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OWNER PREFERENCES REGARDING RENOVATION MEASURES – THE DEMONSTRATION OF USING MULTI-CRITERIA DECISION MAKING

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Abstract. The article describes typical apartment buildings built in Swedish residential areas in the '50s, '60s and 70's. Each of these buildings included calculations on the effects and investment cost of a number of renovation measures aimed at improving energy efficiency. By applying multi-criteria decision making methods *Simple Additive Weighting* (SAW), *Multiplicative Exponential Weighting* (MEW) and *Complex Proportion Assessment* (COPRAS), the preferences of building owners regarding renovation measures were studied. The study highlighted four important criteria, including the use of energy from district heating and electricity, investment cost and payback period. The owner preferences were found to have a major impact on the outcome of the study. These owners gave sufficient weight to renovation measures within a short payback period. Renovation actions falling out to be quite attractive are additional thermal insulation in the attic and heat recovery from exhaust air.

Keywords: energy efficiency, rank, panel houses, renovation, SAW, MEW, COPRAS, AHP methods, MCDM.

1. Introduction

Industry is increasingly focusing on reducing its own energy consumption and CO_2 emissions with the aim of maximizing operational efficiency and reducing its overall carbon footprint (Ministry of Defence 2010). Clean Development Mechanism (CDM) has spurred the development of 4586 projects in 76 developing countries (Fennhan 2009). These projects are expected to reduce global greenhouse gas emissions up to 2.91 Gt CO_2-equivalent by 2012 (Boyd *et al.* 2009). Buildings have a significant and continuously increasing impact on the environment because they are responsible for a large portion of carbon emissions and the use of a considerable amount of resources and energy. The green building movement emerged to mitigate these effects and to improve the building construction process. This paradigm shift should bring significant environmental, economic, financial and social benefits (Castro-Lacouture *et al.* 2009). Protecting the natural environment is not the whole story: companies also must consider their social, economic and cultural impact (Werbach 2009).

In order to stop global warmth due to CO_2 concentration, energy use should be decreased (Gao *et al.* 2001). Energy is an indispensable factor for the social and economic development of societies. The usage level of electricity is an indication of the economic prosperity of nations (Kahraman and Kaya 2010). Nowadays, an increase in carbon dioxide emissions contributes to an increase in surface temperature and is the primary cause for climatic changes. The basic measure that has been taken by the world community for the purpose of confrontation with this phenomenon was the use of Renewable Energy Sources (RES) (Economou 2010).

Energy consumption of buildings accounts for around 20–40% of all energy consumed in advanced countries. Over the last decade, more and more global organizations have been investing significant resources to create sustainably built environments, emphasizing sustainable building renovation processes to reduce energy consumption and carbon dioxide emissions (Juan *et al.* 2010). The construction sector covers one eighth of the total economic activity in the European Union (EU) employing more than eight million people. Intense activity in building construction, in conjunction with the need for energy savings and environmental protection policy, dictate for more reasonable design practices for buildings. The newly released EU Directive "Energy Performance of Buildings" (EPBD) concerns the use of energy in buildings and urges member nations of the EU to set stricter regulations regarding the efficient use of energy in buildings. For this reason, one of the main goals of advanced control systems, as applied to buildings, is to minimize energy consumption (Dounis and Caraiscos 2009). Building energy consumption keeps rising in recent years due to growth in population, increasing demand for healthy, comfortable and productive indoor environment, global climate changing, etc. Most of energy use in buildings is for the provision of heating, ventilation and air conditioning (HVAC). High-level performance of HVAC systems in building lifecycle is critical to building sustainability (Xiao and Wang 2009).

2. Project Description and Data for the Study

In the present study, multicriteria decision making methods will be applied to data on the effects and investment cost for a number of renovation measures aimed at improving energy efficiency. The data used are results from former work done by Bengt Bergqvist, Fredrik Gränne och Joel Kronheffer at Nordic Construction Company (NCC) in Sweden in co-operation with SonjaWidén, Ingela Blomberg and Marina Botta, KTH (Bergqvist *et al.* 2009).

The aim of the undertaken work was to assist in explaining the measures for energy saving that might show up to be profitable when apartment buildings produced in the period 1950 to 1970 have been to be renovated. By using multicriteria analysis, we will show how these results can be combined with the preferences of a group of building users and thus give guidance on how to make choices between renovation methods in a systematic and enlightened way.

2.1. Investigation Methodology

Building performance can be expressed employing different indicators such as primary energy use, environmental load and/or indoor environmental quality; building performance simulation can provide the decision maker with a quantitative measure of the extent to which an integrated design solution satisfies the design objectives and criteria (Heiselberg *et al.* 2009). Multi-criteria decision analysis (MCDA) methods have become increasingly popular in decision-making for sustainable energy because of the multi-dimensionality of the sustainability goal and the complexity of socio-economic and biophysical systems (Wang *et al.* 2009). There are a number of authors who use MCDA methods for the best alternative selection in different areas:

