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TECHNICAL AND ECONOMIC CONSIDERATIONS ON ENERGY EFFICIENCY OF EXISTING BUILDINGS THROUGH REFURBISHMENT

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Abstract:
In today's society sustainable development refers mainly to the efficient use of resources, including energy use in all human activities and the environments where these take place. Currently there is an increased need to make the energy consumption of existing buildings more efficient and the greatest opportunity in this regard is through a refurbishment process. This paper presents an application of a multicriteria optimization model based on a technical and economic analysis of the improvements to be made to buildings with regard to energy consumption and cost saving during the refurbishment process. By utilizing value engineering techniques and a cost-benefit analysis it was identified a set of renovation measures which improve the energy use and then by means of the proposed instrument it was achieved the optimal combination to obtain the maximum energetic benefit within a limited budget. In order to prove the feasibility of the proposed model a case study was conducted on a university building needing refurbishment. The present work aims to develop a specific optimization tool to support the decision maker in the early design stage of a refurbishment project by enhancing the energy efficiency and the sustainability.

Keywords: sustainability, energy efficiency, building refurbishment, optimization, decision maker

1. INTRODUCTION

The energy use in the building sector has a significant contribution to the global energy consumption, especially by existing buildings, both residential and public or commercial, while new buildings represent a very small percentage of the total (Ma, Cooper, Daky, & Ledo, 2012; Magrini, 2014). To reduce the energy use in all aspects of the human life is one of the seven principles of sustainability, therefore an approach of energy consumption of existing buildings represents a major subject also addressed in the literature.

The refurbishment of existing buildings is an opportunity to improve the energy performance of buildings in a sustainable way. The need to take action in this regard is also required from all the member states by European Union directives concerning the energy conservation and the environmental protection (Asadi, Gameiro da Silva, Henggeler Antunes, & Dias, 2012).

The main elements to be considered in a refurbishment project of an existing building in regard to increase of the energy efficiency are: the thermal insulation of the building envelope, the glass surfaces performance and the heating and air conditioning system (Dylewski & Adamczyk, 2011).

This research aims to propose a methodology to support the stakeholders in taking decision in regard to the best refurbishments options of an existing building whereas the energy use is reduced. The methodology proposed can be used in different cases of buildings, but always considering the specific of a construction which requires particular approaches, due to the fact that a construction project is unique, non-repetitive and specific. The study conducted consists of two phases; in the first one it is identified a list of possible interventions to existing buildings whose cost of implementing are later analyzed, as well as the benefit brought in terms of reducing energy consumption. The second phase consists of applying a mathematical model of optimization in order to solve the problem of obtaining energy and economic efficiency.

The present paper is intended to develop a simple tool for the evaluation of possible refurbishment measures called hereinafter also renovation measures, to help stakeholders in deciding on the most suitable options in the early design stage of the refurbishment project so that an optimum will be obtained between the energetic benefits and the costs of implementing renovation measures. The tool aims to determine the optimal configuration of measures particularly for a university building under study within an imposed budget, having no generalization character. To show the feasibility of the method other possible combinations arbitrarily chosen were analyzed for the reference building.

2. THEORETICAL FRAMEWORK. LITERATURE REVIEW

The building and construction sector plays a significant role in sustainable development approach and one of the best ways to minimize the environmental impact is to reduce the energy consumption of buildings and thereby the effect of greenhouse gases.

In literature, there is a lot of research looking at sustainability aspects related to improvement of the energy efficiency of existing buildings by refurbishment measures. Some authors have turned their attention to the study of materials used in the renovation process, assessing the sustainability of various thermal insulation materials during their whole life cycle (Tettey, Dodoo, & Gus, 2014; Rakhshan & Friess, 2013), such as the evaluation of the windows contributions to the energy performance of buildings (Tsikaloudaki K. , Laskos, Theodosiou, & Bikas, 2012; Tsikaloudaki K. , Laskos, Theodosiou, & Bikas, 2015).

