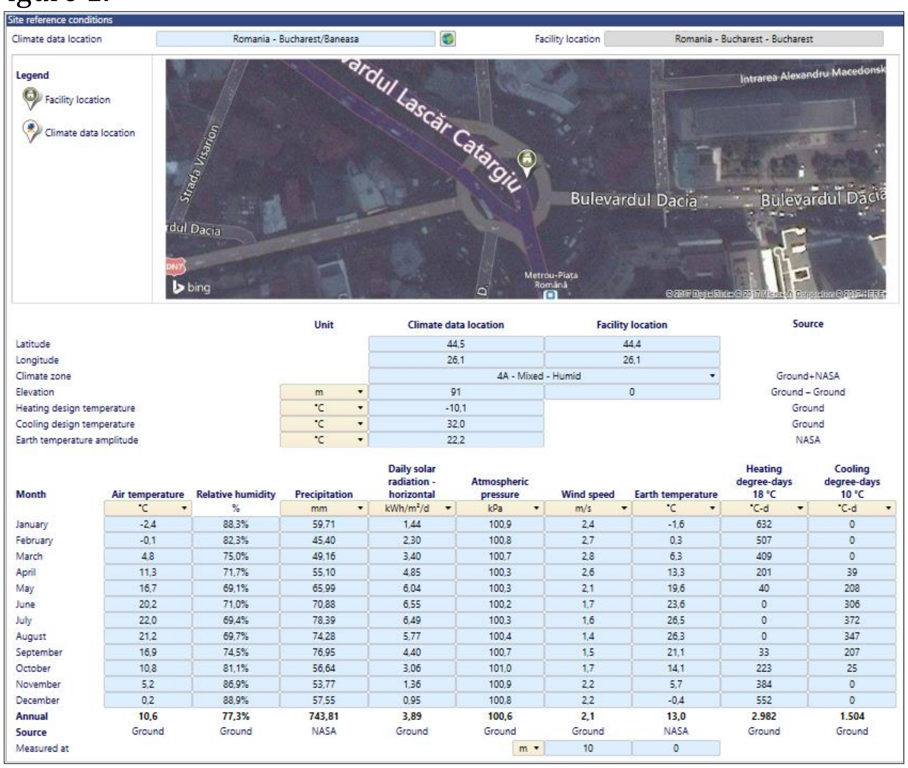
Kim et al., 2016 and Koo et al., 2016 used RETScreen in conjunction with multi-objective optimization models in order to find the optimal solutions for integrating solar electric and thermal renewable energy systems into rooftops of the buildings. The literature survey indicated that the RETScreen software provides satisfactory results for feasibility studies, making it suitable for the subject of this paper.

Simulations and results

Simulations

RETScreen package allows users to develop different energy efficiency models by implementing a five-step procedure, including: energy, cost, emission, financial and sensitivity/risk analysis. Using these features, the authors analyzed the possibility to achieve the desired energy efficiency in residential buildings. The energy consumption of a building is influenced by the exterior environmental conditions of the location, constructions materials, integrated systems, occupancy, etc. Thus, the first step in conducting an efficiency analysis is to select the climate features of the building's location. This enables the database containing weather files, and the data for Bucharest can be analyzed in Figure 1.



	Unit	Climate data location	Facility location	Source
Latitude		44,5	44,4	
Longitude		26,1	26,1	
Climate zone		4A - Mixed - Humid		Ground+NASA
Elevation	m	91	0	Ground – Ground
Heating design temperature	°C	-10,1		Ground
Cooling design temperature	°C	32,0		Ground
Earth temperature amplitude	°C	22,2		NASA

