USING MULTICRITERIAL RANKING MODELS IN CASE OF SOLUTIONS REGARDING THE SUPPLY OF THERMAL ENERGY FOR RESIDENTIAL GROUPS OF BUILDINGS

GIURCA IOAN
PHD. ENG., SENIOR LECTURER, TECHNICAL UNIVERSITY OF CLUJ-NAPOCA, 
e-mail: giurca_ioan@yahoo.com

CĂLDARE IOAN
PHD. ENG., SENIOR LECTURER, TECHNICAL UNIVERSITY OF CLUJ-NAPOCA,
e-mail: ioan.caldare@rezi.utcluj.ro

MUNTEA CORNEL
PHD. ENG., ASSOCIATE PROFESSOR, TECHNICAL UNIVERSITY OF CLUJ-NAPOCA, 
e-mail: cornelmuntea@yahoo.com

NASTAC DORIN CRISTIAN
PHD. STUDENT ENG., ASSISTANT, TRANSILVANIA UNIVERSITY OF BRASOV, 
e-mail: nastaccristi@yahoo.com

Abstract
In this paper we analyze the way of choosing the technical solutions concerning the supply of thermal energy for residential groups of buildings, using the Multicriterial Ordinal Ranking Model, the Relative Distance Comparison model in relation with the maximum performance and the Relative Distance Comparison model in relation with the average performance. The paper ends with the presentation of the numerical results and a few conclusions. The models proposed may be used in practice in case of feasibility studies, for master degree theses as well as for Ph.D. theses.

Keywords: district heating, multicriterial methods, relative distance comparison model, multicriterial ordinal ranking model, optimization, performance.

Clasificare JEL: C61, Q49

1. Introduction
In Romania, multi-criteria methods are well known [8], however there are few studies about their use in the field of installations for constructions.

Lately, several papers approaching the use of multicriterial models in the field of installations for constructions have been published in Romania too, namely Ph.D. theses [3] as well as articles [2].

In this article, we analyzed the way of choosing the technical solutions concerning the supply of thermal energy for groups of residential buildings using the Multicriterial Ordinal Ranking Model, the Relative Distance Comparison model in relation with the maximum performance and the Relative Distance Comparison model in relation with the average performance.

At the end of the paper we present the conclusions of the paper.

The models proposed may be used in practice in case of feasibility studies, for master degree theses as well as for Ph.D. theses.

2. Work method
When performing an actual study, depending on the purpose of the research and the type of available data, one may use only one multicriterial model or a combination of several multicriterial models.

Taking into account the possibilities and the multicriterial ranking model knowledge limits, in this study we have preferred three multicriterial models [5], namely:

a) the multicriterial ordinal ranking model;
b) the relative distance comparison model in relation with the maximum performance;
c) the relative distance comparison model in relation with the average performance.
The multicriterial ordinal ranking model

This model consists in successively granting numbers to each variant, depending on the value of each ranking criteria, thus the variant with the maximum qualitative performance shall be ranked 1, the next variants being ranked 2, 3, ..., n ("n" rank, equaling the number of analyzed variants, being granted to the variant with the minimum qualitative level of each variable).

In case of variants where the status is more favorable as the recorded values are bigger, the variant with the biggest value of the characteristic is ranked 1, the next in decreasing order is ranked 2 and so on and so forth.

In case of variants whose favorable status corresponds to a minimum value of the characteristic, the ranks may be granted backwardly, namely the variant with the minimum value of the characteristic shall be ranked 1, the next variant in increasing order shall be ranked 2 and so on and so forth [1] - [9] - [10].

The score obtained by each variant is established according to the formula [6]:

$$ \sum_{j=1}^{m} r_{ij} S_i $$

(1)

where:

- $S_i$ stands for the score obtained by each variant;
- $r_{ij}$ - the rank of variant “i” depending on the assessment criterion j.

For each “i” variant, one shall determine the average rank by taking into account the positions occupied by that specific variant in relation with all decision-making criteria.

$$ \frac{\sum_{j=1}^{m} r_{ij}}{m} $$

(2)

where m stands for the number of decision-making criteria.

The variant with the lower average rank is the most efficient one, taking into account all criteria, and it obtains the final rank 1. As the average rank increases, the final rank also increases, until reaching the “n” rank granted to the variant that obtained the maximum rank [1] - [9] - [10].

We synthesized this method in Table no. 1.

