



## AN APPROACH TO MULTI-ATTRIBUTE ASSESSMENT OF INDOOR ENVIRONMENT BEFORE AND AFTER REFURBISHMENT OF DWELLINGS

Edmundas Kazimieras Zavadskas<sup>1</sup>, Arturas Kaklauskas, Zenonas Turskis, Darius Kalibatas<sup>2</sup>

Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania

E-mail: <sup>1</sup>edmundas.zavadskas@adm.vgtu.lt; <sup>2</sup>darius.kalibatas@st.vgtu.lt

Submitted 17 Jun. 2008; accepted 9 Sept. 2008

**Abstract.** The paper analyses the correspondence between the present state of indoor environment and needs of habitants and the Lithuanian Hygienic Norm. To investigate the correspondence the authors (a) distinguish measures (attributes) of evaluating dwelling houses and their importance, (b) choose a method of processing the values of attributes, (c) choose a method of evaluating the efficiency of refurbishment and/or renovation of a building and (d) investigate dwelling houses in Naujoji Vilnia and evaluate the efficiency of refurbishment and/or renovation. As a result of the analysis the authors propose an approach to multi-attribute assessment of dwelling houses before and after refurbishment and/or renovation and evaluation of its efficiency. The experiment results, obtained by measuring five dwellings in Naujoji Vilnia, show that the renovation process was the most efficient for the second dwelling.

**Keywords:** indoor environment, multi-attribute, assessment, efficiency, dwelling house, the Lithuanian Hygienic Norm, multiplicative utility function.

### 1. Introduction

Nowadays there are plenty of dwelling houses, which people use to live in. Some of them are characterized as satisfying the Lithuanian Hygienic Norm (HN 42:2004), some of them – unsatisfying. Therefore, the second type of dwelling houses should be refurbished (i.e. upgrading to better condition) and/or renovated (i.e. repairs and restorations to better condition) to meet needs of habitants and satisfy the Lithuanian Hygienic Norm (HN 42:2004).

To determine the correspondence between the present state of dwelling houses and needs of habitants and the Lithuanian Hygienic Norm (HN 42:2004), it is necessary: (a) to distinguish measures (attributes) of evaluating dwelling houses and their importance, (b) to choose a method of processing the values of attributes, (c) to choose a method of evaluating the efficiency of refurbishment and/or renovation of a building.

The problem of measuring according to some criteria is known as multi-attribute decision-making. A number of authors purpose their decision-making methods and models. Some of them are presented in the section of related works. However, these methods and models allow to evaluate the present state of dwelling houses and to choose a suitable one without evaluating the efficiency of refurbishment and/or renovation of the building ( $S_j$ ).

In this paper the authors present the usage of multi-attribute decision-making for the assessment of dwelling houses before and after refurbishment and/or renovation and evaluate its efficiency. The main problem solved here is defining of attributes and their importance for the assessment of dwelling houses, adopting a multiplicative utility function method for the assessment of dwelling houses

according to defined attributes and evaluating the efficiency of refurbishment and/or renovation of the building. Therefore, Section 3 presents an approach of multi-attribute decision-making for the assessment of dwelling houses and evaluating the efficiency of refurbishment and/or renovation of the building. Section 4 presents a case study of the assessment of dwelling houses in Naujoji Vilnia (Vilnius). Finally, Section 5 concludes the paper.

### 2. Related works on attributes for the assessment of dwelling houses

From the perspective of a resident of a building, an ideal situation is an indoor environment that satisfies all the residents (i.e. they have no complaints) and does not unnecessarily increase the risk or severity of illness or injury.

According to the Lithuanian Hygienic Norm (HN 42:2004), balanced inner climate prevents from spreading of bacteria, protecting human immune system, and the inner surfaces of a building from vapour condensing and moulding.

In (Fanger 2006), the air requirements are that the air be perceived as fresh and pleasant, that it has no negative impact on people's health, and that the air is stimulating and promotes their work, i.e. it increases their productivity and the learning of their children in the classroom at school. The authors state that the present ventilation standards and guidelines do not care about productivity and learning and have the very modest requirement that the indoor air shall be acceptable. The paper discusses the development of new methods that can provide substantial improvements of indoor air quality (IAQ) according to 2–7 factors, while maintaining or even decreasing ventilation and energy usage.

In (Braubach 2007) the author identifies the impact of the residential housing environment on (a) the satisfaction with the residential environment and (b) the health status of residents, using the WHO large analysis and review of European housing and health status (LARES) database. For a detailed study on the basis of literature review on residential environments and health, and the results of a correlatitthe, the author selected (a) greenery, public spaces and play areas, (b) noise exposure, (c) public safety, and (d) upkeep and maintenance of independent variables, as some of the most relevant residential and urban stressors. Multivariate regression models were used to obtain the results of satisfaction and health status of residents. To adjust for the confounding influences of known health determinants related to individual characteristics, the four variables – (a) age group, (b) gender, (c) SES score, and (d) functional limitations – were selected as potential confounding variables to be tested. During multivariate analysis the author has identified two key problems – *noise exposure* and *perceived safety* – that showed the highest and most consistent impact on the likelihood to be less satisfied with the residential environment, or to suffer from the three analysed health outcomes.

