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Tesis

Application of Bioacoustic Panels in Sheet Metal Ceilings in Precarious Housing in the Peruvian Andes, City of Huancayo

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Application of Bioacoustic Panels in Sheet Metal Ceilings in Precarious Housing in the Peruvian Andes, City of Huancayo

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Abstract In this research, we propose to measure the effectiveness of materials that can represent a suitable acoustic insulation in homes of social groups of low economic stratum, those who have their living spaces with galvanized steel sheets known as “calaminas” in their roofs, considering the sound impact of rainfall and hailstorms of great magnitude in the central Andean area, specifically in the city of Huancayo. The method used to measure the effectiveness was the application of acoustic prototypes, of which the decibel level was recorded through the use of a professional sound level meter (Benetech model GM: 1356) correctly calibrated, analyzing the different responses of industrial and ecological materials as acoustic barriers to mitigate the amount of decibels harmful to health (75 dB); we elaborated comparative tables of the acoustic indexes collected within 5 tests, considering the cost of each material for the accessibility of the population of scarce resources within the peripheral context of the city of Huancayo in the year 2022, involving a social purpose to the research. It was determined that the prototypes of glass wool, wood fiber and egg crate have optimal qualities to mitigate high decibel levels; in turn, greater emphasis is placed on the last two materials mentioned since a key factor of this research is the ecological, social and economically accessible background, reiterating that the incorporation of industrialized materials in the tests is merely for comparison purposes in their acoustic properties. This study constitutes a possibility to improve the quality of life of the inhabitants of a city in constant growth in the face of not very pressing climatological factors, proposing an economical and accessible alternative of a comfortable space in low-income housing, contributing to sustainable development objectives **SDG 3** and **SDG 11**.

Keywords Acoustic Materials, Acoustic Insulation, Soundproofing Bioacoustic Panel, Ecotechnology, Sheet Metal Ceilings, User Comfort, Substandard Housing, Sustainable Ceilings

1. Introduction

Huancayo, a city in the central Andes that has been characterized by its urban, demographic and sociocultural growth during the last 30 years [1] due to emigrations caused by various factors, has caused an improvised expansion linked to a problem of precarious living spaces in the periphery of the urban area (Figure 1). In the year 2020, there were a total of 516,413 people [2]. This figure will increase considerably over the next 10 years, forcing people to settle in the most disorganized way. These inhabitants are exposed to a vulnerable state of risk, considering the geographical position of the city; located at an altitude of 3,250 meters above sea level, it has a marked cold season [3], with rainfall accompanied by strong winds and hailstorms; precipitation is present from October to April, with its highest peaks between January and March (**Table 1**) [4]. Due to these constant meteorological conditions and taking into account the integral parameters of rainfall and intensity that can be enhanced by other factors such as the phenomenon of "El Niño" [5], there are negative factors that directly affect the health and welfare of ordinary citizens.

Figure 1. Urban periphery of the city of Huancayo - downtown area

The houses are responsible for the protection and shelter of the population, but if they do not have a good design, or have a poor execution, it makes its inhabitants vulnerable; and in the case of this research, we will emphasize those low-income people who for lack of economy or immediate need, come to install on their roofs galvanized steel folds with zinc coating called "calaminas" in the Peruvian construction market [6]. Despite its positive characteristics such as lightness, economic accessibility and resistance during a rainy precipitation, it generates a constant source of noise pollution inside the enclosure, becoming more intense noise if it is rain and hail. This research proposal is linked to a contribution of sustainable development for the well-being and health of people (SDG 3) that emphasizes the prevention of the care and health of the inhabitant regulated by optimal strategies for short and long term, also of a positive growth in the sustainable aspect of cities and communities, which is the implementation of urban and social strategies for the integration of all social strata creating organic connections between these developing the city in a balanced way (SDG 11) [7].

In the national and local social context, there is a very marked typology with respect to the type of families, with a high percentage being "extended families" [8], made up of children, adults and older adults (involving a varied kinship group), living in areas of irregular urban growth. This situation, which is considered chaotic, is not favorable to the inclement weather in the Junin region, the resounding sound caused by rains and hailstorms on the roofs (most of which are made of precarious materials) exposes the members to a number of decibels above 75 dB, considered high and unhealthy by the WHO [9] and also by the Peruvian state in the DIGESA with Supreme Decree No. 085-2003-PCM [10], which specifies that during the day in residential areas, the maximum standard should be 60 dB and at night a maximum of 50 dB. As a consequence of this prolonged exposure, the mental and physical integrity of its occupants is put at risk, resulting in various conditions such as stress, anxiety, depression, insomnia, possible diseases related to the cardiovascular system, hypertension, sleep disorders, poor performance, decreased hearing, tinnitus, cognitive impairment, tinnitus or deafness [11].