- Munier (2006) presented a multi-criteria method for treating difficult environmental problems where several alternatives or options are to be gauged through many different types of criteria;
- Tupenaite *et al.* (2010) describes the concept of the integrated analysis of built and human environment renovation as a whole as well as presents the multiple criteria assessment of alternatives for Bulgarian cultural heritage renovation projects. For this purpose, the widely known multiple criteria assessment methods SAW, TOPSIS and COPRAS and the newly developed method ARAS were used. As a result, the best project for granting was selected;
- Chen *et al.* (2006) presented a multi-criteria decision-making model for lifespan energy efficiency assessment of intelligent buildings (IBs). The decision-making model called IBAssessor is developed using an analytic network process (ANP) method and a set of lifespan performance indicators for IBs selected applying a new quantitative approach called energy–time consumption index (ETI);
- Zavadskas *et al.* (2009b) presents the comparative analysis of dwelling maintenance contractors aimed at determining the degree of their utility for users and a bidding price of services by applying the method of multi-criteria complex proportional assessment (COPRAS);
- ALwaer and Clements-Croome (2010) use a consensus-based model (Sustainable Built Environment Tool – SuBETool) analysed going through the analytical hierarchical process (AHP) for multi-criteria decision-making;
- Juan *et al.* (2010) developed an integrated decision support system for office building renovation that not only assesses the current condition but also provides decision makers with solutions to sustainable renovation implementation;
- Kowalski *et al.* (2009) analyzed the combined use of scenario building and participatory multi-criteria analysis (PMCA) in the context of renewable energy from a methodological point of view;
- In order to help decision-makers with the selection of the right materials, Castro-Lacouture *et al.* (2009) proposed a mixed integer optimization model incorporating design and budget constraints while maximizing the number of credits reached under the Leadership in Energy and Environmental Design (LEED) rating system.

To deal with this task, the authors use three multicriteria decision making methods:

- *Simple Additive Weighting* (SAW) method (MacCrimon 1968; Ginevičius *et al.* 2008a, b);
- *Multiplicative Exponential Weighting* (MEW) method (Zavadskas 1987);
- *COmplex PRoportion Assessment* (COPRAS) method (Zavadskas *et al*. 2008, 2009a).

For SAW and MEW methods as well as and for alternative "*i*", the normalized $\bar{x}_{ij}$ values of criterion "*j*" are calculated as follows:

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i x_{ij}} \text{ if maximum is preferable} \quad (1)$$

and $x_{ij} \geq 0$, under conditions $x_{ij} \geq 0$.

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{x_{ij}} \text{ if minimum is preferable} \quad (2)$$

and $x_{ij} \geq 0$, under conditions $x_{ij} \geq 0$.

$$\bar{x}_{ij} = \frac{\max_i x_{ij}}{x_{ij}} \text{ if maximum is preferable} \quad (3)$$

and $x_{ij} < 0$, under conditions $x_{ij} < 0$.

$$\bar{x}_{ij} = \frac{x_{ij}}{\min_i x_{ij}} \text{ if minimum is preferable} \quad (4)$$

and $x_{ij}<0$, under conditions $x_{ij}<0$.

There may be positive and negative values in one criterion column of the decision making matrix. In these cases, we recommend calculations using these formulas:

$$\bar{x}_{ij} = \frac{\min_i x_{ij}}{-(x_{ij}) + 2\min_i x_{ij}} \text{ if minimum is preferable} \quad (5)$$

and $x_{ij}>0$, under conditions $-\infty \le x_{ij} \le \infty$.

$$\bar{x}_{ij} = \frac{x_{ij}}{\min_i x_{ij}} \text{ if minimum is preferableand } x_{ij}<0, \quad (6)$$

under conditions $-\infty \le x_{ij} \le \infty$.

When applying COPRAS method, the normalized $\bar{x}_{ij}$ values of j criterion for i alternative are calculated as follows:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \text{ if minimum is preferable or maximum} \quad (7)$$

and $x_{ij}<0$, under conditions $x_{ij}<0$,
or $x_{ij} \ge 0$, under conditions $x_{ij} \ge 0$.

For the solution where $x_{ij}<0$, $\forall -\infty \le x_{ij} \le \infty$, all values were transformed to positive values, and the vector of these numbers was taken as a value (distance from the lowest to the given value).

When applying the SAW method, optimality criterion L_i equals to the sum of the weighted criteria values:

$$L_i = \sum_{j=1}^{n} \left(\bar{x}_{ij} q_j\right). \quad (8)$$

When applying the MEW method, optimality criterion L_i equals to the multiplication of the weighted criteria values:

$$L_i = \prod_{j=1}^{n} \bar{x}_{ij}^{q_j}, \quad (9)$$

where q_j is the weight of j criterion.

When applying the COPRAS method, optimality criterion Q_i is determined as follows:

$$Q_i = \frac{S_{+i} + \left(\min_i S_i \cdot \sum_{i=1}^{m} S_{-i}\right)}{S_{-i} \cdot \left(\sum_{i=1}^{m} \min_i S_{-i} / S_{-i})\right)}. \quad (10)$$

The weights of each criterion were determined using the AHP method (Saaty and Erdener 1979).

2.2. Weights for Criteria Applying the AHP-Method

Multi-criteria decision methods need weights that in our case were determined applying the AHP-method (Saaty and Erdener 1979; Podvezko 2009). AHP stands for "Analytical Hierarchy Process". This method provides a proven effective means to deal with complicated decision making. It is useful when identifying and weighting selection criteria, analyzing the data collected and expediting the decision making process.

The essence of the method is to construct a matrix expressing the relative values of a set of criteria. The method contains four steps (Medineckiene *et al.* 2010):

a) to decompose the goal into its constituent parts and to develop a hierarchy of interrelated decision elements describing the problem;
b) to make pair-wise comparisons with decision elements using a 9-point weighting scale to generate input data;
c) to calculate the relative weights of the criteria relevant to the problem, which is technically called the Eigenvector;
d) to aggregate the relative weights of decision elements to calculate ratings for alternative decision possibilities. The consistency ratio (CR) is calculated to check the opinions given as the basis for consistent decisions. A CR>0.1 indicates arbitrary judgments.

