

Application of Multi-Criterion Decision Aid Method in Designing Heating Systems for Museum Buildings

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Received: January 2001

Abstract. The aim of the work is to choose the best heating system for a museum building. The paper presents the criteria describing this problem. The three technically acceptable heating systems have been identified. The method allowing for the multi-criterion analysis has been selected with the assumption that the final result will be a final ranking of all alternatives. The ELECTRE III method has been chosen. This method helped to solve the problem of pointing at the best heating system.

Key words: heating systems, criteria of evaluation, multi-criterion decision aid method – ELECTRE III.

1. Introduction

The key function of design, construction and usage of heating, ventilation and air conditioning (HVAC) systems in museum buildings is to provide proper indoor climate conditions for artefacts, museum staff and visitors. It very often happens that the works of art requirements define the indoor conditions in museum buildings.

Among the thermal parameters influencing the indoor climate conditions, the temperature and relative humidity are of the greatest importance. The allowable range of the parameters mentioned above for museum buildings is listed in Table 1 (Antoniewicz and Mroz, 1999).

Many museums in Poland and other European countries are located in old buildings, e.g., castles, palaces or churches. Because of the change of the way they are used, the majority of those buildings have to be adapted to fulfil exhibition requirements. The renovation has to concern both building function, and technical equipment, including the HVAC systems. The complexity of the problem, together with the choice of the proper technical solution makes it necessary to simultaneously analyse the following factors:

Table 1

The allowable temperature and relative humidity ranges for museum buildings (Antoniewicz and Mroz, 1999)

	Temperature °C	Relative humidity %
Storage	16–18	50–60
Exhibition	18–20	50–60

- interaction of the HVAC system with existing structural elements of the building – localisation factor,
- total investment and running costs of the system – economical factor,
- safety of the operation – insurance factor,
- primary energy consumption – ecological factor,
- life time of the system – reconstruction factor.

2. Description of the Castle Museum Pszczyna

The Castle of Pszczyna, a National Heritage Museum, is located in the former defence character building, refurbished at the end of XIX century to become the summer residence of the princely family of the Hochbergs (Ziembinski, 1983). Nowadays, there is the exhibition of the artefacts located within the castle walls. Thermal comfort in the building is controlled by the water based heating system supplied from the gas boilers located in the basement.

The poor performance of existing heating system determined the need of its total retrofitting. Three heating systems were taken into account as possible technical solutions:

- water based heating system supplied from a gas boiler room (alternative A),
- water based heating system supplied from an oil boiler room (alternative B),
- electrical heating system supplied from the dedicated transformer room (alternative C).

The capacity of the all mentioned above systems has been calculated on the basis of energy balance of the building. The technical information concerning the analysed building and the results of the energy calculations are shown in Table 2.

3. Assuming the Evaluation Criteria

The assumed alternatives have certain characteristic attributes which, within the scope of the analysed problem, play directly the role of evaluation criteria.

Concerning the specific usage of the Pszczyna Castle Museum, the following criteria have been taken into account in the description of the decision problem:

Table 2
Energy balance of the building

Building: total volume	[m ³]	65.000
Building: heated volume	[m ³]	62.000
Shape factor A/V^1	[m ⁻¹]	0.11
Average heat transfer coefficient of building cover k_B	[W m ⁻² K ⁻¹]	0.90
Required heating system capacity	[kW]	550

¹ External barrier surface to heated volume of the building.

- primary energy consumption expressed in kWh a⁻¹ – cr_{PEC} ;
- durability of the heating system – cr_{DHS} ;
- practical implementation difficulties – cr_{PID} ;
- insurance cost – cr_{IC} ;
- total cost of usage expressed in thousand USD – cr_{TEC} .

The assumed criteria make it possible to thoroughly evaluate the compared alternatives of heating systems, as proposed to be implemented in the historical building of the Pszczyna Castle Museum.

The basis for calculating the values for the alternatives under consideration have been presented below.

