JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT
ISSN 1392-3730 print/ISSN 1822-3605 online
2014 Volume 20(1): 103–110
doi:10.3846/13923730.2013.843585

INTEGRATED EVALUATION OF EXTERNAL WALL INSULATION IN RESIDENTIAL BUILDINGS USING SWARA-TODIM MCDM METHOD

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Received 05 Feb 2013; accepted 29 Apr 2013

Abstract. A great part of energy produced in Europe is consumed by old residential buildings. Consequently, it is necessary to retrofit energetically non-efficient buildings. However, there is a mass financial gap between cost effective retrofitting and upgrading to nearly zero energy building levels. The efficiency of apartment building modernization under current requirements applicable in Lithuania and the requirements for 2020 was analysed, focusing on thermal insulation of external walls. Six cases of residential building modernization in Lithuania were studied estimating criteria that are among the most important for implementation of apartment building modernization, such as the total cost of the external wall modernization, simple payback period, work duration, and other parameters related to the characteristics of thermal insulation systems. The weights of the criteria were calculated after an expert survey and using integrated SWARA-TODIM multi-criteria decision-making (MCDM) method the best alternatives were ranked. After analyzing the differences between the current situation and upcoming requirements for rendered and ventilated type of façades, it can be stated that the final result depends more on price, duration of works, payback period, energy losses and water vapour diffusion than on the type of façade or insulation requirements applied at present or future.

Keywords: residential building, renovation, multi-criteria decision-making (MCDM), SWARA, TODIM.

Reference to this paper should be made as follows: Ruzgys, A.; Volvačiovas, R.; Ignatavičius, Č.; Turskis, Z. 2014. Integrated evaluation of external wall insulation in residential buildings using SWARA-TODIM MCDM method, *Journal of Civil Engineering and Management* 20(1): 103–110. http://dx.doi.org/10.3846/13923730.2013.843585

Introduction

Energy efficiency is becoming more and more important as energy prices are constantly raising. The greater part of energy produced in Europe is consumed by buildings. Residential buildings account for 2/3 of final energy consumption in the building sector (Konstantinou, Knaack 2011). Residential buildings constructed in 1960–1990 are among the largest energy consumers; thus, it is necessary to retrofit energetically non-efficient buildings. Two scenarios are applied when retrofitting the blocks of old residential buildings. First scenario is demolition of old buildings and construction of new ones in empty areas. A second method is the modernization of old buildings by adapting them to current standards. Construction of new buildings demands from four to eight times more resources than modernization of analogical buildings (Power 2008). The expectation for the structural life of a building is often more than 60 years while the building envelope starts to deteriorate after 20 or 30 years; thus, renovation of building façades is inevitable (Konstantinou, Knaack 2011).

The recast of Energy Performance of Buildings Directive (EPBD recast 2010) has established several newer strengthened requirements such as the obligation that all new buildings should reach nearly zero-energy levels by the end of 2020. The transposition of these Directives into national legislation influences the achievement of energy saving targets (Annunziata *et al.* 2013; Boermans *et al.* 2011). The main provisions of EPBD are:

- reduce energy consumption by 20% before 2020;
- 20% of energy production must consist of renewable energy sources before 2020;
- 20% reduction of greenhouse gas emissions (compared to levels of 1990) before 2020 and 30% reduction provided international agreement was made;
- the cost-effective requirements for energy saving should be established depending on local weather conditions in each country;
- all public buildings must be nearly zero energy buildings (nZEB) from 2018 and all new buildings must be nZEB from 2020.

The nZEB can be described as a building, which consumes a very low amount of energy and the biggest part of energy required should be covered from renewable sources, including the one produces on-site or nearby.

To achieve these goals, interim requirements are set

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for energy performance classes of new buildings in Lithuania. New buildings must comply with the requirements of:
- before 1 January 2014 – C class buildings;
- from 1 January 2014 – B class buildings;
- from 1 January 2016 – A class buildings;
- from 1 January 2018 – A+ class buildings;
- from 1 January 2021 – A++ class buildings.

It can be found that retrofitting building fabric, building services systems and metering systems requires less cost investment while providing much more environmental benefits, as compared to retrofit measures using renewable energy technologies (Ma *et al.* 2012; Nemry *et al.* 2010). For example, even replacement of all windows in a typical multi-dwelling building can reduce greenhouse gas emissions by 30% (Staniūnas *et al.* 2013).

Although there is a wide range of retrofit technologies readily available, methods to identify the most cost-effective retrofit measures for particular projects is still a major technical challenge (Ma *et al.* 2012). Specialists offer many models for estimation of economically efficient thermal insulation thickness for building renovation in different climatic conditions. The optimum insulation thickness is affected by many economic (inflation rate and energy costs) and physical parameters (wall structure and properties of insulation materials) (Kaynakli 2011; Ozel 2011; Al-Sanea, Zedan 2011).

