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Mechanical and Thermal Performance of Kaolin and Sawdust Stabilized Earth Walls for High Rise Housing

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ABSTRACT

Rural dwellings in the high Andean regions of Peru suffer from a severe lack of thermal comfort, which directly impacts the health of their inhabitants. This study aimed to evaluate the effect of incorporating kaolin and sawdust into earth blocks to simultaneously improve their thermal and mechanical properties. Blocks were manufactured using local materials from Corisorgona, Cajamarca, with additions of 4% kaolin combined with 4% and 8% sawdust. Compressive strength was evaluated according to the Peruvian Technical Standard E.080, and thermal performance was monitored in a full-scale test module. The results showed that the blocks with 4% kaolin and 4% sawdust achieved an average compressive strength of 16.70 kg/cm², exceeding the regulatory minimum of 10.20 kg/cm² by 63%. Thermally, the test module maintained an average temperature of 20.54℃, which was significantly more stable and warmer than that of a traditional home (13.88℃) and the external environment (13.92℃). Statistical analysis confirmed a strong thermal damping effect of the reinforced walls. It is concluded that this combination of additives provides a low-cost, sustainable, and replicable solution that enhances both structural safety and thermal comfort, offering an effective alternative for mitigating extreme weather conditions in the Andean region.

1. INTRODUCTION

In the high Andean rural areas of Peru located above 2500 m a.s.l., thermal comfort in housing is an urgent need with direct implications for public health and quality of life. In the Cajamarca region, nighttime temperatures can drop drastically, leading to an alarming increase in acute respiratory infections and pneumonia, especially in the child population [1-4]. This problem is exacerbated by the fact that active climate control solutions are responsible for high energy consumption on a global level, highlighting the need to develop passive and sustainable building solutions [5-11].

Traditionally, houses in these areas are built with local materials such as adobe or rammed earth, which offer low cost and basic thermal performance. However, these constructions have significant limitations regarding their structural resistance and do not provide efficient thermal insulation to protect their occupants from persistent frosts and low nighttime temperatures. In light of these deficiencies, it is imperative to optimize the use of local materials through sustainable techniques that enhance their properties [12-15].

A promising strategy is the stabilization of soil with low-cost additives. Recent research has shown that the incorporation of organic by-products such as sawdust can reduce thermal conductivity by up to 30% and increase the minimum interior temperature, thanks to its insulating capacity [16-18]. On the other hand, cohesive additives like kaolin have been shown to improve the mechanical properties and compressive strength of soil blocks [18-23]. These findings suggest that the combination of different types of additives could lead to comprehensive improvements in the performance of earthen walls [24-31].

In response to this issue, the general objective of this research is to determine the improvement of thermal comfort in high Andean rural housing through the use of reinforced earth walls. The specific objectives are:

(a) to evaluate the effect of adding kaolin and sawdust on the compressive strength of earth blocks, and

(b) to determine the influence of this addition on the thermal variation of a full-scale test module.

The hypothesis is proposed that the application of kaolin and sawdust in earth walls will significantly improve thermal comfort in the test housing, contributing to a better quality of life for residents of high-altitude rural areas.

2. METHODOLOGY

2.1 Research design

The research adopted an experimental design with a quantitative approach. The independent variable (proportion of kaolin and sawdust) was deliberately manipulated to assess its effect on the dependent variables: compressive strength and thermal variation. Control samples (blocks without additives) were used for a direct comparison of the effects [25-31].

2.2 Study area

The study was conducted in the community of Corisorgona, Cajamarca. The clay soil used was extracted from a local quarry that passed the field tests of the Technical Standard E.080. Kaolin and sawdust were used as additives, both low-cost materials with local availability.

2.3 Characterization of materials

To characterize the soil, standardized laboratory tests were performed. The particle size distribution was determined through a granular analysis by washing (NTP 339.128). The soil's plasticity properties were evaluated through Atterberg limits (NTP 339.129), determining its liquid and plastic limits. Additionally, the specific weight of the fine material was calculated (NTP 339.131). According to the SUCS classification, the soil corresponded to a low plasticity silt (ML).

2.4 Elaboration of earth blocks

Once the matter, such as earth, kaolin, and sawdust, was obtained, the samples were taken, and the earth was put into the mold, thus managing to remove blocks from the soil samples. This procedure was repeated 18 times for blocks for compression testing. The adobe blocks were left to dry in a roofed area for about 28 days for optimal drying.