Faced with such a problem, we have as an object of analysis various materials that have sound mitigation properties that can lead to a proposal for a bioacoustic panel [12], which would have a composition of easily accessible materials, such as panels of pressed strand board (Oriented Strand Board -OSB) [13] and other materials that will be detailed in the tests [14], the technical aspects of each material will make us understand what qualities endow them with sound reduction. It is worth mentioning that within the comparison of tests, industrial materials known as acoustic inhibitors [15] were taken into account, the latter have a high price compared to the average materials on the market; however, they are part of the research for comparative and experimental purposes.

Table 1. Climatological table by month – Huancayo

	Jan.	Febr.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean temperature (°C)	9.2	9.2	9.1	8.8	8.4	7.7	7.3	7.8	8.3	9	9.5	9.4
Minimum temperature (°C)	6	6.2	6.3	5.4	4.3	3.1	2.4	3	4.1	5.1	5.4	5.9
Maximum temperature (°C)	13.7	13.5	13.4	13.4	13.3	13	13	13.5	13.6	14	14.6	14
Precipitation (mm)	254	252	228	125	61	34	32	53	100	157	164	222
Humidity (%)	81%	83%	83%	80%	75%	70%	67%	68%	74%	77%	76%	79%
Rainy days in the month (days)	21	19	21	19	13	7	7	12	18	20	19	20

2. Materials and Methods

2.1. Study Design

This study is an experimental design of multiple time series [16], since it tests a sound response measurement of a set of materials (**Table 2**) in an estimated period of time, thus verifying the noise level that each test can yield, taking into account the frequencies available for comparison [17]. The materials have a range of particularities such as sensitivity, robustness and above all ecological, because others are derived from petroleum (polymers, polyethylene), an agent that in the long term becomes a pollutant, the components considered in the research are: rock wool [18], a product derived from basaltic, a type of volcanic rock that under a process of industrial transformation becomes a material full of fibers that fulfills as a cover with acoustic and thermal insulation capabilities; glass wool, [19], is a material product of melting at high temperatures of sand and subsequently worked into fibers turning it into an insulating blanket that mitigates loud noises, it is valid to consider its good thermal and economic ratio as well; treated cellulose [20], is a thermo-acoustic insulator that has a composition of 90% treated cellulose and 10% of pyro-retardant salts that provide eco-friendly and sustainable benefits for a house; egg carton [21], is a product derived from recycled cardboard and paper that is also very easy to access economically; lastly, wood shavings [22], are the particles that wood gives off when it is sawn, although it could be considered as a waste, this element can be used as an acoustic barrier, having a certain volume under pressure to reinforce the noise dispersion wall.

Table 2. Technical specifications of materials intended for testing.

Universidad Continental	MATERIALS TEST TABLE					
	FACULTY OF ENGINEERING			PROFESSIONAL SCHOOL OF ARCHITECTURE		
APPLICATION OF BIOACOUSTIC PANELS IN SHEET METAL CEILINGS IN PRECARIOUS HOUSING IN THE PERUVIAN ANDES, CITY OF HUANCAYO						
01. MEASUREMENT TOOLS	 Sonometer		Brand: Benetech	 Speaker	Brand: Honor	
			GM 1356 Model		Minispeak model	
			Measuring range: 30 - 130 dB		Maximum equipment volume: 100 dB	
TECHNICAL SPECIFICATIONS OF MATERIALS IN THE TEST						
02. MATERIAL CHARACTERISTICS	UNITS	 **A. WOOD FLAWING**	 **B. ROCK WOOL**	 **C. GLASS WOOL**	 **D. TREATED CELLULOSE**	 **E. EGG BOX (Maples)**
02.01. FORMAT	Meters (m.)	1.20 x 0.60	1.00 x 0.60	1.20 x 0.60	1.50 x 2.00	0.40 x 0.40
02.02. DENSITY	Kilogram per square meter (kg/m^3)	16	70	48	40	12
02.03. THICKNESS	Milimeters (mm)	35.00	50.80	150.00	50.80	48.00
02.04. HUMIDITY	Percentage (%)	10-20	0-10	0-10	0-10	20-30
02.05. TEMPERATURE	° C	Until 100	Until 400	Until 400	Until 400	Until 60
02.06. THERMAL CONDUCTIVITY	W/m °C	-	-	0.02	1.47	-