The Primary Energy Consumption Criterion (cr_{PEC})

This is the cost type criterion describing the energy efficiency of each technically acceptable solution referring to the amount of the primary (fossil fuel) energy consumption. It can be calculated as the ratio of the annual heating energy demand of the building and the primary energy conversion factor of the heating system (1):

$$cr_{PEC} = \sum_{j=1}^n \frac{E_j^r}{\eta_j}, \quad (1)$$

where:

- cr_{PEC} – the value of the primary energy consumption criterion, kWh a⁻¹,
- E_j^r – the j -item annual energy consumption, kWh,
- η_j – the j -item energy conversion factor.

The criterion of the primary energy consumption is the decreasing preference criterion. The rating of the heating systems according to this criterion is based on the comparison of the primary energy consumption for all technically acceptable alternatives. The typical conversion factors of different types of heating systems are listed in Table 3

The amount of annual heating energy demand can be calculated on the basis of energy balance of the building, including heat transfer and ventilation needs in extreme climactic

Table 3
Typical annual conversion factors of the heating systems

Heating system	Energy conversion factor based on the heating value of the fossil fuel
Gas fired boiler – traditional unit	0.85
Gas fired boiler – condensing unit	1.00
Oil fired boiler	0.85
Electricity (condensing turbines)	0.25

conditions, and the degree day data for specific building location (2):

$$E_{heat}^r = \dot{Q}_{heat} \cdot \frac{DD}{t_i - t_e} \cdot 24, \quad (2)$$

where:

DD – the number of degree days (Eq. 3),

t_i – average internal temperature of the building during the heating season, °C,

t_e – minimum external temperature of the heating season, °C,

\dot{Q}_{heat} – calculated heating capacity of the system, kW.

The number of degree days can be calculated according to the following equation:

$$DD = Z \cdot (t_i - \bar{t}_e), \quad (3)$$

where:

Z – the number of the days of the heating season, d ,

t_i – average internal temperature of the building during the heating season, in °C,

\bar{t}_e – average external temperature of the heating season, in °C.

Table 2 is the basis for E_j^r calculations, whereas η_j is calculated basing on Table 3 (compare formula 1). Other values (appearing in formulae 2 and 3), for the Pszczyna Castle Museum, and for the town of Pszczyna itself, are as follows:

$$Z = 228 \text{ days}, \quad t_i = 20 \text{ °C}, \quad \bar{t}_e = 3.975 \text{ °C}, \quad t_e = -20 \text{ °C}.$$

The Durability of Heating System Criterion (cr_{DHS})

This is the profit type criterion describing the assumed time of the exploitation of the system without the need of its total refurbishment. The time of interest is determined as the average time of exploitation of the weakest element of the heating system. For the water based heating systems the lifetime of piping (40 years) is responsible for the durability of the whole system. For the electrical systems the lifetime of wiring (50 years) is the critical parameter. The durability of heating system criterion can be calculated using the following equation:

$$cr_{DHS,i} = \frac{T_i}{T_{max}}, \quad (4)$$

where:

$cr_{DHS,i}$ – the durability of heating system criterion of the i heating system,

T_i – the lifetime of the weakest element of the i heating system, years,

T_{max} – the maximal lifetime of the weakest elements of the heating systems, years.

The criterion is expressed in abstract numbers from the range of (0;1). The following values have been assumed as the basis for calculation:

$T_{max} = 50$ years;

$T_i = 40$ years for the oil burning boiler (alternative A) and for the heating system with the oil burning boiler (alternative B);

$T_i = 50$ years for the electrical heating system (alternative C).

The Practical Implementation Difficulties Criterion (cr_{PID})

The practical implementation difficulties criterion is the cost type criterion. Its construction is based on the analysis of the following point character coefficients:

- the technical space requirements coefficient – $F_{TSR} <1...3>$, regarding the situations listed below:
 - modest space requirements ($< 15 \text{ m}^2$) – value 1,
 - medium space requirements ($15 \div 30 \text{ m}^2$) – value 2,
 - substantial space requirements ($> 30 \text{ m}^2$) – value 3;
- the construction elements interference coefficient – $F_{CEI} <1...15>$, regarding situations listed below:
 - horizontal construction elements – $F_{CEI,h} = 1 + 2n$ (n – the number of horizontal passes),
 - vertical construction elements – $F_{CEI,v} = 1 + m$ (m – the number of vertical passes);
- the internal space requirements coefficient – $F_{ISR} <1...3>$, regarding situations listed below:
 - no space requirements – value 1,
 - modest space requirements – value 2,
 - substantial space requirements – value 3;
- the indoor composition coefficient – $F_{IC} <1...3>$, regarding situations listed below:
 - no change of the indoor composition – value 1,
 - slight change of the indoor composition – value 2,
 - significant change of the indoor composition – value 3;
- the flexibility coefficient – $F_F <1...3>$, regarding situations listed below:
 - full ability of system development – value 1,
 - limited ability of system development – value 2,
 - no ability of system development – value 3;

- the required supervision coefficient – $F_{RS} <1...4>$, regarding situations listed below:
 - minimum supervision requirements (once a year check) – value 1,
 - low supervision requirements (every three month check) – value 2,
 - medium supervision requirements (monthly check) – value 3,
 - high supervision requirements (permanent check) – value 4.

The final value of the practical implementation difficulties criterion can be calculated using the formula:

$$cr_{PID} = \frac{\sum_{i=1}^6 F_i w_i}{\sum_{i=1}^6 F_i^{max} w_i}, \quad (5)$$

$$\sum_{i=1}^6 w_i = 1, 0,$$

where:

cr_{PID} – the practical implementation difficulties criterion,

F_i – the actual value of the i coefficient,

F_i^{max} – the maximum value of the i coefficient,

w_i – the weight of the i coefficient.

The practical implementation difficulties criterion is the decreasing preference criterion. The weights of the factors can be established according to the preference of the decision maker.

The assumed weigh values for individual coefficients, and the values of coefficients for the evaluated alternatives of heating systems have been listed in Table 4.

Table 4

Comparison of data for calculations of values regarding practical implementation difficulties

Coefficient F_i	Weights w_j	F_i^{max}	F_i for an alternative		
			Alternative A	Alternative B	Alternative C
F_{TSR}	0.15	3	3	3	1
F_{CEI}	0.20	15	15	15	5
F_{ISR}	0.15	3	2	2	2
F_{IC}	0.15	3	3	3	1
F_F	0.20	3	2	2	1
F_{RS}	0.15	4	2	2	1

The Insurance Cost Criterion (cr_{IC})

This criterion is calculated as the annual cost of insurance of the building and the exhibited works of art referred to the heating system implemented. It can be derived using the

equation:

$$cr_{IC,i} = 1 - \frac{\Delta IC_i}{\Delta IC_B}, \quad (6)$$

where:

$cr_{IC,i}$ – the insurance cost criterion of the i heating system,

ΔIC_B – the basic insurance annual cost of the building and the works of art, USD,

ΔIC_i – the increase of the insurance annual cost caused by the i heating system, USD.

The insurance cost criterion is the increasing preference criterion. In the case of the electrical heating system, there is no increase in insurance rates ($\Delta IC_i = 0$), whereas in the case of the gas burning boiler and the oil burning boiler, there is an increase in insurance rates and it is, respectively, $\Delta IC_i = 20\%$ for the former, and $\Delta IC_i = 10\%$ for the latter case.

The Total Cost of Usage Criterion (cr_{TEC})

The total cost of usage of a heating system is defined as the present value (calculated for the end of the investment process) and consists of two separately derived cost items: (i) fixed cost and (ii) variable cost.

The annual fixed cost is connected to the group of the investment cost dependent factors and the annual cost of loan interest. It can be calculated employing the equation (Mroz and Thiel, 1995):

$$C_{FIX,i} = I_0 \cdot (r + m + e + i) + LI_{a,i}, \quad (7)$$

where:

$C_{FIX,i}$ – the annual fixed cost of usage, USD a⁻¹,

I_0 – the total investment cost, USD,

r – the redemption factor, %,

m – the maintenance factor, %,

e – the usage factor, %,

i – the insurance factor, %,

$LI_{a,i}$ – the annual loan interest, USD a⁻¹.