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	-2,4	88,3%	59,71	1,44	100,9	2,4	-1,6	632	0
February	-0,1	82,3%	45,40	2,30	100,8	2,7	0,3	507	0
March	4,8	75,0%	49,16	3,40	100,7	2,8	6,3	409	0
April	11,3	71,7%	55,10	4,85	100,3	2,6	13,3	201	39
May	16,7	69,1%	65,99	6,04	100,3	2,1	19,6	40	208
June	20,2	71,0%	70,88	6,55	100,2	1,7	23,6	0	306
July	22,0	69,4%	78,39	6,49	100,3	1,6	26,5	0	372
August	21,2	69,7%	74,28	5,77	100,4	1,4	26,3	0	347
September	16,9	74,5%	76,95	4,40	100,7	1,5	21,1	33	207
October	10,8	81,1%	56,64	3,06	101,0	1,7	14,1	223	25
November	5,2	86,9%	53,77	1,36	100,9	2,2	5,7	384	0
December	0,2	88,9%	57,55	0,95	100,8	2,2	-0,4	552	0
Annual	**10,6**	**77,3%**	**743,81**	**3,89**	**100,6**	**2,1**	**13,0**	**2.982**	**1.504**
Source	Ground	Ground	NASA	Ground	Ground	Ground	NASA	Ground	Ground
Measured at					m	10	0		

Figure 1. **Climatic data for Bucharest (Băneasa), Romania**

Source: RETScreen software database interface.

As highlighted in Figure 1, the weather data provided for computing the energy consumption is composed of monthly average values of air temperature, relative humidity, precipitation, horizontal daily solar radiation, wind speed (measured at 10 m altitude), ground temperature (measured at 0 m depth), and, most important, heating and cooling degree days. Moreover, the RETScreen database offers the same type of data for 57 towns in

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Romania, including Întorsura Buzăului and Omu Mountain, zones characterized by very low temperatures during winter. This feature allows the users to analyze the costs implied for energy efficiency for a wide climatic area, increasing its applicability. For Bucharest, RETScreen database offers climatic data collected from both Băneasa and Otopeni weather stations. Regardless of the chosen climate zone, the fundament of RETScreen is to compare the benchmark case with the results of the implemented energy efficiency strategies, resulting a comprehensive economic and technical analysis. For this paper, the authors analyzed the possibility to reduce the energy consumption for a typical residential building, placed in Piața Romană, Bucharest, Romania, as highlighted in Figure 1. Therefore, the apartment building, or multi-unit housing, was simulated using the RETScreen software, in order to estimate the best cost-effective energy efficiency strategy.

The climate data and the facility information were chosen and integrated within the *Virtual Energy Analyzer*, a feature which allows the user to estimate the energy savings, employing a comprehensive benchmark system for comparison. The facility was considered representative for Romanian buildings culture and has a total useful surface of 1300 m^2 (small flats building). Moreover, the base case energy consumption, for this representative type of building, the predicted total energy consumption was 311 $kWh/m^2/year$, totaling 404.881 kWh/year. The most feasible energy reduction target was considered to be 30%, as highlighted in Figure 2, thus 121.464 kWh/year final energy savings.

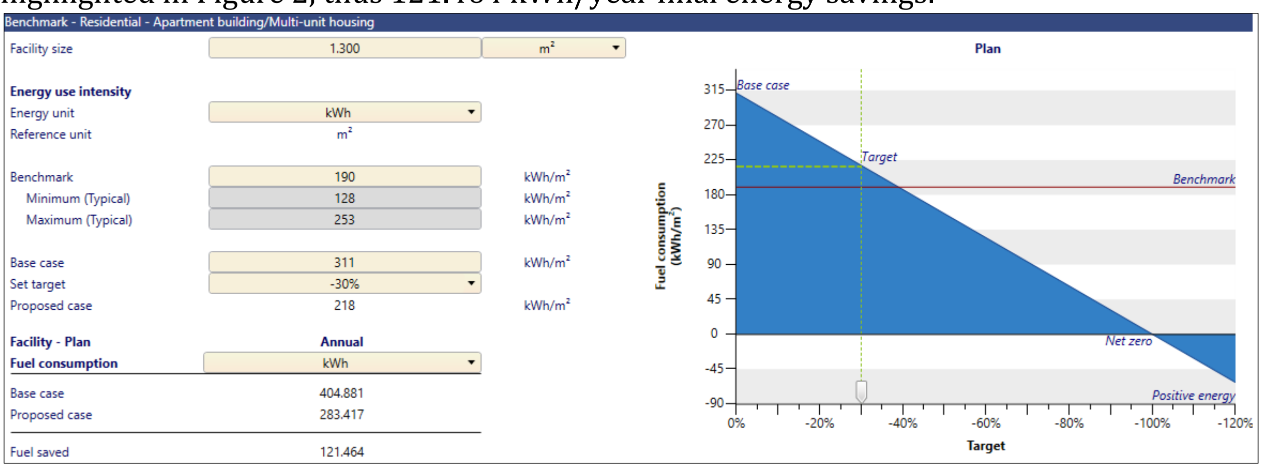

Figure 2. **Energy consumption and reduction target for the analyzed facility**

Source: RETScreen software simulation results.

