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Sustainable Thermal Insulator for prefabricated concrete homes in the Andean Areas

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ABSTRACT*: Thermal insulators have been more welcomed in homes, not only for their comfort stability but also for the costs that are reflected compared to a portable heater, the effect of this system is a home that adapts to climatic conditions and provides comfort to the user, which is lost with a conventional heater, because the stability of comfort can be lost. To satisfy this nuisance, there is a need to propose insulating materials with good characteristics that can satisfy the conditions of the user in a prefabricated concrete house, since the conditions of the materials that make up the concrete prevent having an efficient thermal insulation. The present investigation focuses on the well-being of the user to identify the types of thermal insulators that are commercialized, were evaluated with a multi-criteria tool (delphi), applying the Saaty scale, which it served as a reference to the experts, to carry out a comparative weighting of the listed materials with the AHP method. The results achieved show the best thermal insulators.*

KEYWORDS – *Andean Areas, prefabricated, thermal comfort, thermal conductivity, thermal insulation*

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I. INTRODUCTION

Thermal insulators are materials that are characterized by having a high thermal resistance [1], when considering this concept, it is understood that the materials used to make prefabricated homes do not preserve the necessary amount of thermal conductivity needed to quantify the heat transferred to a surface. On the other hand, the behavior of a thermal insulator is better if its thermal conductivity value is lower and its resistance value is higher [2], It is important to consider the thermal conductivity of reinforced concrete 0.55 Watts per meter per Celsius degrees (W/m. ºC) as a favorable point [3]. This research considers several thermal insulators to propose models to be evaluated, whose materials could solve thermal instability in a house built essentially with concrete, after which the respective analysis was carried out to propose a thermal insulator that meets the requirements of housing in Andean areas. These insulators can be placed inside or outside the home [4], this will depend on the need and the architectural configuration's the most widely used and well-known insulating materials in the Andean areas of Ecuador are those of synthetic and mineral origin [5], due to their great demand and ease of locating them throughout the region, it is also important to know the advantages of thermal insulators, to be able to choose the best option that will provide the required benefits which will also consider economic savings, without minimizing the comfort of users who live in those cold places, leaving aside the unnecessary consumption of basic services such as water, gas or electricity [6]. The research made it possible to inquire about the topic and to consider the hierarchical analytical method (AHP) through a matrix of criteria, in addition, the multicriteria method (Delphi) is carried out with expert professionals in the subject of thermal insulation. These data also allow us to observe the main aspects of the applicant materials, which provides an effective solution to solve the problem. The problem is present in the fact that the planet is affected by the phenomenon of climate change [7], this variation consists of a process of transformation of the climate in different aspects, either from warm to cold, from humid to dry or vice versa [8], these changes in temperature are happening around the world, and consequently at the local level there are also variations in time and great instability in the climate, in addition to its different factors such as temperature, rainfall, cloudiness [9]. The mentioned weather inconsistencies force the need to incorporate a product with properties that can prevent decompensation caused by the climate while maintaining the required temperature inside the home [10], due that the materials currently used in the construction do not provide enough thermal comfort. Thermal insulators have a high resistance to heat by reducing the transfer of heat to the opposite side [11], for this reason, they refer to thermal insulators as cold and heat protectors, and it is also known that it contributes to energy efficiency, in other words, is the reduction of energy consumption without affecting comfort [12]. In the Andean region of

Ecuador there is a variety of thermal insulators classified according to their origin in animal, plant, mineral and synthetic [13]. The guarantee of these materials is quantified by the thickness of the product, but not by its thermal conductivity, due to this, the materials with low conductivity are usually chosen to avoid cost increases [14]. It is important to promote the use of a thermal insulator to publicize the effectiveness of materials in the Andean areas, emphasizing the quality of the product. By having a registry of validated thermal insulating materials, it will make it easier for the development of future local research, in addition to having the security of applying them and knowing that they will work.