The variable cost is determined by the actual price of the energy sources needed for the operation of a heating system. It can be derived using the equation (Mroz and Thiel, 1995):

$$C_{VAR,i} = \sum_{j=1}^n \frac{E_j^r}{\eta_j} \cdot p_{j,i}, \quad (8)$$

where:

$C_{VAR,i}$ – the annual variable cost of usage, USD a⁻¹,

Table 5
Initial data for calculating the total usage costs of the system between 2000 – 2004

	Alternative A	Alternative B	Alternative C
I_0 [in thousand USD]	125.00	131.82	104.55
r [%]	5	5	4
m [%]	2	2	2
e [%]	2.5	2.5	2.5
i [%]	1.5	1.5	1.5
p_{2000} [USD/kWh]	0.07 USD/um ³	0.23 USD/kg	0.06
	$W_d = 9.0$ kWh/um ³	$W_d = 11.8$ kWh/kg	
p_{2001} [USD/kWh]	0.10 USD/um ³	0.23 USD/kg	0.07
	$W_d = 9.0$ kWh/um ³	$W_d = 11.8$ kWh/kg	
p_{2002} [USD/kWh]	0.11 USD/um ³	0.23 USD/kg	0.09
	$W_d = 9.0$ kWh/um ³	$W_d = 11.8$ kWh/kg	
p_{2003} [USD/kWh]	0.15 USD/um ³	0.23 USD/kg	0.11
	$W_d = 9.0$ kWh/um ³	$W_d = 11.8$ kWh/kg	
p_{2004} [USD/kWh]	0.15 USD/um ³	0.23 USD/kg	0.11
	$W_d = 9.0$ kWh/um ³	$W_d = 11.8$ kWh/kg	

* W_d – heating value of the fuel

$p_{i,j}$ – the price of the j -item energy unit during the i -year of analysis, USD kWh⁻¹,

E_j^r – the j -item annual energy consumption, kWh a⁻¹ (Eq. 2).

η_j – the j -item energy conversion factor (Table 3).

The final value of the criterion of the total cost of usage of a heating system is derived from the equation:

$$cr_{TEC} = \sum_{i=1}^t \frac{C_{FIX,i} \cdot (1 + inf_i)^i}{(1 + R)^i} + \sum_{i=1}^t \frac{C_{VAR,i} \cdot (1 + inf_i)^i}{(1 + R)^i}, \quad (9)$$

where:

cr_{TEC} – the criterion of the total cost of usage, USD,

$C_{FIX,i}$ – the annual fixed cost of usage, USD a⁻¹, (Eq. 7),

$C_{VAR,i}$ – the annual variable cost of usage, USD a⁻¹, (Eq. 8),

t – the number of financial years,

inf_i – the rate of inflation in the financial year i , %,

R – the average rate of discount, %.

The criterion of the total cost of usage of a heating system is the decreasing preference criterion. The analysed example assumes that the total cost of usage of the systems will reflect the period of 5 years ($t = 5$ – see formula 9), calculated from the time when the modernisation of the system finishes. The work was to be concluded by the end of 1999. Thus, the end of 1999 was the milestone serving the purpose of calculation of current cost of usage of the system, basing on the estimate of future costs to be incurred in the years to come (from 2000 to 2004). It was assumed at the beginning that the investment in the system would not require a bank loan ($LI_{a,i} = 0$ in Eq. 7). Table 5 compares the

initial data, which consist a basis for calculating the total cost of usage of the compared heating systems (formulae 7–9). Moreover, it has been assumed that:

- the average discount rate (R) in the period of calculation will be 9%;
- the values of inflation rate (inf_i) will be:
 - 10% in the year 2000;
 - 8% in the years 2001 and 2002, and
 - 6% in the years 2003 and 2004.

4. Comparison of Values for Criteria Describing the Heating System Alternatives

Based on the way of calculating the values for individual criteria, described in Section 3 (formulae 1–9), and on the data presented in Sections 2 and 3, we have arrived at a table of estimates (Table 6). The Table contains the values assumed by the criteria in question regarding the estimated alternatives.

