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THERMAL PERFORMANCE ASSESSMENT OF WALL ASSEMBLIES: CRITERIA IMPORTANCE THEORY AND AHP APPROACH

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ABSTRACT

The problem of the "best" choice in terms of the ecological, durable, cheap and energy-effective material of envelope construction has been considered in the paper. For the numerical assessment of the thermal performance, the Multi-Criteria Decision Analysis (MCDA) techniques as Analytical Hierarchy Process (AHP) and Criteria Importance Theory (CIT) were used. There were proposed eight types of wall assemblies from a natural material, namely: hempcrete, adobe, strawbale panel, earthbag, cordwood, structured insulated panel (SIP) (plywood + ecofiber), hempcrete + straw and compositional building thermo-block. As an objective function for the search of the best alternative the integral index was proposed which consist of thermo-physical and economic criteria. As the thermo-physical criteria component of the index were taken the u-value of the envelope W/m^{2}K, the dimensionless decrement factor of the envelope f and the internal areal heat capacity of the envelope k1, kJ/m^{2}K according to ISO 13786:2017. As economic criteria of the integral index, the authors proposed the cost of the wall material Q, UAH/m^2 and the mass of the wall m, kg/m^2. The analysis of the conducted research has shown, that from the one hand there is no absolute "leader" in the ranking of the wall assemblies according to the proposed criteria and considered type of MCDA technique, but from the other hand by comparison of the results, there were revealed that the top three alternatives in both AHP and CIT technique are walls of "B", "D" and "E" type with different point order, achieved in each MCDA calculation technique.

KEYWORDS

Thermal performance, Multi-criteria assessment, Subjective method, Multi-layered wall assembly.

INTRODUCTION

The modern level of the damage from anthropogenic footprint activity and global climate changes caused by such influence born the essential demand to minimize hypothetical damage in short-term and long-term perspectives.

As one of the key strategies presented nowadays, there is a shortening of the building energy consumption's sector as one of the major energy consumers. According to Xiaodong, Dai and Junjie [1] building energy use consumes over 40% of total primary energy in the U.S. and E.U.

Meanwhile, the problem of the "best" choice for the ecological, durable, cheap and energy-effective material of envelope construction from the one hand and compromise/optimal type from the other hand is a big challenge, even today[2]. That is why such state of the art motivates the researchers to use modern tools of the multi-criteria decision analysis (MCDA) methods in attempts to do make this choice. A huge amount of MCDA techniques for energy efficiency problems in general, and in the field of sustainable energy decision-making (DM) particularly have been proposed in the last two decades [3]-[6].

All MCDA techniques, in general, could be conditionally divided into two groups –subjective weighting methods and objective weighting ones [3].

In the present paper, has been conducted the comparison between two subjective weighting techniques of MCDA applying to the problem of thermal performance assessment of multi-layered wall assemblies by the most used in DM practice – the Analytical Hierarchy Process (AHP) method [7] and the method based on the Criteria Importance Theory (CIT) [8]-[14].

The MCDA process involves different criteria to be compared comprehensively. The variety of influence factors that could be taken into consideration in the DM problem model of thermal assessment are very broad and what is the "correct" one in the decision-making process is still a big issue [2], [17]. The most used factors in the specific research of energy supply, sustainable and energy-efficient problems are technical, economic, environmental, social ones [3]. The economic criterion usually is one of the main ones when DM chooses an appropriate alternative. As F. Stazi has shown [2] "… the internal areal heat capacity *k*1 and decrement factor *f* are the main influencers of the summer behaviour, while the steady-state thermal transmittance *U* and the decrement factor *f* of the winter performance". On the other hand, the economic criterion is considered as the most important in terms of problem decision making.

Besides, the influence factors should be simply calculable and have interpretable value. For this reason, the integral index for the thermal performance assessment of multi-layered assemblies, which combines several multidimensional key criteria, was proposed.

As the thermo-physical criteria component of the index were taken the u-value of the envelope W/m^{2}K (steady-state criterion), the dimensionless decrement factor of the envelope f and the internal areal heat capacity of the envelope *k*1, kJ/m^{2}K (unsteady-state criteria according to ISO 13786:2017 [19]. As economic criteria of the integral index, the authors proposed the cost of the wall material, UAH/m^2 and the mass of the wall kg/m^2 (as an indirect parameter of the building fundaments cost). All of the above-mentioned criteria could be calculated simply and could be a good marker for thermal performance assessment of specific envelope type.

TASK OF THE RESEARCH

To assess the thermal performance of multi-layered wall assemblies from natural materials in terms of integral index values by two independent methods – AHP and CIT, which applied for the assessment procedure.

MATERIALS AND RESEARCH METHODOLOGY

This study proposed three thermal performance parameters, which are a key influencer of summer and winter behaviour, according to the research of F. Stazi [2]. The parameters are the u-value of the envelope W/m^{2}K, the decrement factor f of the envelope and the internal areal heat capacity of the envelope k1, kJ/m^{2}K. The above-mentioned criteria have been calculated in "Thermal mass calculation tool according to EN ISO 13786" [18], by assuming the values of internal heat transfer resistance as well as external heat transfer resistance according to Ukrainian National Building Standard DSTU B.V. 2.6-189:2013 [20] and Ukrainian Building Code DBN V. 2.6-31: 2016 [21]. The cost of the 1m^2 of the wall assembly's material Q, UAH/m^2 was calculated by multiplying the width of the wall in meter to the specific material cost UAH/m^3 as an up to dated median one from Ukrainian marketplaces. The mass of the wall m, kg/m^2 have been calculated by multiplying the width of the wall in meter to the material's density ρ, kg/m^3 respectively.

