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Assessment of relevance of different effects in energy infrastructure revitalization in non-residential buildings

Miroslav Kljajić, Aleksandar S. Anđelković*, Igor Mujan

University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Vojvodina, Serbia

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This paper analyses the effects of energy infrastructure revitalization in public non-residential buildings in the contexts of energy planning support and energy policy creation. The approach created acknowledges the different degree of relevance of the specific aspects, the specific interests of different stakeholders in energy activity and the variable degree of influence of each effect on the overall development and sustainability of energy solutions. It is based on the mathematical concept of the analytic hierarchy process (AHP) as a multi-criteria optimization procedure. AHP conclusions provide significant contributions in strategic development and transitional path planning and energy policy instruments implementation, while taking all local society and economic specificities into account.

Given the fact that the effects of energy infrastructure revitalization are diverse and multidimensional, this method provides an analytical framework suitable for a comprehensive understanding and relative relevance evaluation of each of the effects with the use of structured organization of thinking, facts, new knowledge insights, intuition, experience and performance indicators. The method establishes a comprehensive and systematic algorithm for reasoning and revealing all aspects of energy infrastructure revitalization, and results in an arguable alternative choice in correlation with quantitative (economic, technical) and qualitative (environmental, social) criteria.

1. Introduction

Professionals, stakeholders, decision makers, energy policy and strategy creators have different and often conflicting opinions on how the processes of modernization and revitalization of energy systems in buildings should be directed, which instruments should be used, and how the effects of any changes that have been made should be evaluated.

The importance of evaluation and selection of a certain alternative stems from the fact that they regularly refer to the important consumer of energy, that energy users are often vulnerable social groups, that systems have deteriorating energy efficiency trends and are becoming excessive financial burden on local communities and the state, that they represent a threat to the health of users and people in the environment because they do not use clean energy technologies and that they create bad public opinion about energy in society due to inadequate evaluation of energy as a future resource. In this regard, a non-selective strategy that is not adapted to the interests of the stakeholders in the energy business, customers, local conditions and strategic decisions is unacceptable.

Complex decision-making is a process that includes interrelated and interdependent factors. Numerous authors in scientific publications and recently many decision makers, policy makers and others indicate that decision-making based solely on personal reflection or intuition is inadequate. In recent times, when opportunity allows, there is a tendency to make decisions within groups and teams with constant exchange of opinions between individual participant, leading to knowledge improvement, and utilization of the diverse experience of the participants, ultimately leading to consensus and achieving the important psychological effect of common interest in the success of the decision. Complex problems of energy resource management must be treated as multi-criteria with many variables, which demand sophisticated and rigorous mathematical models for complex analysis. On the other hand, using AHP procedure is more accessible, alternatives can be just as reliably evaluated, sensitivity analysis on influence factors of decisions can be performed and the decision's consistency in relation to the objective and criteria can be checked.

Many authors have derived valuable conclusions from the AHP approach, which involves multiple aspects of evaluation and assessment of energy technologies, energy efficiency measures,

* Corresponding author. Tel.: +381 652006060.
E-mail address: aleksandar.andjelkovic@gmail.com (A.S. Anđelković).

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objectives in the field of various energy sources, selection of materials, as well as guidelines for the support of energy policies. For adaptive thermal comfort in buildings, the authors [1] introduced a method of quantifying the physiological, behavioural and psychological portions of the adaptation process by using the analytic hierarchy process (AHP) based on case studies conducted in the UK and China. With the AHP technique, all criteria, factors and corresponding elements were arranged in a hierarchy tree and quantified by using a series of pair-wise judgments. The approach provided a wide array of opportunities to better understand adaptive mechanisms and revealed the significance of each category for the achievement of adaptive thermal comfort.

By prioritizing renewable options using AHP model, the authors [2] revealed that solar is the most favourable resource followed by biomass. Hydro and wind power however, are ranked third and fourth, respectively. The model also shows that each resource is inclined towards a particular criterion; solar towards economical, biomass towards social, hydropower towards technical, and wind towards the environmental aspect.

In order to determine the advantages and disadvantages of the most common construction materials, different constructions types for passive houses, such as solid wood, wood-frame, aerated concrete, and brick, the authors [3] used the AHP model. The AHP analysis revealed that the highest ranking criteria are based on psychological aspect and functionality with wood construction considered as one of the most suitable options for passive houses.