2.5 Experimental design

Three types of samples were established: a standard block (without additives), a block with 4% kaolin and 4% sawdust, and a block with 4% kaolin and 8% sawdust (percentages referred to the weight of dry soil). The blocks were made in manual molds and were left to dry indoors for 28 days to ensure optimal curing before testing. When drying was finished, the blocks were ready for analysis, and the 18 adobes were transferred to the UPN laboratory.

2.6 Mechanical tests on sample blocks

2.6.1 Axial compressive strength test

This test was performed 28 days after the blocks had dried. A total of 18 blocks, including samples with kaolin and sawdust, were analyzed at the UPN soil laboratory. Within these blocks, we have the dosages 4% of kaolin and 4% of sawdust, 4% kaolin and 8% of sawdust of the weight of dry soil.

For the selection of additive dosages, studies suggesting an optimum range of sawdust between 2% and 8% were considered [7]. Based on these findings, it was decided to establish a study range of 4% and 8% sawdust, combined with a low dosage of kaolin (4%), to evaluate its contribution to strength without significantly altering the soil composition.

For the test, the length, width, and height of each sample block were measured to determine the contact surface area where the loads would be applied. Once these dimensions were recorded, each sample was placed in an automatic compression machine, and loads were applied until the block failed. The applied loads were recorded throughout the process.

2.7 Thermal comfort test

A 4 m × 4 m room (external dimensions) was constructed to allow for the determination of temperature parameters. The walls of the room are reinforced walls with the addition of kaolin and sawdust, and consist of dimensions according to the specimen that was determined viable for said structure. So, it will begin with the tracing and excavation of a foundation 50 cm wide by 40 cm deep.

The foundation was built using traditional methods, consisting of irregularly shaped stones larger than 12 inches—not oval, but with the rectangular edges typical of quarry stones to which mud mixed with small straw fibers was added.

Regarding the dosage of 4% kaolin and 4% sawdust (see Table 1), the weight of the soil was determined using a scale. For the construction of the structure, 20 kg of soil was weighed in a 20-liter bucket, and the correct dosage of additives was applied.

Table 1. Dosage of sawdust and kaolin

Dosage: Every 20 kg of Soil			
Percentage (%)	Soil	Sawdust	Kaolin
4%	(kg)	(kg)	(kg)
	20	0.80	0.80

Table 1 shows the dosage of 4% sawdust and 4% kaolin with respect to each 20 kg of soil sample.

For reinforced earth walls or also called caissons, when used in rammed earth, we will use the dosage found above, which starts with 10 cm of stone height, with 40 cm of altered earth height, and so on consecutively until reaching 2 m of height.

As a structural part, wooden beams will be placed horizontally on the walls of reinforced walls, and then the bearings will be built on the sides of the house in order to create a gabled roof like a typical house of the town center and rural areas.

3 beams were also placed, where two of them are on the sides of the bearing and one on top of the bearing. This will serve as a support for the placement of small wooden purlins in the opposite direction, where the reed will be placed to shape the 2-sloped roof.

It was also placed on the reed regrowth, 5 cm of mud in order to make it even more waterproof and thermal, so on this, the straw will be placed as an old traditional house, where it will be fixed by small wooden straps and straps made with the straw itself.

Therefore, at the end of the thatched roof, the test room will consist of windows and doors, in addition to covering any holes to the weather, to maintain an airtight room.

Subsequently, three digital thermometers were placed at different points: one inside a neighboring house, one in the open air, and the last one inside the test room. This setup was used to collect data over 24 hours.

2.8 Procedure for data analysis

After carrying out the necessary studies, the data are analyzed using spreadsheets (Excel) in the office, and the results of the digital thermometers in the 24 hours that were obtained in the locality at the 3 different points are taken into account. With this, it will be possible to determine if there is an improvement in thermal comfort in the sample room.

A 24-hour monitoring period was selected as it is the standard time sufficient to capture a complete diurnalnocturnal cycle. This duration allows for the analysis of the thermal behavior of the module during the times of maximum heat gain (day) and maximum loss (night), which is essential for reliably assessing the damping and thermal lag capacity of the reinforced walls.