To assess and compare the results of thermal performance by proposed techniques, the eight types of wall assemblies from eco-friendly materials were taken into consideration in this research after data analyzing [2], [17], [20], [23], [24]. Represented wall types are Wall type "A" (Hempcrete), Wall type "B" (Adobe), Wall type "C" (Strawbale panel), Wall type "D" (Earthbag), Wall type "E" (Cordwood), Wall type "F" (SIP plywood + ecofiber), Wall type "G" (Hempcrete + straw) and Wall type "H" (Compositional building thermo-block [22]) (see Figure 1).

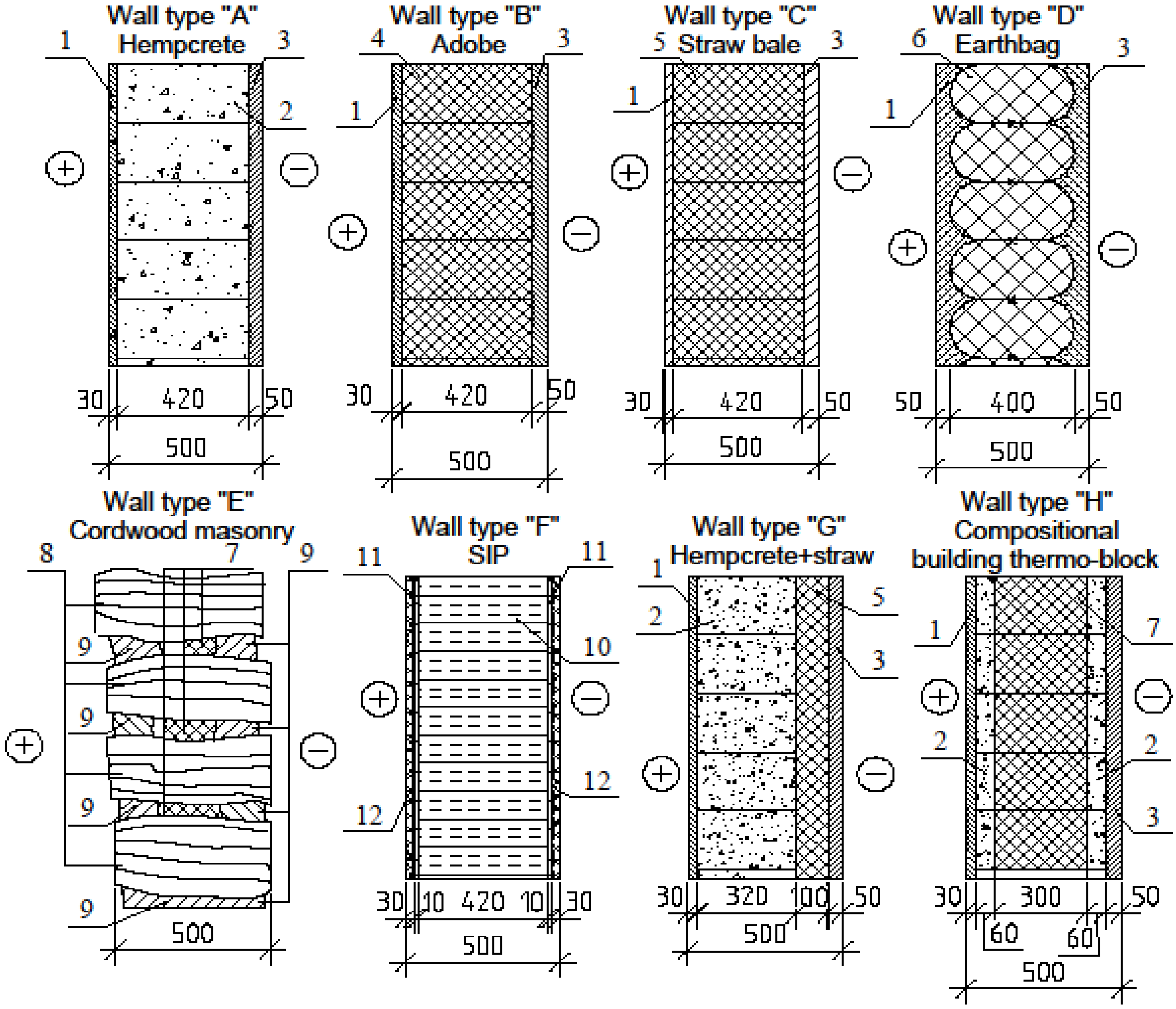

Fig. 1 – Cross-section of investigated wall assemblies
(1 - internal lime-sand plaster, 2 - hempcrete, 3 - external lime-sand plaster, 4 - adobe, 5 - strawbale panel, 6 - earthbag, 7 - chopped straw as an insulator, 8 - cordwood, 9 - lime-sand plaster, 10 - eco fibre, 11 - lime-sand plaster, 12 - plywood)

All of the dimensions in Figure 1 are in mm. Under the accepted dimensions of wall assemblies (Figure 1) and their thermo-physical and economic parameters, general input data for further assessment is calculated in Table 1.