Table 1 shows the results of one of the interviewed owners. Table 2 indicates the pair-wise comparison matrix of the group results of building owners.

Table 1. Pair-wise comparison matrix of one of the interviewed

		District heat, energy consumption, MWh	Electricity for the facility, MWh	Cost for renovation, SEK	Payback period, year	q
		x_1	x_2	x_3	x_4	
District heat, energy consumption, MWh	x_1	1	1.00	3.00	1/5	0.162
Electricity for the facility, MWh	x_2	1	1	3.00	1/5	0.162
Cost for renovation, SEK	x_3	1/3	1/3	1	1/5	0.075
Payback period, year	x_4	5	5	5	1	0.601
CR = 0.06						

Table 2. Pair-wise comparison matrix of the group results

		District heat, energy consumption , MWh	Electricity for the facility, MWh	Cost for renovation, SEK	Payback period, year	q
		x_1	x_2	x_3	x_4	
District heat, energy consumption, MWh	x_1	1.00	0.447	0.656	0.209	0.06
Electricity for the facility, MWh	x_2	2.24	1.00	1.00	0.611	0.23
Cost for renovation, SEK	x_3	1.52	1.00	1.00	0.352	0.24
Payback period, year	x_4	4.78	1.64	2.84	1.00	0.47
CR = 0.01						

The choices in this study were based on the opinions given by persons having attitudes typical to facility owners. All the weights of each criterion were determined applying the AHP method. There was a pair-wise comparing matrix produced to show the owner's possible decisions. In this matrix, the criteria to be compared were the use of energy for district heating and electricity, investment cost and a payback period respectively.

2.3. Case Study

Three apartment buildings in Swedish residential areas built in '50s, '60s and '70s were selected. Each of these buildings included calculations on the effects and investment cost of a number of renovation measures aimed at improving energy efficiency. All actions on renovation were evaluated with regard to the use of energy from district heating and electricity respectively, investment cost and payback time. Energy calculations were done considering E-norm, which is energy calculation software commonly used in Sweden. In the base case, which is reference to each of the buildings, calculations are done using in-data like when the building was new. Costs were calculated based on data about experiences from NCC. Table 3 presents the properties of importance for the buildings discussed in the study.

In calculations on the base case, the following input data is used:

- Room temperature in the apartments is set to +22 °C and in stair houses – to +20 °C;
- The air tightness of the building envelope is described with a leakage flow of 2.0 *l*/s, m^2 in the surrounding area at 50 Pa of pressure difference. Calculations indicate that air flow through the building envelope is constantly 5% of this value. This is calculated on the entire surrounding area of the building;
- Incoming solar radiation through the windows is calculated by assuming a mean sun shading factor of 0.5. This means that the gain of solar energy is 50% of the gain possible through a 2-pane window with no solar shading;
- Annual energy consumption for hot tap water is reckoned to be 25 kWh/m^2 A_{temp}, *a*;
- The consumption of household electricity is set to be 30 kWh/m^2 A_{temp}, *a*;
- The flow of supply air per year is set to be 0.35 *l*/s, m^2 A_{temp};
- The inhabitants airing of their apartments are supposed to result in an additional need for heating of 4 kWh/m^2, *a*.

It should be kept in mind that when a number of measures for renovation are combined into a package, compound savings are usually lower than the sum of the savings from the measures one by one.

The initial matrix describing the problem is presented in Table 4.

Table 3. Description of buildings

The number of the building (marking)	B1	B2	B3
Name of the building	Svärdsidan 1, Östberga Built in 1967–1969.	Förvaltarvägen 4 Built in 1952–1953.	BRF Toppsockret Hökarängen Built in 1964.
Short description	24 apartments in each building Four storeys and a basement (three houses sharing a substation for district heating).	28 apartments in one of five point blocks. Seven storeys and a basement (three houses sharing a substation for district heating).	143 apartments in 17 stairways Four to five storeys (three houses sharing a substation for district heating).
Heated area	The whole area A_{temp} = 3219 m^2, apartments of which cover 2485 m^2 and a subsidiary usable area 734 m^2.	The whole area A_{temp} = 2184 m^2, apartments of which cover 1797 m^2 and a subsidiary usable area 387 m^2.	The whole area A_{temp} = 14 700 m^2, apartments of which cover 10900 m^2 and a subsidiary usable area 3800 m^2.
Description of building construction	Wall construction: 15 cm concrete +15 cm lightweight concrete with rendering; U-value is about 0.75 W/m^2,K. Dual-pane window, U-value is about 2.7 W/m^2,K in the stair-case, Single-pane window; U-value is about 5 W/m^2,K in the gateway.	Wall construction: 25 cm lightweight concrete with rendering; U-value is about 0.7 W/m^2,K. The attic was originally insulated with 5 cm coke and cinder with the U-value of 0.6 W/m^2,K.	Wall construction: 25 cm lightweight concrete with rendering, U-value about is 0.7 W/m^2,K. Three glass windows, U-value is about 2.0 W/m^2,K. Glazed balconies.
Building services	Substation for district heating serving three houses. Balanced ventilation with supply air and exhaust air driven by electrical ventilators.	Substation for district heating serving in one of the buildings. Exhaust air ventilation driven by electrical ventilators.	Substation for district heating serving in one of the buildings. Exhaust air ventilation driven by electrical ventilators with air intake through gap air ventilators in the window frames.