Pearson's correlation was used as a statistical method, where a direct correlation can be identified between the temperature of the environment with the temperature inside the test room. Therefore, the standard deviation and the coefficient of variation of the data collected from the temperatures of the 3 points were determined, and the linear scatter diagram was made to find the correlation coefficients, coefficient of determination, regression coefficient, and standard error.

3. RESULTS

3.1 Results of soil mechanics tests

The following tests were carried out in the soil mechanics laboratories of the Universidad Privada del Norte, in relation to the soil samples and the addition of 4% kaolin and 4%–8% sawdust, obtaining the following results in Tables 2-5.

SUCS Classification. When performing the granulometry, it was determined that more than 50% of the material passed through mesh No. 200, which indicated that it was a fine soil. Subsequently, the liquid limit and plasticity index tests were applied to enter the data into the plasticity chart, obtaining that the soil under study corresponded to an ML, that is, silts of low plasticity.

Table 2 shows the results obtained from the particle size test by washing, of the soil extracted from the Village of Corisorgona, where the percentages that pass through both mesh N° 4 and mesh N° 200 are detailed.

Table 3 shows the result of the consistency limits of the soil extracted from Corisorgone, where the results obtained for both the liquid limit, plastic limit, and plasticity index are detailed.

Table 4 shows the results of the kaolin consistency limits.

Table 2. Granulometry by washing

Granulometry by Sieving by Washing					
Mesh	Opening (mm)	Retained weight (gr)	Retained (%)	Accumulated Withholding (%)	What's Up (%)
4	4.76	18.8	1.88	1.88	98.12
200	0.074	73.00	7.30	43.29	56.71

Table 3. Atterberg limits or consistency limits

Atterberg Boundaries Soil Sample	
Liquid Limit	30.55
Plastic Limit	23.69
Plasticity Index	6.86

Table 4. Atterberg limits or consistency limits

Atterberg Limits Kaolin Sample	
Liquid Limit	42.55
Plastic Limit	22.46
Plasticity Index	20.09

Note: The results of the kaolin consistency limits.

Table 5. Specific weight of thin material

Specific Weight		
Description	1	2
Sample Identification	2.25 gr/cm^3	2.48 gr/cm^3
Average Specific Gravity "Ys"	2.37 gr/cm^3	

Table 5 shows the specific weight of the material obtained from the locality of Corisorgona. As a result, there is an average of two samples being 2.37 gr/cm^3.

3.2 Compressive strength results

We obtain as results that the blocks without addition have a resistance of 7.87 kg/cm² (see Table 6 and Figure 1) not complying with the minimum resistance, comparing the addition of kaolin at 4% increases the resistance, sawdust was added at 4% and 8%, with a resistance of 16.70 kg/cm² (see Table 7 and Figure 2), 12.42 kg/cm² (see Table 8 and Figure 3), the compressive strengths obtained comply with the minimum resistance 10.20 kg/cm², indicated by the E.080 standard.

Table 6 shows the average compressive strength of the standard adobe, where the results obtained from the 6 adobe blocks are detailed, determining the standard deviation, average load, average stress, and deformation, as well as detailing the minimum stress established by the E. 080 standard.

Table 6. Summary of the compressive strength of earth blocks without addition

Sample	Load (kg)	Stress (kg/cm^2)	Deformation (mm/mm)
E. 080	-	10.2	-
P1	1480	7.07	0.06
Q2	1818	8.89	0.07
Q3	1619	8.06	0.06
Q4	1432	6.75	0.06
Q5	1773	8.65	0.07
Q6	1603	7.81	0.06
Dev. Standard	153.52	0.85	0.01
Average	1620.83	7.87	0.06
Coef. Variation	9.47%	10.74%	9.16%