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Tab. 1 - The thermo-physical, physical and economic characteristics of the wall assemblies

Assembly type	*Q*	*m*	*u-value*	*f*	*k*1
Wall "A"	1146.00	275.00	0.15	0.0067	45.61
Wall "B"	358.50	716.00	0.77	0.0586	59.46
Wall "C"	1154.40	161.60	0.16	0.2336	41.77
Wall "D"	360.00	880.00	1.51	0.1219	68.53
Wall "E"*	810.00	272.00	0.24	0.0506	64.20
Wall "F"	918.00	131.10	0.14	0.2225	57.00
Wall "G"	1148.00	248.00	0.15	0.0119	45.59
Wall "H"	1152.00	194.00	0.16	0.1394	46.77

* All calculations for this wall design are made by taking the following assumptions into account:

the ratio of the volumes of clay V_{cl} and wood V_w of the outer and inner layer is 1/3 to 2/3,
wood chocks are from the pine (the fibres parallel to the heat flow), clay – sand mortar,
specific heat capacity of the cordwood mixed layer construction is found as

$$c_{cordwood} = (c_w \cdot V_w + c_{cl} \cdot V_{cl}) / (V_w + V_{cl}), \tag{1}$$

where c_w, c_{cl} – the specific heat capacity of the wood and the clay respectively,
V_w, V_{cl} – the volume of the wood and the clay respectively.

Other parameters as well as the density and the average thermal conductivity are found by the same dependencies.

AHP

The methodology of creating a hierarchical model for the thermal performance assessment in terms of the integral index is listed below. By pairwise comparisons [7] the advantages of each influence factors have been weighed on the value of the integral index of thermal performance. The AHP methodology calculation steps of the integral index are as follows.

Step 1. Each of the influence factors is a matrix, which is filled in a next way [7] as in Equation 2:

$$A = \begin{bmatrix} 1 & \frac{r_1}{r_2} & \frac{r_1}{r_3} \ldots \frac{r_1}{r_n} \\ \frac{r_2}{r_1} & 1 & \frac{r_2}{r_3} \ldots \frac{r_2}{r_n} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots \\ \frac{r_n}{r_1} & \frac{r_n}{r_2} & \frac{r_n}{r_3} \ldots 1 \end{bmatrix}, \tag{2}$$

where r_1, r_2, r_3, r_n are the corresponding values of the priorities of the evaluated parameters of the matrix, which characterize the values of five included criteria (the internal areal heat capacity *k*1, the decrement factor *f*, the u-value (thermal transmittance), the mass of the wall and costs of the wall materials).

By the known line elements of the matrix in Equation (2), elements of all other lines have been calculated. The arbitrary element $a_{jj} = r_i / r_j$, with known elements $a_{kj} = r_k / r_j$, k, and $i = 1,...,n$. of a certain n-th line, is calculated as $a_{jj} = a_{kj} / a_{ki}$, and $j,k = 1,...,n$.

Step 2. The priority vector of each i-th parameter m_i as the average geometric value of each line of matrix elements divided by the sum of all mean geometric values for the estimated parameters is calculated as it presents in Equation (3) below through [7].

$$\sqrt[n]{1 \times \frac{r_1}{r_2} \times \frac{r_1}{r_3} \times ... \times \frac{r_1}{r_n}} = m_1. \quad (3)$$

Step 3. The vector of priorities of the first, second, n-th line of the matrix x_1, x_2, ... x_n should be obtained in Equation (4) as

$$m_1 / (m_1 + m_2 + ... + m_n) = x_1, \quad (4)$$

The components of the eigenvector and the vector of priorities for other m_n lines are determined in the same way.

Step 4. As the set of relative weights of the alternative, we use the components of our eigenvector $\lambda_{\max}$ corresponding to the maximal characteristic number. Moreover, to evaluate the coherence of the matrix, the condition must be fulfilled. As an indicator of the consistency degree of A matrix' elements, the consistency index (CI) is calculated as [7]:

$$CI = \left(\lambda_{\max} - n\right) / n - 1, \quad (5)$$

where n is the rank of the matrix.

Step 5. To evaluate the consistency degree adequacy, the consistency ratio (CR) is used and it is calculated as

$$CR = CI / \text{MRCI}, \quad (6)$$

where $MRCI$ – mean random consistency index, is the average value that is randomly calculated for a large number of pairwise matrices that were generated on a fundamental scale [7].

The resulting vector of the priorities of a certain matrix of pairwise comparisons is considered acceptable if the CR does not exceed the coherence threshold in the range of 0.10 ... 0.20 [7].

Step 6. The resulting value V of j-th wall's assembly alternative integrated index in form of normalized additive composition [7] is calculated in the following manner:

$$V = \sum_{i=1}^{n} a_i \cdot w_i, \quad (7)$$

where a_i – i-th criterion priority, $i = 1,...,n$ $n = 5$; w_i – priority vector of alternatives by the i-th criterion.

THEORY OF CRITERIA IMPORTANCE

The Criteria Importance Theory (CIT) was developed in the USSR in the 1970s by prof. Podinovski V.V. [8], [9] and continues to evolve [10], [14]. The theory is based on formal definitions of the relative importance of criteria, which makes it possible to work with incomplete and inaccurate information about the preferences of the decision-maker (DM).

In this paper, we use a simple ordering of criteria according to their importance and consider two types of criteria scales. Based on this information about the preferences of the DM, conclusions will be drawn about which wall alternatives should be excluded from the candidates for the final choice. Employing the CIT methods, it is possible to obtain a quantitative assessment of the value function of each alternative, specifying quantitative information about the importance of criteria and their scale [11]. However, this is a more laborious process, therefore, in this article, to estimate the value function, we use the approach proposed in [12].

The CIT methodology calculation steps are as follows.