In (Banaitis and Banaitienė 2007) the authors analyse rational housing in Lithuania and propose a theoretical model for complex analysis of rational housing according to variable factors of micro- and macro-levels of surroundings. The authors determine micro- and macro-level factors, systems and subsystems of indices to describe housing at initial stage. A complex system of indices is developed to evaluate trends of a housing policy, activities on a world scale and housing in countries of different economic development. In the system of indices the authors divide indices into five groups: (a) indices describing economics as a whole complex, (b) indices describing housing construction, investments and financing, (c) indices describing the countries of transitional period, (d) indices describing the volume, quantity and density of housing, and (e) indices describing the housing policy. A complex system of housing indices is developed to evaluate housing in Lithuania. Here indices are divided into six groups. They are: (a) economic, (b) social, (c) qualitative, volume and density, (d) institutional structures, (e) legal bases, and (f) political priorities. Conceptual and quantitative description of the present state of Lithuania authors formalise into table, where rows are  $i$  indicators, columns are  $j$  countries and cells are  $x_{ij}$  code that provide the quantitative and conceptual information about the alternative is considered. The magnitude of significance indicates how much (in percentage) one factor is more significant than the other one in multiple-criteria evaluation of the efficiency of housing.

In (Juškevičius and Burinskienė 2007) the authors use mathematical statistical methods for the assessment of the inhabitants' health level, depending on the position of regions. The authors conclude that there is a statistical relationship between the physical space quality of living areas (space size, maintenance of area fixtures, depreciation, etc.), environment quality (noise, air pollution, calm rest facilities) and inhabitants' morbidity and spread of social pathology as well as work efficiency.

In (Zavadskas et al. 2007) the authors model and forecast a rational and sustainable development of Vilnius from the pollution perspective by undertaking a complex analysis of micro-, meso- and macroenvironmental factors, that affect it, and present recommendations for increasing sustainable abilities of Vilnius. For this purpose the authors have analysed the experience of different cities and identified global development trends of pollution prevention. They are: (a) housing (housing and neighbourhoods of the poor, energy use optimisation, housing improvements and urban regeneration), (b) recycling (building waste recycling activities, rationalisation of land use), and (c) indoor air pollution (dust, indoor air pollution and health, amount of ventilation in housing, increasing transparency and effective public participation in the development of urban environmental planning and management strategies, local climate and weather conditions, light pollution).

In (Baltrėnas et al. 2007) the authors investigate the noise process, since the noise level in any environment is one of the basic factors determining the human comfort indicator. In this paper the authors describe the efficiency evaluation of a noise barrier, installed near AB KLASCO fertilizer discharge terminal in Klaipėda, according to the noise level measurements performed, modelling of noise spread and mathematical calculations. According to the measurements, the authors conclude that the noise level is 3–4 dBA above the legal limits in the daytime and 7 dBA at night. The modelling of the noise spread was performed by CadnaA program, which allowed making different models according to variations of the noise level caused by changing conditions.

In (Antuchevičienė et al. 2006; Zavadskas and Antuchevičienė 2006, 2007) the authors analyse modelling renewal of construction objects applying the methods of the Game Theory (Peldschus 2008). The authors present selecting of rational renewal variants of derelict buildings from the viewpoint of sustainable development. The alternatives include reconstruction of rural buildings and adapting them for (a) production or commercial activities, (b) farming or (c) demolition and recycling of demolished waste. The objectives present three main conflicting types of interest: economic, ecological and social. The considered objectives are based on sustainability indicators and represent three typological groups in sustainable decision-making: the current state of abandoned buildings and their environment, revitalization possibilities and impact produced by implementing a particular redevelopment alternative. Each building is evaluated according to the following fifteen attributes: 1 – the average soil fertility grade in the area (cardinal numbers), 2 – the quality of life of the local population (cardinal numbers), 3 – population activity index (%), 4 – GDP in proportion to the average GDP of the country (%), 5 – material investments in the area (Lt per inhabitant), 6 – foreign investments in the area ( $\text{Lt} \times 10^3$  per inhabitant), 7 – building redevelopment costs ( $\text{Lt} \times 10^6$ ), 8 – increase of income of the local population ( $\text{Lt} \times 10^6$  per year), 9 – increase of sales in the area (%), 10 – increase of employment (%), 11 – state income from business and property taxes ( $\text{Lt} \times$

10<sup>6</sup> per year), 12 – outlook of business, 13 – difficulties of purpose-built changes, 14 – degree of contamination, 15 – attractiveness of the countryside (i.e. image, landscape quality, etc.). Variables 2, 7, 13 and 14 are associated with minimization, while the remaining attributes are associated with maximization. Significance coefficients of the attributes were also determined. Bayes's and Laplace's rules are applied for searching rational renewal variants of derelict buildings in Lithuanian rural areas. The case study proved that the methods of the Game Theory are effective in a real life situation and can be successfully applied to solving similar problems.