II. EXPERIMENT

Construction is a branch of engineering with innovative methods that continue to improve over time, one of these is thermal insulation in prefabricated concrete homes, consequently, the research gathers information on thermal insulators that are easily found in the Andean region of Ecuador, to determine a good quality thermal insulator at an affordable price. A hierarchical analytical method (AHP) was proposed, through a matrix of didactic criteria that allowed to appreciate the main aspects of the predetermined materials by researching articles and other experimental documents that have allowed to inquire about this issue, in order to provide a solution according to the particularities of the problem; having little information about thermal insulating materials located in prefabricated concrete homes, the criteria of experts on this topic was used, by using the multicriteria method (Delphi) to provide a significant contribution to the application and efficiency of these materials [15]. In principle, keywords were selected taking into consideration the focus of the research, all the aspects that were evaluated and considered in the decision-making of the best insulating material, for example: thermal insulation, installation of thermal insulators, conductivity, and resistance of thermal insulators. The main characteristics of thermal insulators can be deduced, such as: materials guide and energy efficiency, synthetic thermal insulators, mineral thermal insulators. With these keywords it was possible to obtain files with valuable information for the development of this research. This allowed the Delphi method to be applied, which is a procedure to collect information that allows enriching knowledge and the opinion of experts through interviews, surveys, or other means to collect data [16]. This technique is qualitative in nature, it is used when there is not enough information to make the necessary decisions, there is also the need to gather reconciled and representative opinions of the specialists [17].

2.1 Development of the hierarchical structure

The hierarchical structure is a schematic representation of the problem according to the hierarchy, in terms of the criteria it is in the intermediate level and the alternatives in the lower degree, due to the uncertainty of the criteria selected for the evaluation of the experts, it is almost impossible to know the priority of the alternatives regarding to the criteria [18].

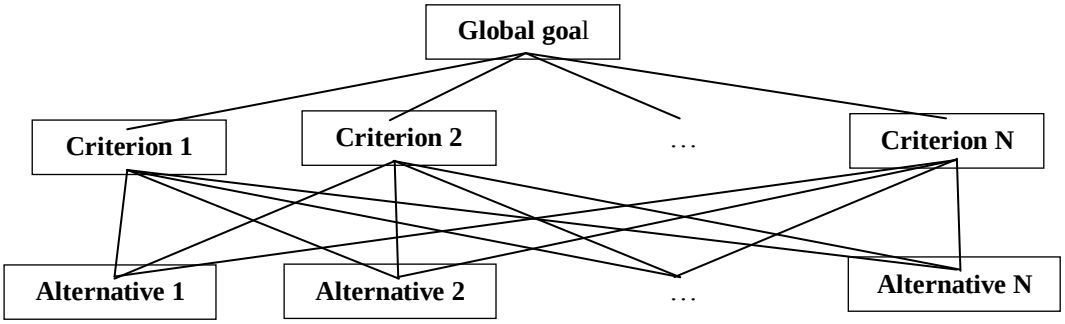

Fig. 1. Hierarchical Analytical Process

2.2 Representation of value judgments

By not having a tool that categorizes the alternatives regarding to the criteria in the hierarchical analytical process, there is a need to use a tool that allows relative responses, but that at the same time will reduce the uncertainty of personal judgments; For this reason, the Saaty scale in Table 1 [19] was chosen, to delimit the values that the experts can provide, this scale is the numerical representation of the judgments made by the experts of the comparison between two alternatives in relation to One criterion, the criteria provided are based on intuition, data, previous analysis or experiences, thus, there is a high degree of confidence in the delivery of each of the comparisons [20].

Table 1. Saaty Scale [14]

Value	**Definition**	**Comments**
1	Equal Importance	Criterion A is equal to criterion B
3	Moderate importance	Experience and judgment slightly favor criterion A over criterion B
5	Big importance	Experience and judgment strongly favor criterion A over criterion B
7	Very great importance	Criterion A is much more important than criterion B
9	Extreme importance	The greater importance of criterion A over criterion B is beyond doubt
2,4,6 y 8	Intermediate values between the previous ones, when it is necessary to qualify	

2.3 Development of normalized and array value judgment

The AHP method allows determining the importance of each of the alternatives to be assessed [21]. If there are n criteria in a certain specific hierarchy, the AHP organizes a pairwise comparison matrix (Criteria A and Criteria B) of n × n, which measures the reasoning of the expert regarding each criterion, to execute the comparison it is first evaluated with whole numbers, in the case that the criteria of the rows (Criteria A) are better in relation to the columns (Criteria B), otherwise the inverse of the credited value will be placed.