Step 1. The individual criteria $C_1,...,C_n$ must be reduced to a homogeneous form with a general scale $Z = \{1,...,q\}$, which can only be ordinal. In the problem under consideration, could be used a 10-point scale: the higher the score, the more valuable (useful, preferable) the values of the criterion for the DM. Each alternative of the compared can be associated with its vector estimate from the set Z^n.

Step 2. The preferences of the DM are modelled using the non-strict preference relation R on the set Z^n: the notation yRz means that the vector estimate y is no less preferable than z. The relation R is reflexive and transitive; it defines the relations of indifference I and (strict) preference P: $yIz \Leftrightarrow yRz$ and zRy, $yPz \Leftrightarrow yRz$ and $\neg\ zRy$.

Since the DM's preferences increase along the criteria scale Z, the Pareto relation is defined on the set of vector estimates Z^n as follows:

$$yR^{\varnothing}z \ \Leftrightarrow y_i > z_i, i = 1, \ \ldots\ , n. \tag{8}$$

Alternatives with vector estimates dominated by $P^{\varnothing}$ should be excluded from the contenders for the best solution.

Step 3. The qualitative importance information Ω is introduced according to basic definitions [10]. Denote y^{ij}, the vector obtained from vector $y = (y_1,\ \ldots\ ,\ y_n)$, by permuting its components y_i and y_j.

Definition 1. The statement "criteria C_i and C_j are equally important", which is denoted as $i : j$ means that any two vector estimates y and y^{ij} are indifferent.

Definition 2. The statement "criterion C_i is more important than criterion C_j", which is denoted as $i \succ j$, means that any vector estimate y, such that $y_i > y_j$, is preferred to y^{ij}.

Complete and consistent information Ω allows us to order criteria following their importance. For notational simplicity, let the criteria be numbered in order of nonincreasing importance in the following manner:

$$1 : \ \ldots : \ n_1 \text{ f } \ n_1+1 : \ \ldots : \ n_1+n_2 \text{ f } \ \ldots \text{ f } \ n_1+\ldots n_{l-1}+1 : \ \ldots : \ n, \tag{9}$$

where l is the number of groups of equally important criteria, so that $n_1 + n_2 + \ldots + n_l = n.$

To fulfil the relation $yR^{\Omega}z$ for arbitrary vector estimates y and z from Z^n, there must be a sequence of vector estimates $u^1, u^2, \ldots, u^L$ from Z^n, for which $yR^{\omega 1}u^1R^{\omega 2}u^2 \ \ldots\ R^{\omega L}u^LR^{\omega L}z.$ Here, the relations $R^{\omega k}$ can be the relations $P^{i \succ j}$, $I^{i \succ j}$ or $P^{\varnothing}.$ Such sequences are called explanatory chains [10]. Alternatives with vector estimates dominated by P^{Ω} should be excluded from the contenders for the best solution.

Step 4. In [12] the DM's preferences are represented in the form of numerical parameters $\alpha = (\alpha_1, \ldots, \alpha_n)$ and $v = (v_1, \ldots, v_q)$, and imprecise information about these preferences determines the sets A and V of potentially possible values of these parameters. Then, to estimate the value function of an alternative with vector estimate y, the centroid values of the parameters on the resulting sets A and V are taken as follows:

$$F(y) = \sum\nolimits_{i=1}^{n} \alpha_i^c v_{y_i}^c. \tag{10}$$

The centroid coefficients of the criteria importance are calculated by the following formulas [12]:

$$\alpha_i^c = \frac{1}{l} \sum\nolimits_{j=k}^{l} \frac{1}{\sum\nolimits_{m=1}^{j} n_m} \tag{11}$$

where $k = 1, \ldots, l$ is the criteria group number, and i is the number of any criterion belonging to this group.

For the ordinal scale of criteria:

$$v_1 < v_2 < \ldots < v_q \tag{12}$$

Therefore, the centroid values of the scale estimates are:

$$\nu_s^c = \frac{s-1}{q-1},\ s = 1,...,\ q. \quad (13)$$

Step 5. In addition to Equation 12, we can assume the rate of growth of preferences along with the criteria scale Z. In practice, the law of diminishing marginal utility is often fulfilled, which means:

$$\nu_2 - \nu_1 > \nu_3 - \nu_2 > ... > \nu_q - \nu_{q-1}. \quad (14)$$

We denote such Information by Δ. The information $\Omega\Delta$ does not contradict but clarifies the information Ω. The preference relations $P^{\varnothing}$ and P^{Ω} are supplemented by the relation $P^{\Omega\Delta}$, the definition and method of calculation of which are described in [12], [14]. Alternatives with vector estimates dominated by $P^{\Omega\Delta}$ should be excluded from the contenders for the best solution.

Step 6. To estimate the value function as it described in Equation 10 based on information $\Omega\Delta$ we can use centroid coefficients of the criteria importance, as described in Equation 11. Wherein, the centroid values of the scale estimates calculated as follows [12]:

$$\nu_1^c = 0; \nu_{s+1}^c = \nu_s^c + d_s^c,\ s = 1,\ ...\ ,\ q-1, \quad (15)$$

Where:

$$d_s^c = \frac{1}{q-1}\sum_{j=s}^{q-1}\frac{1}{j},\ s = 1,\ ...\ ,\ q-1. \quad (16)$$

NUMERICAL MODELLING OF THE THERMAL PERFORMANCE ASSESSMENT IN TERMS OF THE INTEGRAL INDEX' CRITERIA

AHP. To provide the research according to AHP methodology, the three-level hierarchy structure was proposed. As an objective function was chosen the integral index of thermal performance of the multi-layered envelopes from natural materials, which is presented in Figure 2.