Technological problems arise in case retrofitting of old buildings aims to meet future standards. About 350 mm thickness thermal insulation layer is needed when insulating old buildings using most common materials with their thermal conductivity $\lambda = 0.035–0.040$ W/(m·K). This causes many problematic spots along building corners, window–wall junctions, in balconies and lodges. One of the solutions of this problem could be using materials with lower thermal conductivity, however this would be more expensive and would extend the payback period. So far the financial gap between cost effective retrofitting and upgrading to nZEB levels is significant enough; thus, supporting programs and subsidies are needed. This financial gap is influenced by the future evolution of technology costs and production volumes (Boermans *et al.* 2011). Economidou (2011) stated that it is almost unreal to reach EPBD requirements until 2020 if renovation rates in EU will not change; consequently, the financial support from governments is essential.

European countries have adopted different approaches in the design of their national regulatory framework. This difference consists of four factors: different authorities involved in energy regulations, traditional building regulations and enforcement models, different contextual characteristics and maturity of the country in the implementation of energy efficiency measures (Annunziata *et al.* 2013).

Study performed by Finnish experts (Tuominen *et al.* 2013) estimated the economic effects of investing in energy efficiency in buildings in Finnish building stock. Conservation potentials in space heating for two different scenarios with different levels of investment in energy efficiency were quantified and the effects on energy sector and the economy at large were estimated. The results showed that a rather modest increase resulting in a few percent rise in annual construction and renovation investments can decrease the total primary energy consumption 3.8–5.3% by 2020, and 4.7–6.8% by 2050 compared to the baseline scenario. In most European Union countries, cost-effective energy savings of about 10% can be achieved by 2020 and 20% by 2030, the total annual primary energy consumption of 21 000 TWh in all EU countries combined (Tuominen *et al.* 2012).

A research made in various EU countries revealed that the improvements in energy efficiency are hindered by the lack of effect on property prices, low priority for energy efficiency improvements among the consumers and the lack of information on energy efficiency, especially the insufficiency of trusted information (Tuominen *et al.* 2012). It is difficult to reach a nearly zero energy building without using renewable energy sources. Nevertheless, it is possible to save large amounts of energy when using only wall insulation and installation of new windows. A well insulated building envelope is very important attaining nearly zero energy consumption levels (Morelli *et al.* 2012).

MCDM methods are widely applied for building redevelopment and reconstruction problems. Redevelopment alternatives of derelict rural buildings were analysed applying TOPSIS, COPRAS, VIKOR methods (Antucheviciene *et al.* 2011, 2012). MAMVA (Multi-Attribute Market Value Assessment) method was proposed for the analysis and comprehensive assessment of construction and retrofit projects (Kanapeckiene *et al.* 2011). New method WASPAS (Weighted Aggregated Sum Product Assessment) was developed and applied for ranking of possible facades alternatives for public and commercial buildings (Zavadskas *et al.* 2012).

The objective of the study is to analyse the efficiency of old apartment building (built during the period 1970–1990) modernization under current Lithuanian requirements, and to compare the results derived if these buildings were retrofitted under 2020 standards, focusing on external wall thermal insulation. All variables are recalculated to meet the requirements of upcoming standard described in Table 1.

Table 1. Comparison of U values (W/(m^2·K)) (U – coefficient of thermal conductivity) for residential buildings in Lithuania according to current and 2020 standards (STR 2.05.01:2005, STR 2.01.09:2012)

Construction	Current values, W/(m^2·K)	nZEB values, W/(m^2·K)
Walls	0.20	0.10
Roof	0.16	0.08
Slab floor	0.16	0.08
Windows	1.60	0.70
Doors	1.60	0.70

1. Objects

Few residential buildings, renovated in 2008–2010 in accordance with applicable requirements of Lithuanian building codes, were studied. To carry out the analysis of design solutions of retrofitted buildings, six cases of residential building modernizations in Vilnius and Siauliai (Lithuania) were chosen. Three of these buildings were renovated installing external thermal insulation composite system (ETICS) using polystyrene foam and thin plaster. Other three buildings were insulated with external thermal insulation ventilated systems using mineral wool and fibre cement panels. Case study objects are described in Table 2.