The proposed measures for achieving these reductions are: reducing the fresh air flow through the ventilation system and install demand-control ventilation system based on CO emissions for the parking spots, changing the illumination infrastructure with a more efficient one, reducing the hot water usage and install renewable energy sources onsite (solar water heater and photovoltaic systems). Even if the energy intensity remains above the nearly zero energy buildings' standard, this percentage of reduction represents the optimal solution from financial point of view. The software allows the users to create different scenarios and to analyze the financial impact of divers strategies and within this paper only the best cost-effective solution was presented.

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Results and discussions

After the energy audit and energy reduction simulation, it was conducted the environment and financial analyzes. For this, each efficiency measure is quantified by both its cost and energy reduction potential. For a better understanding, the cost-effectiveness of changing the illumination system and integrating roof-mounting photovoltaic (PV) panels are discussed.

For the lights infrastructure in individuals' apartments, the proposed efficiency method is to change all laps, without lowering the illumination level, which, as suggested in norms, should not be under 100 lux for residential usage. The base case infrastructure consists of using usual compact fluorescent screw-in laps, with low efficiency (56.7 lm/W). Changing these laps with LEDs (Light Emitting Diode) with an efficiency of 94 lm/W and a lifetime of 50000 hours, the energy reduction was estimated at 2803 kWh/year, or 21.7 %. Moreover, the costs of the equipment indicate a simple payback time of 18.2 year. The same type of analysis was conducted for the illuminated areas: corridor, parking garage, exterior façade and exterior doors. Moreover, the infrastructure proposed for each case can be analyzed in Table 1, in which, BC is the base case and PC is the proposed case.

Table 1. *Comparison between illumination systems used for efficiency*

Zone	**Corridor**		**Garage**		**Exterior façade**		**Exterior doors**	
-	BC	PC	BC	PC	BC	PC	BC	PC
Lamp type	Fluorescent T5	LED	Fluorescent T8	LED	High pressure sodium	LED	High pressure sodium	LED
Efficiency [lm/W]	90,6	100	85,5	100	104,6	67	104,6	67
No. lamps	4	4	90	90	12	12	6	6
Operating [h/w]	168	168	168	42	84	84	84	84
Electricity [kWh]	4345	2102	26017	3548	2943	1156	1472	578
Costs [€/piece]	38	58	32	58	20	50	20	50
Payback [years]	2.8		1.3		52.4		52.4	

Source: Authors' own research.

Moreover, the same type of analysis is proposed for reducing even more the electricity consumption of the analyzed building. For this, the authors propose roof-mounted photovoltaic panels, designed taking into consideration both efficiency and economic features. The PV panels are fixed (no solar tracking infrastructure – for financial reasons), mounted with a 44^{o} slope and 0^{o} azimuth angle. The 135 mono-Si panels have a nominal power of 27 kW, thus, influenced by the Bucharest solar radiation (presented in Figure 1), implies 33 MWh/year energy savings (considering the manufactures efficiency of 15,75%). Moreover, the total area of the solar collectors is 171 m^2, and are mounted on the building's roof. The losses due to the exterior temperature are considered to be maximum 15%. The chosen inverter has a capacity of 24 kW, an efficiency of 95% and miscellaneous losses estimated at 1%. The manufacturer indicated a specific cost of 3300 €/kW, resulting a total investment of 89100 €, while the OM savings are estimated at approximately 44€/kW/year (1188 € total). The simple payback of this solution is estimated at 42.3 years, indicating a longer period than the PV system's lifetime. In addition, the analyze performed over the proposed integrated renewable energy solar water system is detailed in Figure 3.

