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Modeling the process of choosing energy-saving technologies in the exploitation of transport infrastructure buildings

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Abstract. According to the approved strategy for the development of the country's transport complex, the current trend is to increase the energy efficiency of service and industrial buildings. The analysis of scientific research carried out confirms that the variety of energy-saving technologies complicates the process of choosing optimal design solutions. It is also noted that the primary indicators of the choice of energy-saving technologies do not take into account prospective operating costs, as well as a likely decrease in the reliability of the functioning of buildings and structures of the transport infrastructure during operation. Therefore, the purpose of the study was to develop a model for multi-criteria decision making on the choice of the optimal energy-saving technology. The article proposes four levels of ranging of criteria, taking into account federal requirements, regional and industry specifics, as well as the availability of local mechanisms for the implementation of energy-saving technologies. Normalized indicators are referred to supra-rank criteria. The significance of organizational-technological, technical-economic and operational-technical criteria is determined by the expert method. An example of determining the vector of priorities, both criteria for comparison, and alternative energy-saving technologies by the analysis of hierarchies is given. The result of the study is a decision-making model for choosing the optimal energy-saving technology, taking into account the prospects for the operation of transport infrastructure buildings. The practical application of the results obtained is possible both in new construction and in the repair and reconstruction of buildings as an addition to the quality control system of design solutions.

1 Introduction

The Russian transport system is one of the most developed in the world. Annually, the transport complex provides approximately 7% of the gross value added [1]. According to the analytical center under the Government of Russia, the largest share of freight traffic is accounted for by road transport and is about 67%. Rail transport accounts for about 17% of freight traffic.

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The success of the functioning of the transport system depends on the state of the infrastructure, enterprises, vehicles, and the system of unified coordinated management [2, 3]. The Government of the Russian Federation has developed a transport strategy for the period up to 2030, with a forecast up to 2035. It involves the introduction of standard designs of service buildings with the expansion of the list of energy-saving technologies [4]. Not only well-established traditional technologies are expected to be applied. The use of alternative energy sources is proposed. For example, the installation of solar panels on the roofs and facades of railway stations, at railway station parking lots, on the roofs of depots and industrial buildings, on railway bridges, at remote and isolated transport infrastructure facilities.

The economic efficiency of standard projects for the construction, repair, reconstruction of service, industrial buildings of the transport infrastructure is associated with the use of such energy-saving measures as:

– Alternative energy sources;
– Secondary energy resources;
– Non-energy-intensive technologies and equipment;
– Rational use of available energy resources;
– Assessment of the economic feasibility of using any energy-saving technologies and solutions.

However, the evaluation of only economic efficiency is insufficient, since there is a problem of underestimation of the prospects for the use of energy-saving technologies at the exploitation stage. Consider an example. According to numerous studies, measures to reduce heat loss through building envelopes show greater efficiency [5-7]. Facade insulation not only reduces heat losses, but at the same time gives an easily recognizable corporate style to transport infrastructure buildings. At present, during construction and repair, the technology of insulation based on a hinged ventilated facade system has become the most popular [8, 9]. The largest shares of filling stations are built according to standard designs with different planning characteristics and standard design solutions. Regardless of the modifications, all buildings are functionally divided into two blocks: a block of household premises and a public block (Fig. 1).

Fig. 1. The planning solution of the automated of filling stations: 1 - the room for processing documents; 2 - room for technical equipment (information technology, automation and telecommunications, engineering and technical means of protection); 3 - electrical board; 4 - Bio-toilet; 5 - utility room.

The public block includes a service room for drivers and passengers with a cash settlement area, a fast food area and a toilet for visitors. The household block includes technical premises: pantries, a utility room of a cafe, amenity premises for staff. Taking into account the diversity of planning solutions, as well as the climatic features of the country, it is necessary to install a heating system and energy-efficient external enclosing structures in the premises of the gas station. These structures are sandwich panels of two sheets of rigid material glued together using hot or cold pressing and a layer of insulation between them.

Exploitation practice shows low maintainability of such structures in the case of moistening of the insulation. This leads to the loss of heat-shielding properties at the stage of exploitation [10]. Therefore, the actual task of this study is to develop a model for choosing efficient energy-saving technologies, taking into account their reliability during subsequent exploitation.