Table 2. Case objects

Object	Information about building	External wall structure	U values	External thermal insulation system
 Architektu St. 104, Vilnius	Years built: 1971 Floors: 5 Apartments: 90 Floor area: 5060 m^2 Staircases: 6	Precast ceramsite concrete panels, 350–380 mm thick	Before: U = 1.38 W/m^2K After: U = 0.19 W/m^2K Difference: ΔU = 1.19 W/m^2K	ETICS with 150 mm thickness polystyrene foam with plaster finish
 Grinkeviciaus St. 6, Siauliai	Years built: 1976 Floors: 5 Apartments: 45 Floor area: 2311 m^2 Staircases: 3	Precast ceramsite concrete panels, 350–380 mm thick	Before: U = 1.38 W/m^2K After: U = 0.21 W/m^2K Difference: ΔU = 1.17 W/m^2K	ETICS with 150 mm thickness polystyrene foam with plaster finish
 Sevastopolio St. 5, Siauliai	Years built: 1973 Floors: 5 Apartments: 45 Floor area: 2318 m^2 Staircases: 3	Precast ceramsite concrete panels, 300 mm thick	Before: U = 1.30 W/m^2K After: U = 0.19 W/m^2K Difference: ΔU = 1.11 W/m^2K	ETICS with 150 mm thickness polystyrene foam with plaster finish
 Architektu St. 106, Vilnius	Years built: 1971 Floors: 5 Apartments: 60 Floor area: 3449 m^2 Staircases: 4	Precast ceramsite concrete panels, 350–380 mm thick	Before: U = 1.27 W/m^2K After: U = 0.24 W/m^2K Difference: ΔU = 1.03 W/m^2K	Ventilated system with 150 mm thickness mineral wool insulation and fibrocement panels
 Klevu St. 13, Siauliai	Years built: 1988 Floors: 5 Apartments: 30 Floor area: 1596 m^2 Staircases: 2	Clay bricks masonry, 380 mm thick	Before: U = 1.31 W/m^2K After: U = 0.26 W/m^2K Difference: ΔU = 1.05 W/m^2K	Ventilated system with 130 mm thickness mineral wool insulation and fibrocement panels with marble grain finish
 Valanciaus St. 2, Siauliai	Years built: 1990 Floors: 5 Apartments: 30 Floor area: 1618 m^2 Staircases: 2	Calcium silicate bricks masonry, 510 mm thick	Before: U = 1.31 W/m^2K After: U = 0.26 W/m^2K Difference: ΔU = 1.05 W/m^2K	Ventilated system with 140 mm thickness mineral wool insulation and fibrocement panels

2. Evaluated characteristics

To determine the best case of modernization, five criteria were chosen: price with VAT, duration of works, payback period, energy losses and water vapour diffusion. The weights of the criteria were calculated after the expert survey. All criteria values for each building are shown below in the decision-making matrix (Table 3).

2.1. Price with VAT

The prices (including VAT) of external thermal insulation systems for existing requirements were defined after examining actual design estimations of each building. This is a real market price, for which construction works were carried out. Prices for 2020 standards were calculated by increasing costs of works and amounts of material. This criterion is expressed by the amount of money, needed to install 100 m^2 of thermal insulation system (€/100 m^2).

2.2. Duration of works

The duration of thermal insulation installation works depends on type and thickness of the system. The duration of works is calculated using normative labour inputs. This criterion is expressed by the amount of working days, during which one worker installs 100 m^2 of the thermal insulation system.

2.3. Payback period

Payback period is the amount of time required for the return on an investment, i.e. to pay back the sum of the initial investment. A simple payback period of external wall modernization is calculated dividing the initial investments by yearly thermal energy savings through external walls. To evaluate yearly energy savings after modernization, a difference of energy consumption for heating between heating seasons 2007–2008 and 2011–2012 was found and recalculated to the normative year using degree day methodology. Energy losses through external walls of a building amount to 45% of total energy losses.

2.4. Energy losses

Energy losses of specific thermal insulation systems depend on their thermal conductance. Energy losses for 20 years through external walls were calculated and divided by useful floor area of the building (kWh/m^2/20 year). Energy losses for 20 years determine the expected economic benefits return on investment. Calculations are made using methods described in Lithuanian building regulation documents (STR 2.01.09:2012).

2.5. Water vapour diffusion

External thermal insulation composite systems (ETICS) and external thermal ventilated systems maintain different levels of water vapour diffusion. The ability of water vapour to migrate through walls depends on properties of materials used in thermal insulation systems. If a thermal insulation system is installed using especially airtight materials, a risk of worsening indoor air quality or mould growth rises. Wall structures can be damaged because of detained moisture. The values of this criterion are expressed by scoring (StoTherm 2013).

Table 3. Decision-making matrix

Type of façade		Objects (alternatives)	Criteria				
			Price with VAT, [€/100 m^2 wall]	Duration of works, [m. d./100 m^2 wall]	Payback period, [y]	Energy losses, [kWh/m^2/ 20 year]	Water vapour diffusion, [score]
			c_1	c_2	c_3	c_4	c_5
Current situation	Rendered	Architektu St. 104, Vilnius; a_1	6560	39	17.9	266	3
		Grinkeviciaus St. 6, Siauliai; a_2	4210	39	18.9	337	3
		Sevastopolio St., Siauliai; a_3	4170	39	21.1	307	3
	Ventilated	Architektu St. 106, Vilnius; a_4	9750	51	35.2	301	4
		Klevu St. 13, Siauliai; a_5	6550	49	18.4	325	4
		Valanciaus St. 2, Siauliai; a_6	6480	50	21.7	400	4
2020 requirements	Rendered	Architektu St. 104, Vilnius; a_7	9810	41	24.9	140	3
		Grinkeviciaus St. 6, Siauliai; a_8	6290	41	25.9	153	3
		Sevastopolio St. 5, Siauliai; a_9	6230	41	29.2	162	3
	Ventilated	Architektu St. 106, Vilnius; a_{10}	12415	53	39.4	126	4
		Klevu St. 13, Siauliai; a_{11}	8342	53	20.4	125	4
		Valanciaus St. 2, Siauliai; a_{12}	8253	53	23.1	154	4
Optimality direction			min.	min.	min.	min.	max.

