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# Optimizing Energy-Saving Measures in New Residential Buildings Regarding Life-Cycle Costs

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**Abstract:** This contribution is focused on the issue of the application of energy-saving measures in the construction of new residential properties and their optimal combinations with regard to the life-cycle costs of these buildings. The aim of the research is to create a methodological basis for considering the economic and financial impacts of various combinations of energy-saving measures, aiming at the optimization of these measures and the sustainability of developer projects. The research methodology is based on the principle of building life-cycle costs, which serve as a key criterion for the process of choosing the optimal combination of energy-saving measures and for comparing a conventional solution with an innovative solution including the application of energy-saving measures. The result of the research is the methodological approach for the design of technologically proven combinations of energy-saving measures, which will lead to optimization of the life-cycle costs with regard to the reference variant represented by a conventional solution. This approach is subsequently verified on three case studies of residential properties with a proposal for the optimal combination of energy-saving measures in the form of photovoltaic panels and a water-air heat pump. The added value of the paper consists of the possibility of optimizing the building construction project from the point of view of energy-saving measures already in the design phase.

**Keywords:** energy-saving measures; life-cycle costing; optimization; residential properties

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## 1. Introduction

The European Union places a strong emphasis on the environment and sustainability in its decisions and is at the forefront of actions against climate change. The EU has adopted a policy to reduce greenhouse gas emissions and promote clean energy. The European Green Deal, published in December 2019, is the main document of this Roadmap and represents the EU's largest measure to achieve climate neutrality [1]. The European Green Deal is a roadmap to decarbonize the EU economy by 2050, thus revolutionizing the EU's energy system and revolutionizing the economy. The construction industry is also one of the main areas, with an emphasis on renovated and energy-efficient buildings [2]. This phase of practical prevention and mitigation of undesirable change has already started and has already achieved varying degrees of progress across countries. This article presents the results of the study focused on optimizing the structure of energy-saving solutions in the construction of residential buildings within the developer activity of a private investor. The aim of the research is to create a methodological basis for considering the economic and financial impacts of various combinations of energy-saving measures, aiming at the optimization of these measures and the sustainability of developer projects. The research is triggered by the need for developers to optimize the selection of suitable energy-saving measures already in the design phase of the project so that in the investment phase there are no more fundamental changes in the project documentation and user characteristics in general. The requirement of developers is characterized as the possibility of presenting to

future users an offer of an optimal solution of energy-saving measures that will reflect not only the needs of the investor and the owner or operator of the building but also the needs of future users. In relation to the goal of research and the justification of its necessity and importance for development projects, a key research question is defined in the following wording:

"Which approaches can bring the optimal solution for energy saving measures to be selected for development projects in residential construction, and what aspects must be taken into account in the decision-making process?".

## 2. Literature Review

The issue of electricity consumption, specifically the issue of energy savings in the construction industry, is the subject of a large number of scientific publications. Partial publications are focused on the conceptual solution of the energy situation in the construction industry at the level of the state or region; others are then oriented to the solution of specific populated areas, construction objects, or projects. The subject of a study [3] is to present a systematic overview of various initiatives (official, political, and institutional) and to link them to the concept of sustainability and the Green Deal. Several obstacles stand in the way of the wide spread of complex energy renovations of buildings, including the complexity of financing the initial cost of energy renovations. Despite the different policies implemented to remove some of these obstacles, current investment in buildings remains at sub-optimal levels [4]. The source provides an overview of current financing practices for energy renovations and examines some innovative instruments with a focus on their applicability to residential buildings. The study from Ireland [5] shows testing of the effectiveness of some energy modernization policies. It focuses on the use of the Urban Building Energy Model (UBEM) to support the Green Agreement and the planned wave of renovations. The methodology is then used to quantify the most cost-effective combination of envelope modernization and on-site energy generation to achieve emissions reductions by 2030.

A number of publications in the field of energy-saving measures deal with the issue of national or regional policies aimed at energy savings in the use of buildings. The contribution [6] is aimed at assessing the impacts of a policy aimed at reducing greenhouse gas emissions thanks to energy savings in residential housing in France. Attention is paid here to the prediction of the development of greenhouse gas emissions by 2050 and the possibilities of national policies to reduce these emissions. Support for the creation of an effective policy in the area of the construction sector in Denmark and its impact on the environment is also identified in the contribution [7]. The research is aimed at evaluating the efficiency of energy savings in residential buildings with respect to the impacts on the environment while respecting the impacts of heat production methods. The aim here is to contribute to the reduction of environmental externalities associated with energy production and consumption. The effectiveness of government policies aimed at energy-saving measures is also addressed in the publication [8]. The contribution is aimed at a detailed survey of the impacts of energy saving measures on individual types of households, which also documents an interesting conclusion in the form of a discrepancy between the declared efficiency of measures and the actual (disproportionately low) savings of households. The evaluation of the effectiveness of programs to support the reduction of the energy performance of residential buildings in Ireland is the subject of the contribution [9]. Within the presented research, an ex-post analysis of the efficiency of energy-saving measures implemented in the period 2006–2012 is carried out. For the identified savings, the contribution of the influence of the actual efficiency of implemented measures and the economic crisis, which motivated the users to energy savings itself, is subsequently examined. The article [10] is devoted to a general evaluation of the policy focused on energy-saving measures implemented in Shanghai. The article identifies economically optimal sets of savings measures—technical solutions that, according to the results of the study, show a relatively

