Multiple-criteria decision analysis as a method of ventilation system selection in individual residential houses

Analiză de decizie multicriterială ca metodă de selecție a sistemelor de ventilare pentru case de locuit individuale

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***Abstract**:*
The paper provides a comparison of different ventilation systems used in individual residential houses using multiple-criteria decision analysis as a method. The main result is a quantitative assessment of all the systems according to the end-users evaluation criteria and the development of a practical tool for consumers for a quick selection of an optimal ventilation system in individual residential houses according to their unique set of evaluation criteria and priorities.

Keywords: *ventilation system in private houses, multi-criteria analysis, evaluation criteria*

***Rezumat**:*
Lucrarea prezintă o comparație a diferitelor sisteme de ventilare utilizate în case particulare, folosind metoda de analiză multicriterială. Rezultatul principal al lucrării constă în evaluarea cantitativă a tuturor sistemelor de ventilare în conformitate cu criteriile de evaluare ale utilizatorilor și crearea unui instrument practic pentru consumatori pentru o selecție rapidă a sistemului de ventilare optim în case individuale în conformitate cu setul lor de criterii și priorități.

***Cuvinte cheie**: sistem de ventilare în case particulare, analiza multi-criterială, criterii de evaluare*

Generally, the analysis of modern ventilation systems is performed on the basis of public or residential multi-storey buildings. Individual residential buildings in most cases are either ignored or considered only from a theoretical point of view and mainly in the context of conceptual ideas of the future. However, according to official statistics, the construction of single-family houses is an equal sector of housing construction along with apartment buildings and requires more attention from the community of scientists and engineers. In particular, there is a need of practical recommendations for choosing the ventilation system type according to market opportunities and trends. Therefore, the aim of this paper is to analyze one of the methods for comparing the types of ventilation systems used in individual houses, taking into account the set of evaluation criteria and their priorities for end users, which determine the needs and trends of the market.

At the stage of the technical assignment consideration, the designer, together with the customer, has to solve one of the most important tasks - to choose the type of the ventilation system for the designed house. When choosing the system type, it is necessary to take into account not only the parameters of the house and the characteristics of a particular system, but it is also extremely important to rely on a unique set of evaluation criteria of each customer. The multi-criterial analysis method allows solving this task and provides an opportunity to take into account the evaluation criteria when comparing ventilation systems by various parameters.

Multiple-criteria decision analysis (MCDA) or multiple-criteria decision-making (MCDM) is a method of analysis of a series of criteria that influence decision-making. It is most applicable in cases where the goal is choosing one of a variety of alternatives. It allows focusing on the main questions and tasks. It is a logical, consistent and relatively simple tool [1, 2]. To solve the problem of choosing the optimal ventilation system for a detached house, a structural diagram was made up (Fig. 1). It specifies the aim, criteria, sub-criteria and alternative solutions. [3] As criteria for analysis were chosen: K1 - cost; K2 - energy efficiency; K3 - reliability; K4 - indoor climate quality; K5 - noise level; K6 - aesthetics; K7 - flexibility.

The first step of the MCDA is to determine the degree of influence of the selected criteria. To this end, a consumer survey was conducted. A total number of 62 respondents took part in the survey. The survey was carried out at the stage of the technical assignment consideration, after preliminary presentation of the existing systems and their capabilities. The main point of the survey was the request to place all the proposed criteria in the order of their priority for the respondent. The next step was the distribution of points according to the set priorities. Since seven criteria were chosen, the criteria with the highest priority got 7 points and criteria with the lowest priority - 1 point. The final step in the processing of survey data was the calculation of the degree of influence ("weight") of each criterion, which was determined by the formula:

$$m_i = \frac{k_i}{\sum_{j=1}^{7} k_j}, \qquad (1)$$

where: m_i – weight of the criterion with index “i”;
k_i – average priority rating of the criterion with the index “i”.

The calculation results are shown in Fig. 2.