Table no. 1 Rank matrix

<table>
<thead>
<tr>
<th>Decision-making variant</th>
<th>Assessment criterion</th>
<th>Score</th>
<th>Average rank</th>
<th>Final rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C1</td>
<td>C2</td>
<td>...</td>
<td>Cj</td>
</tr>
<tr>
<td>V1</td>
<td>r11</td>
<td>r12</td>
<td>...</td>
<td>r1j</td>
</tr>
<tr>
<td>V2</td>
<td>r21</td>
<td>r22</td>
<td>...</td>
<td>r2j</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Vi</td>
<td>r1i</td>
<td>r12</td>
<td>...</td>
<td>rij</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Vn</td>
<td>rn1</td>
<td>rn2</td>
<td>...</td>
<td>rnj</td>
</tr>
</tbody>
</table>

Source: processed by the author according to paper [6]

b) The relative distance comparison model in relation with the maximum performance

The specificity of this model consists in the transformation of the initial values of the variables in relative distances to the most efficient value for each criterion:

- in case of criteria that needs to be maximized, the relative distance to the most efficient value is determined with the formula:

$$ d_{ij} = \frac{C_{ij}}{C_{j_{max}}} $$

(3)
where:

dij stands for the relative distance of each “i” variant to the most efficient technical solution, for the “j” variable
[4].

- in case of criteria that needs to be minimized, the relative distance to the most efficient value is determined
with the formula:

\[
dij = \frac{Cj_{\text{min}}}{Cij}
\]

The relative distances are calculated for each “j” criterion, and then one determines the average of relative
distances for each “Vi” variant, as the simple geometric mean of the anterior ratios, calculated for all “j” variables:

\[
Di = m \sqrt[\sum j=1]{dij}
\]

Where “Di” stands for the relative average distance for the “i” variant.

Obviously, the values of the relative distances to the most efficient variant range from 0 to 1, because one
chooses as the comparison basis the maximum performance variant [9].

Eventually, the “Vi” variants are categorized depending on the decreasing values of the “Di” average relative

c) The relative distance comparison model in relation with the average performance

The technical solution variants may be compared between them only if there is a common basis. As the
traditional variant of the relative distance model does not fulfill this requirement, one may apply a new relative distance
model, supposing the replacement of the best performance for the “j” variable (Cj_{\text{max}}) with the average value (Cj_{\text{med}}),
thus resulting the following formula of the multicriterial distance to the average, for each “i” variant:

\[
Di = m \sqrt[\sum j=1]{\frac{Cij}{Cj_{\text{med}}}}
\]

In this way, we obtain a fixed position of each variant as compared to the average, which allows us to compare
the variants.

Both the individual values of the variants as well as the average ones reflect favorable situations when they are
greater than one, and negative situations when they are lower than one [4].

3. Case study

In order to exemplify, we present a case study about how to choose the technical solutions concerning the
thermal energy supply for a residential district, and in order to choose the technical solutions we shall use: the
Multicriterial Ordinal Ranking Model, the Relative Distance Comparison model in relation with the maximum
performance and the Relative Distance Comparison model in relation with the average performance. At present, the
thermal energy necessary to heat and prepare the hot water is supplied by a local heating station, through three thermal
points located in three residential sections.

3.1 Set of decisional versions

In this study, we shall analyze the possibility of independently producing the thermal energy necessary for the
residential district. Thus, we shall take into account four technical solutions in order to supply thermal energy for this
residential district, and these technical solutions shall be marked from V1 to V4.

Starting with this base, we have built up the decisional variant matrix (see table no. 2).
3.2 Set of decisional criteria

Next, at step 2, we identified the basic criteria based on which one may choose the technical solutions in order to supply thermal energy for the residential district.

These criteria are the following: investment, installed thermal capacity, annual natural gas consumption, annual electrical power consumption, investment recovery time and length of methane networks.

Also, for each criterion, one established whether the optimization shall be made by maximization or by minimization. Based on this, we built up the decisional criteria matrix (see table no. 3).