acceptable average payback period depending on the technical characteristics of buildings and up to 80% energy savings.

Another group of publications is subsequently focused on the energy savings of specific types of buildings or specific projects in the areas of residential and non-residential construction. In the case of non-residential construction, it is possible to point, for example, to a contribution [11], which is focused on the great potential of energy savings in the case of the implementation of low-energy measures in the case of hotels with an indicated low time of their economic return. Non-residential buildings, more precisely corporate buildings, are solved in a contribution [12]. The research is carried out in the environment of corporate properties in the Netherlands and is focused on the development of a tool for the economic evaluation of energy-saving measures and other operational solutions in this sector. The tool is subsequently verified in a case study of municipal office buildings.

However, the majority of publications within the scope of the issue are focused mainly on the residential sector, especially on the application of additional measures related to the reduction of the energy performance of buildings. The issue of additional modifications to family houses for the purpose of energy savings is considered in a contribution [13]. The authors here illustrate the possibilities of combinations of saving measures, including all kinds of insulation, renewal of the heating system, solar panels, or lighting, in a case study of the revitalization of family houses in Greece. Based on the evaluation of indicators such as the Net Present Value (NPV) or the Internal Rate of Return (IRR), measures improving the lighting system, roof insulation, and automatic temperature control system were identified as the most effective. A wide portfolio of energy-saving measures is also offered by the analysis presented in the publication [14]. The contribution deals with the robustness of partial combinations of energy-saving measures. The model is carried out on a sample of four Swedish cities on already operated residential buildings in relation to anticipated climate changes as well as the development of electricity prices. Here, measures aimed at reducing the need for heating appear to be the most resilient against future challenges. The contribution [15] is also aimed at identifying solutions with the greatest energy-saving potential, which are, however, put in context with the behavior of property users. Here, energy savings are dealt with together with water savings, which seems to be a logical link given the ecological dimensions of both energy and water consumption. The study concerns a combination of more than 70 measures leading to water or household energy savings in California. The contribution [16] focuses on another dimension of the implementation of energy-saving measures in existing buildings. The subject of the contribution is an assessment of the added value caused by an increase in the value of the building on the real estate market due to the implementation of energy-saving measures. The study is carried out on buildings in Romania and aims to find, in addition to the energy savings themselves, an additional incentive for investors to implement energy-saving measures on buildings. The principle of "Willingness to Pay (WTP)" is introduced in a contribution [17] and is applied to the evaluation of energy-saving measures in buildings. This approach is applied to users of residential buildings in Korea and is aimed at optimizing the decision on the application of the most appropriate option of energy-saving measures. The evaluated options are replacement of windows, facade insulation, and air conditioning. WTP is also a key topic for the authors of the paper [18]. In this paper, the authors present the results of their research aimed at quantifying the benefits associated with the use of office buildings certified according to the BREEM or LEED system. A key tool is a questionnaire survey among office space users aimed at expressing preferences in the case of the quality of the space used in relation to the paid rent. According to the results, the British BREEM system appears to be the preferred option over the overall second American LEED and other subsequent certification systems.

The motivation of owners and users of residential properties to implement complex energy-saving measures is the subject of research carried out by the authors of the publication [19]. Based on a sample of more than 1000 German users, broader reasons, including economic and non-economic motives and objectives, are presented here. Identification of