Table 2 continued

02.07. MINIMUM ASHES	Percentage (%)	0,1-1,0	-	-	-	-
02.08. NOISE REDUCTION COEFFICIENT	(NRC-WA)	0.9	0.95	0.85	0.80	0.70
02.09. COST	(PEN. – USD.)	(0.50 PEN) - 0.13 USD per kg.	(46.66 PEN) - 12.54 USD per m^2	(38.95 PEN) - 9.93 USD per m^2	(27.46 PEN) - 7.38 USD per m^2	(3.00 PEN) – 0.79 USD per m^2
02.10. GRAPHIC OF THE TESTS						

2.2. Data Collection

Tapia [23] mentions that the current market of materials has grown exponentially, opening the use of multiple possibilities to stop the excess of annoying sounds. Mathematical models were used for the measurement of the acoustic section, using methods such as “Delany & Bazley” [24], a model of empirical character that resembles the development of the present research; by means of mathematical models it is possible to define the sensitivity of the materials based on their composition and also refutes that the porosity or fibrousness of the material as an individual particularity has a degree of effectiveness, while having multiple sandwich layers would fill more voids during the acoustic expansion. Quintero et al. [21], indicate that materials considered as waste can be used as a practical option for acoustic insulation in a residential environment, by using musical notes at a certain frequency, the authors took an average of 5 measurements within 10 seconds in a room with and without furniture to see their degree of influence during data collection. The result was that both coconut fiber and egg cartons function as optimal insulators, although they do not have a lower degree of insulation compared to industrialized ones, they are an accessible source for incorporation in homes to mitigate noise pollution.

2.3. Method

Muñoz & Reyes [25] focus their efforts on analyzing solutions to noise pollution in vulnerable people, either economically or physically. Five cubic prototypes of closed boxes [26] were developed for the simulation and subsequent verification of the sound response of materials; under the validity and certainty of this background, the process of design, structuring and manufacture of five cubes of 30cm x 30cm, made with OSB sheets of 18.3mm [13] (large chipboard of pressed wood), which inside has an empty volume to be covered with the materials previously referenced (wood filings, rock wool, glass wool, treated cellulose, and cardboard trays for eggs) began; in the upper part of the prototype a lid with a pressure closing system is integrated, generating totally isolated spaces, in this way we obtained perfect boxes for its use, considering the dimensions of the model we filled with a layer of 10 cm the edges with each analyzed material, thus having an available space for the location of the sound emitter (full range speaker of 2W - 91 dB) (Figure 2). The equipment was controlled via Bluetooth, starting a sound emission that reaches 80 dB which is the maximum figure that reaches the sound in the calamine roofs to be exposed to rain and hailstorms of high intensity [4], which was previously tested for reference of how much sound should be mitigated. Once the speaker was put into operation, the prototype lid was closed, the box was placed at a height of 1 meter to perform the sound measurement, because it is a standard height for sound pickup (considering national minimum height). The Benetech sound level meter model GM1356 [26] programming the equipment in a measurement range of 30 to 130 dB, also a tripod was used to hold the sound level meter at a height of 1.50 m, in addition to positioning it at a distance of 0.10 m from the prototype; it should be noted that the acoustic tests [27] had different environments and conditions for its execution. The four exploratory measurements were of short duration (20 seconds), the first two were carried out in houses of precarious material and with a tin roof [28], in addition to being located in a peri-urban space, in order to see the influence of environmental noise on the habitability of the users. The rain and hail forecasts provided by SENAMHI (National Service of Meteorology and Hydrology of Peru) [29] were used to determine the days when precipitation and hailstorms would occur, and thanks to this information it was possible to obtain data closer to the noise produced by these meteorological phenomena; The first test was performed with the presence of hail and the second with rain; while the other two were conducted in a music recording studio with acoustic panels around the space (thickness of 15mm), replicating both meteorological phenomena with ambient sound of 90 dB. All this to collect concise data and see the degree of acoustic incidence between spaces clearly designed to dissipate any sound frequency and other more everyday environment, such as residential areas.

Figure 2. Preparation of the prototype to take sound samples.

Once the data collection was completed, the information was processed by the sound level meter software, yielding significant results, which were captured in graphs and tables. Finally, the data emitted from the different insulating materials and their external conditions were collected, resulting in several oscillations of decibels, after these tests we selected an average which the best responses to such experimentation.

3. Results

The results obtained with the sound level meter test on the acoustic enclosure prototype are presented below.