In (Bardauskienė 2007) the author analyses the territory planning of Lithuanian cities. They use multi-attribute evaluation of Vilnius (form perspective of citizens and experts) to prepare the Master Plan according to the presented attributes. The Master Plan of Vilnius is also presented in the paper.

In (Kaklauskas *et al.* 2007) the authors use a multiple-criteria approach to define the utility and market value of a real estate. The authors propose the method of multiple-criteria complex proportional assessment (COPRAS), and the method of defining the utility and market value of a real estate assumes the dependence of priority, utility degree and value of investigated versions on a system of criteria adequately describing the alternatives and their direct proportionality to the values and weights of these criteria.

In (Turskis *et al.* 2006) the authors use the method of Game Theory to evaluate and calculate the rate of city compactness. For evaluation of city compactness, efficiency attributes and weights are defined on the basis of expert questioning. The model is applied to Kaunas city. The area of the city was divided by a rectangular grid, and efficiency attributes were calculated for each sector applying Bayes rule. The results were visualized as diagrams showing the most problematic areas.

The problem of assessment of dwellings using multi-attribute decision-making (Ginevičius *et al.* 2008; Turskis 2008; Shevchenko *et al.* 2008) is also analysed in (Banaitienė *et al.* 2008; Bovea and Galarado 2006; Cheong *et al.* 2006; Rutman *et al.* 2005; Gulyas *et al.* 2006; Hui *et al.* 2007; Kaklauskas *et al.* 2005, 2006; Kalibatas and Turskis 2008; Mui and Chan 2006; Martinaitis *et al.* 2004, 2007; Greening and Bernow 2004; Lee *et al.* 2007; Wong *et al.* 2006; Zavadskas *et al.* 2008a, b, c; Zavadskas and Turskis 2008; Turskis 2008; Viteikienė and Zavadskas 2007; Zavadskas and Viteikienė 2006).

The methods and models presented above allow to evaluate the present state of buildings according to some factors without evaluating others and without evaluating the efficiency of refurbishment and/or renovation of the building ( $S_i$ ). The authors of this paper distinguish attributes for the assessment of dwelling houses, adopting a multiplicative utility function method for the assessment of dwelling houses according to defined attributes and evaluating the efficiency of refurbishment and/or renovation of the building.

### 3. An approach to multi-attribute decision-making for the assessment of dwelling houses before and after refurbishment and/or renovation

#### 3.1. Attributes of the assessment model

According to the related works presented above, the authors of this paper distinguish the attributes of evaluating dwelling houses and their importance. The attributes distinguished are the following:

- air exchange (m<sup>3</sup>/h),
- relative air humidity (percents),
- air temperature (C),
- price per 1 m<sup>2</sup> (thousands of LT (1 EUR = 3.4528 LTL)),
- noise isolation (points),
- annual heating expenditures (t/year).

38 experts were questioned to determine the importance of the presented attributes. The results of questioning were summarized as presented in (Zavadskas *et al.* 2007a). Table 1 presents attributes and their level of importance which equals the sum of importance of a particular attribute divided by the sum of importance of all the attributes. To determine the correctness of answers, their compatibility was also evaluated as presented in (Zavadskas *et al.* 2007; Kendall 1970). The result is acceptable.

**Table 1.** Importance of attributes of evaluating dwelling houses

No.	Attribute	Importance level ( $w_j$ )
1	Air exchange	0.094
2	Relative air humidity	0.074
3	Air temperature	0.137
4	Price per 1m <sup>2</sup>	0.261
5	Noise isolation	0.190
6	Annual heating expenditures	0.244

New attributes can be included into the assessment, like chemical and biological agents, dusts, etc. The authors of this paper are concentrated on the listed before six attributes, since, according to the experts, they are the main ones in the assessment of dwellings.

Fig. 1 presents the importance level of all the six attributes. As can be seen, the fourth (price per 1 m<sup>2</sup>) and sixth (annual heating expenditures) attributes have the biggest impact on the assessment of dwellings.

The data of measurements are going to be placed in a decision-making matrix, where columns contain attributes, rows contain dwelling houses before and after refurbishment and/or renovation and cells of the matrix contain the values of attributes for a particular dwelling house before or after refurbishment and/or renovation.

#### 3.2. The multiplicative utility function method

To apply the multiplicative utility function method, the decision matrix should be normalized by formula (1) (Zavadskas 1987) if the values of attributes are maximizing, and by formula 2 (Zavadskas 1987) if the values of attributes are minimizing.