the optimal combination of energy-saving measures in building revitalization is the subject of the paper [20]. Within the paper, the model situation of realization of possible energy saving measures on office buildings in Germany is assessed, and the economic efficiency (using NPV) of partial combinations is calculated. The model also perceives the dependence on the hypothetical energy price development; for these purposes, the Monte-Carlo simulation and the theory of real options are used. The authors of the paper [21] have chosen an interesting approach to the assessment of the suitability of the application of the sub-variants of energy-saving measures. The case study of the revitalization of family houses in Brazil compares the efficiency of energy savings generated by energy-saving measures with the production of cheap energy using photovoltaics. In essence, it is assessed whether it is more efficient to use less expensive energy or to decrease energy consumption under given conditions. The paper [22] is aimed at identifying, assessing, and subsequently selecting the most suitable "packages" of energy-saving measures for building renovation. The proposed method allows the formulation of partial energy-saving combinations of measures ("packages"), and its functionality is subsequently verified in a case study in which, from 131 possible options, "only" 4 "packages" are identified, which are then further analyzed from the point of view of suitability. The proposed method is based on a "decision tree", and the criteria for selecting optimal solutions have been established as energy efficiency, environmental impact, economic rationality, comfort, and duration. The contribution [23] is specifically aimed at savings in electricity consumption. The paper focuses in particular on energy savings associated with the operation of lighting and electrical appliances in residential buildings. The paper points out the rapid economic return of these measures and significant energy savings over ten years. The authors of the article [24] dealt with the collection of data for the possibility of evaluating the economic efficiency of energy-saving measures. In their paper, they focused in particular on the collection of data on investment costs, payback period, lifetime, emissions, and energy savings. The authors of the paper [25] present in their paper the results of research focused on the effectiveness of technical designs of energy-saving measures in residential buildings in France. The research is based on an extensive database of data, which is further processed using Cost-Benefit Analysis (CBA) and simulation. The key result is the identification of the most effective energy-saving measures in the form of temperature reduction, installation of condensing boilers, and thermal insulation of the floor. The issue of green roofs as one of the tools for reducing temperatures and the energy needs of cooling is addressed by the authors of the paper [26]. The published case study presents very positive impacts of the installation of green roofs on indoor temperature and energy consumption for cooling in the case of buildings in Egypt. The technical solution to energy-saving measures is discussed by the authors of the paper [27]. The authors note here the influence of air heating or cooling on the overall energy balance of an energy-saving building. Air heating appears to be a process more sensitive to the thermal insulation performance of the building envelope, while air cooling is perceived as less sensitive to the thermal insulation performance of the building envelope. From this point of view, the authors discuss the use of heat recovery equipment and determine the expected savings in the case study. This topic was also considered by the authors of the presented paper; however, the recovery system was considered a less effective option due to the high acquisition costs than the combination chosen below (in the case study).

The introduction of energy-saving measures in the case of residential real estate realization as one of the paths to carbon neutrality is the subject of the study published in the paper [28]. This study compares approaches and options to achieve carbon neutrality in the residential construction sector in Europe and China. The results of the study show different paths chosen in the compared locations. In the case of China, it is a motivational subsidy policy; in the case of Europe, it is more of a motivation to economize households. The role of the way of financing energy-saving measures in the case of commercial properties is discussed in the paper [29]. Here, the authors address the influence of partial factors on

the decision-making of small and medium-sized enterprises to adopt appropriate energy-saving measures in the data model from 2017.

A very wide range of information can be found and processed within two key databases, including information on buildings and their operations for the United States [30] and for Europe, specifically for individual EU states [31]. The Building Performance Database [30] includes information on residential, mixed, and commercial buildings from across the U.S. through a number of classification criteria, including use, materials, location, building systems, applied technologies, and energy performance. For residential and mixed-use buildings only, the database includes information on 795,857 buildings. The "Database of grey-box model parameter values for EU building typologies" [31] includes information on buildings in the EU, broken down in terms of the building construction period, the country of construction, the use aspect, and other detailed aspects, focusing in particular on parameters related to the size of buildings or their technical and energy characteristics. The data in the database is based on more than 80 million reference buildings; for residential use, the data is based on more than 1.4 million buildings. For the purposes of the presented research, indicative developments in the energy performance of buildings in the Czech Republic from the year 1850 to the present can be given. The data are summarized briefly in Table 1.

**Table 1.** Reference residential buildings and the development of their energy consumption in the Czech Republic [31].

| Reference Building Construction Year Low | Reference Building Construction Year High | Reference Building Useful Floor Area ($m^2$) | Number of Reference Buildings in the Building Stock Segment | Number of Reference Building Storeys | Reference Building Ground Floor Area ($m^2$) | Yearly Energy Use [$kWh/m^2$] |
|---|---|---|---|---|---|---|
| 1850 | 1920 | 1357 | 8451 | 6 | 283 | 282.34 |
| 1921 | 1945 | 967 | 4962 | 5 | 256 | 190.11 |
| 1946 | 1960 | 745 | 18,622 | 3 | 316 | 250.47 |
| 1961 | 1980 | 2812 | 10,321 | 8 | 454 | 155.22 |
| 1981 | 1994 | 6949 | 1315 | 9 | 972 | 116.31 |
| 1995 | 2021 | 5323 | 1622 | 13 | 480 | 117.83 |

Similar information can be obtained from the database [31] for other countries, other uses, as well as for other technical or energy parameters of buildings in the EU. The data are not a direct subject of the analysis presented in this paper; their task is only to provide a general demonstration of the development in energy consumption in residential housing, which can be influenced not only by the development in the area of technical solutions for structures or the energy intensity of resources for heating, cooling, or water heating but also by the development of users' needs in terms of thermal well-being, indoor climate quality in buildings, or the use of other energy-intensive technologies. These values are followed by a brief assessment of the impact of energy-saving measures on the energy consumption of buildings, which are the subject of the case study, presented in Section 5, Discussion.