2 Materials and methods

The primary indicators of choice are the minimum investment in the introduction of energy-saving technologies or the minimum payback period. However, the choice based only on these indicators can lead in the future to underestimation of exploitation costs due to a decrease in reliability, underestimation of maintainability, durability, reliability of structures and engineering equipment [11-13]. Usually, a decision maker has to analyze a large amount of information, make sure of its reliability, take into account a multifaceted set of factors that allows choosing the best solution [14, 15]. However, multicriteria optimization is very complex and rarely used in practice. A scientific approach based on quantitative decision-making methods makes it possible to improve the quality of decisions made [16, 17]. Therefore, the purpose of this study is to develop a decision-making model for choosing the optimal energy-saving technology based on the hierarchy analysis method.

The main objectives of the study are:

– Study of the stages of formation and mechanisms for the implementation of energy-saving technologies in the transport sector;
– Ranging of criteria for comparing energy-saving technologies;
– Modeling the process of evaluation and selection of energy-saving technologies in the transport sector based on the methods of multi-criteria analysis.

The object of the study is the criteria for comparing energy-saving technologies.

The subject of the study is to study the possibility of using multicriteria optimization methods to make a decision on choosing the optimal energy-saving technology in the exploitation of transport infrastructure buildings.

The method of analysis of hierarchies was chosen. It allows taking into account the multicriteria and uncertainty of conditions, as well as choosing a solution from a set of alternatives of various types. This method also allows you to select criteria that have different types of measurement scales.

A feature of the author's approach is the choice of comparison criteria, taking into account all stages of the building's life cycle (Fig. 2). The comparison criteria are ranked taking into account the requirements of the legislation, as well as the opinions of experts in the construction industry at 4 levels. At the federal level, the ranking of criteria is carried out taking into account the primary norms of the law, which make it possible to exclude options that are unacceptable due to technical, architectural, environmental and other requirements. In fact, they are above the ranking criteria, because if the standards for these indicators are not observed, the technology is excluded and is not considered further. For example, such indicators as fire safety, fire resistance and reduced resistance to heat transfer are standardized at the legislative level, so their accounting is mandatory. At the regional level, an assessment is made of the characteristics of the region, for example, climatic, resource. The actual balance of consumption of fuel and energy resources is compiled and the energy saving potential is determined. At this stage, a feasibility study is carried out according to the primary indicators that were discussed above. At the industry level, the selection of energy-efficient technologies currently available for the transport industry is carried out, taking into account the specifics of technological processes and industries. At the local level, the choice of priority technology is justified and the mechanism for its implementation for a particular facility is determined. At this stage, the comparison criteria are selected taking into account the safety, reliability and cost-effectiveness of the implementation of energy-saving technology in the exploitation of the transport infrastructure building.

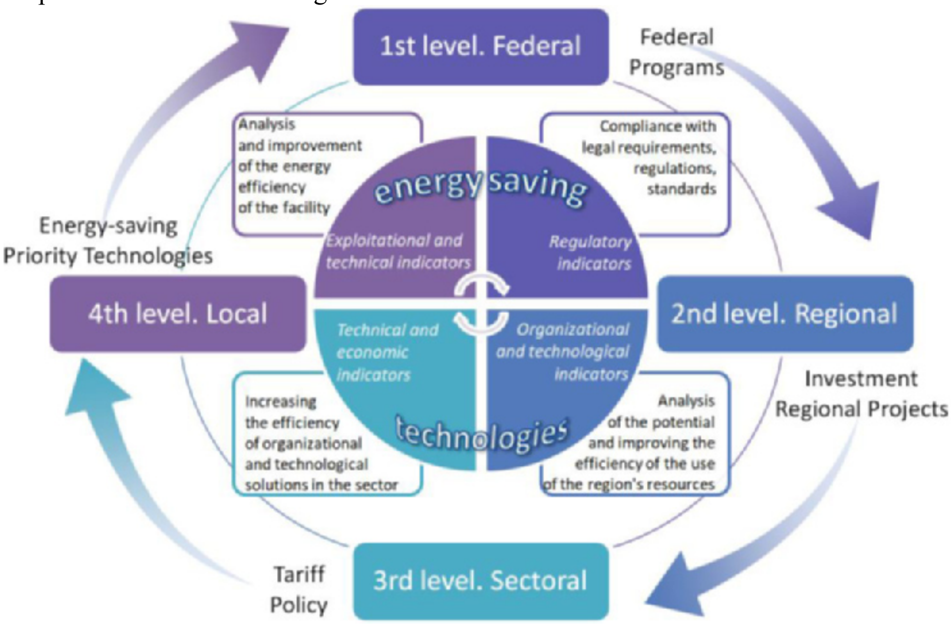

Fig. 2. Ranging of criteria for comparing used in the transport sector energy-efficient technologies.