Table 2. Criteria Matrix

	Criterion B				
Criterion A	**Criterion B1**	**Criterion B2**	**Criterion B3**	**Criterion B4**	**Criterion B5**
Criterion A1	1				
Criterion A2	-	1			
Criterion A3	-	-	1		
Criterion A4	-	-	-	1	
Criterion A5	-	-	-	-	1

2.4 Calculation of priority and consistency vectors

To determine what level of inconsistency is acceptable, a measure of quantifiable consistency must be considered, followed by the calculation of the consistency quotient; for each matrix, the following steps should be checked:

a) For each row of the matrix, a weighted sum is executed.

b) For each component of the vector resulting from the matrix, divide the value of the corresponding criterion by the sum corresponding to its row.

c) Determine the mean (λmax) of the calculated matrix.

d) Deduct the consistency index (CI) for each criterion, where n represents the number of criteria. CI = λmax - n / n −1 (1)

e) Determine the random index (RI), this can be calculated RI = (1,98n - (n-2)) / n

f) Establish the consistency ratio (CR) as presented in the following equation: CR = CI / RI

By having several data greater than 5, the CR result must be less than or equal to 10%, the level of inconsistency is acceptable, with a higher result it is recommended that the expert reassess his estimates [22].

III. RESULTS

Thermal insulators by definition are poor thermal conductors, that is, their ability to transmit heat is almost null [12], various types of thermal insulators, whether synthetic, mineral, organic and inorganic materials or plant fibers, of which only to synthetic and mineral thermal insulators with known properties, they are materials that, according to their characteristics, availability and efficiency, provide individual thermal insulators without any combination with another materials, it should be noted that not all of them provide the same effectiveness, but they can be customized to different needs. To establish a thermal insulator, 16 synthetic and mineral prototypes with good thermal conductivity were started, these materials are used in large quantities, in addition to knowing a suitable maintenance for each type of these thermal insulators since in the future if there is no adequate maintenance the material will deteriorates, and it will lose its properties [23]. In the list of specimens, the only vegetal thermal insulator known as wood fiber was added since, in the Andean areas, it is easily found either by the periodic felling of forests or sawmill waste which does not require previous treatment.

Table 3. Thermal Insulating Materials

Nº	*Insulating*	Installation		Thermal insulation			Characteristics		*(Unit) price m2*	*Availability*
		Source	***Shape***	***Conductivity W/m.K***		***Density (kg/m3)***	***Flammable***	***Biodegradable***		
1	***Extruded Polystyrene (XPS)***	Synthetic	Panel	0,025	0,040	30	Si	No	$ 4,01	Stores
2	***Expanded Polystyrene (EPS)***	Synthetic	In bulk	0,029	0,053	10-25	Si	No	$ 6,24	Stores
		Synthetic	Panel							
3	***Projected Polystyrene***	Synthetic	Projected	0,035		30	Si	No	$ 3,09	Stores
4	***Cellular glass***	Mineral	Panel	0,035	0,055	157-170	No	No	$ 51,25	Stores
5	***The Expanded Perlite***	Mineral	Panel	0,040	0,060	30-150	No	No		Stores
6	***Polyurethane (PUR)***	Synthetic	Panel	0,019	0,040	30	Si	No	$ 3,68	Stores
		Synthetic	Injected							
		Synthetic	Projected							
7	***Fiber or glass wool***	Mineral	Panel	0,030	0,050	25-80	No	No	$ 5,14	Stores
			Roll							
			In bulk							
8	***Rock wool***	Mineral	Panel	0,030	0,050	25-80	No	No		Stores
			Roll							
			Projected							
9	***Wood fiber***	Vegetable	Panel	0,038	0,107	170±20	No	Si	$ 7,76	Waste
10	***Arlita***	Mineral	A granel	0,08	0,1	300-600	No	No		Stores
11	***Pearlite***	Mineral	A granel	0,04	0,06	50-180	No	No		Stores
12	***Vermiculite***	Mineral	A granel	0,065	0,075	60-200	No	No		Stores
13	***Pozzolanic Pomeca***	Mineral	A granel	0,088	0,18	300-700	No	No		Stores
14	***Scrap denim***	Synthetic	Panel	0,0234			Si	Si		Waste
				0,047						
				0,0563						
15	***VIP Vacuum Insulating Panels***	Synthetic	Inflated	0,004	0,02		Si	No	5$ - 8$	Stores
16	***Aerogels***	Synthetic	Panel	0,01	0,02	3-350	No	No	12$ - 29$	Stores

