Methodology of Indicative Analysis to Determine the Municipal Units for Implementation of the Energy-Saving Strategy

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Abstract – This paper proposes a two-stage approach to choose the priority municipal units for implementing required energy efficiency measures in a district heating system. On the first stage the existing state of district heating system of Irkutsk region (Eastern Siberia) was analysed. On the second stage the choice of municipal units is considered as the Multiple Criteria Decision Analysis (MCDA) problem. The authors selected the most valuable criteria such as tariffs, subsidies and etc. that are rather sensitive for consumers and budget. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was applied to identify the priority municipal units for implementing energy efficiency measures.

Keywords – District heating systems; energy efficiency measures; energy-saving strategy; heat tariff; indicative analysis; multiple criteria analysis; municipal units; subsidization indicator

Nomenclature

i	index of municipal unit $i = 1, 2, \dots, m$	—
j	index of indicator $j = 1, 2, \dots, n$	—
$\mathbf{B}$	decision matrix	—
k_{ij}	value of the indicator	—
$\mathbf{C}$	normalized decision matrix	—
c_{ij}	element of matrix $\mathbf{C}$	—
$\mathbf{\Lambda}$	weighted normalized decision matrix	—
λ_{ij}	element of matrix $\mathbf{\Lambda}$	—
μ_j	weight value of the indicator j , $\sum_{j=1}^n \mu_j = 1$	—
B^+	positive ideal alternative	—
B^-	negative ideal alternative	—
Y_U	set of maximized indicators	—
Y_Z	set of minimized indicators	—
h_i^+	Euclidean distance from B_i to the positive ideal alternative	—
h_i^-	Euclidean distance from B_i to the negative-ideal ideal alternative	—
F_i	relative distance to the ideal alternative	—

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1. INTRODUCTION

Currently, the theory and practice of design and operation control of the efficient district heating systems (DHS) are actively developing. These systems are of high socio-economic importance in the countries located in the geographical zones with a cold climate. One of the key conception of DHS development is the transition to the 4th generation of DHS (4GDH systems) [1]–[4]. This technological conception involves a number of both technical and organizational solutions which provide a new level of efficiency of the thermal energy production, distribution and consumption. At the same time, the upgrade of existing systems up to 4GDH implies the solution of many new fundamental methodological and practical problems.

The key features of the 4GDH systems are: use of low-temperature heat energy (low-temperature schedule) in order to reduce losses; recovery of thermal energy from low-temperature sources; use of renewable energy sources (RES) and their integration with other energy supply systems (power, natural gas, etc.); intelligent (with the high level of automation) methods of system control [4]. Also many authors pay attention to the carbon dioxide emissions reduction, for example [5]–[7], which generally depends on the RES share increase [8].

One of the most important problems of effective modernization of Russian DHS is the energy-saving policy making [9]. The potential for thermal energy energy-saving in Russian DHS functioning in the different MU like cities, towns is quite high (from 15 to 25% of the total thermal energy production).

The implementation of an energy-saving policy leads to transformation of the organizational structure in the DHS management. Many authors pay attention to the need of special training of manufacturers, consumers and municipal authorities before the technical re-equipment of existing systems [10], [11]. Some methodological approaches are developed for municipal energy planning: for example, an approach is proposed in [12] for ranking of municipal energy decisions. Special models assess the effectiveness of various scenarios of the DHS development [13]–[15]. Also, it is noted that an comprehensive approach is needed to evaluate the profit of new projects in the energy sector. The authors of [16] proposed an approach for energy planning using the weight coefficients. The role of energy experts in this process is especially highlighted. Another example of an indicative analysis that used for municipal waste management is presented in [17].

In this paper, a methodology for the selection of priority municipal units (MU) for the implementation of the thermal energy-saving strategy is proposed. This task was established by the Government of the Irkutsk Region in 2010 to realize the federal energy-saving program [18]. Usually, the decision making begins with the definition of priority energy-saving measures [19]–[21]. In this case, we at first determined the MUs which DHS's state is the worst and they as soon as possible required the energy-saving policy implementation.

2. METHODOLOGY

The proposed methodology involves two main stages: problem structuring; analysis [22]. Each stage, in its turn, consists of some steps shown in Fig. 1. The first stage aims to understand the decision context and to structure the problem. It begins from structuring the goals of energy-saving development. Then the data analysis phase creates a supportive database. The available data about the existing subsidy, efficiency of boiler capacity use, tariffs, MU statistical data etc.

Average hot water tariff has been collected and analysed for performing two next steps: possible alternative definition and formulation of indicators to assess how each alternative contributes to achieving the goals.

Fig. 1. Conceptual scheme of proposed methodology.

The second stage is the actual analysis, consisting of indicators weighting, assessment, aggregation and alternatives ranking steps.