From the presented literary research, the authors show great interest in the issue of energy-saving measures applied to residential, office, and industrial buildings. The problem is solved from both a technical and an economic point of view, within which the use of Cost-Benefit Analysis, Multicriteria Analysis, or Willingness to Pay can be highlighted, as detailed below. Through the optics of literary research, the use of construction life cycle costs appears to be innovative, even though it is, of course, an approach already known and described. It is also evident from the mentioned literature search that individual researchers focus mainly on the issue of existing or older buildings. From this point of view, the application of a methodical procedure to select the optimal combination of energy-saving measures in the design of buildings appears to be an issue that has so far been rather on the fringes of the scientific community's interest.

The effectiveness of energy-saving measures is monitored on the basis of various approaches and methodologies of the aforementioned authors, in particular the concepts of NPV, IRR, Payback Period [8,10–13,16,20–22,24,25], multicriterial analysis [14], or marginal willingness to pay [17,18]. The authors of this article focused on the monitoring of differing LCCs in new residential buildings.

## 3. Materials and Methods

The design of the methodology for assessing the economic and financial aspects of the implementation of considered combinations of energy-saving solutions beyond conventional solutions in the case of new-build residential properties is based on the general principle of Life Cycle Costing (LCC). In the case of the presented research, LCC is considered according to ISO 15686:2008, Part 5 [32]. The calculation is based on the modeling of the difference in cash flows of the two compared project options: Option 0—a conventional solution (without energy-saving measures) and Option 1—an innovative solution (with energy-saving measures). Following the life cycle costing approach mentioned above, the life cycle costs of the compared variants of projects are determined.

In the case of conventional solutions, the investment costs include the costs of the project documentation and construction costs, which include the implementation of the conventional heating and D.H.W. heating solutions and do not foresee the actual production of electricity. The operating costs include repair and maintenance costs of 1.5% of the investment costs and operating costs for water, heat, and D.H.W. heating and electricity consumption (hereinafter 'water, energy').

In the context of an innovative solution, the investment costs include the costs of design documentation and construction costs, which, in addition to the conventional solution, also include the investment costs for the implementation of the selected energy saving measures. The operating costs include repair and maintenance costs of 1.5% of the investment costs of the standard solutions and operating costs for water consumption, heat consumption for heating and D.H.W. heating, and electricity consumption (hereinafter 'water, energy'). The operating costs for repair and maintenance for the selected energy saving measures are determined separately for the selected energy saving measures, as are the operating costs for running the sub-measures, e.g., electricity in the case of heat pumps.

A key part of the determination of life-cycle costs in the case of an innovative solution is the savings (water, heat, and electricity) generated by the application of a selected energy-saving measure, which are considered negative in the determination of life-cycle costs.

In justified cases, an adjustment of the investment costs can still be made by a reduction of an item per heating system, which in the case of some combinations of energy-saving measures would not be needed.

The relationships below for calculating the life cycle costs of both conventional and innovative solutions are based on the principles set out in ISO 15686-5 [32] and are derived from the relationships set out in this standard.

The life-cycle costs for the conventional option ($LCC_0$) can be characterized by the following Relationship (1):

$$LCC_0 = \sum_{i=1}^{n} (IC_{0i} + OPC_{0i}) \times \frac{1}{(1+r)^i}, \quad (1)$$

where $n$ is the length of the evaluation period, $IC_{0i}$ are investment costs of the zero option in year $i$, $OPC_{0i}$ are operating costs of the zero option in year $i$, and $r$ is the discount rate.

The life-cycle costs for the innovative solution option ($LCC_I$) can be characterized by the following Relationship (2):

$$LCC_I = \sum_{i=1}^{n} (IC_{Ii} + OPC_{Ii}) \times \frac{1}{(1+r)^i}, \quad (2)$$

where $n$ is the length of the evaluation period, $IC_{Ii}$ are investment costs of the innovative option in year $i$, $OPC_{Ii}$ are operating costs of the innovative option in year $i$, and $r$ is the discount rate.

More information on the life cycle costs of buildings and the Net Present Value can be found, for example, in documents [33–35].

