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MCDA ASSESSMENT OF MULTILAYERED ENVELOPES. CASE OF ADDITIVE AND MULTIPLICATIVE CONVOLUTION

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Abstract

The Multi-Criteria Decision Analysis (MCDA)has been proposed for the choice of the "best" multilayered assembly in terms of its thermal resistance, mass and cost assessment. In the general case, the multilayered assembly can consist of the bearing layer and the insulation layer. In some cases (autoclaved aerated concrete (AAC), hempcrete, etc.) it could be enough to erect the external wall of the building without any additional layer of insulator which meets the National Code's thermal resistance requirements. As a basic consideration of current research as a bearing layer such materials were taken – clay brick, AAC and hempcrete. As an insulator, two types of material were taken – Rockwool and expanded polystyrene (EPS) as commonly used in Ukraine. As key influence criteria were taken into consideration as follows: the u-value of the envelope W/m²K, the cost of the wall material, UAH/m² and the mass of the wall kg/m². All possible combinations of single-layered and multilayered assemblies from the initiated types of materials, which met Ukrainian thermal resistance requirements have been created and the calculus of the proposed criteria was performed. The analysis of obtained result revealed that the "best" case of multilayered assembly depends on the method which was applied for the MCDA assessment. Thus, in the case of additive criteria convolution, the "best" alternative is AAC with EPS insulation as well in the case of multiplication convolution. All the above-mentioned highlights that the engineer on site or decision-making person should avoid the temptation to choose the wrong "best" alternative in the erecting of MCDA-evaluated multilayered walls. As well the additional factors of influence should be taken into consideration in terms of compared criteria and assessment methods respectively.

Keywords: MCDA, wall assemblies, the best alternative

Introduction

The plenty of building materials and construction techniques in modern construction practice grab the attention of multi-criteria decision analysis (MCDA) methods [1, 2]. The problem of the "best" choice from a wide variety of current energy-efficient envelopes present on the building market is still the challenge for the developer who intends to make a dwelling which has compliance with the sustainable development idea and not only wants to have financial benefits [3, 4]. On the other hand, the comparison is always a compromise between the alternatives, and, generally is quite complicated to choose the" best" alternative. The word best is taken in quotes here, because in real life with a multicriteria evaluation of alternatives, the optimal alternative could only be chosen by Pareto set [5]. The decision maker must perform a comprehensive analysis of the solution that dominates others and offers the best overall compromise [5]. As criteria which easily could be calculated in the present paper there were taken three ones: the thermal transmittance (*u-value*), mass *m* and the cost of materials of the wall assembly *Q*.

The calculation of the thermal transmittance (*u-value*) proceeded according to the formula [6]:

$$u = \frac{1}{R_{tot}} = \frac{1}{\frac{1}{\alpha_{int}} + \sum\frac{\delta i}{\lambda_i} + \frac{1}{\alpha_{ext}}} \quad (1)$$

where δ_i – the width of the *i*-th material;
R_{tot} – the total thermal resistance of the assembly;
where α_{int} is the heat transfer coefficient of the internal surface of the wall, α_{int} = 23 (W/m²×K) [6];
α_{int} is the heat transfer coefficient of the external surface of the wall, α_{int} = 8.7 (W/m²×K) [6];

The main idea of the present research is to find out the "best" alternative from the set of possible combinations. The objective function would be the minimum *u-value*, with minimum weight and cost of assembly, which meets the National thermal resistance requirement, R = 3.3 W/m^2×K for the first temperature zone of Ukraine [7].

In the present research, initial materials parameters were taken as follows in table 1.

Table 1 The thermo-physical, physical and economic characteristics of materials

Material	Wall width range b, mm	Cost of material Q, UAH/m^3	Material density ρ, kg/m^3	Thermal conductivity of the material λ, (W/m×K)
Clay brickwork	250, 380, 510, 630	3830	1300	0.58
AAC	200, 300, 375	3350	300	0.08
Hempcrete	200, 300, 400, 500	4500	350	0.08
Rockwool	50,100, 120, 150, 200	1668	120	0.064
EPS	50,100, 120, 150, 200	3800	35	0.045

For the proposed materials all possible combinations of bearing layer and insulation layer as well as single-layered bearing constructions were performed.

Results of the research

The steps of the current research were realized as follows:

1. To obtain the total number of possible combinations of single-layered bearing walls and multi-layered (two-layered assemblies of bearing layer + insulation layer).
2. To filter the alternatives that don't match the National thermal resistance requirements.
3. From the filtered list of combinations perform the calculus of key criteria: u-value, cost and mass of 1m^2 of assembly.
4. The goal function is minimizing the total sum of normalized key criteria – the "best" case is the lowest value, "worst" case is the highest one.
5. To compare the additive and multiplicative convolution analysis results.

The mathematical equations for the normalization of obtained results are calculated as follows:

If the desirable criteria have a characteristic of "higher is better"

$$x_{ijnorm} = \frac{x_{ij} - x_{i\min}}{x_{i\max} - x_{i\min}} \tag{2}$$

where $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$, n is the number of assemblies that meet the R_{tot} requirement, m is the number of compared criteria; x_{imin}, x_{imax} - the minimal and the maximal value of the i-th assembly for j-th criteria respectively; x_{ijnorm} – the normalized value of x_{ij}.

If the desirable criteria have a characteristic of "lower is better"

$$x_{ijnorm} = \frac{x_{i\max} - x_{ij}}{x_{i\max} - x_{i\min}} \tag{3}$$

The cross-sectional compositions of considered wall types are shown below in Fig. 1.