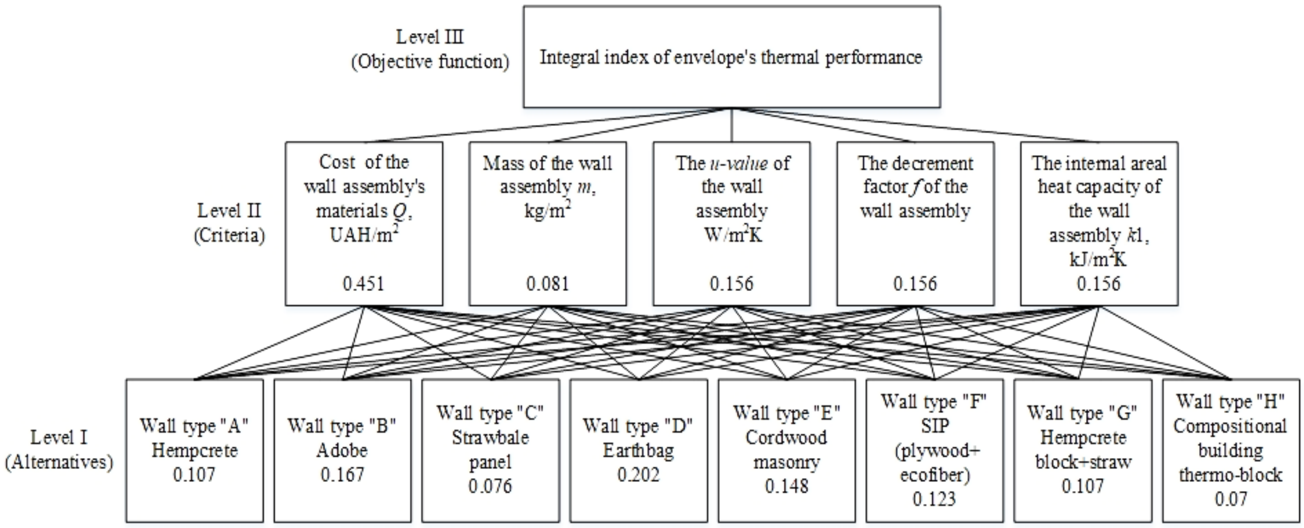

Fig. 2 – Three-level hierarchy for assessment of the envelope's thermal performance

The procedure of calculating according to the AHP methodology is commonly known and widely used [3], [4], [7], [15], [17].

Therefore, the authors allowed themselves to give only the resulting values of the alternatives criteria weights (numbers in rectangles in Figure 2, according to the step-by-step description of this apparatus [7] methodology presented in Equations (1)-(7).

For better visualization of results, the chart bar graph is presented in Figure 3.

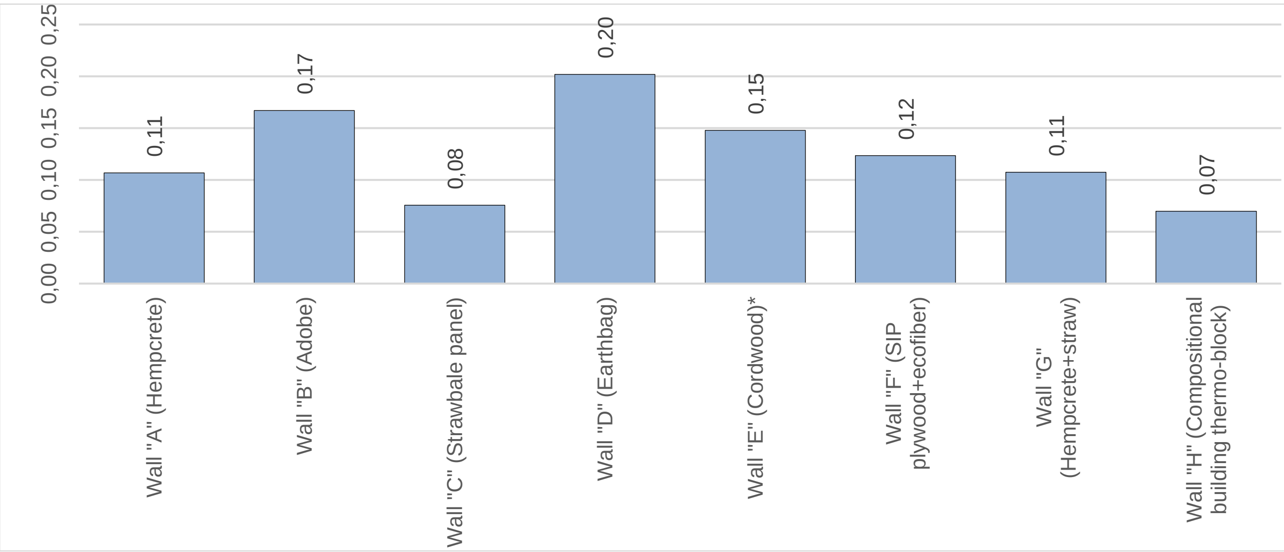

Fig. 3 – Thermal performance assessment of envelopes in terms of integral index' criterion according to AHP

According to Figure 3, the best multi-layered alternative in terms of integral index of thermal performance is the Wall "D" (Earthbag). Such an unobvious solution could be explained by the significant weight of the *Q* criterion (0.451 from Fig. 2). However, from terms of thermal performance parameters, this wall has a contradictive rank (the worst *u-value* from the eights alternatives – 1.51 W/m^{2}K, the average value of the decrement factor *f* = 0.1219 and the best value of the internal areal heat capacity *k*1= 68.53 kJ/m^{2}K) according to the Table 1.