Table 4. The initial matrix describing the problem

Alternative number	Building number	Description of the actions	District heat, energy consumption, MWh	Electricity for the facility, MWh	Cost for renovation, SEK	Payback period, year
1	B1	Thermal insulation added in the attic. Additional insulation is 300 mm loose-fill insulation; the resulting thermal transmittance after adding this insulation will be 0.2 W/m^2,K. Cost will reach 300 SEK/m^2.	–17.40	–0.04	90 000	7
2	B2		–33.00	–0.08	150 000	6
3	B3		–229.10	–0.75	1 215 000	7
4	B1	Thermal insulation added to facades. The example covers 150 mm of thermal insulation assembled on the walls which changes thermal transmittance (U-value) from 0.75 to 0.3 W/m^2,K. Also, the tightness of the building envelope has been improved from 2.0 to 1.5 *l*/s,m^2 at a surrounding area of 50 Pa.	–78.50	–0.20	2 450 000	39
5	B2		–79.80	–0.02	1 750 000	28
6	B3		–202.30	–0.75	7 437 500	46
7	B1	New windows and doors. Exchange to new windows and doors have been assumed to improve the U-value of windows from 2.7 to 1.0 W/m^2,K and that of the gateway parts of the buildings from 4.0 to 2.0 W/m^2,K. The tightness of the building envelope has been improved from 2.0 till 1.0 *l*/s,m^2 at 50 Pa of pressure difference.	–80.50	–0.20	1 600 000	25
8	B2		–95.70	–0.20	1 625 000	22
9	B3		–453.80	–1.70	9 900 000	27
10	B1	Tightening around windows. Tightening windows is assumed to improve the tightness of the windows from 2.0 to 1.0 *l*/s,m^2 at 50 Pa of pressure difference. Cost – 500 SEK/window.	–14.10	0.00	82 000	7
11	B2		–19.30	0.00	70 500	5
12	B3		–85.70	–0.20	357 000	5
13	B1	Heat recovery from ventilation air, using plate heat exchangers with 60% efficiency. When using balanced ventilation with heat recovery, inlet air to living rooms and a sleeping room can be supplied with a low risk of problems with draught, because heat from exhaust air is utilized. A drawback is relatively high expenses of installing such system that is supposed to give the efficiency of 60%.	–64.60	10.50	650 000	17
14	B2		–76.70	5.30	350 000	8
15	B3		–406.30	70.30	1 800 000	9
16	B1	Heat recovery from ventilation air, using regenerative heat exchangers with 80% efficiency. The installation of a system with regenerative heat exchangers is supposed to give the efficiency of 80%.	–86.60	10.50	600 000	11
17	B2		–102.30	5.30	350 000	5
18	B3		–548.00	69.80	1 800 000	5
19	B1	Heat recovery using a heat pump taking heat from exhaust air. A heat pump taking heat from exhaust air can often be installed in apartment buildings with not very high costs. This kind of equipment can give a COP (coefficient of performance) of 2.5 reckoned as annual efficiency. COP means the ratio between the heat produced and the amount of electric energy consumed for driving a compressor and pumps for circulation.	–165.70	65.60	1 500 000	28
20	B2		–201.90	80.60	1 450 000	23
21	B3		–1 169.40	446.20	7 150 000	18
22	B1	Adjustment of a heating system and valves in thermostats. Cost for adjusting the heating system is supposed to give savings because the average temperature in the building can go down with 1 °C. Cost may be at about 1500 SEK per apartment.	–27.60	–0.20	42 000	2
23	B2		–33.80	–0.20	36 000	2
24	B3		–138.60	–1.40	215 000	2
25	B1	Installation of equipment for individual metering for hot tap water. Individual metering for hot tap water is supposed to give savings in the realm of 20%, which means 20–25 KWh/m^2. The cost of installation estimates about 4000 SEK per apartment while the cost of the meter makes about 400 SEK. Cost for reading meters is not included.	–12.40	0.00	112 000	11
26	B2		–9.90	0.00	96 000	12
27	B3		–73.50	0.00	572 000	10
28	B1	Installation of individual metering for heat. Installation costs of energy metering will be much higher than those of systems for temperature metering. Individual energy metering is supposed to give a general decrease in the indoor temperature of 1 °C. Cost may reach about 4000 SEK per apartment.	–27.60	–0.20	112 000	5
29	B2		–33.80	–0.20	96 000	4
30	B3		–138.60	–1.40	572 000	5
31	B1	Installation of solar collectors for hot tap water. A rule of thumb is that a solar collector can produce 200–400 KWh/m^2 per year for hot tap water. The cost of a solar collector is about 5000 SEK per m^2, which also includes a control unit and a pump for circulation and accumulator tank. Solar collectors are supposed to be installed on the roofs of the buildings and to cover an area of about 3 m^2 for each apartment. An accumulator tank for heat storage will be installed in the basement.	–15.30	2.20	154 000	16
32	B2		–13.90	2.00	132 000	15
33	B3		–102.90	14.70	786 500	12
34	B1	Installation of water taps giving lower water flow than usual. By using energy effective water taps, it is possible to save 20–40% of hot tap water and the same amount of cold tap water.	–15.30	0.00	227 000	19
35	B2		–13.90	0.00	195 000	18
36	B3		–102.90	0.00	1 158 000	14

3. Results and Discussion

Table 5 shows the initial decision making matrix of the described problem.

