The implementation of simple additive weighting method in choosing wall bricks

Sử dụng phương pháp SAW khi lựa chọn gạch xây tường

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ABSTRACT

Wall bricks are a fundamental component of wall structures that provide coverage and separation between indoor and outdoor spaces. In addition to their covering function, wall bricks also serve as waterproofing, soundproofing, and heat insulation agents. Nowadays, wall bricks come in a wide variety of types, sizes, strengths, and materials, each with its own unique production process. Bricks are typically divided into two primary categories: fired bricks, which include burnt solid bricks and fired hollow bricks, and unburnt bricks, which include autoclaved aerated concrete (AAC) blocks, silicate blocks, and lightweight concrete blocks. Wall bricks have a significant impact on various factors such as static load, soundproofing, heat insulation, cost, construction time, and structural solutions, including foundation depth. Therefore, it is essential to evaluate and select wall bricks from an economic-technical standpoint. There are many multi-objective decision-making methods available to choose an option that satisfies given criteria. The article introduces the results of calculation, evaluation, and selection of wall bricks using the Simple Additive Weighting (SAW) method with a set of criteria: static load, total thermal resistance, construction time, price, and environmental friendliness. Calculation and comparison results show that autoclaved aerated concrete (ACC) blocks are a good choice due to their outstanding advantages such as light weight, low thermal conductivity, and environmental friendliness. They are most suitable for the goal of reducing power consumption for the building's ventilation and air conditioning system and using energy effectively.

Keywords: Multi criteria analysis; method SAW; solid clay bricks; hollow clay bricks; concrete brick; lightweight concrete - autoclaved aerated concrete bricks (ACC); Calcium silicate bricks.

TÓM TẮT

Gạch xây tường là một trong những vật liệu chính tạo nên kết cấu tường bao che và ngăn cách các khu vực không gian trong ngoài nhà. Ngoài chức năng bao che, gạch xây tường còn đảm nhận nhiệm vụ chống thấm, cách âm, cách nhiệt... Hiện nay, gạch xây tường rất đa dạng, phong phú về chủng loại, kích thước, cường độ, nguồn gốc vật liệu và quy trình sản xuất...Tuy nhiên, chúng thường được phân loại thành hai nhóm chính bao gồm: gạch nung và gạch không nung (một số loại gạch phổ biến trên thị trường hiện nay: gạch đặc nung, gạch rỗng nung, gạch bê tông khí chưng áp (AAC), gạch silicat và gạch bê tông nhẹ). Việc lựa chọn gạch xây tường làm kết cấu bao che cho công trình sẽ ảnh hưởng trực tiếp đến các yếu tố như là: tải trọng tĩnh, khả năng cách âm, cách nhiệt, giá thành, thời gian thi công, giải pháp kết cấu và chiều sâu móng...Do đó cần phải tính toán, đánh giá và lựa chọn gạch xây tường trên quan điểm kinh tế - kỹ thuật. Hiện nay, có rất nhiều phương pháp ra quyết định đa mục tiêu để lựa chọn một phương án thỏa mãn các tiêu chí cho trước. Bài báo giới thiệu kết quả tính toán, đánh giá và lựa chọn gạch xây tường theo phương pháp SAW với bộ tiêu chí: tải trọng tĩnh, tổng nhiệt trở, thời gian thi công, giá thành và tính thân thiện với môi trường. Kết quả tính toán và so sánh cho thấy, gạch bê tông khí chưng áp (ACC) với các ưu điểm nổi bật như là trọng lượng nhẹ, hệ số dẫn nhiệt thấp, thân thiện với môi trường đã trở thành phương án lựa chọn tốt nhất, phù hợp nhất với mục tiêu giảm lượng tiêu thụ điện năng cho hệ thống thông gió - điều hòa của công trình và sử dụng năng lượng tiết kiệm hiệu quả.