Cost criterion *Q* has a dominating influence on the best alternative, according to the obtained evaluation of proposed criteria by AHP assessment methodology. Therefore, the second place of the ranking took the Adobe Wall "B" with 0.167 points. The worst solutions got Wall "C" from strawbale panel (0.076 points and Wall "H" from Compositional building thermo-block (0.07) which have excellent thermal performance parameters according to Table 1.

CIT. To make the criteria homogeneous, the simplest method is used, which involves a uniform change in preferences along with the numerical scales of the criteria. First, the linear normalization of the criteria values to the interval from 0 to 1 is used. Then, the value of the numerical values of the criteria is transformed to the 10-point scale. For the minimized criteria, the correspondence is used: [1; 0.9] → 1 point, (0.9; 0.8] → 2 points, …, (0.1; 0] → 10 points. For the maximized criteria, the opposite correspondence is used: [0; 0.1] → 1 point, (0.1; 0.2] → 2 points, ..., (0.9; 1] → 10 points.

Table 2 contains the calculated values of the criteria according to normalizing and transforming to the 10-point scale CIT methodology [12].

Tab. 2 - Normalized and 10-point scale values of the criteria

Assembly type	Normalized criteria					Normalized criteria transformed to the 10-point scale				
	Q	*m*	*u-value*	*f*	*k*1	*Q*	*m*	*u-value*	*f*	*k*1
Wall "A"	0.989	0.192	0.010	0.003	0.144	1	9	10	10	2
Wall "B"	0.001	0.780	0.458	0.231	0.661	10	3	6	8	7
Wall "C"	0.999	0.040	0.018	0.998	0.000	1	10	10	1	1
Wall "D"	0.003	0.999	0.999	0.508	1.000	10	1	1	5	10
Wall "E"	0.567	0.188	0.079	0.196	0.838	5	9	10	9	9
Wall "F"	0.703	0.000	0.001	0.950	0.569	3	10	10	1	6
Wall "G"	0.991	0.156	0.012	0.026	0.143	1	9	10	10	2
Wall "H"	0.996	0.084	0.016	0.585	0.187	1	10	10	5	2

Using the Pareto relation

According to the Pareto relation $R^{\varnothing}$ according to Equation 8 defined on the set of vector estimates Z^5, we can immediately distinguish the Wall "C", which is dominated by the Walls "F" and "H": $y(\text{"F"})P^{\varnothing}y(\text{"C"})$, $y(\text{"H"})P^{\varnothing}y(\text{"C"})$. This means that the Wall "C" cannot claim to be the best.

Consideration of the criteria relative importance

Let us order the criteria by importance in accordance with the Equation 1 and Equation 2. The qualitative criteria importance information $\Omega = \{1 \succ 3 \sim 4 \sim 5 \succ 2\}$ corresponds to the preferences used in the AHP method. After introducing the preference relation R^{Ω} the Wall "H" has become dominated (Table 3). For example, the relation $y(\text{"A"})P^{\Omega}y(\text{"H"})$ can be checked by constructing the following explanatory chain:

$$y(\text{"A"}) = (1,\underline{9},10,\underline{10},2)P^{4\succ 2}(1,10,10,9,2)P^{\varnothing}(1,10,10,5,2) = y(\text{"H"}).$$

Tab. 3 - Applying the Pareto domination for the alternatives

Assembly type	*Q*	*m*	*u-value*	*f*	*k*1	Is dominated by P^{Ω}
Wall "A"	1	9	10	10	2	
Wall "B"	10	3	6	8	7	
Wall "C"	1	10	10	1	1	"A", "D", "F", "G","H"
Wall "D"	10	1	1	5	10	
Wall "E"	5	9	10	9	9	
Wall "F"	3	10	10	1	6	
Wall "G"	1	9	10	10	2	
Wall "H"	1	10	10	5	2	"A", "F", "G"

At this step, we can calculate the centroid values of the preference parameters and evaluate the value functions by Equation 10 of the alternatives on their basis. According to Equation 9, the information $\Omega = \{1\text{f}\ 3:\ 4:\ 5\text{f}\ 2\}$ breaks down the criteria into l = 3 groups of equally important criteria, where m_1 = 1, m_2 = 3, m_3 = 1. Therefore, we can calculate the centroid coefficients of the criteria importance using the Equation 11:

$$\alpha_1^c = \frac{1}{3}\left(1 + \frac{1}{4} + \frac{1}{5}\right) = 0.483\,,$$

$$\alpha_3^c = \alpha_4^c = \alpha_5^c = \frac{1}{3}\left(\frac{1}{4} + \frac{1}{5}\right) = 0.15\,,$$

$$\alpha_2^c = \frac{1}{3}\left(\frac{1}{5}\right) = 0.067\,.$$

For the ordinal scale of criteria (see Equation 11), the centroid values of the scale estimates by Equation (13) are as follows:

$$v_1^c = 0\,,\ v_2^c = 1/9\,,\ v_3^c = 2/9\,,\ \ldots,\ v_{10}^c = 1\,.$$

Thermal performance assessment of envelopes in terms of integral index' criterion according to CIT is calculated according to Equation 10-13 and DASS software [15] and presented in Table 4.