The names of the criteria can be defined in the following way:

- criterion x_1 is energy consumption of district heat, MWh;
- criterion x_2 is electricity for the facility, MWh;
- criterion x_3 is the total cost of renovation, SEK;
- criterion x_4 is a payback period per year.

Table 5. The initial matrix of the described problem

Alternative	Criteria			
	x_1	x_2	x_3	x_4
	Optimization direction			
	min	min	min	min
q	0.06	0.23	0.24	0.47
A_1	–17.40	–0.04	90 000.00	7.00
A_2	–33.00	–0.08	150 000.00	6.00
A_3	–229.10	–0.75	1 215 000.00	7.00
A_4	–78.50	–0.20	2 450 000.00	39.00
A_5	–79.80	–0.02	1 750 000.00	28.00
A_6	–202.30	–0.75	7 437 500.00	46.00
A_7	–80.50	–0.20	1 600 000.00	25.00
A_8	–95.70	–0.20	1 625 000.00	22.00
A_9	–453.80	–1.70	9 900 000.00	27.00
A_{10}	–14.10	0.00	82 000.00	7.00
A_{11}	–19.30	0.00	70 500.00	5.00
A_{12}	–85.70	–0.20	357 000.00	5.00
A_{13}	–64.60	10.50	650 000.00	17.00
A_{14}	–76.70	5.30	350 000.00	8.00
A_{15}	–406.30	70.30	1 800 000.00	9.00
A_{16}	–86.60	10.50	600 000.00	11.00
A_{17}	–102.30	5.30	350 000.00	5.00
A_{18}	–548.00	69.80	1 800 000.00	5.00
A_{19}	–165.70	65.60	1 500 000.00	28.00
A_{20}	–201.90	80.60	1 450 000.00	23.00
A_{21}	–1 169.40	446.20	7 150 000.00	18.00
A_{22}	–27.60	–0.20	42 000.00	2.00
A_{23}	–33.80	–0.20	36 000.00	2.00
A_{24}	–138.60	–1.40	215 000.00	2.00
A_{25}	–12.40	0.00	112 000.00	11.00
A_{26}	–9.90	0.00	96 000.00	12.00
A_{27}	–73.50	0.00	572 000.00	10.00
A_{28}	–27.60	–0.20	112 000.00	5.00
A_{29}	–33.80	–0.20	96 000.00	4.00
A_{30}	–138.60	–1.40	572 000.00	5.00
A_{31}	–15.30	2.20	154 000.00	16.00
A_{32}	–13.90	2.00	132 000.00	15.00
A_{33}	–102.90	14.70	786 500.00	12.00
A_{34}	–15.30	0.00	227 000.00	19.00
A_{35}	–13.90	0.00	195 000.00	18.00
A_{36}	–102.90	0.00	1 158 000.00	14.00

All these criteria have different units that make normalization necessary to make comparisons. The normalized decision making matrix for SAW and MEW methods is determined according to formulas (1), (2), (3), (4), (5) and (6) and is presented in Table 6.

Table 6. Normalized decision-making matrix (SAW and MEW methods)

Alternative	Criteria			
	x_1	x_2	x_3	x_4
	Optimization direction			
	min	min	min	min
A_1	0.0149	0.0015	0.4000	0.2857
A_2	0.0282	0.0030	0.2400	0.3333
A_3	0.1959	0.0283	0.0296	0.2857
A_4	0.0671	0.0075	0.0147	0.0513
A_5	0.0682	0.0008	0.0206	0.0714
A_6	0.1730	0.0283	0.0048	0.0435
A_7	0.0688	0.0075	0.0225	0.0800
A_8	0.0818	0.0075	0.0222	0.0909
A_9	0.3881	0.0642	0.0036	0.0741
A_{10}	0.0121	0.0000	0.4390	0.2857
A_{11}	0.0165	0.0000	0.5106	0.4000
A_{12}	0.0733	0.0075	0.1008	0.4000
A_{13}	0.0552	0.4173	0.0554	0.1176
A_{14}	0.0656	0.4545	0.1029	0.2500
A_{15}	0.3474	0.2149	0.0200	0.2222
A_{16}	0.0741	0.4173	0.0600	0.1818
A_{17}	0.0875	0.4545	0.1029	0.4000
A_{18}	0.4686	0.2158	0.0200	0.4000
A_{19}	0.1417	0.2234	0.0240	0.0714
A_{20}	0.1727	0.1984	0.0248	0.0870
A_{21}	1.0000	0.0531	0.0050	0.1111
A_{22}	0.0236	0.0075	0.8571	1.0000
A_{23}	0.0289	0.0075	1.0000	1.0000
A_{24}	0.1185	0.0528	0.1674	1.0000
A_{25}	0.0106	0.0000	0.3214	0.1818
A_{26}	0.0085	0.0000	0.3750	0.1667
A_{27}	0.0629	0.0000	0.0629	0.2000
A_{28}	0.0236	0.0075	0.3214	0.4000
A_{29}	0.0289	0.0075	0.3750	0.5000
A_{30}	0.1185	0.0528	0.0629	0.4000
A_{31}	0.0131	0.4801	0.2338	0.1250
A_{32}	0.0119	0.4818	0.2727	0.1333
A_{33}	0.0880	0.3914	0.0458	0.1667
A_{34}	0.0131	0.0000	0.1586	0.1053
A_{35}	0.0119	0.0000	0.1846	0.1111
A_{36}	0.0880	0.0000	0.0311	0.1429

When using the COPRAS method, normalization was made by applying the algorithm in equation (7) after all values, including $x_{ij} < 0$, $\forall -\infty \leq x_{ij} \leq \infty$, were transformed into positive values.