The cr_{PEC} , cr_{PID} and cr_{TEC} criteria are the “cost” type criteria, whereas cr_{DHS} and cr_{IC} are the “profit” type criteria. The cr_{DHS} , cr_{IC} and cr_{PID} assume abstract values, though the values for cr_{DHS} and cr_{IC} are calculated basing on the quantitative data (time scale – cr_{DHS} , money scale – cr_{IC}). The basis of arriving at cr_{PID} is a number of qualitative sub-scales, proposed for individual categories of difficulties, defined by means of specific coefficients expressed in points allocated to them. Additionally, the decision maker defines the significance of individual difficulties. The values for this criterion, obtained with the help of formula 5 are also expressed in abstract numbers. As to the two remaining quantitative criteria, the values are defined, respectively, for the cr_{PEC} criterion in kWh a^{-1} , and in thousands of USD, for the cr_{TEC} criterion.

The table comparing the estimates concludes the description of the problem, and is a starting point for further analysis related to all issues of estimation of the compared alternatives for the heating system of the Castle Museum in Pszczyna.

There is an interesting aspect of the analysed problem, namely the simultaneous consideration of criteria relating to the phase of usage of the heating system, and the criterion relating to the phase of practical implementation of the system (the practical implementation difficulties criterion).

Table 6
Comparison of estimates of heating system alternatives for the Pszczyna Castle Museum

Criteria	cr_{PEC} [kWh a^{-1}]	cr_{DHS} [-]	cr_{PID} [-]	cr_{IC} [-]	cr_{TEC} [*1000 USD]
Heating system alternatives					
Alternative A	1250	0.8	0.883	0.8	149.7
Alternative B	1250	0.8	0.883	0.9	194.3
Alternative C	4252	1	0.351	1	545.8

5. The Calculation Method

5.1. *The Possibility of Using the Multi-Criterion Decision Aid (MCDA) Method in Solving the Analysed Problem, and Selection of the Most Appropriate Method*

The description of the problem, presented in Sections 1, 2, and 3 was feasible thanks to close co-operation between the analyst and the decision maker. Both are primordial participants of the process of aiding the decision. Their identification is characteristic for the MCDA methodology. The role and participation of both participants in the process of aiding the decision have been described in (Roy, 1985) and (Thiel, 1996). What is worth stressing is that the director of the museum was the decision maker. There is a set of potential alternatives within the problem (Roy, 1985). Every alternative is described by values attached to individual criteria. The assumed family of criteria is coherent (Roy, 1985). Mathematically, the problem is poorly defined. Only on the basis of additional information on the decision maker's preferences, assuming the way those preferences will be modelled, and using an appropriate calculating procedure allowing for an extensive comparison and final assessment of all alternatives, can the problem be solved.

It has been initially assumed that the final ordering of all alternatives, from the best to the worst, would be the aim of the analysis. The data to define the values of the criteria for individual alternatives is not completely precise, and it has some significance in modelling the decision maker's preferences. The values for the cr_{PID} criterion are not precise due to the lack of precision and arbitrariness of the assumed qualitative scale describing this criterion. It is assumed that during the comparison of the two alternatives, the decision maker will want to communicate his preferences not only basing on the fact that the values for a given criterion for the alternatives differ (a strict preference), or are equal (equality), i.e., consist the true criterion. Perhaps the decision maker will want to highlight the fact that the alternatives being compared are not equal and, simultaneously, none is preferred over any other (a situation weak preference). Moreover, the decision maker may come to conclusion that the context of equality of preferences comes up also with a defined difference in values for a given criterion which may occur for any given pair of compared alternatives. Thus, a concept of a pseudo-criterion may be applied (Roy, 1985). This concept gives way for modelling the following situations: equality, weak preference, and preference, by means of introducing indifference and preference thresholds separately for each given criterion.

All issues described above are characteristic for the methodology of multi-criterion decision aid. Their occurrence within the problem influenced the fact that this methodology has been assumed, and influenced the choice of the calculation method as part of a group of multi-criterion analysis methods.