Từ khóa: Phân tích đa tiêu chí; phương pháp SAW; gạch đất sét nung; gạch rỗng đất sét nung; gạch bê tông; bê tông nhẹ - gạch bê tông khí chưng áp (ACC); Gạch silicat canxi.

1. INTRODUCTION

Geographic location of Vietnam has a lot of potential such as: solar radiation energy, wind energy and ocean wave energy. In which there is abundant source of radiant energy with approximately between 1,500 and 1,600 kWh/m²/year and total sunshine hours from 4,300 to 4,500 hours/year [1,2]. This is a huge

energy resource for producing solar power and natural lighting. However, large solar radiation penetrates the house structure to cause the increasing energy consumption for the air-conditioning and ventilation system. Therefore, the requirement green design in energy-saving buildings is an urgent issue in Vietnam and also a trend in the world in the context of climate change and exhausted fossil resources [3 - 5]. The application of wall bricks with low thermal conductivity in buildings and constructions is one of the solutions to reduce energy consumption for the air conditioning-ventilation system, to creat a microclimate, and to improve the quality of life of people in buildings [6].

Bricks are among the primary materials used in construction, alongside sand, stone, cement, and steel. They have been widely used in the construction process from the past to the present. The history of building bricks' development and productive technologies is associated with building material production technologies. Previously, there were few kinds of bricks such as burnt clay, silicate, and concrete bricks but now bricks with new materials and production technology have been introduced: Autoclaved Aerated Cement Blocks (ACC), lightweight concrete bricks, ... with outstanding advantages such as: light weight, good insulation, and friendly environment. Research on masonry and bricks has been conducted worldwide, including in Vietnam. Some of the notable researchers in this field are F. Christy, F. Wu, G. Li, S.B. Singh, Хамдамова Ш.Ш., Адилходжаев А.И., B.D. Ewing, Hoang Minh Duc, and Dao Trieu Kim Cuong. However, recent research has focused primarily on issues such as chemical composition, aggregate gradation, brick production technology, and brick and block strength [7 - 13].

Bricks chose for wall construction affects directly the load, quality, structural durability, construction time, and insulation ability of the building's outer walls. Therefore, the process of evaluating and selecting them should be considered from an economic - technical point of view with the following criteria: static load, total thermal resistance (R0), construction time, cost and eco-friendly, etc.

Currently, there are many methods to solve this problem as follows: Simple Additive Weighting (SAW); TOPSIS method; electre I and electre II methods, etc. [14–20]. The SAW is one of the most well-known and widely used methods for multi-attribute decision making. The basic concept of the SAW method is to find the number of weighted performance ratings for each alternative on all attributes.

In this paper, the SAW method is proposed to solve the problem of selecting bricks for building walls in tropical countries (Vietnam, Myanmar, Indonesia, Thailand, etc. The next part of the paper is arranged as follows: part 2, the principles of SAW are presented briefly; part 3, presents an empirical application of the proposed approach to brick selection for building in Vietnam; and the last part, discuss the research results.

2. RESEARCH METHOD

Simple Additive Weighting method is a method that is widely used in making decisions that have a lot of attributes (loads, heat resistance, cost, time, etc), so that by applying the method of SAW on decision support systems the completion of various decision-making processes can be easily. The basic concept SAW method is to find the sum of the weighted performance rating for each alternative on all attributes.

The usefulness of the basic concept of the SAW method is to find the number of weighted performance ratings for each alternative on all attributes. Some other advatages of the method are: Using the weight to take the importance of each indicator into account, quantifying indicators expressed in words (qualitative) by scoring.

However, the disadvantage of this method is the subjectivity of choosing the comparative criteria and the experts' opinion about the importance of the indicators, leading to the important indicators being easily obscured.

Using the SAW method to choose wall bricks is followed these steps [21,22]:

Step 1 - Select criteria for comparison namely C_i (The criteria must be independent of each other).

Step 2 - Define the objective function to compare (maximum or min value).