3. Determination of criteria weights by SWARA method

Each specialized decision-making support system for selection of the rational resolution method should have 4 main groups of regulations and procedures:

- Generating of feasible alternatives to resolution;
- Formation of criteria systems describing alternatives, meanings and importance;
- Having set priority, degree of usefulness and value of alternatives, rules of subsystem would offer the alternatives that are worth to be analyzed further and why;
- Generation of proposals to the interested parties, which alternatives are the best and can be investigated in the future (Keršulienė *et al.* 2010).

There are different ways to determine values of criteria and their weights. The weights of criteria can be determined by applying:

- Subjective methods (AHP – Analytic Hierarchy Process);
- Objective methods (Entropy);
- Integrated methods (which are a combination of several methods) (Keršulienė *et al.* 2010).

Only well-founded weighting factors should be used because weighting factors are always subjective and influence the solution. The main feature of SWARA (Step-wise Weight Assessment Ratio Analysis) method is the possibility to estimate opinions of experts or interest groups on significance ratio of the criteria in the process of their weight determination (Keršulienė *et al.* 2010).

The procedure of SWARA method for the criteria weights determination can be described as follows:

1. Drawing the general list of criteria;
2. Expert survey (experts arrange criteria according to rank, the most important index being listed as the first, etc.);
3. Evaluation of how much c_j criterion is more important than c_{j+1} criterion (s_j – comparative importance of average value);
4. Determination of coefficient $k_j = s_j + 1$;
5. Determination of recalculated weight $w_j = \frac{w_{j-1}}{k_j}$;
6. Determination of weight (criterion importance) $q_j = \frac{w_j}{\sum_{j=1}^{n} w_j}$, where n is number of criteria.

Solving the current problem, authors selected 5 most important criteria that had the greatest influence for implementation of apartment building modernization. Next, a survey of 25 experts was carried out and these criteria were rated and listed from the most important to the least important as follows:

1. Payback period, [y];
2. Energy losses, [kWh/m^2/20 year];
3. Price with VAT, [€/100 m^2 wall];
4. Water vapour diffusion, [score];
5. Duration of works, [m. d./100 m^2 wall].

After determining the order of importance for criteria, the authors of the article made individual rankings comparing criteria between each other using SWARA method and parameters that determine the extent by which one criterion is better than another (s_j). Finally, data was processed (the arithmetic mean was derived) and further calculations of the SWARA method were performed. Results are given in Table 4.

Table 4. Criteria parameters by SWARA method

Criterion	s_j	k_j	w_j	q_j
c_3	–	1.000	1.000	0.269
c_4	0.150	1.150	0.870	0.234
c_1	0.083	1.083	0.803	0.216
c_5	0.450	1.450	0.554	0.149
c_2	0.133	1.133	0.488	0.132

4. Problem solution by TODIM method

The TODIM method (an acronym in Portuguese of Interactive and Multi-criteria decision-making), conceived in its current form at the beginning of the nineties, is a discrete multi-criteria method based on Prospect Theory. This means that underlying the method is a psychological theory, which was the subject of the Nobel Prize for Economics awarded in 2002. Thus, while practically all other multi-criteria methods start from the premise that the decision maker always looks for the solution corresponding to the maximum of some global measure of value – for example, the highest possible value of a multi-criteria utility function, in the case of MAUT – the TODIM method makes use of a global measurement of value calculable by the application of the paradigm of Prospect Theory. In this way, the method is based on a description, proved by empirical evidence, of how people effectively make decisions in the face of risk (Gomes, Rangel 2009).