Tab. 4 - Thermal performance assessment of envelopes according to the relative importance criteria by CIT

Assembly type	Integral index of envelope's thermal performance
Wall "A"	0.376
Wall "B"	0.798
Wall "C"	0.217
Wall "D"	0.700
Wall "E"	0.691
Wall "F"	0.407
Wall "G"	0.376
Wall "H"	0.300

It should be noted, that obtained results in Table 4 of the centroid values of the integral index of envelope's thermal performance are quite close to the ones of the AHP method. Thus, the first criterion is about 3 times more important than the third (and the fourth with the fifth), and the third is about 2 times more important than the second is. So, in this problem, we can limit ourselves to qualitative information Ω and not try to refine it quantitatively. Nevertheless, at the next step, when refining the scale, it is possible to reduce the number of non-dominated alternatives to two.

Clarification of information on the scale of criteria

Initially, it was only assumed that preferences grow along the scale of criteria as in Equation 12. Additionally, we can assume about the rate of growth of preferences along the criteria scale Z. In practice, the law of diminishing marginal utility is often fulfilled as in Equation 14. We denote such Information by Δ. The information $\Omega\Delta$ does not contradict, but clarifies the information Ω. The preference relations $P^{\varnothing}$ and P^{Ω} are supplemented by the relation $P^{\Omega\Delta}$, the definition and method of calculation of which are described in [12],[14]. As a result, there are only two non-dominated Walls

“B” and “E” (Table 5). Also, value functions 10 were evaluated in DASS software in accordance with Equation 12, 15, 16.

Tab. 5 - Thermal performance assessment of envelopes according to the clarified information about criteria scale by CIT

Assembly type	Is dominated by $P^{\Omega\Delta}$	Integral index of envelope’s thermal performance
Wall "A"	“B”, “E”	0.413
Wall "B"		0.929
Wall "C"	“A”, “B”, “D”, “E”, “F”, “G”, “H”	0.217
Wall "D"	“B”	0.750
Wall "E"		0.887
Wall "F"	“B”, “E”	0.596
Wall "G"	“B”, “E”	0.413
Wall "H"	“A”, “B”, “E”, “F”, “G”	0.380

Obtained results in Table 5 reveals that the best alternative of the multi-layered envelope is the Wall "B" from adobe - 0.929 points, the second place is taken by Wall "E" from cordwood masonry with 0.887 points. This fact could be explained by a comprehensive consideration of both thermal performance and economic criteria.

From the data presented in Table 1, it could be seen, that both of the “best” assembly type alternatives has a moderate level of performance in the terms of their thermal parameters (*u-value*, *f* and *k*1). Furthermore, Wall "B" has a *u-value* of 0.77 W/m^{2}K, which is significantly higher than all envelope types, except for Wall "D" with 1.51 W/m^{2}K with approximately the same order of the decrement factor *f*. In other words, even without taking into consideration the economic criteria, Wall "E" is considered the best alternative, according to the scale range in Table 3.

Applying the CIT method of MCDA assessment of integral index of envelope’s thermal performance, which comprehensively considers assumed relative importance criteria and clarified information about criteria scale (Table 4, 5) the bar chart, is given in Figure 4.

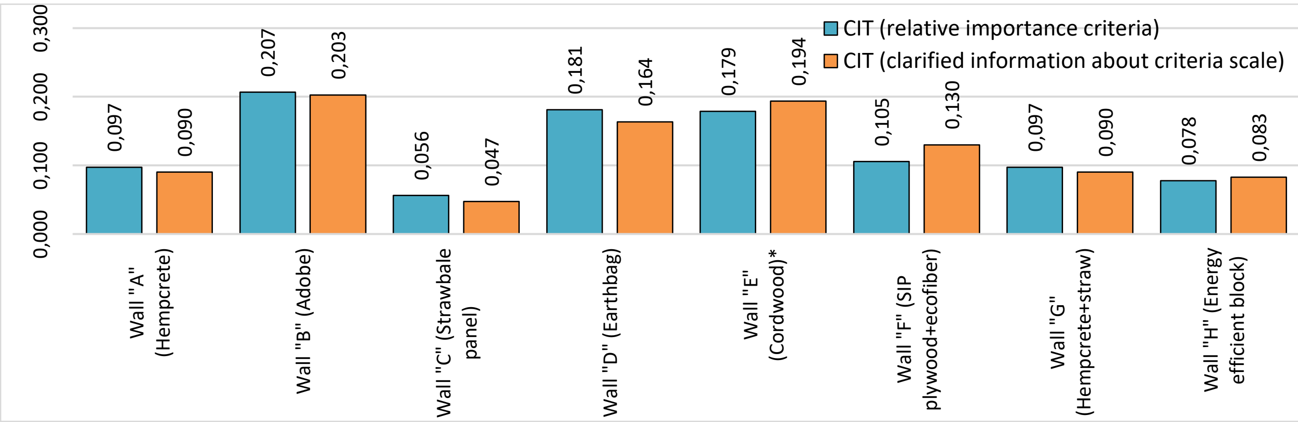

Fig. 4 – Thermal performance assessment of envelopes in terms of integral index’ criterion according to CIT

Presented comparison in Figure 4 shown that both CIT attitudes as relative importance criteria and clarified information about criteria scale demonstrate the same ranking priority of alternatives.

More interest has the comparison of the result by AHP and CIT technique, which is given in Figure 5.