For each technically appropriate combination of measures, the following results can be determined for a specific building:

- The value of the measure's benefit, i.e., the life-cycle cost savings (Net Savings—*NS*) between Option 0 and Option 1, is the difference in costs between the options that arises as a result of the application of the chosen energy-saving measures, which can be written by the following Relationship (3):

$$NS = LCC_0 - LCC_I \tag{3}$$

- Annual savings in operating costs ($NS_{OPC}$) per building, average flat, or square meter, of floor area due to selected energy-saving measures.

$$NS_{OPC} = C_{OPC0} - C_{OPC1}, \tag{4}$$

  where $C_{OPC0}$ are operating costs (Option 0) and $C_{OPC1}$ are operating costs (Option 1).

- The pay-off period (the time of the return of investment costs in years with positive cash flow) of the implemented measures.
- The profitability (PI) of implemented measures in nominal/discounted values as a proportion of the operating cost savings of the evaluated period and the increment of investment costs in the year of implementation.

$$PI = \frac{n \times B_{OPC}}{\Delta IC} \quad or \quad PI = 1 + \frac{B_{LCC}}{\Delta IC}, \tag{5}$$

  where $n$ is the number of years of the assessment period and $\Delta IC$ are investment costs for the sub-energy measure in CZK.

In general, residential properties allow, in most cases, the following innovative measures and their combinations:

- photovoltaic power plant without a battery system,
- photovoltaic power plant with a battery system,
- solar panels,
- water-to-air heat pumps,
- ground-to-water heat pumps,
- recuperation units,
- use of heat recuperation from gray waste water in order to preheat the D.H.W.,
- use of grey water,
- local heating of the VRV (Variable Refrigerant Volume), direct heating in the bathroom, and local heating of the D.H.W.,
- central heating of the air conditioning + direct heating in the bathroom, local heating of the D.H.W.

The following data are required as key input data for the calculation:

- investment costs (including construction costs and project documentation costs) in €,
- investment costs of the heating system in €,
- floor area of the building in $m^2$,
- area of flats in $m^2$,
- built-up area of the building in $m^2$,
- number of flats,
- number of residents,
- area of commercial units in $m^2$,

- projected annual water demand in $m^3$,
- projected annual electricity demand in MWh,
- estimated annual heat demand for heating in GJ,
- estimated annual heat demand for D.H.W. in GJ,
- estimated annual heat demand for air conditioning in GJ,
- estimated unit price of energy in CZK (or another currency unit) per MWh or GJ.

Lastly:

- length of the evaluation period in years,
- discount rate in %.

The proposed methodological procedure is fundamentally based on life cycle costs (LCC). Life cycle costs are separately determined for variant 0 (conventional) and for variant 1 (innovative). The conventional variant of the LCC calculation considers the investment costs of the building, the annual costs of repairs and maintenance, and the annual operating costs (mainly energy and water consumption), all for the building without the application of energy-saving measures. For the innovative option(s), in addition to the costs mentioned above, investment costs, annual repair and maintenance costs, annual operating energy costs, and annual savings associated with a defined combination of energy-saving measures are also included. The LCC of innovative variants is then compared with the LCC of conventional variants. The optimal combination of energy-saving measures is therefore the combination with the lowest LCC. The optimization process is carried out using a calculation table processed in MS Excel; it is described in more detail in the Results section.

## 4. Results

The section is divided into three subsections: data, case study, and results of case studies.

### *4.1. Data*

The initial research sample consists of three residential properties in the city of Brno. These are projects in the design phase, so it is possible to select and subsequently implement the optimal combination of energy-saving measures according to the criteria described in the previous chapter using the proposed methodological procedure. The selected sample of buildings serves mainly to verify the functionality of the proposed methodical procedure. The goal of the case study is not to provide statistically proven information about possible financial or energy savings but to demonstrate the technical usability of the proposed procedure for practical application. Using the procedure described in the methodological section, a number of energy-saving combinations were economically assessed in the case study. The key limit for the formulation of individual combinations of energy-saving measures, which are listed in the previous part of the contribution, was their meaningfulness and technical feasibility, which were assessed by the energy specialist of the investor providing the basis for the case studies. The authors of the article then created a calculation table in the MS Excel environment, with the help of which the life cycle costs were determined for individual combinations. Life cycle costs thus serve as a key criterion for choosing the optimal variant. The option with the lowest life-cycle costs is optimal.

As part of the optimization process, all technically meaningful combinations of energy-saving measures, which are listed in the previous chapter, were assessed using the above-mentioned calculation table. For each individual measure, investment costs, annual repair and maintenance costs, annual energy operating costs, and the total annual energy savings achieved by applying the given measure were determined individually. These data were subsequently used as input data for determining the life cycle costs of the chosen combination of energy saving measures, which were subsequently compared with the life cycle costs of the reference variant, i.e., Option 0—conventional.