The main steps of the TODIM method are as follows (Gomes *et al.* 2009; Gomes, Rangel 2009; Moshkovich *et al.* 2011):

1. Formation of decision-making matrix.
2. The sum of all criteria weights must be equal to 1:

$$q_1 + q_2 + \ldots + q_j = 1; \; j = \overline{1,n}. \tag{1}$$

3. Quantitative criterion scales are normalized to produce comparable values $\bar{x}_{ij}$. These estimates are then normalized in the same way as quantitative scales to produce comparable values. Eqn (2) is used for maximizing criteria while the set of Eqns (3–5) are used for minimizing criteria. Eqn (3) normalizes values. Eqn (4) reverses the higher values into smaller ones to give more value to lower initial alternatives estimates. Eqn (5) normalizes new values:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}; \; i = \overline{1,m}; \; j = \overline{1,n}; \tag{2}$$

$$\overline{p}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}; \ i = \overline{1,m}; \ j = \overline{1,n}; \qquad (3)$$

$$\overline{p}'_{ij} = \frac{\min_j \overline{p}_{ij}}{\overline{p}_{ij}}; \ i = \overline{1,m}; \ j = \overline{1,n}; \qquad (4)$$

$$\overline{x}_{ij} = \frac{\overline{p}'_{ij}}{\sum_{i=1}^{m} \overline{p}'_{ij}}; \ i = \overline{1,m}; \ j = \overline{1,n}. \qquad (5)$$

4. Individual criterion weights are recalculated using the most important one (criterion c_j with the highest weight – q_c):

$$q_{jc} = \frac{q_j}{q_c}; \ j = \overline{1,n}. \qquad (6)$$

5. For each criterion $j = \overline{1,n}$ for each two alternatives a_i and a_k $i,k = \overline{1,m}$ the "single-criterion dominance" is calculated as:

$$\Phi_j\ a_i, a_k\ = \begin{cases} -\sqrt{\dfrac{\sum_{j=1}^{n} q_{jc}\left|\overline{x}_{ij} - \overline{x}_{kj}\right|}{q_{jc}}}, \ \textit{if} \ \ \overline{x}_{ij} - \overline{x}_{kj} < 0 \\ 0, \ \textit{if} \ \ \overline{x}_{ij} - \overline{x}_{kj} = 0 \\ \sqrt{\dfrac{q_{jc}\left|\overline{x}_{ij} - \overline{x}_{kj}\right|}{\sum_{j=1}^{n} q_{jc}}}, \ \textit{if} \ \left(\overline{x}_{ij} - \overline{x}_{kj}\right) > 0 \end{cases}; \qquad (7)$$

$i,k = \overline{1,m}; \ \ j = \overline{1,n}.$

6. For each pair of alternatives a_i and a_k $i,k = \overline{1,m}$ the "relative dominance" is calculated as the sum of "single-criterion dominance" measures:

$$\delta\left(a_i, a_k\right) = \sum_{j=1}^{n} \Phi_j\left(a_i, a_k\right); \ j = \overline{1,n}. \qquad (8)$$

7. The "global dominance" $G(a_i)$ of each alternative a_i $i = \overline{1,m}$ is calculated as a sum of "relative dominances" over all other alternatives:

$$G\left(a_i\right) = \sum_{k=1}^{m} \delta\left(a_i, a_k\right); \ k = \overline{1,m}. \qquad (9)$$

8. The last step normalizes "global dominances" to produce the "relative overall value $V(a_i)$ of each alternative using the following equation:

$$V\left(a_i\right) = \frac{G\left(a_i\right) - \min_i G\left(a_i\right)}{\max_i G\left(a_i\right) - \min_i G\left(a_i\right)}; \ i = \overline{1,m}. \qquad (10)$$

The "relative overall values", obtained through Eqn (10) ranging from 0 to 1, are used to rank order alternatives. Notations used in Eqns (1–10) are as follows:
a_i – alternative;
c_j – criterion;
i – alternative number;
j – criterion number;
m – number of alternatives;
n – number of criteria;
x_{ij} – decision-making matrix elements;
$\overline{x}_{ij}, \overline{x}_{kj}$ – normalized matrix elements;
$\overline{p}_{ij}$, $\overline{p}'_{ij}$ – intermediate matrix elements (for minimizing criteria);
$\min \overline{p}_{ij}$ – minimum $\overline{p}_{ij}$ value of alternatives;
q_j^i – weight of criterion;
q_c – highest weight of criteria;
q_{jc} – individual weight of criterion;
$\Phi_j\left(a_i, a_k\right)$ – single-criterion dominance of alternatives;
$\delta\left(a_i, a_k\right)$ – relative dominance of alternatives;
$G(a_i)$ – global dominance of alternatives;
$\min_i G\left(a_i\right)$ – minimum $G(a_i)$ value of alternatives;
$\max_i G\left(a_i\right)$ – maximum $G(a_i)$ value of alternatives;
$V(a_i)$ – relative overall value of alternatives.

To determine the most rational alternative of the modernization of the 12 case alternatives, calculations of above described TODIM method are performed using data of Table 3 and Table 4.

A normalized decision-making matrix, shown in Table 5 is calculated using Eqns (2–5). Individual weights of criteria, shown in Table 6, are calculated using Eqn (6). A small part of single-criterion dominance and relative dominance data, calculated using Eqns (7–8), is shown in Table 7. Global dominance and relative overall value, calculated using Eqns (9–10) are shown in Table 8.