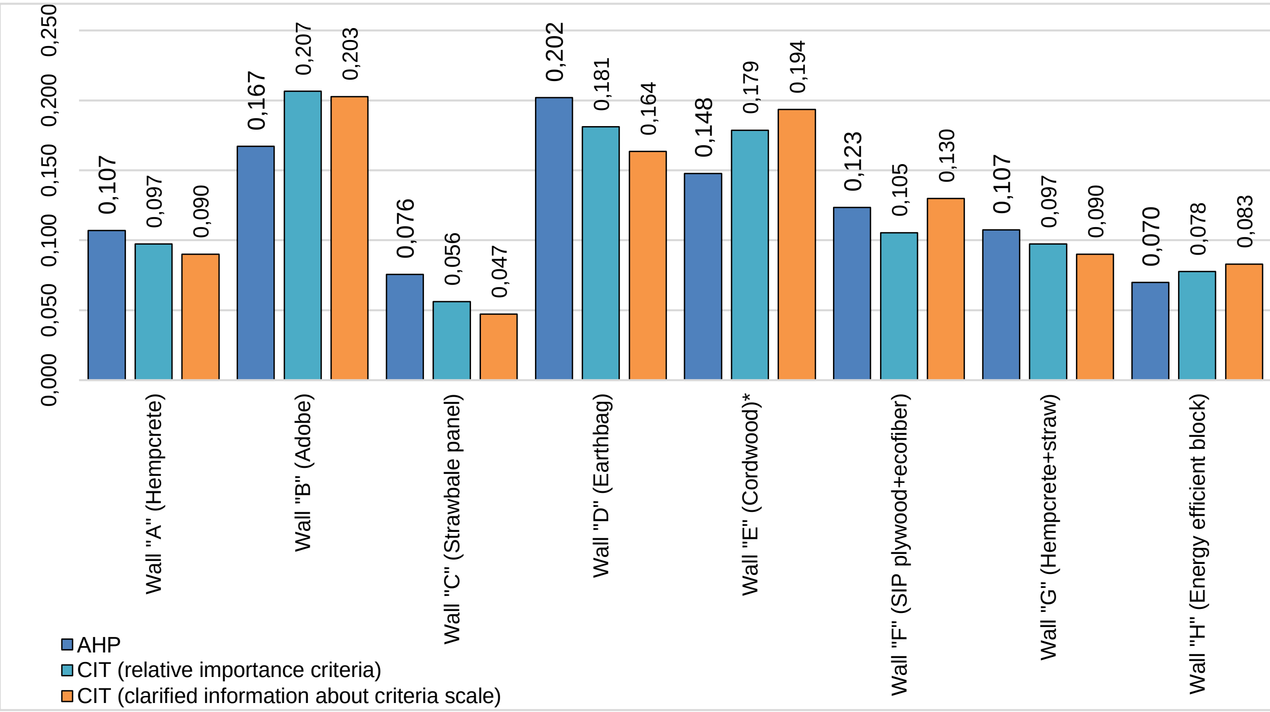

Fig. 5 – Thermal performance assessment of envelopes in terms of integral index' criterion according to AHP and CIT

DISCUSSION OF THE RESULTS

From Figure 5 it could be noted that there is no absolute "leader" in terms of the integral index of thermal performance assessment according to the above-mentioned techniques. Thus, the wall type "D" takes first place by the AHP with 0.202 points, but it is only the third, according to CIT (0.164 points by the clarified information about the criteria scale). However, if decision-maker needs to know the top three envelopes alternatives (from the highest evaluation to the smaller one, it would be: wall "D" – wall "B" – wall "E" by AHP, wall "B" – wall "D" – wall "E" by CIT (relative importance criteria scale) and wall "B" – wall "E" – wall "D" by CIT (clarified information about criteria scale). The final decision by the decision-maker should be made after comprehensive consideration of additional data, which can be determinative in terms of assessed criteria.

Despite a ranking difference of wall assemblies by AHP and CIT techniques, the top three assemblies of each technique are the same variants. It means that both Wall type "D" or "B" could not be the best ones, but they could be with high probability. Also, it could be considered, that any additional information about the assemblies, which does not correlate with assumed criteria should be taken into consideration in each MCDA technique.

To summarize the above-mentioned, it could be noted, that at least several MCDA techniques should be applied for verifying the best alternative of a multi-layered wall assembly in terms of thermal performance assessment by proposed criteria. As a reference point in decision making according to the result analysis by different MCDA techniques the correlation coefficient could be taken as a yardstick – the more result's correlation is obtained by different methods, the more trustable are results.

CONCLUSIONS

The analysis of the conducted research has shown that:

there is no absolute “leader” in the ranking of the wall assemblies according to the proposed criteria and MCDA technique,

there is no universal “right” method or technique for MCDA assessment, but it could be considered, that the more comprehensive and objective analysis of real, simply measurable and interpretable influence factors, with no correlation between each other, will be conducted the more correct and trustable will result,

non-contradictional, balanced decision making according to the results, obtained by different MCDA techniques should be considered as a reasonable one if the correlation between results, obtained by different MCDA techniques for all alternatives in terms of proposed criteria, has maximized values,

the common top three alternatives in both AHP and CIT technique are wall “B”, “D” and “E” type with different values of integral index’ criterion, achieved in each MCDA technique calculation,

with the high level of probability, it could be noted that the best wall assembly according to the proposed criteria of integral index’ criterion would be Wall “D” (Earthbag) or/and Wall “B” (Adobe), but in this case, the *u-value* must meet Building code requirement and have to be reviewed.

As a further step of the investigations, authors see in supplementing of the results by Building Energy Modelling (BEM) of the case study house. Also, at the next step, the optimization model for the best wall assembly could be designed, which should meet the requirement of minimum value of the decrement factor *f*, *u-value* of the wall, mass *m* and cost *Q* and maximum value of the internal areal heat capacity *k*1.

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