On the other hand, Chidiac (2011) focused his study of the existing building and of the possible measures according to its needs. He developed a method for assessing the relevant characteristics for the evaluation of the office buildings energy consumption and the refurbishment potential in order to reduce energy consumption. He combined an energy calculation model with an economic analysis, while for the economic dimension of the evaluation model of the most effective measures the basic element is considered the payback time of the investment.

There are numerous researches aimed at developing a decision-making tool for choosing the most effective combination of measures primarily considering their costs. Diakaki et al. (2008) investigates the feasibility of applying a multi-objective optimization technique to the problem of building energy efficiency. The problem presented is actually an optimization considering the existence of multiple and competing objectives of environmental, energetic, financial and social nature, defined by a set of parameters and constraints. Research results show that by transposing the problem of improving energy efficiency in the real world, difficulties can occur that complicate the modeling and the theoretical approach (Diakaki, Grigoroudis, & Kolokotsa, 2008).

Subsequently, a similar multi-objective optimization model was developed to quantify technical solutions in a renovation project (Asadi, Gameiro da Silva, Henggeler Antunes, & Dias, 2012). It simultaneously takes into account all possible combinations of technical solutions for renovation following the resolution of the conflict between the two objectives: reducing cost and energy consumption. To solve the problem Asadi expressed cost and energy equations in MATLAB language and by using Tchebycheff programming he managed to find the closest solution to the ideal.

Another multicriteria tool for optimizing the renovation of building was developed by Chantrelle (2011) - MultiOpt, based on previous work related to the buildings assessment and renovation optimization using a non-dominated sorting genetic algorithm. In this study four optimization criteria were considered: energy consumption, cost, life-cycle environmental impact and thermal comfor and the parameters were established in regard to proposed building renovation operations (Chantrelle, Lahmidi, Keilholz, El Mankibi, & Michel, 2011).

The study of Z. Ma et al. (2012) presents a comprehensive review of the existing methodology and current state in the refurbishment process of existing buildings in terms of energy, referring to a series of articles and relevant research in this area. It also developed a systematic approach for selecting and identifying the best options for renovating existing buildings (Ma, Cooper, Daky, & Ledo, 2012).

The studies mentioned above showed that there are different approaches to solve the problem of improving energy efficiency by renovation measures, each dealing with different aspects of a buildings refurbishment and using various methods to develop decision support tools. As Kaklauskas affirmed back in 2005, an exhaustive buildings refurbishment evaluation is difficult to undertake, because the building and its environment are complex systems (technical, technological, ecological, social, esthetical, etc.), where the interdependence between sub-systems play significant role in the total efficiency performance (Kaklauskas, Zavadskas, & Raslanas, 2005).

Briefly, the study presented in this paper proposed a methodology based also on a multicriteria tool, in order to support the stakeholders in their practical decisions in case of a refurbishment of the building with the constraint of a limited budget which is a particularity in comparison with the previous studies mentioned above. The first phase consisted into a specific research on the particular case under study, in order to identify the possible measures, to assess the costs and to assess the energetic benefits, while the second phase is a mathematical model of optimization where the objective is to maximize the energetic benefit at a fixed cost.

3. RESEARCH

3.1. Research methodology

This paper is based on solving a mathematical linear optimization problem of options and costs by renovating an existing building. Following, the problem elements were defined: the objective, the options matrix, the variables and the conditions in order to obtain the solution. The goal is to get the optimal set of technical options for refurbishment with regard to achieve the highest energetic benefit (reducing energy consumption) in conditions of limited costs.

In the first part of the research it was necessary to identify possible renovation measures, so a study of the profile market in Romania was conducted, based on more than 20 websites of companies from this industry. The information was then analyzed by means of a focus group of four specialists in order to identify renovation measures available in Romania. It was conceived a list of technical measures for building refurbishment, grouped by categories, which aim to improve the energy efficiency of:

- the exterior walls;
- the windows;
- the basement floor;
- the terrace floor;

- the heating and cooling system of the building;
- the lightning system.

Identification of the options was realized based on the study of a university building, which in essence presents the characteristics of an office building. Technical measures were established based on the study literature and on the offers on the market in Romania and most important, based on several discussions with experts in the field.