All weighted and normalized values from calculations employing SAW, MEW and COPRAS methods are presented in Tables 7, 8 and 9 for each separate building.

This table also presents optimality criteria calculated for each of the methods using equations (8), (9) and (10) respectively. These criteria show the weight of each alternative. The highest value means the best alternative.

According to the results of the SAW method, the most preferred solution to the renovation method for all (B1), (B2) and (B3) buildings is additional thermal insulation in the attic. On the contrary, according to MEW and COPRAS methods, the most preferred alternative for all three buildings is the adjustment of a heating system and valves in thermostats.

Table 7. Weighted-normalized decision-making matrix and optimal results of building 1 (B1)

Name of action		Weighted-normalized matrix of SAW method				Weighted-normalized matrix of MEW method				Weighted-normalized matrix of COPRAS method				SAW	MEW	COPRAS
		x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4			
Attic insulation	A_1	0.0016	0.0004	0.0748	0.1343	0.6375	0.2159	0.8425	0.5550	0.0004	0.0035	0.0004	0.0063	**0.2110**	0.0643	0.0335
Facade insulation	A_4	0.0072	0.0018	0.0027	0.0241	0.7490	0.3156	0.4542	0.2476	0.0017	0.0035	0.0097	0.0350	0.0358	0.0266	0.0087
Windows and doors	A_7	0.0074	0.0008	0.0024	0.0086	0.7510	0.3156	0.4919	0.3051	0.0017	0.0035	0.0063	0.0224	0.0191	0.0356	0.0122
Tightening windows and doors	A_{10}	0.0013	0.0000	0.0470	0.0306	0.6233	0.0000	0.8573	0.5550	0.0003	0.0035	0.0003	0.0063	0.0788	0.0000	0.0336
Recovery 60%	A_{13}	0.0059	0.0447	0.0059	0.0126	0.7335	0.8136	0.5821	0.3657	0.0014	0.0049	0.0026	0.0152	0.0691	0.1271	0.0162
Recovery 80%	A_{16}	0.0079	0.0447	0.0064	0.0195	0.7569	0.8136	0.5909	0.4488	0.0019	0.0049	0.0024	0.0099	0.0785	0.1633	0.0215
Heat pump	A_{19}	0.0152	0.0239	0.0026	0.0076	0.8113	0.7021	0.4979	0.2893	0.0036	0.0122	0.0059	0.0251	0.0493	0.0820	0.0113
Adjust heat system	A_{22}	0.0025	0.0008	0.0917	0.1070	0.6697	0.3156	0.9716	1.0000	0.0006	0.0035	0.0002	0.0018	**0.2020**	**0.2054**	**0.0623**
Individual metering tap water	A_{25}	0.0011	0.0000	0.0344	0.0195	0.6148	0.0000	0.8088	0.4488	0.0003	0.0035	0.0004	0.0099	0.0550	0.0000	0.0246
Individual metering heat	A_{28}	0.0025	0.0008	0.0344	0.0428	0.6697	0.3156	0.8088	0.6501	0.0006	0.0035	0.0004	0.0045	0.0805	0.1111	0.0406
Solar collectors	A_{31}	0.0014	0.0514	0.0250	0.0134	0.6288	0.8410	0.7620	0.3763	0.0003	0.0038	0.0006	0.0144	0.0912	0.1516	0.0183
Water taps	A_{34}	0.0014	0.0000	0.0170	0.0113	0.6288	0.0000	0.7087	0.3471	0.0003	0.0035	0.0009	0.0170	0.0296	0.0000	0.0160

Table 8. Weighted-normalized decision-making matrix and optimal results of building 2 (B2

Name of action		Weighted-normalized matrix of SAW method				Weighted-normalized matrix of MEW method				Weighted-normalized matrix of COPRAS method				SAW	MEW	COPRAS
		x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4			
Attic insulation	A_2	0.0030	0.0007	0.0449	0.1567	0.6827	0.2542	0.7658	0.5967	0.0007	0.0035	0.0006	0.0054	0.2053	0.0793	0.0362
Facade insulation	A_5	0.0073	0.0002	0.0038	0.0336	0.7503	0.1833	0.4837	0.2893	0.0017	0.0035	0.0069	0.0251	0.0449	0.0192	0.0112
Windows and doors	A_8	0.0088	0.0008	0.0024	0.0097	0.7650	0.3156	0.4905	0.3240	0.0021	0.0035	0.0064	0.0197	0.0217	0.0384	0.0134
Tightening windows and doors	A_{11}	0.0018	0.0000	0.0546	0.0428	0.6446	0.0000	0.8819	0.6501	0.0004	0.0035	0.0003	0.0045	0.0992	0.0000	0.0411
Recovery 60%	A_{14}	0.0070	0.0486	0.0110	0.0268	0.7471	0.8302	0.6536	0.5212	0.0017	0.0042	0.0014	0.0072	0.0934	0.2113	0.0280
Recovery 80%	A_{17}	0.0094	0.0486	0.0110	0.0428	0.7705	0.8302	0.6536	0.6501	0.0022	0.0042	0.0014	0.0045	0.1118	0.2718	0.0355
Heat pump	A_{20}	0.0185	0.0212	0.0027	0.0093	0.8287	0.6826	0.5010	0.3173	0.0043	0.0142	0.0057	0.0206	0.0517	0.0899	0.0126
Adjust heat system	A_{23}	0.0031	0.0008	0.1070	0.1070	0.6844	0.3156	1.0000	1.0000	0.0007	0.0035	0.0001	0.0018	0.2179	0.2160	0.0627
Individual metering tap water	A_{26}	0.0009	0.0000	0.0401	0.0178	0.6002	0.0000	0.8324	0.4308	0.0002	0.0035	0.0004	0.0108	0.0589	0.0000	0.0232
Individual metering heat	A_{29}	0.0031	0.0008	0.0401	0.0535	0.6844	0.3156	0.8324	0.7220	0.0007	0.0035	0.0004	0.0036	0.0975	0.1298	0.0458
Solar collectors	A_{32}	0.0013	0.0516	0.0292	0.0143	0.6223	0.8417	0.7843	0.3879	0.0003	0.0038	0.0005	0.0135	0.0963	0.1594	0.0193
Water taps	A_{35}	0.0013	0.0000	0.0198	0.0119	0.6223	0.0000	0.7291	0.3560	0.0003	0.0035	0.0008	0.0161	0.0329	0.0000	0.0168