Using the procedure proposed in (Thiel, 1996), and following the rapport with the decision maker (which in itself is part of the procedure), the ELECTRE III method has been chosen. The method:

- takes into account the vagueness and lack of precision of the values describing the criteria,

- allows the decision maker to provide information on preferences regarding the individual criteria in the form of indifference and preference thresholds – applying the pseudo-criterion model, and the veto threshold, as well as information on relative significance of individual criteria,
- allows the final result to be presented as an outranking final graph, pointing at the levels of outranking, and identifying the respective levels for the compared alternatives.

5.2. Description of the Selected MCDA Method

The ELECTRE III method is based on the binary outranking relation (Skalka *et al.*, 1986). The basic set of data in this method consists of the following: a finite set of alternatives, a family of criteria, and information provided by the decision maker reflecting his preferences. This information encompasses the following: indifference thresholds, preference and veto thresholds for each criterion (the thresholds may be constant or take the form of a linear function (Skalka *et al.*, 1986)), and relative significance defined for all criteria. The veto threshold gives space for defining a so called strong opposition context regarding one of the criteria. Exceeding this threshold value for a criterion results in a situation that, if one of the compared alternatives is much more strongly preferred than another alternative, it is not possible to assume a hypothesis that the first alternative outranks the other one.

The binary outranking relation in ELECTRE III is built on the basis of the so called concordance and discordance tests (Roy, 1985). The values of fuzzy outranking relation, arrived at as a result of using the calculation procedure, provides information about the degree of credibility of occurrence of this relationship for all pairs of compared alternatives. The graph of outranking is a final form of presentation of the result in ELECTRE III. Such a graph is an effect of cross-section of two complete pre-orders, arrived at by means of the so called distillation procedure (Skalka *et al.*, 1986). Basing on the interpretation of the final result, the decision maker can accept the form of the graph of outranking, or modify the initially provided values which reflect his preferences.

6. Using ELECTRE III to Solve the Problem

6.1. Input Data for Calculations

The input data used in calculations are the values presented in Table 6 (the evaluation table). All compared alternatives and criteria have been taken as the foundation for the calculation. Information about the preferences of the decision maker, namely, the values of indifference thresholds, preference and veto thresholds for each criterion (defining α and β coefficients for threshold functions), and values of relative significance of criteria have been presented in Table 7.

It has been assumed that for all criteria, the values of thresholds will be constant ($\alpha = 0$). None of the criteria has been allocated a veto threshold. The values of relative

Table 7

Information about preferences of the decision maker required in the ELECTRE III method

Information about the preferences of the decision maker	indifference threshold	preference threshold	veto threshold	relative significance of a criterion
Criterion				
Primary energy consumption [kWh a ⁻¹]	$\alpha = 0;$ $\beta = 100$	$\alpha = 0;$ $\beta = 1000$	–	0.1
Durability of the heating system [–]	$\alpha = 0;$ $\beta = 0.05$	$\alpha = 0;$ $\beta = 0.15$	–	0.2
Practical implementation difficulties [–]	$\alpha = 0;$ $\beta = 0.05$	$\alpha = 0;$ $\beta = 0.15$	–	0.4
Increase in insurance rates connected to the chosen heating system [–]	$\alpha = 0;$ $\beta = 0.05$	$\alpha = 0;$ $\beta = 0.1$	–	0.1
Total cost of usage of the heating system [in thousands of USD]	$\alpha = 0;$ $\beta = 20$	$\alpha = 0;$ $\beta = 65$	–	0.2

significance of criteria point at the fact that, for a decision maker, the most important seems to be the criterion of difficulties at the stage of practical implementation of the heating system. The least important criteria, in view of the decision maker's attitude, were the criteria of primary energy consumption, and of the increase in insurance in relation to the chosen system of heating.

Basing on the data presented in the evaluation table (Table 6), and information about the decision maker's preferences (Table 7), calculations have been performed using the ELECTRE III computer software package.

7. Calculation Results

The outranking final graph, shown in Fig. 1, which is a conclusive presentation of the selected order of in ELECTRE III, has been the basis of assessment of the compared heating system alternatives which can be introduced in the Castle Museum in Pszczyna.