The given input data for calculating the life cycle costs of the individual evaluated variants and partial combinations was taken from the project documentation, technical reports, and certificates of energy efficiency of the buildings evaluated. The data was provided by the investor. Source [36] was also used as a source of input data on partial

solutions for energy-saving measures. This report was elaborated upon at the request of the investor in the evaluated buildings.

One of the possible combinations of energy-saving measures, which includes the implementation of FVE (without battery system) in combination with a water-air heat pump, is presented in this paper. From the LCC point of view, it is the most economically advantageous combination of energy-saving measures of all possible previously evaluated technologically meaningful combinations. It is the combination that is also the most economically advantageous for all the residential property construction projects evaluated below. This option is labeled Option 1 (innovative) and is compared with the option without the implementation of energy-saving measures labeled Option 0 (conventional).

### *4.2. Case Study*

A description of the basic parameters of individual project variants of residential property construction projects for LCC calculation is contained in Table 2.

**Table 2.** Basic parameters of residential property.

| Item | Real Estate 1 | Real Estate 2 | Real Estate 3 |
|---|---|---|---|
| Investment costs: Variant 0—conventional (CZK) | 40,800,000 | 425,000,000 | 206,000,000 |
| Investment costs: Variant 1—innovative (CZK) | 42,083,867 | 432,165,440 | 210,018,133 |
| Floor area of flats ($m^2$) | 858 | 6275 | 3629 |
| Annual operating costs—Variant 0, conventional solution (CZK/year) | | | |
| Repair and maintenance—a conventional part of design | 612,000 | 6,375,000 | 3,090,000 |
| Energy and water | 644,967 | 9,074,497 | 4,348,483 |
| Annual operating costs—Variant 1, innovative solution (CZK/year) | | | |
| Repair and maintenance—a conventional part of design | 612,000 | 6,375,000 | 3,090,000 |
| Repair and maintenance—measure | 16,064 | 215,295 | 100,008 |
| Energy and water | 429,644 | 6,208,667 | 3,017,202 |

Energy and water costs for the case of "Option 1—innovative solution" set out in Table 2 are based on the energy and water needs defined under the conventional solution. This need is reduced by the savings in water and energy consumption made possible by the application of energy-saving measures. The savings caused by energy-saving measures have been determined separately for the individual measures compared to the conventional solution, and then the total savings generated by the chosen combination of energy-saving measures are added to the subsequent calculation. The need is further increased by the water and energy consumption required for the operation of the chosen combination of energy-saving measures. The detailed calculation of the operating costs of energy and water for Option 1—innovative solutions is presented in Table 3.

**Table 3.** Calculation of energy and water costs for Option 1—innovative solutions.

| Annual Operating Costs—Option 1, Innovative Solutions (CZK/Year) | | | |
|---|---|---|---|
| Energy and water—a conventional part of the proposal (+) | 644,967 | 9,074,497 | 4,348,483 |
| Energy and water—savings in the application of measures (-) | 408,656 | 6,904,164 | 3,202,948 |
| Energy and water—operation of measures (+) | 193,333 | 4,038,333 | 1,871,667 |
| Energy and water—the resulting cost of the innovative solution | 429,644 | 6,208,667 | 3,017,202 |

The energy prices used in the calculations are shown in Table 4.

**Table 4.** Input energy prices at price level 9/2022.

| Item | Unit Price | M. u. |
|---|---|---|
| Electrical energy | 6000 | CZK/MWh |
| Central heat source | 862 | CZK/GJ |
| Water/bilge | 86.66 | CZK/$m^3$ |

Following the methodological part, further input variables were also determined, namely:

| | |
|---|---|
| length of the evaluation period | 11 years (1-year construction (year 0) + 10 Years of operation (years 1–10)), |
| Discount rate | 5%. |

The discount rate generally expresses an alternative return on invested capital, so in the case of a private investor, it is a very individual rate. For this reason, a discount rate of 5% was used in the case study, which, in accordance with the methodological documents, is used for the economic analysis of projects in the public sector [37,38].

### *4.3. Results of Case Studies*

The results of the case study are summarized in Table 5. Table 5 presents the value of life-cycle costs and cost savings on individual buildings. "Option 1—innovative solution" is represented here by the combining of the realization of photovoltaic panels (without battery system) with the realization of a water-air heat pump.