Figure 3 shows the acoustic contrast in the materials in the test in the precarious housing; the box with the glass wool was shown to have the best capacity to isolate noise, yielding a total of 33.40 dB as the minimum measured value, while the egg box obtained 46.20 dB, showing a lower noise isolation.

Figure 4 shows that the egg carton demonstrated the best capacity to isolate noise, with a minimum measured value of 30.00 dB, while the treated cellulose had 45.20 dB, demonstrating a lower noise isolation in this test.

Figure 5 shows that the egg carton demonstrated the best capacity to isolate noise, with a minimum measured value of 29.50 dB, while the treated cellulose had 35.90 dB, demonstrating a lower noise isolation in this test.

Figure 6 shows that the rock wool demonstrated the best capacity to insulate noise, with a minimum measured value of 27.30 dB, while the treated cellulose had 35.90 dB, demonstrating lower noise insulation in this test.

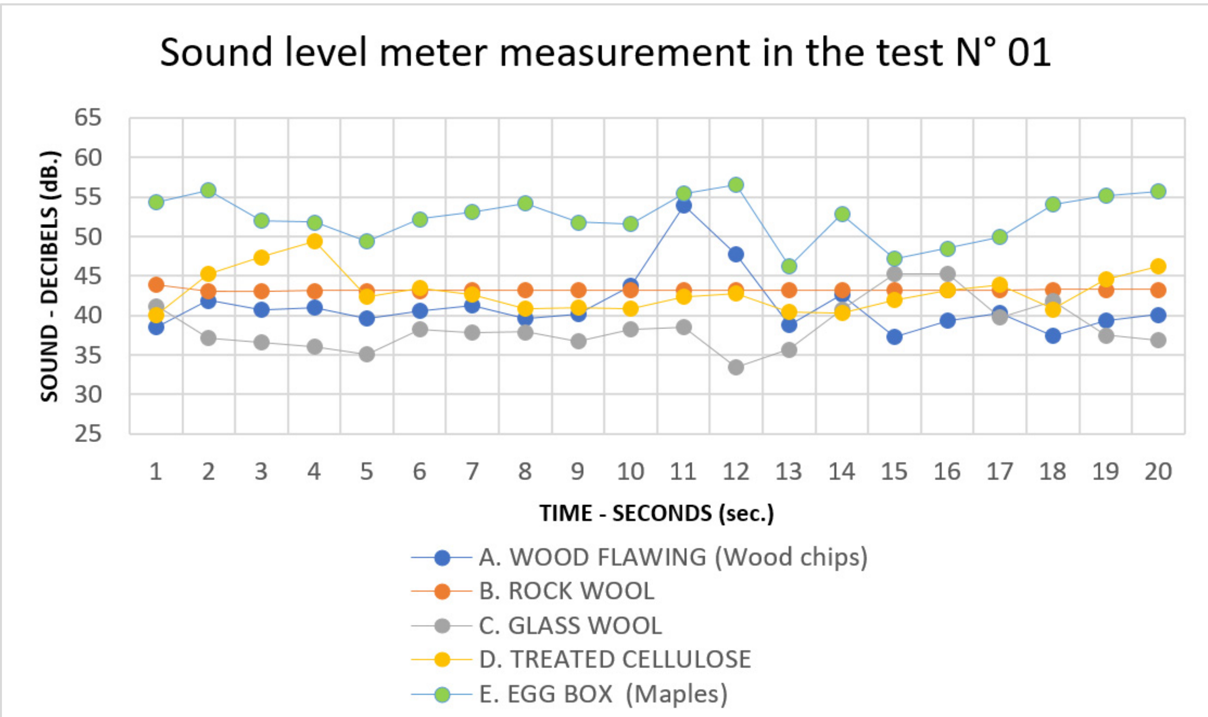


Figure 3. Result of test N° 01

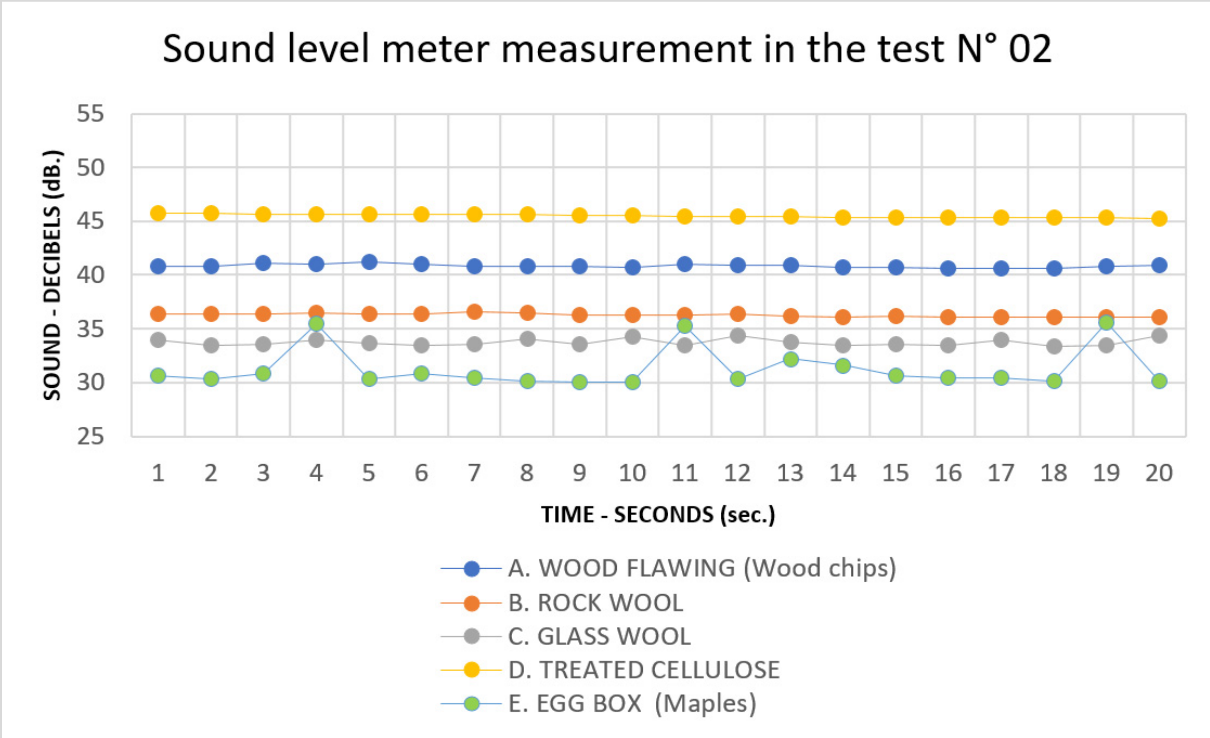


Figure 4. Result of test N° 02

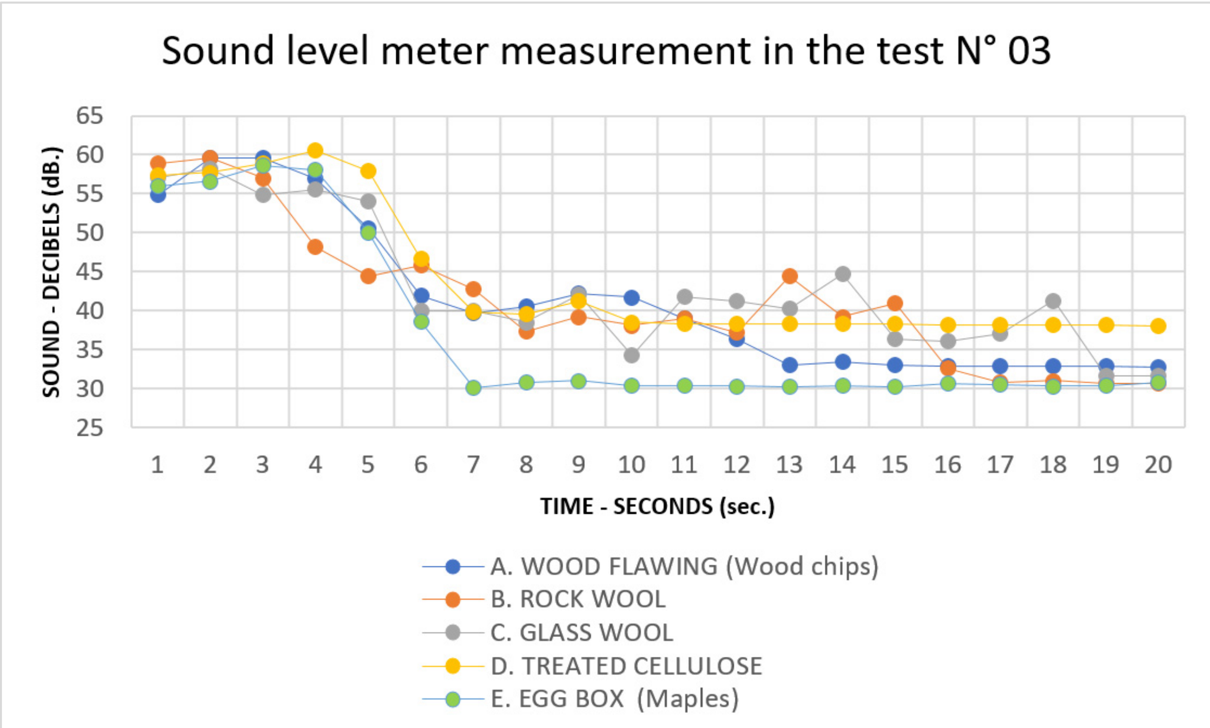


Figure 5. Result of test N° 03