AHP analysis was used for identifying the key factors for the TFT–LCD chiller system collaborative service design. The authors [4] noticed the main advantage of AHP is its effectiveness in managing tangible and intangible or qualitative and quantitative factors. Their AHP result implied that the TFT–LCD chiller is preferable because it has the advantages of operating synergy and energy-saving research.

The complexity of power plant evaluation is steadily increasing, as more criteria are involved in the overall assessment while evaluation data changes rapidly. For the authors [5] a multi-criteria analysis based on hierarchically structured criteria is necessary. Ten types of power plant were evaluated using nine end node criteria structured under AHP, according to the technological, economic and sustainability aspects. In China, coal-fired power plants are the main supplier of electricity, and the authors [6] considered the importance of establishing a scientific, reasonable, and feasible comprehensive evaluation system for coal-fired power plants to guide them in achieving multi-optimization of their thermal, environmental, and economic performance. AHP is used to assess the multi-objective performance of power plants.

2. Sample forming and situation analysis

The survey was conducted on a sample group of public non-residential buildings in AP Vojvodina, Republic of Serbia and includes educational, health care and administrative institutions [7,8]. The survey was conducted in different municipalities and cities throughout the region of AP Vojvodina, at randomly selected facilities from a group of municipalities and cities with organized and implemented elements of energy management or with organized and systematic activities of energy data recording and processing.

2.1. Educational buildings

Representative sample consists of 149 schools (118 primary, 25 secondary and 6 mixed), which is 27.6% of the total number of schools in Vojvodina (540) [7]. The percentage representation is: 79% primary, 17% secondary and 4% mixed schools. Table 1 shows the energy indicators in educational institutions.

2.2. Health care facilities

Representative sample consists of 55 health care institutions, 67.1% of health care institutions in AP Vojvodina (82) [7]. Table 2 shows the energy indicators in health care institutions, organized by type of health care institutions.

2.3. Administrative buildings

Representative sample consists of 26 administrative buildings which is 57.8% of the total number of administrative buildings in Vojvodina (45). Table 3 shows the systematization of data collected. Administrative buildings were divided into three groups, by the model for thermal energy payment. The first group consists of buildings that pay heating bills on expenditure (52%). The second group consists of buildings that pay a flat rate (19%) while the third group consists of exceptions, i.e. objects with unreliable data on energy consumption (29%).

2.4. Assessment of situation in public non-residential buildings

The largest part of energy consumed in the public non-residential buildings is related to the need for heating in the winter and domestic hot water systems while the rest is used by lighting systems, air conditioning and related services: food preparation, laundry, sterilization and others. During energy audits it was noted that most facilities cannot control the heat load, the heating system is not regulated and balanced, existing buildings had poor ventilation, poor heating, poor window and door sealing, inadequate lighting, frequent system failures, inadequate maintenance, significant use of inefficient split systems and at the same time central air conditioning systems were not automated or automatic control equipment was not in use. In addition, in a number of institutions employees exhibit a lack of interest in and lack of motivation for the energy efficient use of energy resources and energy systems.

The biggest problem is presented by the boiler and distribution systems. A large number of boilers have already outlived their economic lives and with the use of high sulphur fuel (fuel oil, heating oil) have a low efficiency, which directly causes inefficiency of the heat supply system as a whole. Dilapidated water pipes (district heating or steam lines) which are laid underground and very inaccessible for maintenance present another problem. The modernization and revitalization of this infrastructure is more than necessary [11,13].

Average indicator values for specific annual heat consumption per unit of facility surface surpass the limit for maximum permissible annual final energy needs for heating according to applicable regulations. Data indicates current energy supply problems and the existence of significant potential for the rational use of energy [15].

3. Directed structure of improvements

Alternatives are options for energy infrastructure revitalization in the context of future systematic improvement in the sector and public non-residential buildings. As a starting point we considered the broad list of available appropriate alternatives for the successful start of the energy infrastructure revitalization process in public non-residential buildings [9,10]. In the selection process, it was necessary to define the term of success of each alternative and the relevance of each alternative within regional circumstances. In this paper, success is defined and evaluated through the achievement of a top three finish in the energy