We used five key criteria to outline the 29 materials to be evaluated: Thermal insulation, characteristics, price, availability, and installation. Synthetic and mineral materials present a similarity both in the installation and in the efficiency and maintenance [24]. Unlike other investigations that are focused on non-commercial prototypes, such as natural fibers of cardboard and cork [25], animal wool [26] or they were simply based on the useful life of the material [27], in this way some materials with natural fiber but designed as sandwich panels are on the market but are not document for the Andean regions and are not easily found.

3.1 Construction of value and normalized judgment matrix

Using the Saaty scale and the judgment of the experts, each matrix was evaluated, with the criteria of thermal insulation, characteristics, availability and installation, the price parameter was discarded because there is a lack of research on the production costs of the materials, for this reason the evaluation of the AHP method was carried out only with the 4 criteria mentioned above.

Table 4. Criteria Evaluation

	Thermal insulation	Characteristics	Availability	Instalation
Thermal insulation	1	3	5	3
Characteristics	1/3	1	1	3
Availability	1/5	1	1	1
Instalation	1/3	1/3	1	1

3.2 Thermal insulation

Thermal conductivity is a fundamental characteristic parameter of thermal insulators, which is why all the research on these types of materials evaluate it regarding to each material without distinction of its origin or shape. In the development of this research, a main factor for the evaluation of each material was the thermal conductivity, that is, the lower this characteristic, the higher the score, since through this parameter the quality of the material is better qualified for the effect that is being looked for. The most used and commercialized models in the Andean area are synthetic materials, since they have conductivities suitable to work as thermal insulators, in addition to having an adequate presentation, which allows it to be coupled to the needs of the user in its different presentations, as either as panel, in bulk, roll, injected, projected, blown or in foams.

3.3 Characteristics

The precaution of using non-flammable materials is one of its primary characteristics for the safety of a home, it is important to assess the flammability of the materials [28], since greater caution must be taken in their handling or use, always placing first the safety of the resident. Another characteristic that stands out is their low density, as they have ease of handling the material, that is why in this and other research related to these types of materials, they include it in the analysis of categorizing thermal insulators [3] Another significant aspect is the biodegradability of the material, this drawback occurs more in materials of plant or animal origin [29].

3.4 Availability

In the construction of any type of structure, the availability of the materials to be used must be ensured. For this reason, the document uses commercial materials or those found in the area where the building was planned.

3.5 Installation

For the installation of a thermal insulator, an evaluation was made evaluated according to its shape, due to not all insulators needing the same tools and availability of workers for their installation, whether those are panels, rolls, in bulk or simply projected. The installation of a thermal insulator must ensure that it is not in contact with water, much less that it absorbs it, in addition to exposing it to excessively large loads or supporting loads of exceptionally long duration, thus avoiding weakness in the product.

3.6 Calculation of priority and consistency vectors

For each row of the matrix, a weighted sum is executed and for each component of the resulting vector of the matrix, the value of the corresponding criterion is divided by the sum corresponding to its row. In this way, the consistency index (CI), the random index (RI) and the consistency ratio (CR) are established.