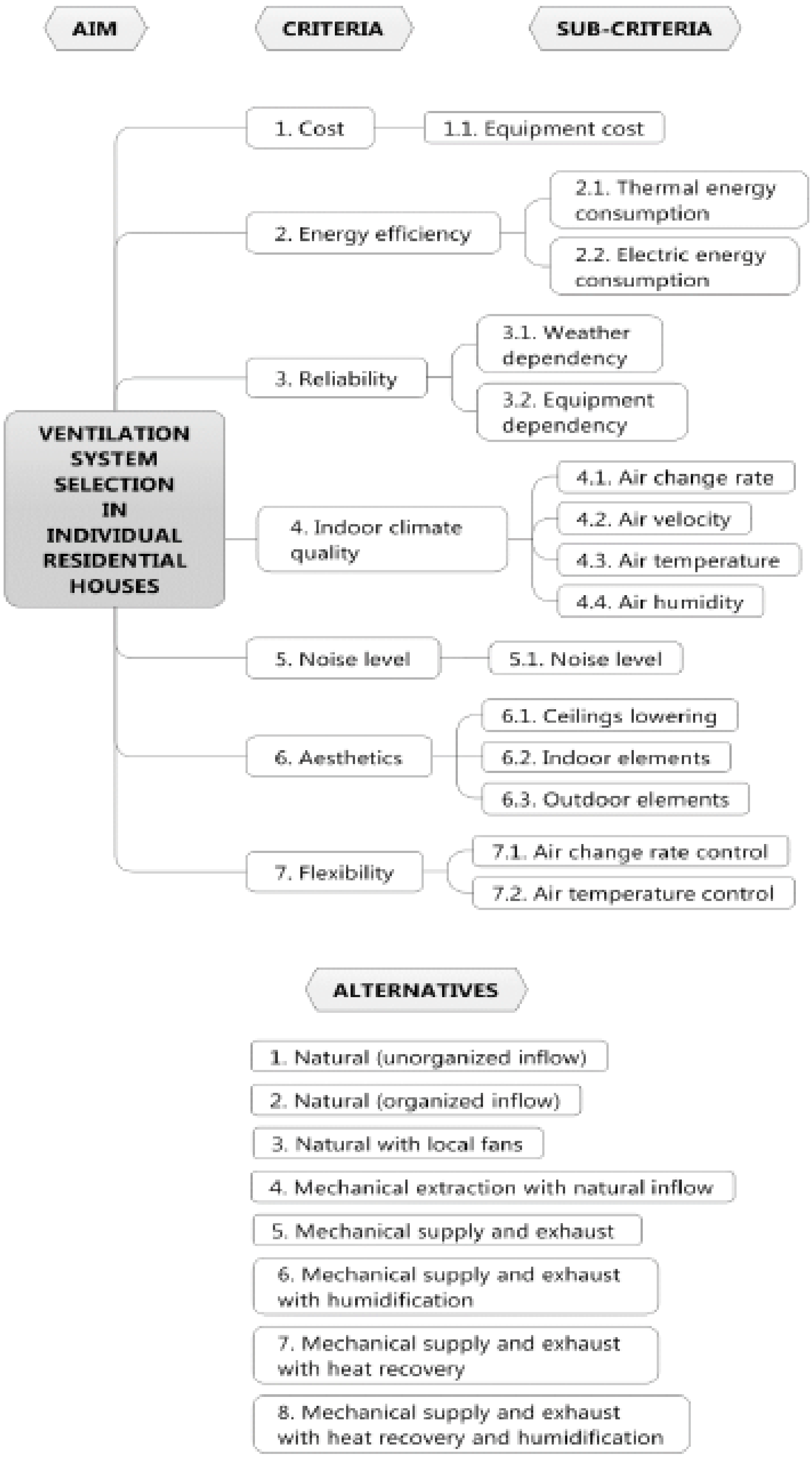


Figure 1. MCDA structural diagram

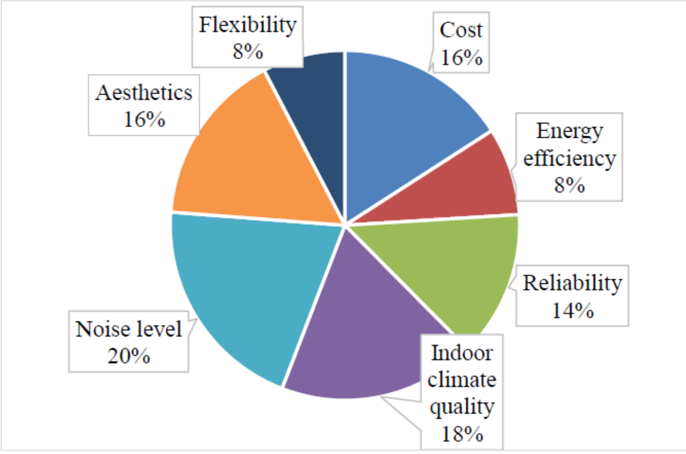
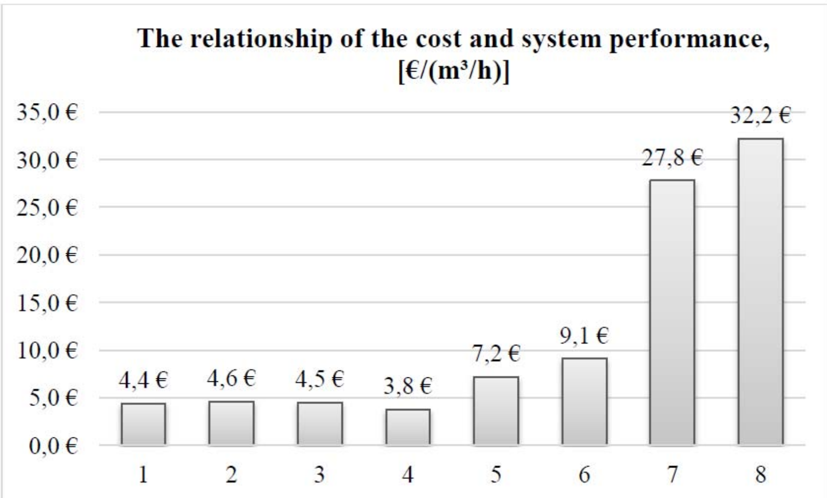