The methodological toolkit includes the definition of the vector of priorities of comparison criteria $\omega = \{\omega_{k1},\ldots, \omega_{ki}, \ldots, \omega_{kn}\}$:

$$\omega_{ki} = \frac{(v_{i1} \cdot v_{i2} \cdot \ldots v_{in})^{1/n}}{\sum_{i=1}^{n}(v_{i1} \cdot v_{i2} \cdot \ldots v_{in})^{1/n}} \tag{1}$$

Where v_{ij} is the degree of preference of the k_i criterion relative to the k_j criterion; ω_{ki} is the weight coefficient k_i of the comparison criterion (the vector of priorities).

The ranging is done according to the importance of the criteria, starting with the criterion that is expected to have the highest weight to the criterion of the least importance:

$$k_1 > k_2 > \ldots > k_n \tag{2}$$

Where k_j is a criterion for comparing energy-saving technologies.

The significance of the criteria is determined on the basis of two basic assumptions: the assessment of urgency and the assessment of importance. The assessment of urgency depends on the relevance for the region of the current legal requirements. The assessment of importance depends on the share of the deviation of the current actual consumption of resources in the region and in the industry from the required standard values.

Next, paired comparison matrices are compiled and the ranking of alternative options for energy-saving technologies is performed S_j. The combined weighting factor for each alternative is then determined by linear convolution:

$$\Omega(S_j) = \sum_{i=1}^{n} \omega_{ki} \cdot \omega_{ji} \rightarrow max \quad (3)$$

Where, ω_{ki} is the weight coefficient of the k_i comparison criterion; ω_{ji} is the weight coefficient of the S_j alternative solution according to the k_i comparison criterion (the vector of priorities alternatives); n is the number of comparison criteria.

3 Results

An analysis of the factors, strategies and programs of energy saving made it possible to create a model for assessing and choosing energy efficient technologies in the exploitation of transport infrastructure buildings (Fig. 3).

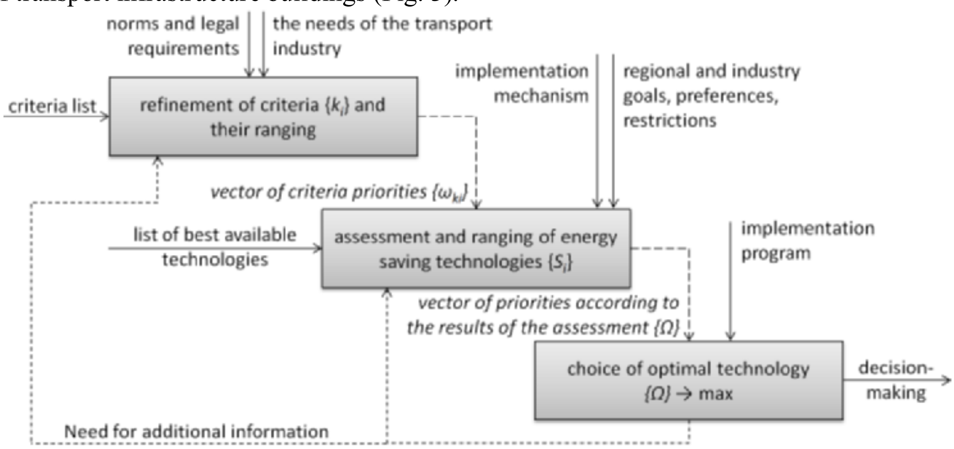

Fig. 3. Decision-making model when choosing energy-saving technologies at the stage of exploitation of transport infrastructure buildings.

To assess the validity of the presented model, based on the opinion of experts, the comparison criteria were ranked (Table 1).

Table 1. The results of calculating the priority vector of comparison criteria according to expert evaluation.