Table 5. Normalized decision-making matrix

Alternatives	Criteria				
	c_1	c_2	c_3	c_4	c_5
a_1	0.086	0.096	0.108	0.061	0.071
a_2	0.133	0.096	0.103	0.049	0.071
a_3	0.135	0.096	0.092	0.053	0.071
a_4	0.058	0.074	0.055	0.054	0.095
a_5	0.086	0.077	0.105	0.050	0.095
a_6	0.087	0.075	0.089	0.041	0.095
a_7	0.057	0.091	0.078	0.117	0.071
a_8	0.089	0.091	0.075	0.107	0.071
a_9	0.090	0.091	0.066	0.101	0.071
a_{10}	0.045	0.071	0.049	0.130	0.095
a_{11}	0.067	0.071	0.095	0.131	0.095
a_{12}	0.068	0.071	0.084	0.106	0.095

Table 6. Individual weight of criterion

Individual weight of criterion	q_{1c}	q_{2c}	q_{3c}	q_{4c}	q_{5c}
	0.803	0.491	1.000	0.870	0.554

Table 7. Single-criterion dominance and relative dominance

Single-criterion dominance		
$\Phi_1(a_1, a_1) = 0.000$	$\Phi_2(a_1, a_1) = 0.000$	$\Phi_3(a_1, a_1) = 0.000$
$\Phi_1(a_1, a_2) = -0.470$	$\Phi_2(a_1, a_2) = 0.000$	$\Phi_3(a_1, a_2) = 0.039$
$\Phi_1(a_1, a_3) = -0.476$	$\Phi_2(a_1, a_3) = 0.000$	$\Phi_3(a_1, a_3) = 0.066$
…	…	…
$\Phi_1(a_2, a_1) = 0.102$	$\Phi_2(a_2, a_1) = 0.000$	$\Phi_3(a_2, a_1) = -0.146$
$\Phi_1(a_2, a_2) = 0.000$	$\Phi_2(a_2, a_2) = 0.000$	$\Phi_3(a_2, a_2) = 0.000$
$\Phi_1(a_2, a_3) = -0.077$	$\Phi_2(a_2, a_3) = 0.000$	$\Phi_3(a_2, a_3) = 0.054$
…	…	…
$\Phi_1(a_{12}, a_{10}) = 0.070$	$\Phi_2(a_{12}, a_{10}) = 0.000$	$\Phi_3(a_{12}, a_{10}) = 0.097$
$\Phi_1(a_{12}, a_{11}) = 0.013$	$\Phi_2(a_{12}, a_{11}) = 0.000$	$\Phi_3(a_{12}, a_{11}) = -0.203$
$\Phi_1(a_{12}, a_{12}) = 0.000$	$\Phi_2(a_{12}, a_{12}) = 0.000$	$\Phi_3(a_{12}, a_{12}) = 0.000$
Single-criterion dominance		Relative dominance
$\Phi_4(a_1, a_1) = 0.000$	$\Phi_5(a_1, a_1) = 0.000$	$\delta(a_1, a_1) = 0.000$
$\Phi_4(a_1, a_2) = 0.055$	$\Phi_5(a_1, a_2) = 0.000$	$\delta(a_1, a_2) = -0.376$
$\Phi_4(a_1, a_3) = 0.044$	$\Phi_5(a_1, a_3) = 0.000$	$\delta(a_1, a_3) = -0.366$
…	…	…
$\Phi_4(a_2, a_1) = -0.235$	$\Phi_5(a_2, a_1) = 0.000$	$\delta(a_2, a_1) = -0.280$
$\Phi_4(a_2, a_2) = 0.000$	$\Phi_5(a_2, a_2) = 0.000$	$\delta(a_2, a_2) = 0.000$
$\Phi_4(a_2, a_3) = -0.142$	$\Phi_5(a_2, a_3) = 0.000$	$\delta(a_2, a_3) = -0.166$
…	…	…
$\Phi_4(a_{12}, a_{10}) = -0.318$	$\Phi_5(a_{12}, a_{10}) = 0.000$	$\delta(a_{12}, a_{10}) = -0.151$
$\Phi_4(a_{12}, a_{11}) = -0.324$	$\Phi_5(a_{12}, a_{11}) = 0.000$	$\delta(a_{12}, a_{11}) = -0.515$
$\Phi_4(a_{12}, a_{12}) = 0.000$	$\Phi_5(a_{12}, a_{12}) = 0.000$	$\delta(a_{12}, a_{12}) = 0.000$