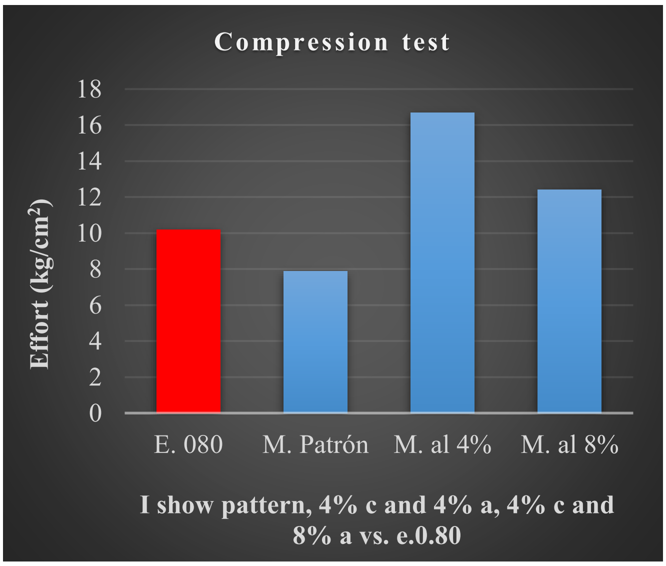

Figure 1. Compressive strength – standard sample summary chart, and addition of 4% kaolin and 4%–8% sawdust

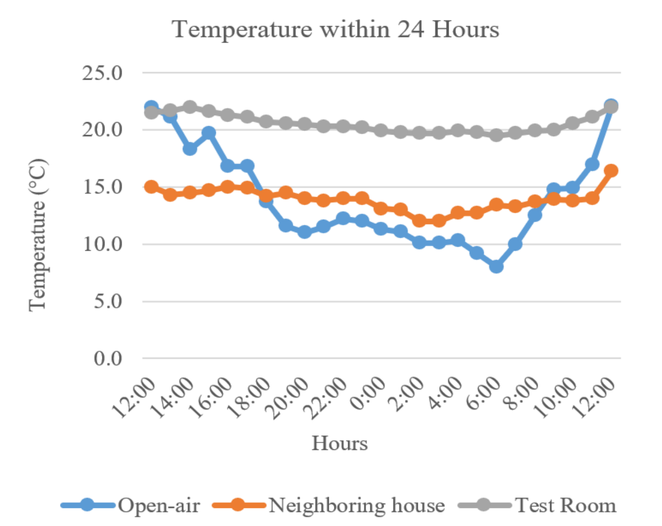

Figure 2. Temperature variation of the 3 points over 24 hours

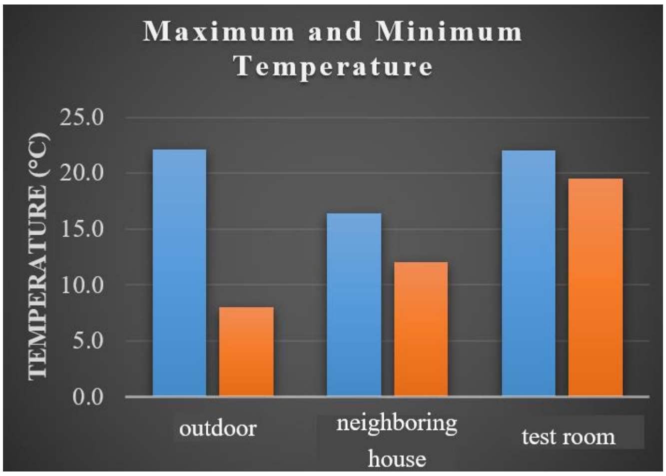

Figure 3. Maximum and minimum temperature (°C) taken at the 3 different points

Table 7 shows the average compressive strength of adobe with the addition of 4% kaolin and 4% sawdust, determining the standard deviation, average load, average stress, and deformation, as well as detailing the minimum stress established by the E. 080 standard.

Table 8 shows the average compressive strength of adobe with the addition of 4% kaolin and 8% sawdust, determining the standard deviation, average load, average stress, and deformation, as well as detailing the minimum stress established by the E. 080 standard.

Table 7. Summary of the compressive strength of earth blocks with 4% kaolin and 4% sawdust

Sample	Load (kg)	Stress (kg/cm^2)	Deformation (mm/mm)
E. 080	-	10.2	-
1–4%	3202	15.13	0.12
2–4%	3317	16.22	0.13
3–4%	3526	17.56	0.13
4–4%	3291	15.52	0.12
5–4%	3949	19.26	0.14
6–4%	3386	16.49	0.13
Desv. Standard	269.52	1.51	0.01
Average	3445.17	16.70	0.13
Coef. Variation	7.82%	9.05%	5.92%