Indicators weighting step assigns a value to each indicator that indicates its relative importance with respect to the other considered indicators. The indicators can be of different importance or not but the sum of their weights must be equal to 1.

Indicators assessment is the quantification of the impact of each alternative against each indicator defined in the first stage. The result is a matrix providing information about the effects of each alternative on each indicator. Indicators aggregation refers to the application of a rule to process the output of indicators assessment and weighting steps and evaluate the total performance of each alternative. Various MCDA approaches apply different decision rules to aggregate the performance of the alternatives across indicators. Last, outranking the alternatives is one of several methods to summarize the results of the indicators aggregation and to distinguish the best ones.

The choice of priority MU for implementing required energy efficiency measures and energy efficiency is MCDA problem. If you solve this problem by expert means, it may turn out that each expert will have his own preferences for choosing. In turn, the methods of MCDA help decision-makers evaluate a set of objects to choose the most preferable one, classify or rank a set of objects according to several indicators in accordance with given preferences. In this work, the MU are considered as objects, so the indicators are criteria of their energy efficiency.

Today, there are a number of MCDA methods, each of which has a certain set of advantages [23], [24]. The TOPSIS method requires only a minimal number of inputs from the user and its output is easy to understand [25], [26].

The purpose of this practical study is to select a list of MUs, i.e. definition of not one, but a set of the best MU. In TOPSIS, the values of the indicators are first normalized, according to which the position of the alternative under investigation is determined relative to the best and worst variants, as well as in relation to each other, then the calculated distances between them are used to classify alternatives.

The TOPSIS method consists of five steps [27]:

1. Calculate the normalized decision matrix **B**.

The decision matrix **B** is filled with the values of the k_{ij} indicators, and then a normalized matrix **C** is built on the basis of the matrix **B**. The element C_{ij} of matrix **C** is defined as follows:

$$c_{ij} = \frac{k_{ij}}{\sqrt{\sum_{i=1}^m k_{ij}^2}}. \quad (1)$$

2. Determine the weighted normalized decision matrix Λ . The weighted normalized decision matrix Λ based on matrix C . The weighted normalized value λ_{ij} is defined as follows:

$$\lambda_{ij} = \mu_j c_{ij}. \quad (2)$$

3. Determine the ideal and negative ideal alternative. The ideal alternative and the negative ideal alternative denoted as B^+ and B^- respectively, are defined as:

$$B^+ = \{(\lambda_1^+, \lambda_2^+, \dots, \lambda_n^+)\} = \{(\max_i \lambda_{ij} | j \in Y_U), (\min_i \lambda_{ij} | j \in Y_Z)\}, \quad (3)$$

$$B^- = \{(\lambda_1^-, \lambda_2^-, \dots, \lambda_n^-)\} = \{(\min_i \lambda_{ij} | j \in Y_U), (\max_i \lambda_{ij} | j \in Y_Z)\}, \quad (4)$$

where, Y_U is the set of maximized indicators, Y_Z is the set of minimized indicators.

4. Calculate as well as the distance between alternative. The Euclidean distance from B_i to the ideal and negative-ideal alternatives is calculated as follows:

$$h_i^+ = \sqrt{\sum_{j=1}^n (\lambda_{ij} - \lambda_j^+)^2}, \quad (5)$$

$$h_i^- = \sqrt{\sum_{j=1}^n (\lambda_{ij} - \lambda_j^-)^2}, \quad (6)$$

5. Calculate the relative distance to the ideal alternative. Calculate the relative distance F_i to the ideal alternative, defined as:

$$F_i = h_i^- / (h_i^+ + h_i^-). \quad (7)$$

The calculated values F_i are in the range $[0; 1]$ and they can be ordered in descending order. The object B_i with the highest value F_i is selected as the most preferred.

3. CASE STUDY

Cost of heat to consumers is one of the most important indicators of assessing the energy situation that impacts heat tariffs. Many boilers of MU have high operating costs caused by excessive consumption of fuel due to low efficiency and by high fuel costs, primarily in the northern regions. This results in high heat tariffs for population (Fig. 2). Difference between economically feasible (corresponding to production cost) and valid heat tariffs in many areas is subsidized, therefore, it is difficult to get a realistic idea of the heat supply at present day tariffs. However, despite this fact, they give a certain idea on motives of the directions of modernizing the municipal DHS.

Subsidization indicators for preparation of municipal infrastructure facilities for heating season divided by the value of heat consumed by population and utilities in MU of Irkutsk region are shown in Fig. 3.

Specific MU subsidization indicator allows more certain identification (as compared to tariffs regulated by subsidies) of the priority MU that need urgent solution of DHS problems [28], [29].

Fig. 2. Heat and hot water tariffs established by regulatory organizations for population of MU in the Irkutsk region.