Table 5 Matrix Normalization

	Extruded Polystyre	Expanded Polystyr	Projected Polystyr	Cellular glass	Polyurethane (PUR)	Fiber or glass wool	Rock wool	Wood fiber	Arlita	Pearlite	Vermiculite	Expanded Perlite	Pozzolanic Pomeca	Scrap denim	VIP Vacuum	Aerogels
Extruded Polystyrene (XPS)	0,04	0,04	0,02	0,07	0,04	0,04	0,04	0,05	0,09	0,09	0,09	0,03	0,09	0,04	0,03	0,04
Expanded Polystyrene (EPS)	0,04	0,04	0,02	0,07	0,04	0,04	0,04	0,05	0,09	0,09	0,09	0,03	0,09	0,04	0,03	0,04
Projected Polystyrene	0,13	0,13	0,07	0,20	0,13	0,13	0,13	0,23	0,12	0,12	0,12	0,10	0,13	0,13	0,03	0,04
Cellular glass	0,04	0,04	0,02	0,07	0,04	0,04	0,04	0,05	0,09	0,09	0,09	0,03	0,09	0,04	0,17	0,18
Polyurethane (PUR)	0,04	0,04	0,02	0,07	0,04	0,04	0,04	0,05	0,05	0,05	0,05	0,03	0,05	0,04	0,03	0,04
Fiber or glass wool	0,04	0,04	0,02	0,07	0,04	0,04	0,04	0,05	0,09	0,09	0,09	0,03	0,09	0,04	0,03	0,04
Rock wool	0,04	0,04	0,02	0,07	0,04	0,04	0,04	0,05	0,09	0,09	0,09	0,03	0,09	0,04	0,03	0,04
Wood fiber	0,04	0,04	0,01	0,07	0,04	0,04	0,04	0,05	0,05	0,05	0,05	0,03	0,05	0,04	0,06	0,06
Arlita	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,01	0,02	0,01	0,03	0,04
Pearlite	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,01	0,02	0,01	0,03	0,04
Vermiculite	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,01	0,02	0,01	0,03	0,04
Expanded Perlite	0,04	0,04	0,02	0,07	0,04	0,04	0,04	0,05	0,05	0,05	0,05	0,03	0,01	0,04	0,02	0,03
Pozzolanic Pomeca	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,10	0,02	0,01	0,03	0,04
Scrap denim	0,04	0,04	0,02	0,07	0,04	0,04	0,04	0,05	0,05	0,05	0,05	0,03	0,05	0,04	0,06	0,03
VIP Vacuum Insulating Panels	0,22	0,22	0,35	0,07	0,21	0,22	0,22	0,14	0,09	0,09	0,09	0,23	0,09	0,13	0,17	0,18
Aerogels	0,22	0,22	0,35	0,07	0,21	0,22	0,22	0,14	0,09	0,09	0,09	0,23	0,09	0,30	0,17	0,18
	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Table 6. Calculation of the Consistency Ratio

	Average vector	Row vector	Row (λ) λma	
Extruded Polystyrene (XPS)	0,053	0,9154	17,21	
Expanded Polystyrene (EPS)	0,053	0,9154	17,21	
Projected Polystyrene	0,122	2,1485	17,64	
Cellular glass	0,071	1,1947	16,90	
Polyurethane (PUR)	0,044	0,7775	17,49	
Fiber or glass wool	0,053	0,9154	17,21	
Rock wool	0,053	0,9154	17,21	
Wood fiber	0,047	0,8078	17,26	
Arlita	0,016	0,2718	17,15	
Pearlite	0,016	0,2718	17,15	
Vermiculite	0,016	0,2718	17,15	
Expanded Perlite	0,040	0,7004	17,42	
Pozzolanic Pomeca	0,021	0,379	17,70	
Scrap denim	0,045	0,7897	17,45	
VIP Vacuum Insulating Panels	0,169	3,2172	19,02	
Aerogels	0,180	3,3982	18,89	
			17,50	
		CI	0,10	
		RI	1,7325	
		CR	6%	**≤ 10%**

Once the matrix of thermal insulators had been evaluated with regards to each criterion, another matrix was obtained with the final average vectors of each criterion to be evaluated.