Table 8. Summary of the compressive strength of earth blocks with 4% kaolin and 8% sawdust

Sample	Load (kg)	Stress (kg/cm^2)	Deformation (mm/mm)
E. 080	-	10.2	-
1–8%	2829	13.36	0.09
2–8%	2869	14.03	0.09
3–8%	2716	13.53	0.09
4–8%	2510	11.84	0.09
5–8%	2226	10.86	0.07
6–8%	2240	10.91	0.08
Desv. Standard	285.83	1.40	0.01
Average	2565.00	12.42	0.09
Coef. Variation	11.14%	11.26%	9.81%

Table 9. Summary of the compressive strength of the standard

Sample	Load (kg)	Stress (kg/cm^2)	Deformation (mm/mm)
E. 080	-	10.2	-
M. Patron	1620.83	7.87	0.06
M. at 4%	3445.17	16.70	0.13
M. at 8%	2565.00	12.42	0.09
Desv. Standard	912.35	4.41	0.04
Average	2543.67	12.33	0.09
Coef. Variation	35.87%	35.79%	38.23%

Summary table of the compressive strength of traditional adobe blocks and the addition of 4% kaolin and sawdust in percentages of 4%–8% shown in Table 9 and Figure 1. Table 9 shows the summary of the compressive strength of the standard adobe and with the addition of 4% kaolin and 4%–8% sawdust, specified with the E.0.80 standard. Therefore, the test room was carried out with the dosage of addition of 4% kaolin and 4% sawdust, this being the one that reached a higher compressive strength of 16.70 kg/cm^2 on average.

Table 10. Comparison of temperatures in the test room, the neighboring house, and outdoors

Hour	Open-Air	Neighboring House	Test Room
12:00	22.0	15.0	21.5
13:00	21.1	14.3	21.7
14:00	18.3	14.5	22.0
15:00	19.7	14.7	21.6
16:00	16.8	15.0	21.3
17:00	16.8	14.9	21.1
18:00	13.7	14.2	20.7
19:00	11.6	14.5	20.6
20:00	11.0	14.0	20.5
21:00	11.5	13.8	20.3
22:00	12.2	14.0	20.3
23:00	12.0	14.0	20.2
00:00	11.3	13.1	19.9
01:00	11.1	13.0	19.8
02:00	10.1	12.0	19.7
03:00	10.1	12.0	19.7
04:00	10.3	12.7	19.9
05:00	9.2	12.7	19.8
06:00	8.0	13.4	19.5
07:00	10.0	13.3	19.7
08:00	12.5	13.7	19.9
09:00	14.8	13.9	20.0
10:00	14.9	13.8	20.6
11:00	17.0	14.0	21.1
12:00	22.1	16.4	22.0
Desv. Standard	4.20	0.99	0.79
Average	13.92	13.88	20.54
Coef. Variation	30.13%	7.14%	3.84%

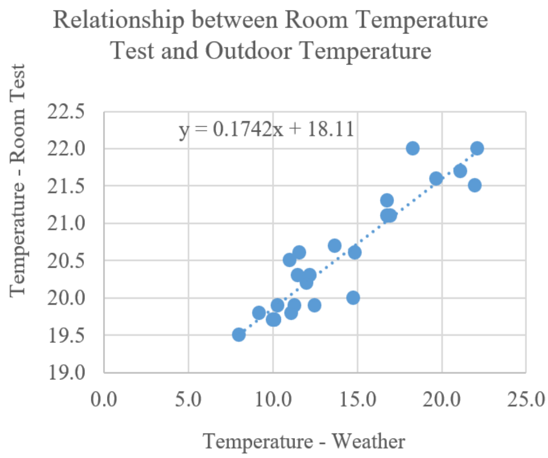

Figure 4. Straight linear scatter plot

3.3 Thermal variation results in the test room

Pearson's correlation statistic will be used to determine if there is a relationship between ambient temperature and temperature within the test room.

2 digital Herald&Barnes thermohygrometer sensors were used with an indoor temperature range -10°C to + 50°C for the test rooms and neighboring house, while for the exterior part 1 digital thermohygrometer model D5 Bestone was used with an outdoor temperature range -10°C to + 50°C (see Table 10 and Figure 4), where we conclude that the test room with the reinforced walls with the addition of 4% kaolin and 4% sawdust, achieves an average temperature of 20.54°C while in the neighboring house there is an average temperature of 13.88°C and an average outdoor temperature of 13.92°C, so it is possible to improve thermal comfort compared to a local house and the outdoors, the built house is shown in Figure 5.