Month	Percent of month used - base case %	Percent of month used - proposed case %	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Heating delivered kWh
January	100%	100%	1,44	2,64	613,364
February	100%	100%	2,30	3,49	910,865
March	100%	100%	3,40	4,20	1.323,765
April	100%	100%	4,85	5,10	1.623,738
May	100%	100%	6,04	5,61	1.844,696
June	100%	100%	6,55	5,75	1.809,628
July	100%	100%	6,49	5,85	1.879,690
August	100%	100%	5,77	5,78	1.829,274
September	100%	100%	4,40	5,21	1.558,832
October	100%	100%	3,06	4,55	1.366,652
November	100%	100%	1,36	2,12	393,548
December	100%	100%	0,95	1,50	107,697
Annual	**100%**	**100%**	**3,89**	**4,32**	**15.261,748**

Annual solar radiation - horizontal	MWh/m²	1,42
Annual solar radiation - tilted	MWh/m²	1,58
Solar water heater		
Type		Glazed
Manufacturer		
Model		
Gross area per solar collector	m²	2,96
Aperture area per solar collector	m²	2,78
Fr (tau alpha) coefficient		0,64
Fr UL coefficient	(W/m²)/°C	4,65
Temperature coefficient for Fr UL	(W/m²)/°C²	
Number of collectors - suggested		10
Number of collectors		10
Solar collector area	m²	29,6
Capacity	kW	19,5

Figure 3. **Technical data and hot water production of the solar system**

Source: Authors' simulation in RETScreen.

Using this type of solar water heater combined with a 75 l/m² storage system and an efficient heat exchanger, the solar fraction (representing the percentage of hot water provided by the system from total required hot water) was estimated at 42%, while the initial cost increased at approximately 25000 €, implying a playback period of 45.5 years.

Regarding the greenhouse gases emissions (GHG), the totality of the adopted energy reduction strategies has a significant impact. Considering the GHG emission factor of 0,536 $kgCO_2/kWh$ (representative for Romania), the gross annual emission reduction is estimated at approximately 100 tCO_2. Moreover, this quantity is equivalent with: approx. 18 cars and trucks not used, 42.385 litres of gasoline not consumed, 230 barrels of crude oil not consumes, 9 hectares of forest absorbing carbon or 34 tonnes of recycled waste. The total GHG reduction avenue is estimated at 99 tCO_2/year (1973 tCO_2 over the project's lifetime).

After the energy and environmental impact, the authors simulated the project's financial impact. For this, the above presented assumptions were considered over the most important financial parameters: fuel cost escalation rate – 2%, inflation rate: 2%, discount rate – 9% and the project's life time – 20 years.

Moreover, we did not take into consideration any incentives or grants provided by Government, for example. Form the total proposed investment, summing 194.762 €, we considered a debt ratio of 70%, representing 136.333 €. Thus, the equity, representing the portion of the total investment required to finance the project is considered to be funded directly by the apartments' owners. The debt interest rate was set at 7%, while the debt term is considered to last 15 years, resulting a yearly debt payment of approx. 15.000 € or 1250 €/month. The monthly payment for each apartment will not exceed 39 €, representing approx. 12% of the Romanian minimum wage. Moreover, the software simulated the savings and revenue of the project, totaling 47.451 €. The financial viability is detailed in Table 3, while the yearly cash flows (pre-tax and cumulative cash flows) are presented in Figure 4.

Table 3. *Project's financial viability indexes*

Pre-tax IRR – equity [%]	16,2
Pre-tax IRR – assets [%]	3,4
Simple payback [years]	9,2
Equity payback [years]	7,3
Net Present Value [€]	47.821
Annual life cycle saving [€/year]	5.239
Benefit – Cost (B-C) ratio [-]	1,8
Debt service coverage	1,4

Source: Authors' own research.