Step 3 - Determine the direction of each indicator and co-orient the indicators that are not in the same direction as the objective function (using the inverse).

Step 4 - Determine the dimensionless value of each criterion according to the following formula:

$$P_{ij} = \frac{C_{ij}}{\sum_{j=1}^{n} C_{ij}} \times 100 \tag{1}$$

P_{ij} - dimensionless value of the criterion i of the option j;
n – number of options, j=1, 2,…, n;
C_{ij} – value of the criterion i of the option j;

Step 5 - determine the importance of each criterion in the comparison.

The use of the Warkentin square matrix and the evaluation of criteria on a scale, the use of the L_{ij} coefficient is the importance of the BK_j criterion according to the rules:

- level is not important when $BK_i << BK_j$ $L_{ij} = 1$;
- level of less importance when $BK_i < BK_j$ $L_{ij} = 2$;
- importance levels are equal when $BK_i = BK_j$ $L_{ij} = 3$;
- the level of importance when $BK_i > BK_j$ $L_{ij} = 4$;
- level is very important when $BK_i >> BK_j$ $L_{ij} = 5$.

With the following rules:
$L_{ij} = L_{ji} = 3$, for which i = j
$L_{ij} + L_{ji} = 5$, for which i ≠ j

Determination of the weight coefficient of each criterion and control of the results by the formula (2 ÷ 4).

$$W_i = \frac{L_{ij}}{\sum L_{ij}} \tag{2}$$

$$3.m^2 = \sum L_{ij} \tag{3}$$

$$\sum W_i = 1 \tag{4}$$

m – number of initial criteria for comparison
L_{ij} - level of importance of the criterion i of the option j
W_i - weight coefficients of the criterion i in all criteria

Step 6 - determination of the dimensionless value for each option using the formula (5):

$$V_j = \sum_{i=1}^{m} P_{ij}.W_i \tag{5}$$

V_j - dimensionless value of the option j
P_{ij} - dimensionless value of the criterion i of the option j;
W_i - weight coefficients of the criterion i in all criteria.

Step 7 - analysis and rating of options by dimensionless values with a comparative goal at the beginning (maximum or minimum).

3. DATA ANALYSIS

To evaluate, compare and choose bricks for building exterior walls,

it is necessary to consider and pay attention to the following quantities:

* Technical requirements of bricks: Geometric sizes and specific gravity of bricks are determined according to the following standards: TVCN 1451-1998; TCVN 1450-2009; TCVN 6477-2011; TCVN 7959-2011.

* **Cost and construction time:** Determined on the basis of construction norms promulgated by Ministry of Construction according to Circular 12/2021/TT-BXD dated August 31, 2021 with the calculation assumption: two workers, build straight wall with thickness ≤ 33 cm, height ≤ 6 m.

* **Total heat resistance:** Determined according to QCVN 09:2017/BXD National technical regulation on energy efficient construction works.

- The total heat resistance (R_0) of the outer wall structure is determined as follows:

$$R_0 = \frac{1}{h_N} + \sum_{i=1}^{n} \frac{b_i}{\lambda_i} + R_a + \frac{1}{h_T} \quad (m^2.K/W)$$

+ h_N, h_T - the heat exchange coefficient of the outer and inner surfaces of the enclosure structure (PL 3 - QCVN:09/2017/BXD), W/(m^2.K);

+ b_i - thickness of material layer i, m;

+ λ_i - the thermal conductivity coefficient of the material layer ith in the enclosure (PL 2 - QCVN:09/2017/BXD), W/m.K;

+ n - number of material layers in cover structure;

+ R_a - thermal resistance of the air layer inside the enclosure structure (PL 4 - QCVN:09/2017/BXD), m^2.K/W.