Comparison criteria	k_1	k_2	k_3	k_4	k_5	**vector of criteria priorities** $\{\omega_{ki}\}$
k_1	1	1	4	4	5	0.39
k_2	1	1	1	3	3	0.26
k_3	0.25	1	1	1	3	0.16
k_4	0.25	0.33	1	1	3	0.13
k_5	0.2	0.33	0.33	0.33	1	0.06

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Criterion k_1 is the cost of implementing the technology in the repair or reconstruction of a building, k_2 is the payback time of the technology, k_3 is the complexity of implementing the technology, k_4 is the maintainability of the technology in the event of failures, k_5 is the adaptability of the technology to a specific building, to regional conditions.

Using a similar methodology, as an example, the weights of several alternative options for energy-saving technologies were determined according to the criteria given in Table 1. Three technologies are considered:

S_1 - insulation of the facade of the building according to the system of a hinged ventilated facade;

S_2 - modernization of the heating system using pipelines made of efficient materials and an automated resource release system;

S_3 - use of alternative energy sources in the form of solar panels.

S_1 technology is mandatory if the building does not meet the requirements of the legislation on energy efficiency indicators. The S_2 technology is substantiated by real application practice and is optimal according to the assessment of primary indicators. The S_3 technology is recommended by the transport strategy developed by the Government of the Russian Federation.

At the final stage, the priority vector of alternative options was determined, taking into account the weight of the comparison criteria (Table 2).

Table 2. The results of calculating the priority vector of alternative options for energy-saving solutions.

Alternatives	**vector of priorities alternatives ω_{ji}**					**vector of priorities alternatives $\{\Omega_{Sj}\}$**
	ω_{Sjk1}	ω_{Sjk2}	ω_{Sjk3}	ω_{Sjk4}	ω_{Sjk5}	
S_1	0.16	0.09	0.23	0.22	0.25	0.17
S_2	0.28	0.55	0.31	0.44	0.50	0.39
S_3	0.56	0.36	0.46	0.33	0.25	0.45

According to the totality of indicators, option S_3 is the leader.

4 Discussion

The scientific significance of the study lies in the fact that the proposed model allows you to choose the option with the best prospective performance. The results obtained in the work can be applied in planning repairs, reconstruction of transport infrastructure buildings, as well as in new construction. The proposed model can be included in the quality control system when developing design solutions.

The results of the assessment of the options for energy-saving technologies according to the proposed criteria are presented in Fig. 4.

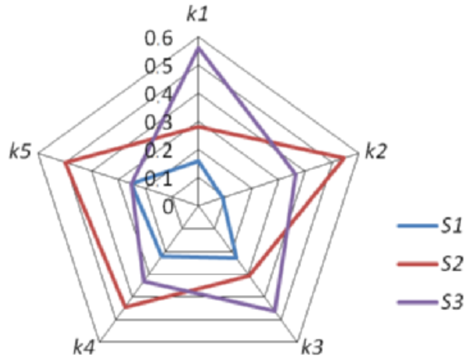

Fig. 4. Selection of alternative options S_j, taking into account the criteria for comparison k_i.

The reliability of the results obtained was assessed in terms of consistency. For the priority matrix of comparison criteria, the consistency index λ_{max} was 0.075, the consistency ratio was 0.067, which is less than the allowable 0.1. The determination of the weight of alternatives for each comparison criterion was carried out on the basis of actual data in natural units of change, for example, cost in rubles, time in years, labor costs in man-hours. The assessment of alternatives in terms of quality indicators of maintainability and adaptability was carried out by an expert method based on a 9-point scale of preferences. The value of the consistency ratio was also less than the allowable value of 10%.

5 Conclusions

The main scientific provisions obtained in the course of the study:

– it has been established that the variety of energy-saving technologies requires the development of scientifically based approaches with the possibility of automating the decision-making process;
– a flexible system of criteria for selecting energy-saving technologies with the possibility of mathematical processing to obtain reliable results, taking into account all stages of the building's life cycle, was proposed;
– a model for evaluating and selecting energy-saving technology based on multicriteria optimization has been developed.

A feature of the proposed model is that it takes into account not only the norms of legislation, but also regional characteristics, the availability of an implementation mechanism, as well as prospective exploitation costs.

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