Table 8. Global dominance and relative overall value

Global dominance	Relative overall value
$G(a_1) = -4.649$	$V(a_1) = 0.927$
$G(a_2) = -4.230$	$V(a_2) = 0.991$
$G(a_3) = -4.336$	$V(a_3) = 0.975$
$G(a_4) = -10.741$	$V(a_4) = 0.000$
$G(a_5) = -5.439$	$V(a_5) = 0.807$
$G(a_6) = -7.747$	$V(a_6) = 0.456$
$G(a_7) = -7.285$	$V(a_7) = 0.526$
$G(a_8) = -5.121$	$V(a_8) = 0.855$
$G(a_9) = -6.277$	$V(a_9) = 0.679$
$G(a_{10}) = -10.225$	$V(a_{10}) = 0.079$
$G(a_{11}) = -4.171$	$V(a_{11}) = 1.000$
$G(a_{12}) = -6.321$	$V(a_{12}) = 0.673$

Alternatives according to the problem solution results are ranked as follows:

1. Klevu St. 13, Siauliai (2020 requirements);
2. Grinkeviciaus St. 6, Siauliai (current situation);
3. Sevastopolio St. 5, Siauliai (current situation);
4. Architektu St. 104, Vilnius (current situation);
5. Grinkeviciaus St. 6, Siauliai (2020 requirements);
6. Klevu St. 13, Siauliai (current situation);
7. Sevastopolio St. 5, Siauliai (2020 requirements);
8. Valanciaus St. 2, Siauliai (2020 requirements);
9. Architektu St. 104 (2020 requirements);
10. Valanciaus St. 2, Siauliai (current situation);
11. Architektu St. 106, Vilnius (2020 requirements);
12. Architektu St. 106, Vilnius (current situation).

Analyzing the results of TODIM method it was found that the best alternative is Klevu St. 13, Siauliai, modernized under 2020 requirements. The external walls of the building are insulated installing ventilated type of façade using 350 mm thickness mineral wool, stainless steel frame and fibre cement façade panels. Alternatives 2 and 3 are not far behind (Grinkeviciaus St. 6, Siauliai (modernization under current requirements) and Sevastopolio St. 5, Siauliai (modernization under current requirements)). These two buildings are insulated using rendered type of façade.

After studying the differences between the current situation and 2020 requirements, rendered and ventilated type of façades, it can be stated that the final result depends more on specific meanings of criteria (price with VAT, duration of works, payback period, energy losses and water vapour diffusion) than on buildings' type of façade or insulation requirements applied at present or future. These values of criteria depend on situation in country's building market (price), technology of construction works (duration of works), quality of construction works and design solutions (payback period, energy losses), etc.

Conclusions

Six cases of residential building modernization were studied. Three of the buildings were renovated installing rendered external thermal insulation composite systems, other three buildings were insulated with ventilated façade systems.

Following the expert survey, criteria that have the greatest influence on implementation of apartment building modernization and their weights were determined.

The best solution for apartment building modernization was proposed applying the integrated SWARA-TODIM MCDM method. The rank order of alternatives was determined and the best alternatives of modernization were found: Klevu g. 13, Siauliai (modernization under 2020 requirements), Grinkeviciaus g. 6, Siauliai (modernization under current requirements) and Sevastopolio g. 5, Siauliai (modernization under current requirements).

Values of individual criteria have a greater influence on retrofit efficiency than the type of façade or insulation requirements of present or future.

References

Annunziata, E.; Frey, M.; Rizzi, F. 2013. Towards nearly zero-energy buildings: the state-of-art of national regulations in Europe, *Energy* 57: 125–133. http://dx.doi.org/10.1016/j.energy.2012.11.049

Antucheviciene, J.; Zavadskas, E. K.; Zakarevicius, A. 2012. Ranking redevelopment decisions of derelict buildings and analysis of ranking results, *Journal of Economic Computation and Economic Cybernetics Studies and Research* 46(2): 37–62.

Antucheviciene, J.; Zakarevicius, A.; Zavadskas, E. K. 2011. Measuring congruence of ranking results applying particular MCDM methods, *Informatica* 22(3): 319–338.

Al-Sanea, S. A.; Zedan, M. F. 2011. Improving thermal performance of building walls by optimizing insulation layer distribution and thickness for same thermal mass, *Applied Energy* 88(9): 3113–3124. http://dx.doi.org/10.1016/j.apenergy.2011.02.036

Boermans, T.; Hermelin, A.; Schimschar, S.; Grözinger, J.; Offermann, M. 2011. *Principles for nearly zero-energy buildings*. Brussels: Buildings Performance Institute Europe (BPIE). 124 p.

Economidou, M. 2011. *Europe's buildings under the microscope, a country-by-country review of the energy performance of buildings*. Brussels: Buildings Performance Institute Europe (BPIE). 132 p.

EPBD recast. 2010. *Directive of the European Parliament and of the Council on the energy performance of buildings (recast)*, adopted by the Council on 14/04/2010, Brussels.