* **Environmental friendliness:** To assess the level of environmental impacts during the brick production process is based on the production process, the source of input materials and the amount of toxic waste discharged into the environment. The production process of fired solid bricks and hollow bricks 60 involves the use of clay as the primary raw material, which is fired under high temperatures to create the final products. This process has a negative impact on the environment, including increased CO_2 emissions, high energy consumption, and reduced agricultural land. In contrast, the remaining types of bricks are produced using an unburned process, which results in almost no CO_2 emissions (the main cause of the greenhouse effect). This production process is considered to be the most environmentally friendly. The procedure for assessing the technical and economic parameters of the alternatives is executed in the following manner: data inputs are collected, total thermal resistance is computed, unit price and construction time for 1 m^3 under identical conditions are determined. The evaluation of the environmentally friendly criteria is based on the positive or negative effects on the environment (qualitative). The results of the calculations are presented in Table 1.

Table 1. Economic and technical criteria of the options [23-27]

No	Criterion	Unit	Burnt clay solid brick	Burnt clay hollow 60 brick	AAC block	Silicate block	Light weight concrete block
1	Specific weight	kg/m³	1,800	1,350	600	1,900	1,400
2	Wall width	m	0.22	0.22	0.2	0.22	0.22
3	Area density	kg/m²	450	351	174	472	362
4	Thermal conductivity coefficient (λ)	W/m.K	0.81	0.58	0.153	0.87	0.58
5	Total Heat Resistance (Ro)	m².K/W	0.474	0.582	1.509	0.455	0.582
6	Unit price	VND/m³	2,378,247	2,229,599	2,636,724	2,006,627	2,155,275
7	Labor	Man-hour	1.63	1.63	1.13	1.63	1.63
8	Construction time	hours	6.52	6.52	4.52	6.52	6.52
9	Eco-friendly		medium	medium	good	good	good

Step 1.

Select criteria for comparison and evaluation.

Table 2 presents the analysis and selection of 5 indicators in the whole set of indicators (Table 1), in which the properties of the criteria are independent of each other. The value of indicator 5th (Eco-friendly) is determined by the method of analysis and assessment of specialized experts.

Table 2. Economic and technical criteria chosen for comparision

No	Criterion	Unit	Burnt clay solid brick (Opt. 1)	Burnt clay hollow 60 brick (Opt. 2)	AAC block (Opt. 3)	Silicate block (Opt. 4)	Light weight concrete block (Opt. 5)
1	Specific weight	kg/m³	1,800	1,350	600	1,900	1,400
2	Total Heat Resistance (Ro)	m².K/W	0.474	0.582	1.509	0.455	0.582
3	Unit price	VND/m³	2,378,247	2,229,599	2,636,724	2,006,627	2,155,275
4	Construction time	hours	6.52	6.52	4.52	6.52	6.52
5	Eco-friendly		medium	medium	good	good	good

Step 2. *Determining functional targets for comparison.*

The choice of minimum values is a functional purpose for comparison.

Step 3. *Determination of the direction of each criterion and translation of the criteria not corresponding to the direction of the functional goal.*

It can be seen that in table 2, the criterion (2nd, 5th) is in the opposite direction of the objective function so it must be in the same direction by using the inverse. The results are shown in Table 3.

Table 3. Results after translating criteria that are contrary to the direction of the functional goal

No	Criterion	(Opt. 1)	(Opt. 2)	(Opt. 3)	(Opt. 4)	(Opt. 5)
1	Specific weight	450	351	174	472	362
2	Total Heat Resistance (Ro)	2.11	1.72	0.66	2.20	1.72
3	Unit price	2,378,247	2,229,599	2,636,724	2,006,627	2,155,275
4	Construct-ion time	6.52	6.52	4.52	6.52	6.52
5	Eco-friendly	0.2	0.2	0.1	0.1	0.1

Step 4. *Determine the dimensionless value of each criterion.*
The dimensionless values of the criterion are determined according to the formula (1), the results are shown in Table 4.