### Table no. 3 Set of Criteria [Cj]

<table>
<thead>
<tr>
<th>No.</th>
<th>Criterion</th>
<th>Name</th>
<th>M.U.</th>
<th>Optimization made by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C1</td>
<td>Investment</td>
<td>Euro</td>
<td>minimization</td>
</tr>
<tr>
<td>2</td>
<td>C2</td>
<td>Installed thermal capacity</td>
<td>Gcal/h</td>
<td>minimization</td>
</tr>
<tr>
<td>3</td>
<td>C3</td>
<td>Annual natural gas consumption</td>
<td>m³/an</td>
<td>minimization</td>
</tr>
<tr>
<td>4</td>
<td>C4</td>
<td>Annual electrical power consumption</td>
<td>kWh</td>
<td>minimization</td>
</tr>
<tr>
<td>5</td>
<td>C5</td>
<td>Investment recovery time</td>
<td>year</td>
<td>minimization</td>
</tr>
<tr>
<td>6</td>
<td>C6</td>
<td>Length of methane networks</td>
<td>km</td>
<td>minimization</td>
</tr>
</tbody>
</table>

3.3 Set of assessment criteria consequences

After establishing the set of decisional variants and the set of decisional criteria, at step 3 we identified the consequences corresponding to the decisional variants and to the decisional criteria, and afterwards we elaborated the matrix for the set of assessment criteria consequence set (see table no. 4).

### Table no. 4 Consequence matrix [aij]

<table>
<thead>
<tr>
<th>No.</th>
<th>Variant’s code</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V1</td>
<td>3 751 527.561</td>
<td>13.029</td>
<td>2 002 746.578</td>
<td>320 047.525</td>
<td>10.52</td>
<td>1.209</td>
</tr>
<tr>
<td>2</td>
<td>V2</td>
<td>995 821.337</td>
<td>11.950</td>
<td>2 068 393.067</td>
<td>285 211.547</td>
<td>11.03</td>
<td>0.512</td>
</tr>
<tr>
<td>3</td>
<td>V3</td>
<td>3 010 557.335</td>
<td>11.922</td>
<td>1 197 729.066</td>
<td>126 825.690</td>
<td>14.36</td>
<td>2.224</td>
</tr>
<tr>
<td>4</td>
<td>V4</td>
<td>2 446 855.385</td>
<td>18.722</td>
<td>1 197 729.000</td>
<td>136 473.000</td>
<td>15.05</td>
<td>2.446</td>
</tr>
<tr>
<td>5</td>
<td>Maximum</td>
<td>3 751 527.561</td>
<td>18.722</td>
<td>2 068 393.067</td>
<td>320 047.525</td>
<td>15.05</td>
<td>2.446</td>
</tr>
<tr>
<td>6</td>
<td>Average</td>
<td>2 728 706.360</td>
<td>12.490</td>
<td>1 197 729.000</td>
<td>126 825.690</td>
<td>10.515</td>
<td>0.512</td>
</tr>
<tr>
<td>7</td>
<td>Minimum</td>
<td>995 821.337</td>
<td>11.922</td>
<td>1 197 729.000</td>
<td>126 825.690</td>
<td>10.515</td>
<td>0.512</td>
</tr>
</tbody>
</table>

4. Results and discussions

4.1 Results obtained

These results are obtained after making the calculations using the three models, namely:

a) the multicriterial ordinal ranking model;

b) the relative distance comparison model in relation with the maximum performance;

C) the relative distance comparison model in relation with the average performance.

**a) The multicriterial ordinal ranking model**

At step 4, one shall draw the rank matrix based on the data taken from table no. 3. In order to set the ranks, we used the multicriterial ordinal ranking model.
Further on, we have written the results in table no. 5.

<table>
<thead>
<tr>
<th>No.</th>
<th>Variant's code</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>Score</th>
<th>Average rank</th>
<th>Final rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V1</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>17</td>
<td>2.83</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>V2</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>13</td>
<td>2.17</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>V3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>13</td>
<td>2.17</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>V4</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>16</td>
<td>2.67</td>
<td>3</td>
</tr>
</tbody>
</table>

The data from table no. 5 have also been presented as a chart in figure no. 1.

![Figure no. 1 Ranking the technical solutions using the multicriterial ordinal ranking model (the lowest rank stands for the most favorable situation)](image)

From table no. 5 as well as from figure no. 1, one may notice that variants V2 and V3 are on the first place, the variant V4 is on the third place, while the variant V1 is on the fourth place.

b) The relative distance comparison model in relation with the maximum performance

At step 5, one shall rank the technical solutions using the relative distance comparison model in relation with the maximum performance. Further on, the results have been written in table no. 6.