To build the options matrix it was necessary to evaluate the costs and benefits obtained by every measure, in regard to the reference building under study. To obtain data, three categories of sources were used:

1) websites of suppliers for construction and building materials;
2) offers from suppliers and companies from the local construction industry;
3) discussions with construction professionals.

The options matrix showed in Table 1 and is divided in two parts: the values of costs and of benefits, where:

- i = 1, ... n is the number of categories for renovation options;
- j = 1, ... m is the number of renovation options for each category;
- a_{ij} represents the cost of the renovation option;
- b_{ij} represents the energetic benefit of the renovation option;
- x_{ij} represents the variable to be optimized;

and respectively the conditions based on the sum of the values mentioned above.

Table 1: The options matrix

category 1	x_{11}	x_{12}	x_{13}			x_{ij}	$\sum_j x_{ij}$		
	a_{11}	a_{12}	a_{13}			a_{ij}		$\sum_j a_{ij}x_{ij}$	
	b_{11}	b_{12}	b_{13}			b_{ij}			$\sum_j b_{ij}x_{ij}$
category 2	x_{21}	x_{22}	x_{23}			x_{i+1j}			
	a_{21}	a_{22}	a_{23}			a_{i+1j}			
	b_{21}	b_{22}	b_{23}			b_{i+1j}			
category n	x_{n1}	x_{n2}	x_{n3}			x_{nj}			
	a_{n1}	a_{n2}	a_{n3}			a_{nj}			
	b_{n1}	b_{n2}	b_{n3}			b_{nj}			
	costs / benefits						conditions		

The optimization solution consists of a combination of renovation options for the reference building so that the refurbishment project can be performed within a fixed budget, maximizing energy gains. For simplifying, it has been considered that from each category of possible interventions, only one option or no option will be chosen, these being mutually exclusive.

The choice of an option in the matrix is given by the variable x_{ij} which can only takes the values 1 and 0, as follws:

$$\begin{cases} 1, \text{ if j option from i category is chosen;} \\ 0, \text{ if j option from i category is not chosen.} \end{cases}$$

So the problem formulation presented above will have the following conditions:

1. $\sum_j x_{ij} \leq 1$, where x_{ij} is an integer;

2. $\sum_i \sum_j a_{ij}x_{ij} \leq A$, where A is the refurbishment budget;

3. $\sum_i \sum_j b_{ij}x_{ij} = B$ maximum, where B is the total energy gain.

The problem expressed shows a conflictul relationship between the cost of implementing an option and the energy gain brought, because these are directly proportional. As Z.Ma et al (2012) also states, the selection of renovation measures is a trade-off between costs and benefits of implementing measures.

The problem was introduced in an easy-to-use calculation solver – an add-in within Microsoft Excel that will give values for the variables x_{ij} taking into consideration the constraints named, so that from each category of measures an option or none will be selected resulting in a set of optimal measures.

The advantage of this approach is that it offers a solution for optimizing the measures selection for a refurbishment project, maximizing energy reduction, with a limited budget available. The model is easily understandable and can be used by people with minimal professional knowledge in this field. A generalization for all types of buildings is difficult to obtain. But this study aims to achieve a simple model easily applicable and understandable, to support the decision maker in the early design stage.

3.2. Research description

Building under study

To illustrate the proposed model an existing building was chosen for the case study. The reference building belongs to the Technical University of Cluj-Napoca and can be included in the category of office buildings; it is used for teaching, research and administrative purposes.

The building under study was built in 1982; it has a height of approx. 15 m, consisting of 5 floors, including basement, its footprint is approximately 600 m^2 and has a total area of approx. 3000 m^2. This data will be used to estimate the approximate costs and benefits of renovation measures.

All floors are connected by a staircase and no elevator is in place; the floor height is 3.3 m. The upper floor is terrace type and the basement is unheated. The glass surface represents 40% of the exterior walls which are made of 30 cm concrete, without insulation. The windows have double glazing with wooden frames. Heating and hot water are provided by the central heating system of the city. Average consumption reported in the last two years (2013 and 2014) for thermal energy was 247 kWh/m^2 year and for electricity 38 kWh/m^2 year. All data is obtained with help of the technical and administrative office of the University.

