Energy and Buildings 76 (2014) 64–71

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Evaluation of energy efficiency measures sustainability by decision tree method

Rūta Mikučionienė*, Vytautas Martinaitis, Eugenijus Keras

Vilnius Gediminas Technical University, Department of Building Energetics, Sauletekio ave. 11, LT-10223 Vilnius, Lithuania

ARTICLE INFO

Article history:
Received 10 August 2013
Received in revised form 10 January 2014
Accepted 14 February 2014

Keywords:
Building renovation
Criteria of sustainability
Energy efficiency measures
Decision tree.

ABSTRACT

Renovation of the existing buildings is straight way to perform the targets of the Energy Efficiency Directive. Qualitative renovation begins by choosing energy efficiency measures and evaluation and prioritization of them depends on the chosen criteria. In order to increase sustainability of the renovation the criteria for energy efficiency measures evaluation reflecting sustainable attitude should be chosen. In this paper the five main criteria (energy efficiency, environmental impact, economical rationality, comfort and duration under Life cycle point of view) are defined and analyzed. Sequential prioritization and distribution decision tree is formed for distribution of energy efficiency measures to the basic and additional energy efficiency measures. The presented method optimizes the formation of packets of energy efficiency measures. The case study with five energy efficiency measures show the optimization results, when only four packets are formed instead 131 possible variants. All packets formed according the distribution decision tree has higher values of general sustainability criteria and small distribution of values (difference only 12%). This systemization is convenient tool for decision maker, independently if decision maker is machine or person.

1. Introduction

The one of major energy consumers in the Europe and in the world is buildings sector, which consumes about 40% of primary energy [1]. The requirements for new buildings are tightening gradually to achieve Energy Efficiency Directive [2] target to save 20% of primary energy by 2020. Rate of new buildings construction in Europe is about 1% and rate of renovation for existing buildings is only about 1%–2% per year according different sources [3]. The Energy Efficiency Directive [2] is reflected to the fact that global energy savings will be achieved when majority of the buildings will be energy efficient, with obligation of 3% renovation rate for public buildings. Renovation of the existing buildings is straight way to this target. The annual energy consumption in Europe varies depending on climate, regulations and historical features, but the average energy consumption for heating of existing buildings in continental climate countries is near 200 kWh/m^2 and more (in France is 210 kWh/m^2 [4], in Lithuania about 200 kWh m^2 [5]), when future buildings will consume not more than 50 kWh/m^2 per year for heating. Qualitative renovation begins by choosing energy efficiency measures (EEM). But to choose EEM – to make decision which alternative is the best – the criteria should be defined first. When criteria are defined the clear structure and procedure for decision making should be defined.

1.1. Decision-making criteria – from economical towards sustainable

Decision-making methods need the targets for optimization, which usually are described by criteria. The evaluation and prioritization of EEM depends on the chosen criteria. The most commonly used criterion is economical evaluation, because “money or cost” is understandable and clear to evaluate, also it is advisable for investors. Payback is easily motivating and is popular advisor for decision making. A lot of studies for evaluation of EEM are done with only one economic criterion, especially when loans are needful to implement EEM. For investors only EEM with financial benefit are appropriate [6]. So the economic criterion is often used among professionals to evaluate EEM. The Greek scientists [7] in intelligent decision support model for assessing energy saving measures

Abbreviations: EEM, energy efficiency measures; NPV, net present value; IRR, internal rate of return; LCA, life cycle analysis; MCDM, multicriteria decision making; DT, decision tree; EE, energy efficiency; EI, environmental impact; ER, economical rationality; C, comfort; LCD, life cycle duration; DDT, distribution decision tree; GSC, general sustainability criteria.

* Corresponding author.
E-mail address: ruta.mikucioniene@vgtu.lt (R. Mikučionienė).

http://dx.doi.org/10.1016/j.enbuild.2014.02.048
0378-7788/

use only economic criteria and define it by three attributes: payback period, net present value (NPV) and internal rate of return (IRR). These attributes of economic criteria are most popular [8], the list of economic criteria is extended payback period evaluating depreciation of the building and ratio of savings and investment [9].

Another popular criteria for evaluation of EEM is energy efficiency or energy saving. It is related with economic criteria, because without saving will be no financial benefit of implementation of EEM. So the measure which is economically feasible has energy savings as well. As described in [10] the measures are evaluated by energy savings. The energy efficiency criteria often are used together with criteria of environmental impact and in literature is presented as 2E criteria [11] and with economic criteria 3E evaluation [12]. Environmental and energy efficiency criteria usually are met Life cycle analysis (LCA) [13,14]. But LCA usually is performed for separate building elements, or not for impact of whole building [15]. The LCA evaluation together with energy efficiency lets to analyze the EEM in two-fold benefit, related to energy savings and improvement of buildings element conditions [8,16].

The state-of-art and sustainable evaluation of EEM usually is performed using not only one criterion, but composing several ones. The selection of criteria depends on the aim of analysis.