Table 9. Weighted- normalized decision-making matrix and optimal results of building 3 (B3)

Name of action		Weighted-normalized matrix of SAW method				Weighted-normalized matrix of MEW method				Weighted-normalized matrix of COPRAS method				SAW	MEW	COPRAS
		x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4			
Attic insulation	A_3	0.0210	0.0067	0.0055	0.1343	0.8399	0.4312	0.5179	0.5550	0.0049	0.0034	0.0048	0.0063	**0.1675**	0.1041	0.0281
Facade insulation	A_6	0.0185	0.0067	0.0009	0.0204	0.8288	0.4312	0.3690	0.2291	0.0044	0.0034	0.0295	0.0413	0.0465	0.0302	0.0089
Windows and doors	A_9	0.0415	0.0069	0.0004	0.0079	0.9037	0.5230	0.3498	0.2943	0.0098	0.0033	0.0393	0.0242	0.0567	0.0487	0.0148
Tightening windows and doors	A_{12}	0.0078	0.0008	0.0108	0.0428	0.7561	0.3156	0.6511	0.6501	0.0018	0.0035	0.0014	0.0045	0.0622	0.1010	0.0377
Recovery 60%	A_{15}	0.0372	0.0230	0.0021	0.0238	0.8930	0.6957	0.4812	0.4932	0.0087	0.0129	0.0071	0.0081	0.0861	0.1474	0.0207
Recovery 80%	A_{18}	0.0501	0.0231	0.0021	0.0428	0.9221	0.6964	0.4812	0.6501	0.0118	0.0128	0.0071	0.0045	0.1182	0.2009	0.0256
Heat pump	A_{21}	0.1070	0.0057	0.0005	0.0119	1.0000	0.0000	0.0000	0.0000	0.0252	0.0629	0.0283	0.0161	0.1251	0.0000	0.0283
Adjust heat system	A_{24}	0.0127	0.0057	0.0179	0.1070	0.7960	0.4996	0.7159	1.0000	0.0030	0.0033	0.0009	0.0018	**0.1433**	**0.2847**	**0.0593**
Individual metering tap water	A_{27}	0.0067	0.0000	0.0067	0.0214	0.7437	0.0000	0.5962	0.4693	0.0016	0.0035	0.0023	0.0090	0.0349	0.0000	0.0244
Individual metering heat	A_{30}	0.0127	0.0057	0.0067	0.0428	0.7960	0.4996	0.5962	0.6501	0.0030	0.0033	0.0023	0.0045	0.0679	0.1541	0.0364
Solar collectors	A_{33}	0.0094	0.0419	0.0049	0.0178	0.7710	0.8014	0.5617	0.4308	0.0022	0.0055	0.0031	0.0108	0.0740	0.1495	0.0196
Water taps	A_{36}	0.0094	0.0000	0.0033	0.0153	0.7710	0.0000	0.5225	0.4007	0.0022	0.0035	0.0046	0.0126	0.0280	0.0000	0.0185

According to the MEW method, the obtained results also showed that the owners would prefer heat recovery from ventilation air with regenerative heat exchangers having 80% efficiency. When comparing all results, we can state that the most preferred measure for the renovation of this group of facility owners is the adjustment of a heating system and valves in the thermostat, because MEW and COPRAS disclosed the best results of preferences for this alternative; the application of the SAW method also shows good results of this renovation measure.

For all buildings and decision making methods, the adjustment of heating systems come high up on the list. In this case, one of the reasons might be short pay back-time which is prioritized by the building owners. It is, however, doubtful if this action really should be considered a renovation method while it is more likely to be ordinary upkeep. Tightening windows and doors and changing water taps into more efficient ones should also be included in normal upkeep. Individual metering for heating and hot tap water will certainly influence energy consumption of the building; however, it is something more related to the user's behaviour than to the properties of the building.

Additional thermal insulation in the attic and on facades, the installation of new windows, doors and equipment for heat recovery using heat exchangers or a heat pump are, however, real investments that reduce the use of energy in buildings in different ways.