Figure 2. The degree of influence of criteria

The second step of the MCDA is to quantify all alternative solutions. For this purpose, eight projects with different types of ventilation systems were considered. As an example, the paper presents the results of rating calculating for the "cost" and "energy efficiency" criteria.

The evaluation of ventilation systems by the "cost" criterion. In order to compare the systems by cost, the estimated cost for each project was calculated. Since all projects differ in area, architecture, and the technical requirements for ventilation systems, the defining criterion rating was calculated as a relationship of the cost and system performance, which allows comparing the cost of systems in terms of an equal airflow and reflects the difference more accurately. The relationship of the cost and system performance for various ventilation system types is shown in Fig.3.



1: Natural (unorganized inflow)
2: Natural (organized inflow)
3: Natural with local fans
4: Mechanical extraction with natural inflow
5: Mechanical supply and exhaust
6: Mechanical supply and exhaust with humidification
7: Mechanical supply and exhaust with heat recovery
8: Mechanical supply and exhaust with heat recovery and humidification

Figure 3. The relationship of the cost and system performance for various ventilation system types

The evaluation of ventilation systems by the "energy efficiency" criterion. The energy efficiency of a ventilation system includes two components: the consumption of thermal energy and the consumption of electric energy. In order to compare the systems by energy efficiency, the calculation of the heat and power consumption for each project was made. The average daily values of the outside air temperature for the corresponding region were used (according to the statistical data for 2015 [4]). The calculation of electric energy consumption was made on the basis of consumption data of the main ventilation equipment for each system, taking into account the duration of its use. Then the relationship of the energy consumption and system performance was calculated. The relationship of the annual energy consumption and system performance for various ventilation system types is shown in Fig.4.

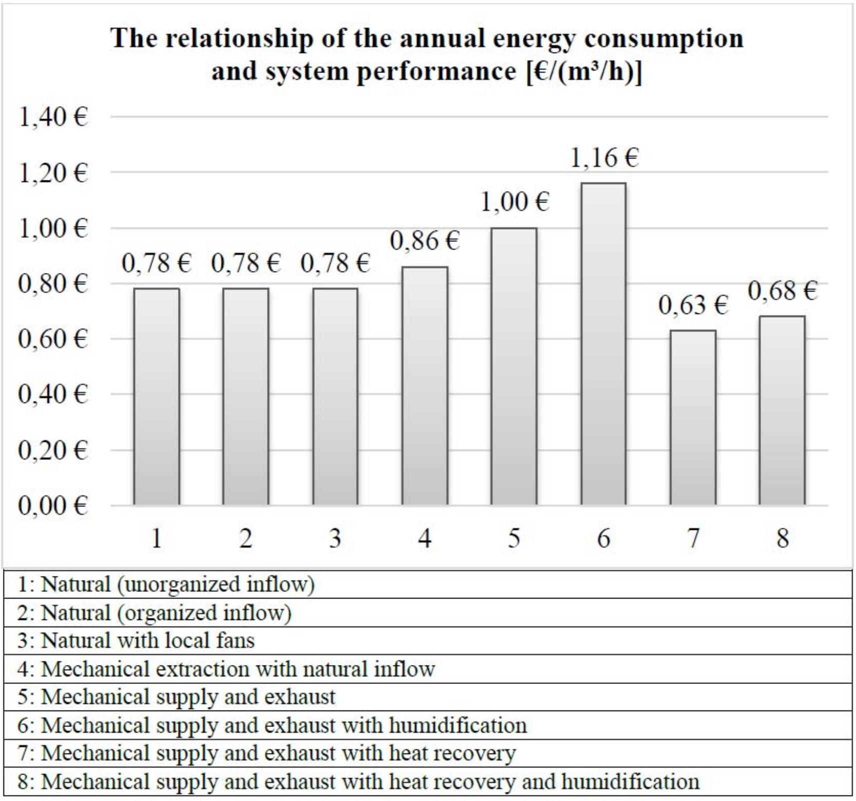


Figure 4. The relationship of the annual energy consumption and system performance for various ventilation system types

A similar approach was used to evaluate ventilation systems by the rest of criteria, and as a result, each alternative solution was quantified.