Table 10 shows the average of the temperatures taken in the test room, in a neighboring house, and outdoors, also determining that the test room has a better standard deviation of 0.79.

Table 11 shows the maximum and minimum temperatures taken in the test room, in a neighboring house, and outdoors, also determining the standard deviation.

Figure 5. Room construction

Table 11. Comparison of maximum and minimum temperatures

Temperature (°C)	Open-Air	Neighboring House	Test Room
Maxim	22.1	16.4	22.0
Minimum	8.0	12.0	19.5
Average	15.05	14.20	20.75

$$\Delta T_{max} = 22.0 - 16.4 = 5.6°C \quad (1)$$

$$\Delta T_{min} = 19.5 - 12.0 = 7.5°C \quad (2)$$

Therefore, we conclude that the test room with sawdust and kaolin reinforced walls presents greater thermal comfort compared to a typical house with a y (see Table 11 and Figure 3). ΔT_{max} = 5.6°C, ΔT_{min} = 7.5°C.

3.3.1 Result of correlation of temperatures inside the test room and outside the outdoor test room

After collecting temperature data for 24 hours from both inside and outside the test room, a linear correlation (see Figure 4) was performed to understand the thermal behavior of the test room. Regression analysis was also conducted to correlate the outdoor temperature with the temperature inside the test room, yielding the following graphs and results. Pearson's statistical measure of correlation will be used, since it could take values between -1 and +1, so a value of +1 indicates a perfect positive correlation (when one variable increases, the other also increases), -1 indicates a perfect negative correlation (when one variable increases, the other decreases), and 0 indicates the absence of linear correlation.

The correlation coefficient (r = 0.93) indicates a very high positive linear relationship between the outdoor temperature and the temperature inside the test room. Since r values range from −1 to +1, values closer to ±1 indicate stronger relationships, while values closer to 0 indicate weaker relationships. In this case, r = 0.93 confirms that variations in outdoor temperature are closely mirrored indoors, although the amplitude is reduced due to the insulating effect of the reinforced walls.

The coefficient of determination (R^2 = 0.8584, or 85.84%) means that approximately 85.84% of the variation in the indoor temperature can be explained by the variation in outdoor temperature. This demonstrates a strong thermal coupling, while also evidencing the damping capacity of the kaolin–sawdust mixture in minimizing indoor thermal fluctuations.

The regression coefficient results were a = 18.11 (y-intercept) and b = 0.17 (slope). The regression Eq. (3) was:

$$y = 18.11 + 0.17x \quad (3)$$

where, y is the estimated indoor temperature (°C) and x is the outdoor temperature (°C). The slope (b = 0.17) indicates that for each 1°C-increase outdoors, the indoor temperature rises only 0.17°C, highlighting the wall's insulating effect.

The standard estimation error was 0.30°C, meaning that predictions of indoor temperature based on outdoor temperature have a margin of error of ± 0.30°C.

The temperature difference analysis showed that the test room maintained a maximum temperature 5.6°C higher (ΔT_{max} = 22.0 – 16.4) and a minimum temperature 7.5°C higher (ΔT_{min} = 19.5 – 12.0) than a traditional house. These results confirm the improved thermal comfort provided by the reinforced walls, validating the study hypothesis.

4. DISCUSSION

In the course of this study, one of the main obstacles was the transport of the material, since its location was difficult to access and did not allow the entry of vehicles. This forced the transport to be carried out manually, generating delays in the initial phase of manufacturing the adobes. Likewise, the collection of the material coincided with the rainy season, which prolonged the process by requiring additional time for drying. During this period, the material formed lumps that had to be ground before preparing the mixture. Once ready, the Adobe samples were fabricated.

Regarding the objective "Determine how much the addition of kaolin and sawdust influences the compressive strength of reinforced earth blocks", the laboratory analyses provided relevant data. From a material science perspective, kaolin acts as a fine, cohesive additive that fills voids between soil particles and increases particle–particle bonding due to its plate-like morphology and aluminosilicate composition, which promotes a denser matrix. This contributes to higher compressive strength at moderate dosages. Sawdust, on the other hand, has a lower density and introduces pores within the matrix, reducing bulk density and increasing thermal insulation but potentially weakening mechanical strength if added in excess.