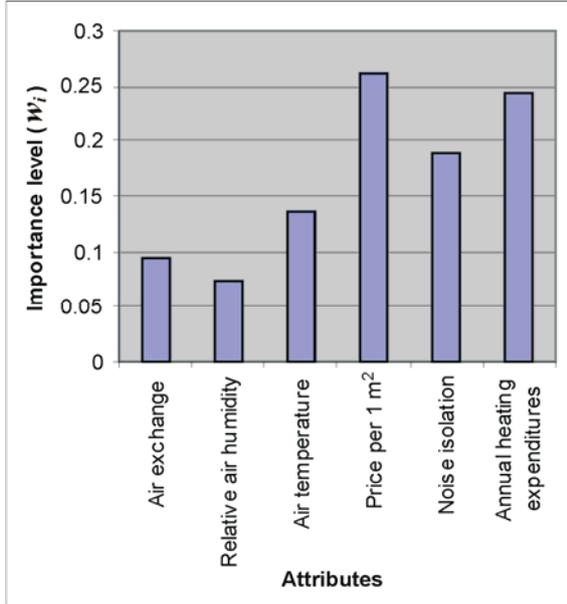


Fig. 1. Importance level ( $w_i$ ) of attributes

$$\bar{x}_{ij} = \frac{x_{ij}}{x_j^{opt}}, i = \bar{1}, \bar{m}; j = \bar{1}, \bar{n}; \text{ if } x_j^{opt} \geq x_{ij}, \quad (1)$$

$$\bar{x}_{ij} = \frac{x_j^{opt}}{x_{ij}}, i = \bar{1}, \bar{m}; j = \bar{1}, \bar{n}; \text{ if } x_j^{opt} \leq x_{ij}, \quad (2)$$

where  $x_{ij}$  denotes the value of the  $j$ -th attribute for the  $i$ -th dwelling house in the decision matrix,  $\bar{x}_{ij}$  denotes the normalized value of the  $x_{ij}$  attribute. In formula (1),  $x_j^{opt} = x_j^{\min}$  denotes the minimum value of  $j$ -th attribute from existing values of this attribute. In formula (2),  $x_j^{opt} = x_j^{\max}$  denotes the maximal value of  $j$ -th attribute from existing values of this attribute.

Dwelling houses are going to be assessed by the multiplicative utility function, which allows to calculate the multiplicative optimality criterion, presented in formula (3) (Zavadskas 1987).

$$K_j = \max_i \prod_{j=1}^n \bar{x}_{ij}^{w_j}, i = \bar{1}, \bar{m}; j = \bar{1}, \bar{n}; \sum_{j=1}^n w_j = 1, \quad (3)$$

where  $K_j$  denotes multiplicative optimality criterion for  $j$ -th attribute,  $\bar{x}_{ij}$  is calculated by formula (1) or (2),  $w_j$  is the importance level of the  $j$ -th attribute.

The ratio ( $R_i^K$ ) of multiplicative optimality criteria of a dwelling before and after refurbishment and/or renovation and the ratio ( $R_i^P$ ) of prices of dwellings before and after refurbishment and/or renovation should be calculated, to determine the efficiency of refurbishment and/or renovation ( $S_i$ ).

The ratio ( $R_i^K$ ) of multiplicative optimality criteria of a dwelling before and after refurbishment and/or renovation is calculated by formula (4).

$$R_i^K = K_j^+ / K_j^-, \quad (4)$$

where  $K_j^+$  denotes the multiplicative optimality criteria of a dwelling after refurbishment and/or renovation, and  $K_j^-$  denotes the multiplicative optimality criteria of a dwelling before refurbishment and/or renovation.

The ratio ( $R_i^P$ ) of prices of dwellings before and after refurbishment and/or renovation is calculated by formula (5).

$$R_i^P = P_i^- / P_i^+, \quad (5)$$

where  $P_i^+$  denotes the price of a dwelling after refurbishment and/or renovation, and  $P_i^-$  denotes the price of a dwelling before refurbishment and/or renovation.

The efficiency of refurbishment and/or renovation of a dwelling ( $S_i$ ) is calculated by formula (6).

$$S_i = R_i^K \cdot R_i^P. \quad (6)$$

The next section presents a case study of evaluating the efficiency of refurbishment and/or renovation of a dwelling in Naujoji Vilnia before and after refurbishment and/or renovation.

#### 4. A case study: assessment of dwelling houses before and after refurbishment and/or renovation in Naujoji Vilnia

The proposed approach to multi-attribute decision-making for the assessment of dwelling houses before and after refurbishment and/or renovation was applied to assess 5 single-flat houses situated in Naujoji Vilnia. The values of attributes were measured by Metrel device MI 6201 EU, having the calibration certificate. The data of measurements are presented in Table 2, where optimal values of some attributes are taken from the Lithuanian Hygienic Norm (HN 42:2004).