Fig. 3. Indicator of volumes of state subsidies of MU in the Irkutsk region.

The efficiency of boiler capacity use is one of indicators characterizing the condition and efficiency of operation of the main facilities of DHS (Fig. 4). The reserve of 25 % is sufficient for ensuring normal operation (the solid line in Fig. 4). The collected Irkutsk region MU data is shown in the Table 1.

Fig. 4. Efficiency of boiler capacity use in MU of the Irkutsk region.

TABLE 1. INDICATORS FOR ASSESSING THE STATE OF THE HEAT POWER INDUSTRY IN SEVERAL MU OF IRKUTSK REGION

Name of MU	Subsidization indicator, Rur/MWt	Efficiency of boiler capacity use, %	Average tariff, Rur/MWt	
			Hot water	Heat
Angarsk Town	1	19	715	1007
Nizhneilimsk province	1140	27	1306	1338
Shelekhov province	431	27	831	988
Cheremkhovo MU	138	28	893	1042
Zima province	383	30	1069	1568
Taishet province	406	33	1670	1208
Zalari province	317	34	1886	1175
Ust-Ilmsk province	252	37	816	816
Usole MU	247	38	816	816
Mamsko-Chuisky province	238	39	1515	1515
Kirensky province	294	42	1160	1167
Chuna MU	84	43	1241	1144
Cheremkhovo Town	24	43	1094	1094
Kachug province	428	44	0	1401

Bodaibo MU and the area	1029	45	1179	1413
Zhigalovo province	509	46	0	1297
Balagansk province	230	49	0	2232
Irkutsk province MU	131	52	1495	1583
Nizhneudinsk province	32	52	1306	1338
Bratsk province	155	53	1574	2011
Ust-Uda province	274	53	893	971
Slyudyanka province	189	56	1521	1513
Kuitun province	166	58	0	1222
Tulun Town	62	58	1358	1517
Sayansk town	4	60	818	818
Svirsk Town	370	61	1088	1088
Ust-Kut MU	565	64	1587	1620
Zima MU	48	68	1136	1058
Kazachinsko-Lensk province	255	72	1434	1530
Katangsky province	2073	72	0	599
Tulun province	523	73	1963	1303
Alarsky province	1706	77	618	892
Olkhon MU	116	82	0	1493

Table 2 shows the weight values of the energy efficiency indicators according to their importance. The subsidization indicator and efficiency of boiler capacity use have equal high values of weights. The value of tariff indicator weight is lower, since the tariff for the population is not so significant as the rational use of budget found. The difference between weights of the heat tariff and hot water is explained by the fact that many MUs are not provided with hot water.

TABLE 2. WEGHT VALUE OF INDICATOR

Name of indicator	Weight value
Subsidization indicator	0.3
Efficiency of boiler capacity use	0.3
Average heat tariff	0.25
Average hot water tariff	0.15

The TOPSIS was applied to the Irkutsk region MU data (Table 1). 10 MU are ranked out and shown in Table 3. They are recommended for more detailed consideration of measures on upgrading the municipal DHS, and deciding on methods for their implementation. Along with selection of priority MU for DHS retrofitting, the priority directions for retrofitting the heat sources, heat networks and consumption systems can be chosen in future research.

TABLE 3. INDICATORS FOR ASSESSING THE STATE OF THE HEAT POWER INDUSTRY IN SELECTED MU OF IRKUTSK REGION

Name of MU	Subsidization indicator, Rur/MWh	Efficiency of boiler capacity use, %	Average tariff, Rur/MWh	
			Hot water	Heat
Tulun province	523	73	1963	1303
Nizhneilmsk province	32	52	1306	1338
Katangsky province	2073	72	0	599
Bodaibo MU and the area	1029	45	1179	1413
Alarsky province	1706	77	618	892
Kazachinsko-Lensk province	255	72	1434	1530
Zima province	383	30	1069	1568
Zhigalovo province	509	46	0	1297
Kachug province	428	44	0	1401
Ust-Kut MU	48	68	1136	1058

4. CONCLUSIONS

The municipal DHS of the Irkutsk region, as well as the country as a whole, is characterized by problems associated with the unsatisfactory condition of fixed assets, the difficult economic situation in municipalities, the shortage of fuel to hard-to-reach, remote areas and, as a result, high tariffs for the population and the public sector for heat and hot water.

To select priority areas of the region for the purpose of conducting priority measures, the most significant indicators for assessing the state of municipal DHS of the MU under consideration were selected and a methodology based on the application of the TOPSIS method was proposed. The TOPSIS was applied to the Irkutsk region MU data and 10 provinces were ranked by energy efficiency and chosen for the implementation of the necessary measures to improve the state of municipal DHSs.

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