The superior performance of the 4% kaolin + 4% sawdust mix compared to 4% kaolin + 8% sawdust can be explained by the balance between these mechanisms: at 4% sawdust, the porosity generated enhances insulation without critically compromising the soil's load-bearing capacity, and kaolin compensates for potential strength losses by improving cohesion. At 8% sawdust, however, the greater volume of low-density organic matter increases pore connectivity and reduces the effective cross-section of the load-bearing soil matrix, resulting in lower compressive strength.

According to the comparative analysis, traditional adobe samples reached 7.87 kg/cm², while blocks with 4% kaolin + 4% sawdust achieved 16.70 kg/cm², and those with 4% kaolin + 8% sawdust reached 12.42 kg/cm²—both exceeding the minimum resistance of 10.20 kg/cm² established by Standard E.080 [2, 5, 26]. These findings are consistent with previous studies where moderate kaolin additions improved compressive and tensile strength [2, 5], while excessive organic inclusions reduced it [26].

For the objective "Determine how much the addition of kaolin and sawdust influences the thermal variation in a test room built with reinforced walls", the results show that the insulating effect of sawdust, combined with the increased thermal mass from kaolin-stabilized earth, led to a more stable indoor environment. The standard deviation of indoor temperatures in the test room was 0.79, indicating minimal fluctuations compared to the neighboring house. The recorded differences, ΔT_{max} = 5.6℃ and ΔT_{min} = 7.5℃, confirm a significant improvement in thermal comfort.

Comparing these ΔT values to previous works, Peña and Román [17, 20, 29] reported smaller gains for similar interventions, such as internal surface covers with adobe, plaster, wool fiber, and sawdust. Likewise, the Design of a thermal insulation based on natural fibers to mitigate frost in the community of Cupisa achieved a 26% average reduction in heat flow compared to standard adobe, while the addition of sawdust in mortar obtained temperature gains of only 1.95℃ between treated and untreated environments. This places the performance of the reinforced walls in the present study at a higher relative impact, particularly in terms of nighttime temperature retention, which is critical in frost-prone high-altitude environments.

Finally, there is a clear trade-off between mechanical strength and thermal insulation: increasing sawdust content generally improves thermal performance but reduces compressive strength, while kaolin addition strengthens the matrix but has a lesser effect on insulation. The 4% kaolin + 4% sawdust combination represents an optimal balance, delivering both structural adequacy and significant thermal comfort improvements, making it suitable for sustainable rural housing in the Andean region.

5. CONCLUSIONS

In this research, the improvement of thermal comfort in high Andean rural housing, Cajamarca 2025, was determined.

It has been shown that the addition of kaolin in percentages of 4% and sawdust in percentages of 4% and 8% its resistance is higher compared to what is established by the E. 080 standard, but compared to the compressive strength of adobe made traditionally it is lower, since in the results there is evidence of a compressive strength value of 16.70 kg/cm² for 4% kaolin with 4% sawdust and 12.42 kg/cm² for 4% kaolin with 8% sawdust, on the other hand the standard sample adobes have a compressive strength of 7.87 kg/cm², which shows that the higher the percentage of sawdust addition, the lower the compressive strength.

The thermal variation between the test room and a traditional house in the area was determined, and it was observed that the maximum and minimum temperature variation were as follows: ΔT_{max}= 22.0 – 16.4 = 5.6℃ and ΔT_{min}= 19.5 – 12.0 = 7.5℃, demonstrating that it favorably influences and maintains the temperature inside the room.

It is recommended for future research to conduct a comparative study of thermal comfort by constructing a second test module with the dosage of 4% kaolin and 8% sawdust. Although this mixture presented a slightly lower compressive strength, it is still suitable according to the standard, and its thermal insulation properties are probably superior.

It is also recommended for future research to subject the blocks with the dosages studied to accelerated erosion tests and wetting-drying cycles to evaluate their performance and durability against weathering.

It is recommended to carry out tests such as those of the research in months that are not within the rainy season, to perform a better job, since it also directly intervenes in the construction and transportation of materials for the test room.

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