Gomes, L. F. A. M.; Rangel, L. A. D. 2009. An application of the TODIM method to the multicriteria rental evaluation of residential properties, *European Journal of Operational Research* 193(1): 204–211. http://dx.doi.org/10.1016/j.ejor.2007.10.046

Gomes, L. F. A. M.; Rangel, L. A. D.; Maranhão, F. J. C. 2009. Multicriteria analysis of natural gas destination in Brazil: an application of the TODIM method, *Mathematical and Computer Modelling* 50(1–2): 92–100. http://dx.doi.org/10.1016/j.mcm.2009.02.013

Kanapeckiene, L.; Kaklauskas, A.; Zavadskas, E. K.; Raslanas, S. 2011. Method and system for multi-attribute market value assessment in analysis of construction and retrofit projects, *Expert Systems with Applications* 38(11): 14196–14207.

Kaynakli, O. 2011. Parametric investigation of optimum thermal insulation thickness for external walls, *Energies* 4(6): 913–927. http://dx.doi.org/10.3390/en4060913

Keršulienė, V.; Zavadskas, E. K.; Turskis, Z. 2010. Selection of rational dispute resolution method by applying new stepwise weight assessment ratio analysis (SWARA), *Journal of Business Economics and Management* 11(2): 243–258. http://dx.doi.org/10.3846/jbem.2010.12

Konstantinou, T.; Knaack, U. 2011. Refurbishment of residential buildings: a design approach to energy-efficiency upgrades, *Procedia Engineering* 21: 666–675. http://dx.doi.org/10.1016/j.proeng.2011.11.2063

Ma, Zh.; Cooper, P.; Daly, D.; Ledo, L. 2012. Existing building retrofits: methodology and state-of-the-art, *Energy and Buildings* 55: 889–902. http://dx.doi.org/10.1016/j.enbuild.2012.08.018

Morelli, M.; Ronby, L.; Mikkelsen, S. E.; Minzari, M., G.; Kildemoes, T.; Tommerup, H. M. 2012. Energy retrofitting of a typical old Danish multi-family building to a "nearly-zero" energy building based on experiences from a test apartment, *Energy and Buildings* 54: 395–406. http://dx.doi.org/10.1016/j.enbuild.2012.07.046

Moshkovich, H. M.; Gomes, L. F. A. M.; Mechitov, A. I. 2011. An integrated multicriteria decision-making approach to real estate evaluation: case of the TODIM method, *Pesquisa Operacional* 31(1): 3–20. http://dx.doi.org/10.1590/S0101-74382011000100002

Nemry, F.; Uihlein, A.; Colodel, C. M.; Wetzel, C.; Braune, A.; Wittstock, B.; Hasan, I.; Kreissig, J.; Gallon, N.; Niemeier, S.; Frech, Y. 2010. Options to reduce the environmental impacts of residential buildings in the European Union: potential and costs, *Energy and Buildings* 42(7): 976–984. http://dx.doi.org/10.1016/j.enbuild.2010.01.009

Ozel, M. 2011. Thermal performance and optimum insulation thickness of building walls with different structure materials, *Applied Thermal Engineering* 31(17–18): 3854–3863. http://dx.doi.org/10.1016/j.applthermaleng.2011.07.033

Power, A. 2008. Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability?, *Energy Policy* 36(12): 4487–4500. http://dx.doi.org/10.1016/j.enpol.2008.09.022

Staniūnas, M.; Medineckienė, M.; Zavadskas, E. K.; Kalibatas, D. 2013. To modernize or not: ecological-economical assessment of multi-dwelling houses modernization, *Archives of Civil and Mechanical Engineering* 13(1): 88–98. http://dx.doi.org/10.1016/j.acme.2012.11.003

StoTherm 2013. *Architect's Façade Manual. Products and systems. Details. Solutions* [online], [cited 25 March 2013]. Available from Internet: http://www.sto.co.uk/webdocs/0212/ebooks/facades_binder/flash.html#/1/

STR 2.05.01:2005 Pastatų atitvarų šiluminė technika [Thermal technique of buildings partitions], *Žin*., 2005, No. 100–3733.

STR 2.01.09:2012 Pastatų energinis naudingumas. Energetinio naudingumo sertifikavimas [Energy efficiency of buildings. Certification of energy efficiency], *Žin*., 2005, No. 151–5568.

Tuominen, P.; Klobut, K.; Tolman, A.; Adjei, A.; de Best-Waldhober, M. 2012. Energy savings potential in buildings and overcoming market barriers in member states of the European Union, *Energy and Buildings* 51: 48–55. http://dx.doi.org/10.1016/j.enbuild.2012.04.015

Tuominen, P.; Forsström, J.; Honkatukia, J. 2013. Economic effects of energy efficiency improvements in the Finnish building stock, *Energy Policy* 52: 181–189. http://dx.doi.org/10.1016/j.enpol.2012.10.012

Zavadskas, E. K.; Turskis, Z.; Antucheviciene, J.; Zakarevicius, A. 2012. Optimization of weighted aggregated sum product assessment, Elektronika ir Elektrotechnika – *Electronics and Electrical Engineering* 122 (6): 3–6. http://dx.doi.org/10.5755/j01.eee.122.6.1810

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