**Table 5.** Result recapitulation—costs/savings in CZK.

| Item | Real Estate 1 | Real Estate 2 | Real Estate 3 |
|---|---|---|---|
| LCC Option 0—conventional solution | 50,505,966 | 544,296,924 | 263,437,996 |
| LCC Option 1—innovative solution | 50,251,207 | 530,995,634 | 257,948,564 |
| LCC project savings over the entire evaluation period | 254,759 | 13,301,290 | 5,489,432 |
| Annual operating savings per object | 199,259 | 2,650,535 | 1,231,273 |
| Annual operating savings per $m^2$ of floor area of the apartment | 232 | 422 | 328 |
| Increase in cost per $m^2$ of floor area of the apartments | 1496 | 1142 | 1070 |
| Return period | 7 | 3 | 4 |
| Discounted return period (years) | 8 | 3 | 4 |
| Profitability [a] | 1.55 | 3.70 | 3.06 |
| Discounted return [b] | 1.20 | 2.86 | 2.37 |

[a] sum of nominal (non-discounted) savings related to the increase in investment costs incurred by the implementation of partial energy saving measures; [b] sum of discounted savings related to the increase in investment costs incurred by the implementation of partial energy saving measures.

These results are very important for the investor (developer) as well as for the future user. For the investor, information relating mainly to life-cycle costs and life-cycle cost savings for the building as a whole is important; here it will be a key indicator for choosing the optimal option—i.e., the option with the lowest life-cycle costs. For the future user, on the other hand, information relating to the annual operating savings related to one square meter of the floor area of the apartment will be crucial. With knowledge of the floor area of the apartment, it is then easy to determine the annual operating cost savings related to a particular apartment when choosing the appropriate option of energy-saving measures.

## 5. Discussion

Life-cycle cost savings (LCC) are a key parameter for the investor in the building. It includes initial and additional investment and operating costs for the entire evaluation period, with the inclusion of costs associated with partial energy-saving measures. This indicator accurately captures the economic meaningfulness of the construction implementation, including the selected energy-saving measures. Due to the fact that the life cycle cost criterion is generally very well-known and used, it is necessary to specify more closely the novelty and added value of the presented research results. The key added value of the contribution consists in determining the input parameters (investment costs, operating costs, and energy savings) for individual energy-saving measures and in creating a calculation tool that enables the determination of the life cycle costs of the construction project considering partial combinations of energy-saving measures and thus testing individual variants with regard to this evaluation criterion. The case study subsequently presents

only one optimal combination of energy-saving measures. Subsequent annual savings (per building, apartment, or square meter) are a key piece of information for future users of the building, who have a decisive interest in the costs associated with the use of the property. It follows from Table 3 that the efficiency of the implemented measures given by the cost-effectiveness is above 1, i.e., 1 CZK invested will result in savings of 1.55 CZK to 3.64 CZK in nominal values and 1.2 to 2.37 CZK in discounted values. The resulting value depends on the size of the building and the amount of investment required for the conventional solution. It should also be noted that in some cases, the chosen combination of measures may be interesting from the user's point of view (high annual savings), but from the LCC's point of view (e.g., because of high investment costs for the implementation of the measures), it may be less advantageous than another, less investment-intensive alternative.

Further to Table 1, it is also advisable to evaluate the impact of the chosen combination of energy-saving measures on the energy consumption of individual buildings evaluated in the case studies. In the case of Real Estate 1, a very favorable energy balance of the building can be observed. Already in the case of a conventional solution, the energy consumption per unit of energy reference area is very favorable, namely 101.3 kWh/m$^2$. The savings due to energy-saving measures are 62.1 kWh/m$^2$, and the resulting energy consumption for the innovative option is then 39.18 kWh/m$^2$. On the contrary, the worst of the evaluated case studies was Real Estate 2. In the case of a conventional solution, the energy consumption per unit of energy reference area is relatively high, namely 211.3 kWh/m$^2$. The savings due to energy-saving measures are 79.56 kWh/m$^2$, but the resulting energy consumption for the innovative option is consequently still very high, namely 131.75 kWh/m$^2$. In the case of this property, the reason for such poor results is, among other things, the fact that it is a mixed building in terms of use, which besides residential units also includes administrative areas, business premises, studios, or underground parking spaces. Residential units here make up less than 50% of functional units. In the case of Real Estate 3, in the conventional solution, the energy consumption per unit of energy reference area is set at 218.3 kWh/m$^2$, which is the highest consumption of the solved buildings. However, the savings due to energy-saving measures are the most interesting of all options, at 131.85 kWh/m$^2$. The resulting energy consumption for the innovative option is therefore 86.49 kWh/m$^2$.