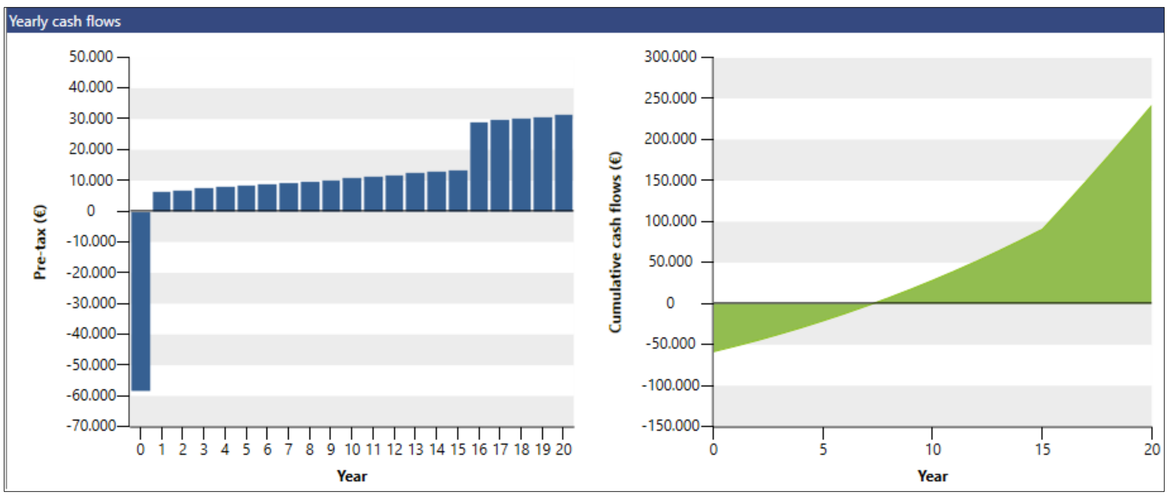

Figure 4. **Project's yearly pre-tax and cumulative cash flows**

Source: Authors' simulation in RETScreen.

This comprehensive financial analysis shows the project's feasibility, and, the resulted payback of 9,2 years (compared with the project's lifetime) strengthens the applicability of the proposed energy efficiency methods. Moreover, due to the renewable energy sources, the cumulative cash flow shows, that, starting from the eighth year of usage, the values are positive, increasing the project's feasibility. Without this measure, the project's payback period decreases at 4,4 years (compared with 9,2 years), but the overall benefits are also lowered. Moreover, the simple risk analysis performed over on the equity payback (detailed in Figure 5) strengthens the positive impact of the proposed energy efficiency solutions.

Perform analysis on: Equity payback
Sensitivity range: 25%
Threshold: 7 yr

- Remove analysis

Initial costs €

Fuel cost - base case		146.072	170.417	194.762	219.107	243.453
€		-25,0%	-12,5%	0,0%	12,5%	25,0%
35.588	-25,0%	18,6	> project	> project	> project	> project
41.520	-12,5%	8,0	11,9	15,7	17,3	18,9
47.451	0,0%	4,0	5,4	**7,3**	9,7	12,9
53.382	12,5%	2,6	3,4	4,3	5,4	6,9
59.314	25,0%	1,9	2,4	3,0	3,7	4,5

Figure 5. **Project's sensitivity analysis performed on the equity payback**

Source: Authors' simulation in RETScreen.

Conclusion

This paper analyses the technical and financial possibility to increase the energy efficiency of a residential multi-unit housing located in Bucharest, Romania. The idea emerged from the need of the European Union's Members to decrease their fossil fuels consumption, and the fact that the buildings sector became the major end-use energy consumer. Moreover, there are no national studies regarding the best technical and financial strategies, that need to be adopted in order to increase the energy efficiency of residential multi-unit housing.

In this study, a block of flats composed of 32 apartments (1300 m^2 total surface) was subject to a retrofit strategy, involving, among others solutions, changing the illumination system and integrating renewable energy sources to decrease the energy requirements for electrical devices and hot water preparation. The project's objective was to decrease the overall energy consumption with 30%, considered to provide the best technical and economical solution. The total investment was 194.762 €. While it was considered that only 30% are paid immediately by the owners, the rest of the sum was paid through debt over 15 years. The resulted overall savings are quantified by approx. 151.000 kWh energy, 99 tCO_2 emissions and 47.451 € annual savings and revenue. Moreover, the 7.3 year-equity payback time increases the project's feasibility.

Future researches are ongoing, and this study will extend to analyse more efficiency strategies and more type of buildings, including residential – attached and detached dwellings, commercial and institutional. Moreover, this paper represents the starting point of more complex research strategies, involving the integration of multi-objective optimization methods, used to find the optimal solution for any buildings. This complex mathematical approach will be integrated within a user-friendly interface and is intended for non-expert. The idea was proposed for financing through national postdoctoral research projects competition.

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