Table 2. Decision-making matrix of 5 single-flat houses in Naujoji Vilnia

House No	House period	Attributes and their measuring units					
		Air exchange	Relative air humidity	Air temperature	Price per 1 m <sup>2</sup>	Noise isolation	Annual heating expenditures
	<b>Measure</b>	m <sup>3</sup> /h	%	C	×10 <sup>3</sup> LT	points	t/year
	<b>w<sub>j</sub></b>	0.094	0.074	0.137	0.261	0.190	0.244
1	<b>Before refurbishment</b>	21	65	16	7.00	6	4.88
2		22	69	17	6.15	7	5.37
3		29	68	17	3.63	6	4.99
4		22	55	18	7.06	7	5.36
5		33	73	16	6.78	6	4.57
6	<b>After refurbishment</b>	16	45	22	7.77	8	3.29
7		17	48	23	6.75	9	3.66
8		18	48	22	3.95	8	3.75
9		19	52	21	7.82	9	3.56
10		18	43	21	7.46	9	3.24
11		<b>x<sub>j</sub><sup>opt</sup></b>	33	50	22	3.63	9
		max	min/max	min/max	min	max	min
	<b>Optimal value</b>	≤ 90	40÷60	20÷24			

Table 3 presents the normalised values of attributes, calculated by formulas (1) and (2).

Table 4 presents the multiplicative optimality criterion ( $K_i$ ), calculated by formula (3), for a  $i$ -th dwelling; the ratio ( $R_i^K$ ) of multiplicative optimality criteria of a dwelling before and after refurbishment and/or renovation, calculated by formula (4); the ratio ( $R_i^P$ ) of prices of dwellings before and after refurbishment and/or renovation, calculated by formula (5); and the efficiency of refurbishment and/or renovation of a dwelling ( $S_i$ ), calculated by formula (6).

Fig. 2 presents the multiplicative optimality criterion ( $K_i$ ) of dwellings in Naujoji Vilnia before and after refurbishment.

Fig. 3 presents the efficiency ( $S_i$ ) of refurbishment and/or renovation of dwellings in Naujoji Vilnia.

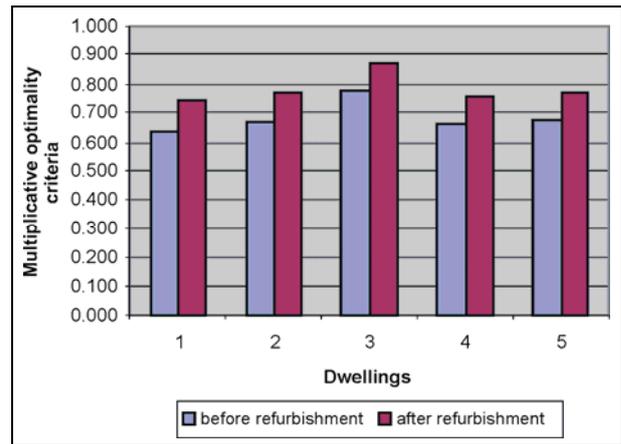
The results presented in Table 4 show that the renovation process was the most effective for the second dwelling.

**Table 3.** Normalised decision-making matrix

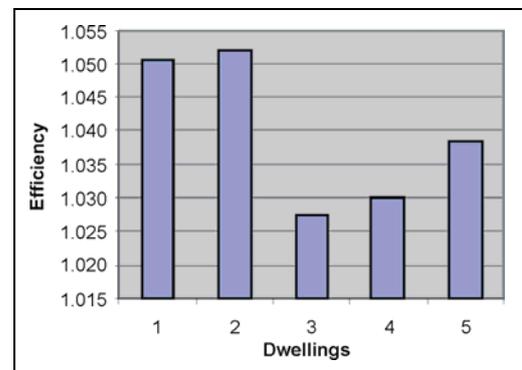
House No	House period	Attributes and their measuring units					
		Air exchange	Relative air humidity	Air temperature	Price per $\text{m}^2$	Noise isolation	Annual heating expenditures
	$w_j$	0.094	0.074	0.137	0.261	0.190	0.244
1	Before refurbishment	0.636	0.769	0.727	0.519	0.667	0.664
2		0.667	0.725	0.773	0.590	0.778	0.603
3		0.879	0.735	0.773	1.000	0.667	0.649
4		0.667	0.909	0.818	0.514	0.778	0.604
5		1.000	0.685	0.727	0.535	0.667	0.709
6	After refurbishment	0.485	0.900	1.000	0.467	0.889	0.985
7		0.515	0.960	0.957	0.538	1.000	0.885
8		0.545	0.960	1.000	0.919	0.889	0.864
9		0.576	0.962	0.955	0.464	1.000	0.910
10		0.545	0.860	0.955	0.487	1.000	1.000
11	$x_j^{opt}$	1.000	1.000	1.000	1.000	1.000	1.000