Table 7. Calculation of Total Weights

Thermal Insulation	Characteristics	Availability	Installation		Criterions		Results	
0,076	0,020	0,067	0,051				0,060	Extruded Polystyrene (XPS)
0,066	0,020	0,067	0,051	**x**		=	0,054	Expanded Polystyrene (EPS)
0,038	0,020	0,067	0,119				0,048	Projected Polystyrene
0,031	0,084	0,067	0,068				0,052	Cellular glass

0,127	0,020	0,067	0,043		0,086	Polyurethane (PUR)
0,041	0,084	0,067	0,051		0,055	Fiber or glass wool
0,041	0,084	0,067	0,051	0,529	0,055	Rock wool
0,031	0,084	0,025	0,045	0,212	0,043	Wood fiber
0,009	0,084	0,067	0,015	0,138	0,034	Arlita
0,031	0,084	0,067	0,015	0,121	0,045	Pearlite
0,014	0,084	0,067	0,015		0,036	Vermiculite
0,032	0,084	0,051	0,039		0,046	Expanded Perlite
0,008	0,084	0,074	0,021		0,035	Pozzolanic Pomeca
0,067	0,060	0,031	0,044		0,058	Scrap denim
0,284	0,020	0,074	0,180		0,186	VIP Vacuum Insulating Panels
0,104	0,084	0,074	0,190		0,106	Aerogels

With the planned methods, the best thermal insulator is given to the vacuum insulating panel, with a score of 0.186, then the aerogels with a score of 0.106, these materials were considered the best compared to the 16 materials selected at the beginning of the document. Technological advances in construction are never far behind, one of the new materials mentioned is air gel, its main component is silica, considered highly porous and by some sources the least dense in the world, it has less than 10% solid maximizing Thus, the percentage of pore filled with gas, considering that gases are poor thermal conductors, this allows it to have such high insulating qualities with very reduced thicknesses, being very advantageous by optimizing space to the maximum [30]. Another relevant material is polyurethane (PUR), this material is a good thermo-acoustic insulator of synthetic origin that is manufactured rigidly as a panel, in the same way, it is projected or injected in the form of foam, this is widely used for its density and its low conductivity, it is not only used in homes but also in airplanes, refrigerators [31], the main advantages of this material is that it is not necessary to have a thickness greater than 2cm to enjoy the benefits and it prevents the passage humidity, in addition its easy installation is emphasized.

IV. CONCLUSIONS

Insulating materials frequently used in civil works are in decline over time, since research advances and promotes better quality products as well as benefits that exceed the old insulators, an example of this is air gel, whose characteristics are favorable to be applied in Andean areas without affecting the comfort of the resident, the new thermal insulators are applied in a distrustful way, because despite the research carried out there is still a certain ignorance about the materials, for this reason a series of insulators low in conductivity were considered whose materials are of importance and useful in the construction of prefabricated concrete houses. Thermal insulators are created as extra models of a structure, but not as a structural part since, due to its fragility, a structure is required. The AHP method specifies a help process, which allows to interpret the relationships between different systems, or in this case between different criteria to be analyzed, these tools serve as support to define which one of the insulating materials is the best. The results when applying the AHP method indicate that the Vacuum Insulating Panels (VIP) insulation is the best option based on the criteria evaluated by the experts, this is due to one of its characteristics that it has a low thermal conductivity and a price which is accessible to the public. In addition, it has a greater impact on the criteria of thermal insulation, characteristics, availability, and installation. Insulating materials Polyurethane (PUR) and Air gel are not the first choice, but they are still a viable choice to minimize heat transfer in buildings, the use of weighting factors such as the Saaty scale is defined with the help of experts to obtain a reliable result in the decision making.

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