Renovation measures

Based on characteristics of the reference building and on the study of the profile market in Romania, a list of possible options for renovation was compiled. These measures are showed in the Table 2, grouped by categories:

Table 2: The renovation measures

Building element	**Refurbishment options**				
External walls	Expanded polystyrene 10 cm	Stone wool 10 cm	Insulating plaster for exterior	Polyurethane foam 10 cm	Mineral wool for interior
Windows	PVC windows with double glazing U=1.60W/mpK	PVC windows with double glazing U=1.30 W/mpK	PVC windows with double glazing U=1.1W/mpK		
Basement floor	Expanded polystyrene 5 cm	Stone wool 5 cm	Polyurethane foam 3 cm		
Terrace floor	Extruded polystyrene 20 cm	Stone wool 20 cm			
Heating, air conditioning and hot water system	Distribution pipe insulation	Dx conventional HVAC system	Air-water heat pump	Geothermal pump	
Lightning system	Economic lamps	Economic lamps + motion light sensors			

The options above were chosen as a result of the study of materials and technical solutions available on the market in Romania, and considering as well some existing research. The options were then analyzed with help of 3 construction professionals during some discussion sessions. To estimate the cost of implementing each option, information was collected from the websites of suppliers and also offers were requested from three local companies in the construction industry. The costs used in the analysis are average values and include the price of the materials used and the workmanship. To facilitate obtaining a viable solution, the costs required to implement each measure and the energetic benefits were estimated in relation to 100 m^2 building; the measure unit is € / 100 m^2.

3.3. Research results

The scope of this study was to provide a support for beneficiaries and investors in a refurbishment project where the costs are restricted to a limited budget, by achieving in the same time the maximum energy efficiency results with cost saving.

Table 3: Simulation for a maximum accepted cost of € 250,000 (unit measure is €/100 m^2)

	0	0	1	0	0	1		
category 1	520	775	550	1120	1960		550	
	220	260	225	220	125			225
	1	0	0	0	0	1		
category 2	1290	1830	2235				1290	
	170	205	215					170
	0	0	1	0	0	1		
category 3	50	100	185				185	
	95	95	110					110
	1	0	0	0	0	1		
category 4	470	680					470	
	190	215						190
	0	1	0	0	0	1		
category 5	9	5730	6990	8020			5730	
	1	115	219	410				115
	0	1	0	0	0	1		
category 6	80	90					90	
	120	130						130
							249450	**28200**