**Table 4.** Efficiency of refurbishment and/or renovation of dwellings in Naujoji Vilnia

Dwellings	$K_j$		Price ( $\times 10^3$ LT)		Ratio		Efficiency ( $S_i$ )
	$K_j^-$	$K_j^+$	$P_j^-$	$P_j^+$	$R^K$	$R^P$	
1	0.635	0.740	420	466	1.166	0.901	1.051
2	0.666	0.769	560	614	1.154	0.912	1.052
3	0.777	0.869	370	403	1.119	0.918	1.027
4	0.659	0.752	600	665	1.142	0.902	1.030
5	0.673	0.769	590	649	1.142	0.909	1.039



**Fig. 2.** Multiplicative optimality criterion ( $K_i$ ) of dwellings in Naujoji Vilnia before and after refurbishment



**Fig. 3.** Efficiency ( $S_i$ ) of refurbishment and/or renovation of dwellings in Naujoji Vilnia

### 5. Conclusions

The analysis of related works on the assessment of dwelling houses shows that a number of methods and models of multi-attribute assessment of dwelling houses at the present state are proposed. However, there is lack of methods and models of evaluating the efficiency of refurbishment and/or renovation of the building ( $S_i$ ).

The proposed approach to multi-attribute decision-making for the assessment of dwelling houses before and after refurbishment and/or renovation allows to evaluate the efficiency of refurbishment and/or renovation by measuring dwellings before and after refurbishment and/or renovation according to air exchange ( $\text{m}^3/\text{h}$ ), relative air humidity (percents), air temperature (C), price per  $\text{m}^2$  (thousands of LT), noise isolation (points), and annual heating expenditures (t/year), and calculating the efficiency by calculating the multiplicative optimality criterion.

The experimental results, obtained by assessing five dwellings in Naujoji Vilnia, show that:

- the fourth (price per  $1 \text{ m}^2$ ) and sixth (annual heating expenditures) attributes have the biggest impact on the assessment of dwellings;
- the renovation process was the most effective for the second dwelling.

The results presented in this paper show that the proposed approach to multi-attribute decision-making for

the assessment of dwelling houses before and after refurbishment and/or renovation can be used for a global evaluation of dwellings.

The next step of the research is extending and verifying the proposed approach and defining of particular criteria to determine the degree of its validity.