<table>
<thead>
<tr>
<th>No.</th>
<th>Variant's code</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>Average relative distance</th>
<th>Final rank</th>
<th>Position in comparison with the maximum performance variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V1</td>
<td>0.265</td>
<td>0.915</td>
<td>0.598</td>
<td>0.396</td>
<td>1.000</td>
<td>0.423</td>
<td>0.538</td>
<td>4</td>
<td>0.6808</td>
</tr>
<tr>
<td>2</td>
<td>V2</td>
<td>1.000</td>
<td>0.998</td>
<td>0.579</td>
<td>0.445</td>
<td>0.953</td>
<td>1.000</td>
<td>0.791</td>
<td>1</td>
<td>1.0000</td>
</tr>
<tr>
<td>3</td>
<td>V3</td>
<td>0.331</td>
<td>1.000</td>
<td>1.000</td>
<td>0.732</td>
<td>0.230</td>
<td>0.618</td>
<td>0.7814</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>V4</td>
<td>0.407</td>
<td>0.637</td>
<td>1.000</td>
<td>0.929</td>
<td>0.699</td>
<td>0.230</td>
<td>0.582</td>
<td>3</td>
<td>0.7354</td>
</tr>
</tbody>
</table>

The relative distance comparison model in relation with the maximum performance somehow removes the limits of the multicriterial ordinal ranking model, which ranks the technical solutions without also showing the gaps between them [7].

The data from table no. 6 have also been presented as a chart in figure no. 2.
c) The relative distance comparison model in relation with the average performance

At step 6, one shall rank the technical solutions using the relative distance comparison model in relation with the average performance. Further on, the results have been written in table no. 7.

Table no. 7 Ranking the technical solutions using the relative distance comparison model in relation with the average performance

<table>
<thead>
<tr>
<th>No.</th>
<th>Variant's code</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>Average relative distance</th>
<th>Final rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V1</td>
<td>0.727</td>
<td>0.959</td>
<td>0.799</td>
<td>0.659</td>
<td>1.207</td>
<td>1.420</td>
<td>0.926</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>V2</td>
<td>2.740</td>
<td>1.045</td>
<td>0.774</td>
<td>0.739</td>
<td>1.151</td>
<td>3.353</td>
<td>1.360</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>V3</td>
<td>0.906</td>
<td>1.048</td>
<td>1.336</td>
<td>1.662</td>
<td>0.884</td>
<td>0.772</td>
<td>1.063</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>V4</td>
<td>1.115</td>
<td>0.667</td>
<td>1.336</td>
<td>1.545</td>
<td>0.844</td>
<td>0.772</td>
<td>1.000</td>
<td>3</td>
</tr>
</tbody>
</table>

The data from table no. 7 have also been presented as a chart in figure no. 3.
From table no. 7 as well as from figure no. 3, one may notice that variant V2 is on the first place, variant V3 is on the second place, variant V4 is on the third place, while variant V1 is on the fourth place.

4.2 Discussions

The results obtained using the three models are synthetically presented in the following table.

Table no. 8 Variant ranking

<table>
<thead>
<tr>
<th>No.</th>
<th>Variant’s code</th>
<th>Rank obtained through Multicriterial ordinal ranking model</th>
<th>The relative distance comparison model in relation with the maximum performance</th>
<th>The relative distance comparison model in relation with the average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V1</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>V2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>V3</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>V4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

The data from table no. 8 have also been presented as a chart in figure no. 4.

Figure no. 4 Ranking the technical solutions in accordance with the three models (the lowest rank stands for the most favorable situation)

From table no. 8 as well as from figure no. 4, one may notice that variant V2 is on the first place, variant V3 is on the second place, variant V4 is on the third place, while variant V1 is on the fourth place.

One may also notice that when applying the ordinal ranking model, variants V1 and V2 obtained the sale score, both being on the first place.

Practically, the three models recommend the same solution, namely to choose variant V2 to be practically implemented.

5. Conclusions

Based on this case study, it is recommendable to practically implement the variant marked V2.

It results that the models used in this study may be also used in order to select the technical solutions concerning the supply of thermal energy for groups of residential buildings. Obviously, by analogy, the methods used in this study may also be used in order to select the technical solutions for other types of installations for constructions.

The models proposed may be used in practice in case of feasibility studies, for master degree theses as well as for Ph.D. theses.

This work is among the first of this kind in Romania.

According to necessities, the readers may develop further the concepts and the results presented.
6. References