Model for selection of renovation actions [17] evaluate EEM by two criteria: environmental impact and functionality. The environmental impact is expressed by the potential of reduction of CO_2 emissions. The functionality criteria are expressed in by 10 aspects, which evaluate complexity of the renovation process and effect for inhabitants. Another example of criteria selection for specific purpose is study for EEM evaluation in political aspects [18]. This study is performed by Multi Criteria Decision Making (MCDM) analysis for promotion of retrofit actions. The aim of this MCDM analysis is to find optimal EEM in governmental point of view. The sustainable renovation of hotel buildings for Energy Performance Contracting Project [19] has quality, energy system management, project cost benefit, energy consumption and resources saving, health and safety, stakeholders satisfaction criteria. The special criteria are useful for specific cases, but focusing for sustainable and comprehensive evaluation should have comprehensive and universal indicators.

The multi criteria evaluation of sustainable EEM performed by [20] use four criteria: use of energy, thermal comfort, cost and environmental impact. This combination of criteria comparing with others is sustainable, but is focused more on usage of the building, and not in life cycle aspects. Sustainable office building renovation presented by [21] has five criteria: sustainable site – evaluating current situation of building, energy efficiency, water efficiency, material and resources – evaluation renewability and waste management and indoor environment quality.

Summarizing the criteria expressing sustainability concept, environmental aspect can be expressed by impact to the nature, or called environmental impact, and environment in building, which usually is understood as comfort conditions. Environmental impact can be expressed as climate change (in units kg of CO_2 eqv.), depletion of ozone layer, acidification and other pollutant extracted to the air [13]. The most popular is evaluation of impact to climate change, which is presented by calculation of the emitted amount of the CO_2 gases equivalent. But term comfort is used and expressed not uniformly in scientific society. The most popular criteria are thermal comfort [20] or indoor environmental quality (IEQ) [21–23]. Thermal comfort evaluates the only thermal characteristics of indoor environment, but it is not enough to satisfy human comfort. The overall comfort is formed from physical and personal comfort. The physical comfort depends on thermal comfort, air quality, acoustic comfort and luminosity [24].

All described criteria can be divided into quantitative and qualitative criteria. The quantitative criteria (investment cost, energy savings, etc.) are indicators which can be calculated and evaluated objectively. The qualitative (aesthetics, comfort, etc.) are subjective and evaluation of them depend on decision maker. But sustainable evaluation of renovation should be evaluated according both quantitative and qualitative factors.

1.2. Decision making procedures under decision tree basis

When criteria are defined the structure and procedure for decision making should be defined. Over the past decades a growing penetration of electronics is going to all areas of industry and technology – as well to the building's energy control and management. The aim is to transfer as more as possible functions of management, decision-making from human to the technology. However, the decision-making usually is over determined by human: the algorithms in any computer equipment should be formed and only then it can participate independently in decision-making.

It is easier to implement energy efficiency measures to newly designed and constructed buildings than to old ones (already built ones). To assess their situation and adapt energy efficiency measures there is a need of deep knowledge and expertise of various specialists. This raises the need for this expertise to organize, generate the optimal, best individually suited kits of building energy efficiency measures. Multi criteria decision making-separate area of science and its application in choosing correct building EEM requires interdisciplinary approach.

DT is a versatile information clustering and classification tool used in a wide range of scientific and industrial fields. The development of IT, enabled greater use of various artificial intelligence tools and contributed to a breakthrough in the use of this tool as well. Scientists comparing the use of this tool with other machine learning tools, attempt to combine the advantages of different tools, avoiding the disadvantages: Dylewski and Adamczyk [25] analyses combination of DT and neural network. Kumar et al. [26] describe fuzzy binary DT (combination of fuzzy logic and DT) advantages and disadvantages compared to ordinary DT. However, any combination of DT with other artificial intelligence means loses its main advantage–the clarity of DT use.

Large IT penetration in the various branches of the economy leads to an extremely wide range of DT usage: from astronomy [27], to image processing [28], evaluation of financial indicators of business companies [29,30]. Yu et al. [31] highlight the advantages (high accuracy, ranking energy intensity factors, for the user of DT deep knowledge of IT is not needed) of using the method of DT for building energy demand modeling. DT is also applied to the energy efficiency of buildings.

For the optimal renovation process it is necessary to make the building energy audit and suggest the best renovation measures according to the results of audit. It is desirable this procedure to be cyclical. It is proposed much less decisions for proper selection of EEM than decisions to conduct audits [21]. The same authors [21] propose a hybrid decision-search method combining A *graph search algorithm with genetic algorithms. This method lacks clarity, simplicity of use as methods mentioned above.

The use of DT for researches in the building sector is rare today [31]. Most commonly this method is used for optimization of construction processes [6,32]. The Japanese scientists applied DT method for rating of the building according the energy demand. The building energy demand predictive model based on DT method was created. Another study performed by Alanne [17], use DT method for criteria tree formation to evaluate the optimal renovation actions in multicriteria "knapsack" model, which has sequential repeating for decision making.