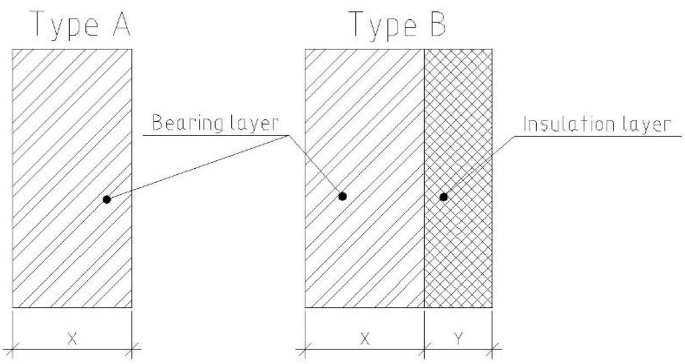

Fig.1 Cross-section of the researched assemblies

Mathematical realization of the abovementioned algorithm was performed in Python 3.9 [8]. Total calculus of all possible combinations, namely 121, has shown, that only 93 have met the National thermal resistance requirement (see Table 2).

As it was mentioned, the "best" alternative in the present research is one which has the maximum value of goal function with the additive convolution of criteria.

Table 2 List of assemblies that meet National thermal resistance requirement

Assembly Number	Goal function criteria			Assembly Number	Goal function criteria		
	mass, kg/m^2	cost, UAH/m^2	u-value, W/m^2×K		mass, kg/m^2	cost, UAH/m^2	u-value, W/m^2×K
1	90	990	0.256	48	97	1750	0.120
2	112.5	1237.5	0.206	49	114.25	1427.5	0.168
3	105	1350	0.256	50	116	1617.5	0.141
4	140	1800	0.194	51	116.7	1693.5	0.133
5	175	2250	0.156	52	117.75	1807.5	0.122
6	374	1291.1	0.270	53	119.5	1997.5	0.108
7	556	1789	0.254	54	76	983.4	0.291
8	746	2241.8	0.294	55	82	1066.8	0.237
9	752	2325.2	0.239	56	84.4	1100.16	0.221
10	900	2663.1	0.279	57	88	1150.2	0.200
11	906	2746.5	0.229	58	94	1233.6	0.173
12	355.25	1527.5	0.255	59	111	1433.4	0.213
13	357	1717.5	0.199	60	117	1516.8	0.183
14	536.2	1911.4	0.287	61	119.4	1550.16	0.173
15	537.25	2025.4	0.241	62	123	1600.2	0.160
16	539	2215.4	0.190	63	129	1683.6	0.142
17	732.2	2447.6	0.269	64	146	1883.4	0.168
18	733.25	2561.6	0.228	65	152	1966.8	0.149
19	735	2751.6	0.182	66	154.4	2000.16	0.142
20	885.5	2792.9	0.288	67	158	2050.2	0.133
21	886.2	2868.9	0.256	68	164	2133.6	0.121
22	887.25	2982.9	0.218	69	181	2333.4	0.139
23	889	3172.9	0.176	70	187	2416.8	0.125
24	66	743.4	0.291	71	189.4	2450.16	0.121
25	72	826.8	0.237	72	193	2500.2	0.114
26	74.4	860.16	0.221	73	199	2583.6	0.105
27	78	910.2	0.200	74	71.75	1090	0.265
28	84	993.6	0.173	75	73.5	1280	0.205
29	96	1073.4	0.213	76	74.2	1356	0.188
30	102	1156.8	0.183	77	75.25	1470	0.167
31	104.4	1190.16	0.173	78	77	1660	0.141
32	108	1240.2	0.160	79	106.75	1540	0.199
33	114	1323.6	0.142	80	108.5	1730	0.163
34	118.5	1320.9	0.178	81	109.2	1806	0.152
35	124.5	1404.3	0.156	82	110.25	1920	0.138
36	126.9	1437.66	0.149	83	112	2110	0.120
37	130.5	1487.7	0.139	84	141.75	1990	0.159
38	136.5	1571.1	0.125	85	143.5	2180	0.136
39	61.75	850	0.265	86	144.2	2256	0.128
40	63.5	1040	0.205	87	145.25	2370	0.118
41	64.2	1116	0.188	88	147	2560	0.104
42	65.25	1230	0.167	89	176.75	2440	0.133
43	67	1420	0.141	90	178.5	2630	0.116
44	91.75	1180	0.199	91	179.2	2706	0.110
45	93.5	1370	0.163	92	180.25	2820	0.103
46	94.2	1446	0.152	93	182	3010	0.092
47	95.25	1560	0.138				

After the list of assemblies which are appropriate to the thermal resistance requirements, the normalization was performed according to formula (3) and formula (4). Thus, the "best" alternative is assembly number 43, which is AAC with 200 mm of EPS insulation and got the maximum value of 2.474 points after being normalized. In the case of the multiplication convolution technique application (without criteria weight's assignment, the best result is the same in terms of the proposed criteria.

If other essential criteria of the assembly thermal behaviour will be added to the calculation of the goal function, the gained traction of the best alternative is different. The present research is only a small part of the general, comprehensive research, which is aimed at the optimal wall assembly definition in terms of the thermal performance criteria. Further influence factor analysis should be conducted to reveal the possible correlation of considered criteria to include only the most sufficient ones into consideration for such MCDA issue of choosing the best wall alternative.

Conclusions

According to the proposed materials, criteria and method of evaluation, the conducted analysis of the "best" alternative revealed that the "best" assembly consist of a 200 mm AAC bearing layer which is insulated by 200 mm of EPS. Both the additive and multiplicative convolution methods gave the same result. It is obvious that the best choice of the multilayered wall in general is always a compromise decision, which should be made after the comprehensive result analysis of different MCDA techniques for verifying the obtained evaluations.

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