The calculation of the final rating was made for each ventilation system according to the formula:

$$r_t = \sum_{i=1}^{7} k_i \cdot r_i, \qquad (2)$$

where: r_t – final system rating according to all criteria;

k_i – degree of influence of the criterion with the index "i";

r_i – system evaluation by criterion with index "i".

The results of the final rating calculation depending on the criteria degree of influence for the analyzed projects are presented in Table 1.

Table 1

Results of the final rating calculation

Criteria	**K1**	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**FINAL RATING**
Degrees of influence	0,16	0,08	0,14	0,18	0,20	0,16	0,08	
VENTILATION SYSTEMS								
Natural (unorganized inflow)	86%	81%	20%	36%	100%	100 %	20%	68%
Natural (organized inflow)	83%	81%	45%	57%	100%	80%	60%	74%
Natural with local fans	84%	81%	51%	51%	80%	80%	60%	70%
Mechanical extraction with natural inflow	100 %	73%	100%	65%	80%	60%	60%	**78%**
Mechanical supply and exhaust	53%	63%	100%	91%	60%	40%	100%	70%
Mechanical supply and exhaust with humidification	42%	54%	99%	100%	60%	40%	100%	69%
Mechanical supply and exhaust with heat recovery	14%	100%	99%	92%	60%	20%	100%	64%
Mechanical supply and exhaust with heat recovery and humidification	12%	93%	98%	99%	60%	20%	100%	64%

As a result of the analysis of the criteria degree of influence and the quantitative assessment of all systems, the hybrid system (mechanical extraction with natural air inflow) was determined as the most optimal one. It should be emphasized that these results are based on the mean values of the survey results, and there is a unique optimal solution for each particular case.

Thus, a methodology of ventilation system valuation depending on the input values of the criteria degrees of influence was developed. This methodology can be considered as a practical tool for the selection of an optimal ventilation system, using various degrees of influence of criteria as initial data.

For more clarity, an example that is very often encountered in practice is considered below. This example represents a different distribution of the criteria degree of influence. Changing the "weight" of the criteria for considered case, already other results are obtained (Table 2).

Table 2

Rating calculation for the considered case

Criteria	**K1**	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**FINAL RATING**
Degrees of influence	0,30	0,10	0,00	0,15	0,20	0,15	0,10	
VENTILATION SYSTEMS								
Natural (unorganized inflow)	86%	81%	20%	36%	100%	100%	20%	76%
Natural (organized inflow)	83%	81%	45%	57%	100%	80%	60%	**79%**
Natural with local fans	84%	81%	51%	51%	80%	80%	60%	75%
Mechanical extraction with natural inflow	100%	73%	100%	65%	80%	60%	60%	78%
Mechanical supply and exhaust	53%	63%	100%	91%	60%	40%	100%	64%
Mechanical supply and exhaust with humidification	42%	54%	99%	100%	60%	40%	100%	61%
Mechanical supply and exhaust with heat recovery	14%	100%	99%	92%	60%	20%	100%	53%
Mechanical supply and exhaust with heat recovery and humidification	12%	93%	98%	99%	60%	20%	100%	53%

As can be seen in Table 2, the optimal system for the considered case is natural exhaust ventilation with an organized inflow. This example demonstrates the proposed method and the developed tool for the selection of an optimal ventilation system in a single-family house.

Conclusion: using the MCDA method as a method of comparison of different ventilation systems, it is possible to determine the most optimal ventilation system for most consumers or for any particular case, taking into account the set of evaluation criteria and their priority for each consumer.

As recommendations for using the described method and tool, it is important to mention:

1. When assessing the criteria degree of influence it is important to understand what they include and what they specifically mean.

2. When choosing a ventilation system for the end user, it is necessary to determine not only the optimal solution, but also take into account the boundary conditions that may affect the final choice. In most cases, the boundary condition is the final cost, which can "cut off" the most optimal solution because of its high cost threshold. Increased requirements for noise level, aesthetics, etc. can also represent a boundary condition.

3. On the other hand, when the cost constraints are completely absent (the degree of influence of the criterion is zero), this factor can be eliminated, and relatively more expensive solutions can be considered.

4. In order to find the optimal solution more accurately, it is possible to improve the proposed tool by dividing the criteria into sub-criteria and making an assessment taking into account the degree of influence of each sub-criterion separately.

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