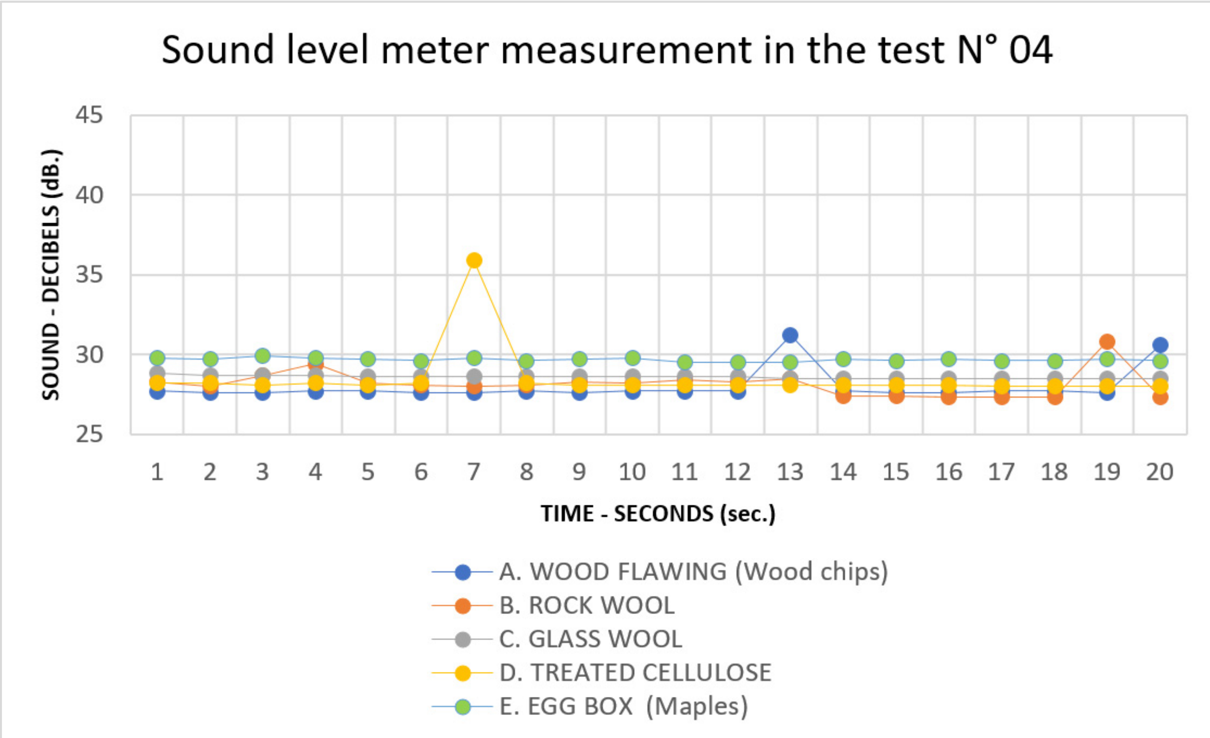


Figure 6. Result of test N° 04

4. Discussion

Figure 7 shows the average results of the tests performed, and the response with respect to sound mitigation is favorable. During test 1, the material with the greatest capacity to isolate sound was glass wool with 38.49 dB, during the second experimental phase, the egg crate had more favorable results, with an average of 31.27 dB, in the third test, the egg box was again the element that stood out with 37.21 dB, finally, in the fourth test, wood filings had a good response to reduce sound with 27.98 dB.