When limiting views on alternatives that are not only ordinary upkeep, the results will be slightly different. Calculations will remain valid because in any selection of alternatives those with the highest values are the ones that should be chosen.

If one method for heat recovery is selected, the other two will not be applicable. Thus, in that case, only thermal insulation in the attic or on facades as well as new doors and windows will remain as alternatives.

For all three buildings and for almost all decision methods, "heat recovery of 80%" falls out as the best or second best option with regard to the preferences of building owners.

Additional thermal insulation in the attic always falls out with high priority in the limited selection of remaining alternatives when one method of heat recovery is chosen.

Rather short pay back-times characterize the actions that come first when multi criteria decision methods are applied to the data obtained. Nevertheless, we should not forget that these calculations are made according to the owner's opinion.

This result could mean that there is not enough information and motivation for the dwellers about energy savings. They only care about having a short payback period. Information or subsidiaries (or even taxation) could motivate building owners to take care more about energy savings and Global Warming Potential (GWP) situation in the world.

If a decision maker wants to know the least desirable solution, s/he has to refer to the results of COPRAS and SAW methods, because a general action of the MEW method is multiplication, and this is the case why some of the results equal to 0. However, it does not mean that this result is the worst.

These calculations can be helpful from some other aspects because when using them we can make choices not only between all alternatives in the matrix but also between two or three of the alternatives. If the building owner has a limited amount of money, these calculations can help him with choosing the most attractive presented solution.

For example, if the owner wants to add more thermal insulation and s/he is hesitant when choosing between the alternatives to put it in the attic or on facades, we can state that the most preferable solution is additional thermal insulation in the attic (see Tables 7, 8 and 9; the results of alternatives 1 to 6).

If the owner is going to either change his/her windows and doors or tight around the windows, we can accept that the best solution, according to the opinion of the owner, is tightening around the window (see Tables 7, 8 and 9; the results of alternatives 7 to 12).

Moreover, if the owner decided to renovate the ventilation system, choosing between solutions to recover 60% of heat from exhaust air with plate heat exchangers, 80% of heat from exhaust air with regenerative heat exchangers and by using a heat pump to take heat from exhaust air, the result shows that the best alternative is the regenerative heat exchanger giving recovery of 80% of heat from exhaust air (see Tables 7, 8 and 9; the results of alternatives 13 to 21).

4. Conclusions

1. Three building apartments built in residential areas in the '50s, '60s and '70s were selected. For each of these buildings, a series of energy calculations have been done using E-norm energy calculation software. The best alternatives for all above introduced building apartments were selected using multi-criteria decision making methods.

2. This determination was made according to recommendations produced by Simple Additive Weighting (SAW), Multiplicative Exponential Weighting (MEW) and Complex Proportion Assessment (COPRAS) methods. The obtained results point to the usefulness of combining different multi-criteria decision making methods, because in this case, the decision maker can compare results that are not always the same.

3. According to the achieved results, the best alternative was adjusting the heating system and valves in thermostats. The cost of adjusting the heating system is supposed to give savings because the average temperature in the building can decrease in 1 °C. This alternative was chosen because of the short payback period, which, as the results showed, was very important for building owners.

4. When limiting choices for the above mentioned renovation actions that cannot be considered to be normal, upkeep heat recovery from ventilation air and additional thermal insulation in the attic fall out to be quite attractive for building owners.

5. The opinion of the decision maker has a big impact on the results. In this case study, building owners gave a lot of votes for the payback period. Thus, the obtained results also showed the best solution like an alternative to the shortest payback period.

6. The received results show it is necessary to inform and motivate the dwellers about the energy consumption problem and help them with becoming more motivated about their needs with reference to the Global Worming problem in the world.

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SAVININKŲ TEIKIAMI PRIORITETAI PASTATŲ ATNAUJINIMO PRIEMONĖMS: DAUGIAKRITERINIŲ SPRENDIMO PRIĖMIMO METODŲ TAIKYMO PAVYZDYS

M. Medineckienė, F. Björk

S a n t r a u k a

Straipsnyje išnagrinėti trys tipiniai švedų daugiabučiai, pastatyti 6-ajame, 7-ajame ir 8-ajame dešimtmečiais. Buvo atlikti kiekvieno šių pastatų atnaujinimo priemonių skaičiavimai, įvertinantys efektyvumą ir investavimo apimtis, kuriomis siekiama didinti energijos vartojimo efektyvumą. Taikant daugiakriterinius sprendimo priėmimo metodus, tokius kaip *Simple Additive Weighting* (SAW), *Multiplicative Exponential Weighting* (MEW) and *COmplex PRoportion ASsessment* (COPRAS), buvo tiriami savininkų teikiami prioritetai pastatų atnaujinimo priemonėms. Tyrimas buvo atliekamas vertinant keturis pastatų kriterijus: energija, vartojama centralizuotam šildymui, ir elektros energija, investicijų sąnaudos ir atsipirkimo laikotarpis. Atlikus skaičiavimus buvo nustatyta, kad didelę įtaką tyrimo rezultatams daro savininkų nuomonė. Šie savininkai daugiausia dėmesio skyrė trumpam renovacijos priemonių atsipirkimo laikotarpiui. Viena patrauklesnių renovacijos priemonių yra papildoma šilumos izoliacija palėpėje ir šilumos gavimas iš ištraukiamo oro.

Reikšminiai žodžiai: energinis efektyvumas, rangavimas, stambiaplokščiai namai, atnaujinimas, SAW, MEW, COPRAS, AHP metodai, MCDM.

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