Table 4. Dimensionless values of indicators

No	Criterion	(Opt. 1)	(Opt. 2)	(Opt. 3)	(Opt. 4)	(Opt. 5)
1	Specific weight (P)	24.88	19.40	9.62	26.09	20.01
2	Total Heat Resistance (Ro)	25.10	20.45	7.88	26.13	20.45
3	Unit price (G)	20.85	19.55	23.12	17.59	18.90
4	Construct-ion time (T)	21.31	21.31	14.77	21.31	21.31
5	Eco-friendly (M)	28.57	28.57	14.29	14.29	14.29

Step 5. *Determine the importance of each criterion in the comparison*

The importance of the criteria sorted from most important to least important in the following order was determined from the opinions of 5 experienced experts (2 main engineers, 2 construction managers and 1 PhD in construction materials research):

Unit price (G) >> Construction time (T) = Total Heat Resistance (R$_0$)>> Specific weight (P) = Eco-friendly (M)

The results of using the Warkentin square matrix to determine the weighting coefficients for each criterion are shown in Table 5.

Table 5. The matrix determines the importance coefficient of each criterion

No	Criterion	(P)	(R$_0$)	(G)	(T)	(M)	L$_{ij}$	W$_i$
1	(P)	24.88	19.40	9.62	26.09	20.01	11	0.15
2	(Ro)	25.10	20.45	7.88	26.13	20.45	16	0.21
3	(G)	20.85	19.55	23.12	17.59	18.90	21	0.28
4	(T)	21.31	21.31	14.77	21.31	21.31	16	0.21
5	(M)	28.57	28.57	14.29	14.29	14.29	11	0.15
Check:		$3 \times 5^2 = \sum Lij = 75;$		and		$\sum W_i = 1$	75	1

Step 6. *Specify the dimensionless value for each alternative.*
The dimensionless value for each alternative is determined by formula (5) and the results are shown in table 6.

Table 6. Dimensionless value of each alternative

No	Criterion	W_i	(Opt.1)		(Opt.2)		(Opt.3)		(Opt.4)		(Opt.5)	
			P_{i1}	$P_{i1}.W_i$	P_{i2}	$P_{i2}.W_i$	P_{i3}	$P_{i3}.W_i$	P_{i4}	$P_{i4}.W_i$	P_{i5}	$P_{i5}.W_i$
1	P	0.15	24.88	3.65	19.40	2.85	9.62	1.41	26.09	3.83	20.01	2.93
2	R_o	0.21	25.10	5.35	20.45	4.36	7.88	1.68	26.13	5.57	20.45	4.36
3	G	0.28	20.85	5.84	19.55	5.47	23.12	6.47	17.59	4.93	18.90	5.29
4	T	0.21	21.31	4.55	21.31	4.55	14.77	3.15	21.31	4.55	21.31	4.55
5	M	0.15	28.57	4.19	28.57	4.19	14.29	2.10	14.29	2.10	14.29	2.10
				23.58		21.42		14.81		20.97		19.23

***Step 7.** Evaluate. compare and rank alternatives.*

According to the set objective function: the option with the smallest dimensionless value is the best option.

Option 3 which has the smallest value is best option.

4. CONCLUSION

Based on the results of the problem, it has been demonstrated that the use of autoclaved aerated concrete (AAC) blocks is the most optimal option compared to other types. This option not only meets the thermal resistance requirements of the wall but is also environmentally friendly. Additionally, the use of AAC blocks can reduce the static load of the building, providing a basis for selecting a more flexible load-bearing structural solution and reducing the depth of foundation burial. This can help to reduce construction costs and shorten construction time. The SAW method used to select bricks can combine all criteria with different measurement units into a single criterion to rank the plan in a simple and consistent way. However, this method is easily subjective when consulting experts in determining the importance of indicators. Future research directions include using other methods to limit subjectivity such as the Analytic Hierarchy Process (AHP), cost and value in use method, and mathematical method. etc. to compare results when using the SAW method.

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