Aguilar and Beltrán [30] evidenced the consequences of prolonged exposure to 70 dB; in environments as congested as local markets where decibels are close to the maximum exposure in the national standard, influencing the comfort and mental concentration of the person, leading to stress or loss of attention; with this background it is reaffirmed that prolonged exposure to loud noise influences negatively, bringing these situations to an environment as everyday as a house would have harmful effects on its members. On the other hand, Martinez, Perez and Llimpe [14], in their research using the coconut fiber substrate, concluded that the placement of multiple or thicker layers has a positive influence; achieving greater reduction of external noise, it should be noted that the authors also added a layer of living plant cover that had no impact on the mitigation of decibels.

According to the tests carried out, the materials can be qualified in relation to their benefits and disadvantages for their incorporation in housing; we have glass wool which is an excellent candidate for acoustic insulation, however, it is not recommended for handling and installation to people not qualified in the handling of this material, since, if there is a misuse or implementation of the material, it can have health consequences such as possible cancer due to improper exposure; this according to Huang [31] who in his research explains that fiberglass wool is made of artificial glass microfibers which is classified as a carcinogenic agent. On the other hand, rock wool [32], similar to the previous material, presents good characteristics, even in thermal aspect; but if the assembly is not done correctly, when it comes into contact with humidity it will progressively start to lose its acoustic insulating properties. As for treated cellulose [33], it is an environmentally sustainable alternative, acoustically optimal, and low energy consumption for its manufacture, despite this, direct application in housing may have problems due to its minimal mechanical strength and stability.

Wood filings, due to their composition that includes tiny air bubble cells, achieve an acoustic and thermal insulating function at the same time [22]. The panels based on wood waste and adhesives are suitable for use as thermoacoustic insulating materials in regional housing construction, providing greater added value and a more environmentally friendly use, by reducing its carbon footprint; on the other hand, the egg carton [21] had optimal results, achieving greater efficiency if more boxes are superimposed on each other, this has a very positive point since it is a material product of recycling and easy to obtain.

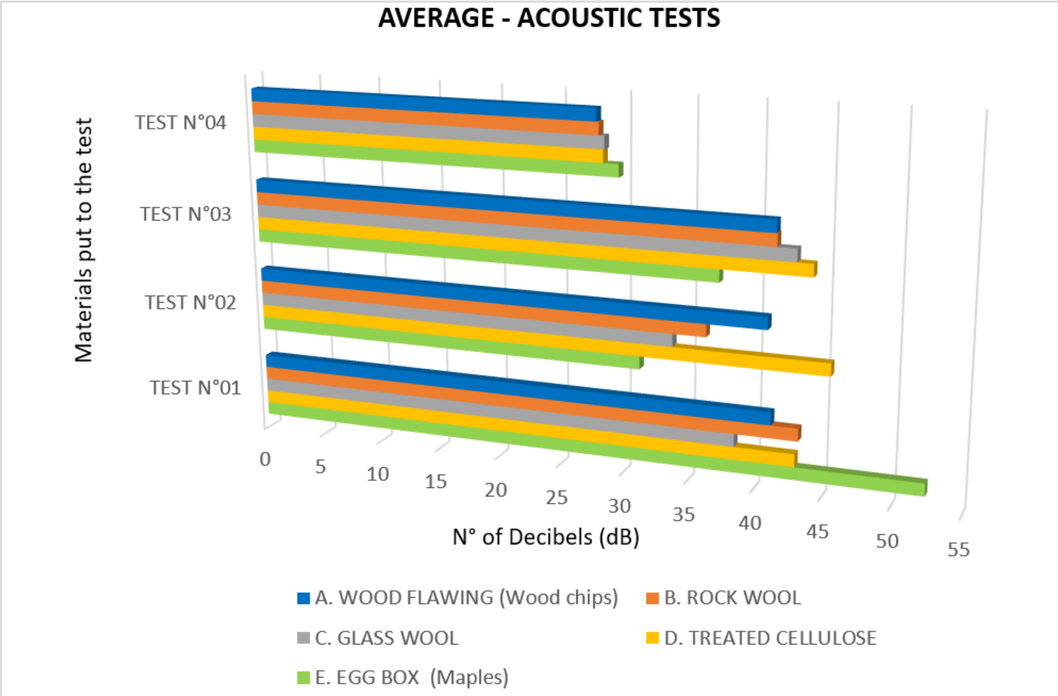


Figure 7. Averages of acoustic tests results

Regarding the economic issue, although we can affirm that all of them have a positive acoustic capacity, they have a notorious difference in their obtainability; first we have 3 elements product of intensive industrialization such as glass wool, rock wool and treated cellulose; these are born from the product of reusing waste construction materials, a very interesting proposal as long as one has the economic capacity to acquire them since their value exceeds 25 dollars, which is 11. 19% of the monthly economy of low-income people [34] (only the material, not including installation). The research has an emphasis on people with scarce resources and for them it would not be easy to be able to buy them, therefore, two materials derived from recycling, egg cartons and wood filings (sawdust) were included in the tests, whose acquisition value is less than 1 dollar for each material.