Research results show that by selecting appropriate energy-saving measures, significant energy savings can be achieved in two out of the three cases evaluated. In these situations, energy consumption reductions of more than 60% have been achieved. In parallel, an analysis of the economic aspects of these saving measures revealed financial savings in the range of 28–30%. The apparent discrepancy between the savings in the amount of energy consumed and the total financial savings is due to the overall complexity of the situation, which is thus influenced by several factors. The most crucial of these is the transition from gas to electricity use. Although electricity is currently a more expensive alternative, its use allows better integration with renewable energy systems and provides more flexibility in the management of consumption. One of the case studies where smaller energy savings were achieved is Real Estate 2. The energy savings reached only 37.65% here. The reason for these lower savings is the specificity of the building, which requires ventilation of the premises with air-conditioning systems. These systems are a significant source of energy consumption and thus affect the overall energy balance of the building.

The results shown are deterministic and do not consider possible changes in inputs. In particular, it can be changes in investment costs or maintenance costs for the proposed technical solutions. The impact of changes in energy unit prices can also be significant when a general increase in energy prices leads to an increase in the economic efficiency of energy-saving measures. This assessment is not the subject of the presented research, whose aim was to propose and verify the functionality of the approach for optimizing the selection of energy-saving measures in case studies. However, as part of the economic analysis of a specific project, it is possible to recommend, for example, a sensitivity analysis or a quantitative risk analysis, which can analytically process possible input variables.

It should be stressed that although air conditioning can have a significant impact on the energy consumption of buildings, its use is often necessary to ensure the comfort and health of residents. Therefore, the selection and correct implementation of these systems are key aspects of the design and operation of energy-efficient buildings. Overall, the research results point to the importance of a combination of different energy-saving measures to achieve optimal results. However, it is necessary to carefully select and implement these measures, considering the specific conditions and needs of individual buildings.

In the introduction to the paper, the research question was defined as follows: "What approaches can be used to select the optimal solution of energy-saving measures for residential development projects, and what aspects need to be taken into account in the decision-making process?". The verification of the proposed methodology shows that the key to choosing the optimal combination of energy saving measures in the case of a development project targeting residential buildings are the life-cycle costs of the construction project, including not only the investment and operating costs but also the potential savings associated with the application of partial (technically meaningful) combinations of energy saving measures. However, it is also important to note that in the decision-making process, it is necessary to distinguish between the views of the investor, who bears the full life-cycle costs covering the impacts of both the investment and the operational phases, and the user, for whom the operational phase in particular and the costs or savings associated only with that phase are crucial. If the investor is also an end user, the same criteria apply to him as to investors in general. In his interest, he will implement a building with the lowest life cycle costs, of course, while respecting the achievement of the required user standard.

According to the study [18], residential property users appear to be less willing to use sustainable properties with advanced technologies to optimize the indoor environment of a building (such buildings are linked to BREEAM and LEED certifications in Article [18]) when this is associated with higher costs. This trend differs from the behavior of administrative and office space users, who are willing to accept higher costs. In the context of residential buildings, therefore, the aspect of user savings is a key factor.

## 6. Conclusions

The proposed methodological procedure meets the objective of research aimed at assessing the economic and financial aspects of the implementation of considered energy-saving measures in addition to conventional solutions in the case of residential buildings prepared for implementation by a private investor.

The key output of the presented research is a methodical procedure for choosing the optimal combination of energy-saving measures implemented in new residential real estate buildings. The proposed methodological procedure is fundamentally based on the search for a technically meaningful combination of energy-saving measures that will be associated with the lowest life cycle costs from the investor's point of view. The functionality of the proposed methodological procedure is subsequently verified in three case studies based on residential building projects. The results of the optimization process are presented and commented on in the previous chapter.

Given the breadth and complexity of the topic being processed, the authors of this research allow themselves to formulate further possible steps leading to the development of the topic by considering the socio-economic impacts of partial combinations of energy-saving measures and thus extending it to calculations of the whole life costs (WLC) of the building in order to assess the environmental externalities of the individual evaluated options. These outputs can be further used in the presentation of proposed building solutions to future users or owners of realized residential buildings or to authorities of the state administration and self-government in negotiations on the final form of prepared residential areas. Another research path is the development of a system for automating the process of optimizing combinations and partial parameters of energy-saving measures in new residential buildings. It will then be possible to adapt the procedure to other types of properties, e.g., office buildings, where the requirements of users for the operation of

a building are somewhat different from those for residential buildings. Due to the great interest of authors of scientific publications in the field of energy sustainability in the operation of residential properties, which is evident from the literature research carried out, it is also possible to state a non-negligible international overlap of the contribution. Verification of the proposed optimization procedure is verified on case studies planned for implementation in the Czech Republic, but it is evident from the results presented in the article that, from a technical and economic point of view, the proposed procedure is transferable to the environment of investment projects in the area of residential construction in other European countries.

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