On the highest level of outranking in the graph, we find the electrical heating system supplied from the dedicated transformer room (alternative C) outranks all other alternatives. Two other heating systems, namely the water based heating system supplied from

FINAL GRAPH

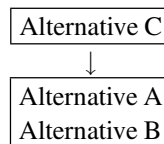


Fig. 1. The final ordering of the compared alternatives of heating systems in ELECTRE III – a graph of outranking.

a gas boiler room (alternative A) and water based heating system supplied from the oil boiler room (alternative B) can be found on the lower level of the outranking graph. Both alternatives are assessed equal.

The high score of the electrical heating system supplied from the dedicated transformer room (alternative C) was influenced by: the criterion of practical implementation difficulties (identified by the decision maker as the most important), and the criterion of durability of the heating system (which also had been identified as crucial by the decision maker). This alternative has been given such a high ranking in spite of the fact that the running costs of the electrical system are the highest (this criterion has been equally ranked as the criterion of durability of the system).

Basing on the evaluation table, on the matrix of credibility, the graph of outranking, and information provided by the decision maker, the electrical heating system supplied from the dedicated transformer room (alternative C) has been identified as the best. This alternative has been recommended by the analyst and accepted by the decision maker.

The analysis of the final result shows that pointing at the alternative which may be considered as the best is pointing at the compromise (not unequivocally the best alternative) which is the closest to decision maker's system of values (and the information on preferences provided by him reflect this system of values)

8. Conclusions

1. The ELECTRE III multi-criterion decision aid method used in this case made it possible to thoroughly evaluate the assumed alternatives of heating systems in a historical building, taking also into account the technical (practical implementation), economic, and usage aspects of the systems to finally point at the best alternative.
2. The result which has been arrived at, is in keeping with the decision maker's preferences. The form of presentation of the final result, namely, the graph of outranking, and the intermediate results, looking from the point of view of the decision maker, is clear and communicative. Should the decision maker be not completely convinced that the information he has provided reflects his preferences, or that the final form is not right, the sensitivity analysis or the stability analysis of the final result ought to have been performed.
3. The solution to the analysed problem gives evidence enough to say that the multi-criterion decision aid methods should take a position they deserve at the planing stages of working on both new construction designs, and in the course of modernisation and maintenance of existing buildings.

9. Acknowledgements

The authors are grateful to Dr Bronislawa Antoniewicz from Poznan University of Technology for supplying the energy balance of the Museum Castle of Pszczyna.

References

- Antoniewicz, B., T. Mroz (1999). Mikroklimat budynków zabytkowych. Wymagania i rzeczywistość. *Materiały Konferencji Fizyka Budowli*, Łódź (in Polish).
- Mroz, T., T. Thiel (1995). Kryteria wyboru sposobu zaopatrzenia w ciepło obiektów. *Ogrzewnictwo Praktyczne*, 4, 34–37 (in Polish).
- Roy, B. (1985). *Methodologie Multicritere d'Aide a la Decision*, ed. Economica, Paris.
- Skalka, J.M., D. Bouyssou, Y.A. Bernabeu (1986). *ELECTRE III et IV. Aspects methodologiques et guide d'utilisation*, Document No. 25, LAMSADE, Paris.
- Thiel, T. (1996). *Metodyczne aspekty wielokryterialnego wspomagania decyzji w inżynierii produkcji budowlanej*, Rozprawa doktorska, Wydział Budownictwa, Architektury i Inżynierii Środowiska, Politechnika Poznańska, Poznań (in Polish).
- Ziembinski, J. (1983). *Dyspozycja wnętrza Zamku Pszczyńskiego na początku XX wieku*, Materiały Muzeum Wnętrz Zabytkowych w Pszczynie, tom II, Pszczyna (in Polish).

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Daugiakriterinių sprendimų metodų pritaikymas muziejų pastatų šildymo sistemoms projektuoti

Tomasz THIEL, Tomasz MROZ

Darbe nagrinėjama geriausios muziejaus šildymo sistemos parinkimo problema. Įvedus šią problemą nusakančius kriterijus, trys techniškai priimtinos šildymo sistemos yra palyginamos ELECTRE III metodu.