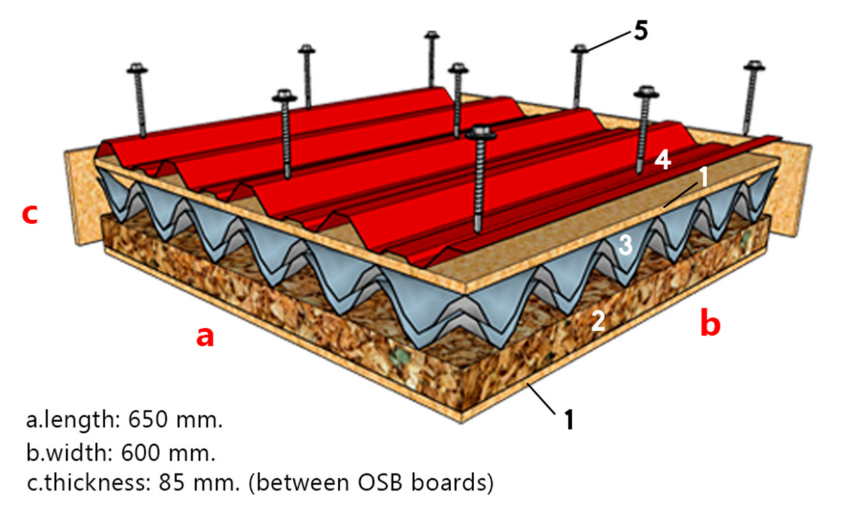
5. Conclusions

In conclusion, it is worth mentioning that the comparison of components tested in the experimentation was to measure the effectiveness in terms of the ability to reduce external noise caused by rainfall, in order to be flexible in the use of "high-end" and "low-end" materials, noting characteristics and properties at the acoustic level that can be incorporated in housing in the peri-urban area of Huancayo, classified as precarious urban areas of early development.

After the respective tests with the sound level meter in two different environments, it was determined that the use of materials derived from the industrial process has a favorable result for noise insulation; however, these materials are of difficult economic access for the social group where this research is focused, highlighting that their use, incorporation and purchase are not the best option for people with limited economic capacity. A more affordable possibility is the alternative recycled materials, since in the experimentation they have similar acoustic properties to those already mentioned, in addition to having a higher percentage of obtaining due to their low cost.

It can be confirmed that the implementation of recycled materials in the development of low-cost bioacoustic panels can contribute to the comfort in the habitability of vulnerable social groups, in order to promote sustainable growth, contributing to an environment with health and well-being (**SDG 3**), minimizing the exposure of citizens to uncomfortable noise in long periods of time that can cause physical and mental disorders; also giving a better image to the city, strengthening the character of sustainable community in the city of Huancayo (**SDG 11**), creating social orientation groups with the neighbors of growing areas, providing them with ideas on habitability and improvement for the quality of life; hand in hand with municipal management and public entities so that they can create support campaigns for these strata; thus to have more conscious, inclusive and participatory cities.

Based on the research, a prototype of an acoustic block composed of materials qualified as accessible (egg crate and wood filings) is proposed, which can be installed on the roof of precarious dwellings (Figure 8).



Prototype materials	Units	Material thickness	Material costs
1. OSB board	2	9 mm	18.70 PEN - 4.92 USD
2. Wood flawing	1	35 mm	0.50 PEN - 0.13 USD
3. Eggs boxes (maples)	2	50 mm	6.00 PEN - 1.58 USD
4. Metal ceiling	1	40 mm	19.90 PEN - 5.24 USD
5. Self-tapping screws	6	140 mm	12.00 PEN - 3.16 USD

Figure 8. Proposed acoustic block with the highlighted materials

The proposal incorporates an internal sandwich system where the use of different layers of materials is tested to mitigate sound more effectively, incorporating the metal roof and the enclosure system with self-drilling screws; each "Econo-acoustic" plate covers 3.90 m² and costs US$15, which compared to the acquisition of industrialized materials, this already comes as a complete piece ready for installation.

Under the support of entities and organizations in favor of sustainable development, the creation of several prototypes can be promoted for easy access as a social strategy to support environments that are affected by meteorological phenomena in their homes at the acoustic level.

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