## References

- Antuchevičienė, J.; Turskis, Z.; Zavadskas, E. K. 2006. Modelling renewal of construction objects applying methods of the Game Theory, *Technological and Economic Development of Economy* 12(4): 263–268.
- Baltrėnas, P.; Butkus, D.; Nainys, V.; Grubliauskas, R.; Gudaitytė, J. 2007. Efficiency evaluation of a noise barrier, *Journal of Environmental Engineering and Landscape Management* 15(3): 125–134.
- Banaitienė, N.; Banaitis, A.; Kaklauskas, A.; Zavadskas, E. K. 2008. Evaluating the life cycle of a building: a multivariate- and multiple-criteria approach, *Omega* 36(3): 429–441.
- Banaitis, A.; Banaitienė, N. 2007. Development of the rational housing model: the Lithuanian case, *Int. J. Environment and Pollution* 30(3/4): 430–442.
- Bardauskienė, D. 2007. Ekspertinių vertinimų taikymas rengiant miesto bendrąjį planą, *Technological and Economic Development of Economy* 13(3): 223–236.
- Bovea, M. D.; Gallardo, A. 2006. The influence of impact assessment methods on materials selection for eco-design, *Materials and Design* 27(3): 209–215.
- Braubach, M. 2007. Residential conditions and their impact on residential environment satisfaction and health: results of the WHO large analysis and review of European housing and health status (LARES) study, *Int. J. Environment and Pollution* 30(3/4): 384–403.
- Cheong, K. W. D.; Yu, W. J.; Kosonen, R.; Tham K. W.; Sekhar, S. C. 2006. Assessment of thermal environment using a thermal manikin in a field environment chamber served by displacement ventilation system, *Building and Environment* 41: 1661–1670.
- Fanger, P. O. 2006. What is IAQ? *Indoor Air* 16(5): 328–334.
- Ginevičius, R.; Podvezko, V.; Raslanas, S. 2008. Evaluating the alternative solutions of wall insulation by multicriteria methods, *Journal of Civil Engineering and Management* 14(4): 217–226.
- Greening, L. A.; Bernow, S. 2004. Design of coordinated energy and environmental policies: use of multi-criteria decision-making, *Energy Policy* 32(6): 721–735.
- Gulyas, A.; Unger, J.; Matzarakis, A. 2006. Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements, *Journal of Building and Environment* 41: 1713–1722.
- Hui, P. S.; Wong, L. T.; Mui, K. W. 2007. Evaluation of professional choice of sampling locations for indoor air quality assessment, *Building and Environment* 42(8): 2900–2907.
- Juskevicius, P.; Burinskiene, M. 2007. Quality factors of the residential environment in urban planning, *Int. J. Environment and Pollution* 30(3/4): 471–484.
- Kaklauskas, A.; Zavadskas, E. K.; Raslanas, S.; Ginevičius, R.; Komka, A.; Malinauskas, P. 2006. Selection of low-e windows in retrofit of public buildings by applying multiple criteria method COPRAS: A Lithuanian case, *Energy and Buildings* 38(5): 454–462.
- Kaklauskas, A.; Zavadskas, E. K.; Banaitis, A.; Šatkauskas, G. 2007. Defining the utility and market value of a real estate: a multiple-criteria approach, *International Journal of Strategic Property Management* 11: 107–120.
- Kaklauskas, A.; Zavadskas, E. K.; Raslanas, S. 2005. Multi-variant design and multiple-criteria analysis of building refurbishments, *Energy and Buildings* 37(4): 361–372.
- Kalibatas, D.; Turskis, Z. 2008. Multicriteria evaluation of inner climate by using MOORA method, *Information Technology and Control* 37(1): 79–83.
- Kendall, M. G. 1970. *Rank correlation methods*, 4<sup>th</sup> ed. Griffin, London.
- Kosonen, R.; Tan, F. 2004. Assessment of productivity loss in air-conditioned buildings using PMV index, *Energy and Buildings* 36: 987–993.
- Lee, D. H.; Lee, K. C.; Kang, S.; Baik, J. 2007. A priori ordering protocols to support consensus-building in multiple stakeholder contexts, *Information Sciences* 177(15): 3129–3150.
- HN 42:2004. Lithuanian Hygienic Norm ‘Microclimate of residential and administrative buildings’. Vilnius. 2004 (in Lithuanian).
- Martinaitis, V.; Kazakevičius, E.; Vitkauskas, A. 2007. A two-factor method for appraising building renovation and energy efficiency improvement projects, *Energy Policy* 35(1): 192–201.
- Martinaitis, V.; Rogoža, A.; Bikmanienė, I. 2004. Criterion to evaluate the “twofold benefit” of the renovation of buildings and their elements, *Energy and Buildings* 36(1): 3–8.
- Mui, K.W.; Chan, W.T. 2006. Building calibration for indoor air quality management, *Building and Environment* 41: 877–886.
- Peldschus, F. 2008. Experience of the game theory application in construction management, *Technological and Economic Development of Economy* 14(4): 531–545.
- Rutman, E.; Inard, C.; Bailly, A.; Allard, F. 2005. A global approach of indoor environment in an air-conditioned office room, *Building and Environment* 40: 29–37.
- Shevchenko, G.; Ustinovichus, L.; Andruškevičius, A. 2008. Multi-attribute analysis of investments risk alternatives in construction, *Technological and Economic Development of Economy* 14(3): 428–443.
- Turskis, Z.; Zavadskas, E. K.; Zagorskis, J. 2006. Sustainable city compactness evaluation on the basis of GIS and Bayes rules, *International Journal of Strategic Property Management* 10: 185–207.
- Turskis, Z. 2008. Multi-attribute contractors ranking method by applying ordering of feasible alternatives of solutions in terms of preferability technique, *Technological and Economic Development of Economy* 14(2): 224–239.
- Viteikienė, M.; Zavadskas, E. K. 2007. Evaluating the sustainability of Vilnius city residential areas, *Journal of Civil Engineering and Management* 13(2): 149–155.
- Wong, L. T.; Mui, K. W.; Hui, P. S. 2006. A statistical model for characterizing common air pollutants in air-conditioned offices, *Atmospheric Environment* 40: 4246–4257.
- Zavadskas, E. K.; Antuchevičienė, J. 2006. Development of an indicator model and ranking of sustainable revitalization alternatives of derelict property: a Lithuanian case study, *Sustainable Development* 14(5): 287–299.
- Zavadskas, E. K.; Vilitienė, T. 2006. A multiple-criteria evaluation of multi-family apartment block maintenance contractors: I-Model for maintenance contractor evaluation and the determination of its selection criteria, *Building and Environment* 41(5): 621–632.

- Zavadskas, E. K.; Kaklauskas, A.; Kaklauskienė, J. 2007. Modelling and forecasting of a rational and sustainable development of Vilnius: emphasis on pollution, *Int. J. Environment and Pollution* 30(3/4): 485–500.
- Zavadskas, E. K.; Antuchevičienė, J. 2007. Multiple-criteria evaluation of rural building regeneration alternatives, *Building and Environment* 42(1): 436–451.
- Zavadskas, E. K.; Turskis, Z. 2008. A new logarithmic normalization method in the Game Theory, *Informatica* 19(2): 303–314.
- Zavadskas, E. K.; Raslanas, S.; Kaklauskas, A. 2008a. The selection of effective retrofit scenarios for panel houses in urban neighborhoods based on expected energy savings and increase in market value: The Vilnius case, *Energy and Buildings* 40(4): 573–587.
- Zavadskas, E. K.; Kaklauskas, A.; Turskis, Z.; Tamošaitienė, J. 2008b. Selection of effective dwelling-house walls by applying attribute values determined at intervals, *Journal of Civil Engineering and Management* 14(2): 85–93.
- Zavadskas, E. K.; Turskis, Z.; Tamošaitienė, J.; Marina, V. 2008c. Multicriteria selection of project managers by applying grey criteria, *Technological and Economic Development of Economy* 14(4): 462–477.
- Завадскас, Э.-К. 1987. Комплексная оценка и выбор ресурсосберегающих решений в строительстве [Zavadskas, E. K. Complex evaluation and choosing of constructions' resource saving solutions in construction]. Vilnius: Mokslas. 210 p. (in Russian).