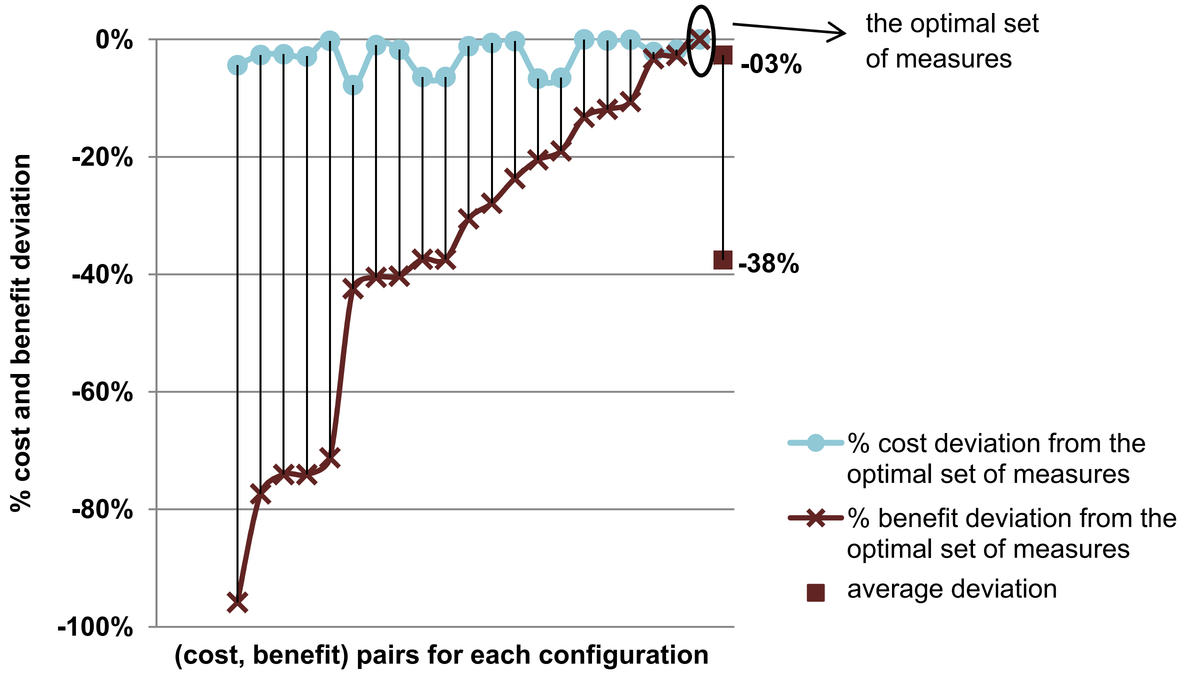
The proposed model was applied for a maximum acceptable cost of € 250,000, as it is shown in Table 3. The option displayed represents the optimum set of measures for refurbishment, where the value 1 on the first line of each category means the choice of the respective measure. In this case the optimal set of refurbishment measures is the combination (M_{13}, M_{21}, M_{33}, M_{41}, M_{52}, M_{62}). On the bottom of the table are summed the total costs and energetic benefits associated with this set.

From the above application of the proposed model it can be seen that it presents a set of viable solutions that meet the condition imposed: improving the energy efficiency at a maximum acceptable cost. The proposed model allows an unlimited number of refurbishment measures to be considered in the evaluation. In the present study, the measures proposed are the ones most often encountered in the practice in Romania.

To assess the feasibility of the proposed instrument, it was compared with other 25 combinations of measures chosen so as to be within the budget set with a small margin of error – only 3%. Their choice was made arbitrarily; the only condition being imposed was the upper limit of the budget.

The analysis revealed that by a cost difference of only 2.7 percent the energy gain varies greatly, with about 37% in conditions where extreme values were eliminated from the calculation. So any other measures configuration which satisfies the limited budget criteria with small margin of error will generate lower energy gains, and in some cases the difference is substantial, as displayed in Figure 1. The cost and benefit deviations are illustrated in pairs in comparison with the optimal set of measures considered to be the reference point.

Figure 1: Cost and benefit deviation from the optimal set of measures (in percentage)



Thus the proposed optimization solution provides reliable results, as shown in this case study. However, it should keep in mind that these values are only estimative, supporting the decision in the early design phase of a refurbishment project and that for an accurate assessment it must take into account a number of interrelations between the renovation measures and building characteristics, and other factors such as reducing the cost of maintenance of the building, primary energy consumption in the production process of materials or energy price variation. Another important element in choosing refurbishment measures is the comfort obtained after renovating the building which should be evaluated in terms of beneficiary's requirements.

4. CONCLUSIONS

In the current global context it is necessary to improve the energy efficiency of buildings, and a great opportunity in this respect is the refurbishment of existing buildings. For improving building energy efficiency a plenty of measures are available that consider all the elements of a construction. But the choice involves a conflict between the main objectives: maximizing energy reduction and minimizing cost. The constraint of a limited budget occurs in this case of taking decision tool.
This work aimed to develop a simple optimization model for the problem of choosing the optimal set of measures in the design phase of a refurbishment project, taking into account the limitations imposed by the available budget. To show its feasibility, it was applied to a university building, simulating the optimal combination of measures by evaluating all technical options simultaneously. As it was shown in the present study, the model presents reliable results which are better than others possible configurations.

In the future it may consider developing a complex model to define a relationship between the characteristics of the building and the energy efficiency classification in order to find a solution to increase the energy class by refurbishment.

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