## DAUGIATIKSLIO GYVENAMŪJŲ NAMŲ VIDINĖS APLINKOS VERTINIMO PRIEŠ IR PO RENOVACIJOS BŪDAS

E. K. Zavadskas, A. Kaklauskas, Z. Turskis, D. Kalibatas

### Santrauka

Nagrinėjama, kaip gyvenamųjų namų vidinė aplinka atitinka gyventojų poreikius ir Lietuvos higienos normas. Išvados gali būti daromos: a) nustatius rodiklius, pagal kuriuos galima vertinti gyvenamuosius namus, ir jų reikšmingumą, b) pasirinkus rodiklių apdorojimo metodą ir c) pasirinkus metodą renovacijos efektyvumui nustatyti. Pateiktas daugiatis vidinės aplinkos vertinimo prieš ir po renovacijos bei renovacijos efektyvumo nustatymo būdas. Šis būdas pritaikytas penkiems gyvenamiesiems namams Naujojoje Vilnioje (Vilnius) įvertinti.

**Reikšminiai žodžiai:** vidinė aplinka, daugiatis vertinimas, efektyvumas, gyvenamasis namas, Lietuvos higienos normos, daugiatis naudingumo funkcija.

## КОМПЛЕКСНАЯ ОЦЕНКА ВНУТРЕННЕЙ СРЕДЫ ЖИЛЫХ ДОМОВ ДО И ПОСЛЕ РЕНОВАЦИИ

Э.-К. Завадскас, А. Каклаускас, З. Турскис, Д. Калибатас

### Резюме

Жилые дома Литвы не всегда соответствуют литовским нормам гигиены (HN 42:2004) и потребностям жителей. Поэтому они нуждаются в реконструкции. Несоответствие литовским нормам гигиены (HN 42:2004) может быть установлено не только по жалобам жителей, но и по результатам измерения внутреннего климата жилья. При этом важно (а) установить критерии оценки климата жилья и их приоритеты, (б) подобрать метод для обработки данных по установленным критериям оценки климата и их приоритетам, (в) подобрать метод для установления необходимой реконструкции и ее эффективности. Авторы предлагают метод многокритериальной оценки жилых домов до и после реновации и установления эффективности реконструкции жилых домов. Предложенный метод был применен для многокритериальной оценки жилых домов в Новой Вильне.

**Ключевые слова:** внутренний климат, многокритериальная оценка, эффективность, жилой дом, литовские нормы гигиены, многокритериальная функция эффективности.

**Edmundas Kazimieras ZAVADSKAS.** Academic Experience: Lecturer (1973–1974), Senior Lecturer (1974–1978), Associate Professor (1978–1985), Senior Researcher (1985–1987), Professor (1988–), Head of Construction Technology Department (1987–1990), Rector of Vilnius Technical University (1990–1996), Rector of Vilnius Gediminas Technical University (1996–2002). E. Zavadskas is participating in two Framework 5 programmes. The spheres of his current research are internet-based and e-business systems (property, construction and export), decision-making theory, decision-support systems, etc. E. Zavadskas is the author of 527 research publications and some monographs.

**Arturas KAKLAUSKAS.** Academic Experience (Vilnius Gediminas Technical University): PhD Student (1987–1989), Senior Lecturer (1990–1995), Associate Professor (1995–2000), Chairman of the Department of Construction Technology and Management (1996–2001), Professor (2000), Chairman of the Department of Construction Economics and Property Management (2001). A. Kaklauskas is participating in four Framework five programmes and is the leader of the CIB Study group SG1 'The Application of Internet Technologies in Building Economics'. The spheres of his current research are internet-based and e-business systems (property, construction ethics, sustainable development, export, etc.), decision-making theory, decision-support systems, etc. A. Kaklauskas is the author of 87 research publications and 5 monographs.

**Zenonas TURSKIS.** PhD student, senior research worker, Dept of Construction Technology and Management, Vilnius Gediminas Technical University. His major research interests: building technology and management, decision-making theory, expert systems, operation research.

**Darius KALIBATAS.** PhD student, Dept of Construction Technology and Management, Vilnius Gediminas Technical University (VGTU). Bachelor of Science (construction management), VGTU, 2001. Master of Science (construction management), VGTU, 2003. Research interests: multi-attribute assessment.