Bioclimatic criteria and life quality in high Andean rural housing in Cajamarca – Peru 2022

Doris Esenarro
Ricardo Palma University
Lima,Peru
doris.esenarro@urp.edu.pe

Howard Cox
Ricardo Palma University
Lima, Perú
h.g.j.8991@outlook.com

Nicole Guerra
Ricardo Palma University
Lima, Perú
nicole.guerra@urp.edu.pe

Vanessa Raymundo
Ricardo Palma University
Lima, Perú
202112586@urp.edu.pe

Alejandro Gomez
Ricardo Palma University
Lima, Perú
Alejandro.gomez@urp.edu.pe

Abstract

The objective of this research is to propose an architectural design with bioclimatic criteria that affects the quality of life of users of high Andean rural housing in Cajamarca, where the lack of comfort is due to multiple factors, one of which is low economic levels. of the area, the presence of frosts and cold waves that are causing serious health damage to the population, such as respiratory diseases, low educational performance. The methodology consisted in the application of bioclimatic criteria in the design to seek the comfort of the users, such as (climatic analysis, eco-friendly materials, construction systems), also supported by digital tools (AutoCAD, SketchUp, Lumion and Design Builder). As a result, a rural house model was obtained, which applies multiple active and passive strategies and achieves illuminated environments 12 hours a day, properly ventilated and reaching interior temperatures between 18°C and 24°C in an environment where temperatures oscillate between -0.1ºC and 24ºC. In conclusion, the strategies help to reduce the effects of climate change and allow the use of climate resources.

Keywords: Comfort, bioclimatic criteria, life quality

I. INTRODUCTION

In Peru, the high Andean areas have always been the most disadvantaged in many aspects, being subjected to extreme cold weather conditions in the southern, central and north-eastern areas of the country, with the department of Cajamarca being one of the most affected. [1]

It is also known that the inhabitants, living in rural adobe dwellings, have been subjected to extreme weather conditions in the departments of Arequipa, Ayacucho, Cajamarca, Ancash, Apurímac, Cusco, Huancavelica, Huánuco, Junín, La Libertad, Moquegua, Pasco, Puno and Tacna [2].The impact of these frosts and cold waves is causing serious damage to the population, for which policies and regulations have been developed to implement actions such as the development of specific plans for each type of disaster. [3] There is a direct relationship between difficult weather conditions and the frequency of development of respiratory diseases, due to the lack of thermal comfort [4]. A report published on July 10 by the Ombudsman's Office revealed that 182 people have died so far this year in 9 regions due to frost. This area of Peru is characterized by cold weather, which causes different types of damage to materials and the destruction of houses (caused by strong winds and extreme snowfall). The material used by the inhabitants for the construction of their houses is adobe (60.40% of the total number of houses); this is because it is a good insulator, it is manageable and economical. The houses found in this region probably do not have adequate thermal comfort, the National Disaster Risk Management Plan mentions that these houses are precarious buildings and were built without architectural direction and being a vernacular architecture, it does not provide the desired thermal comfort for the inhabitants [5].

The lack of comfort is aggravated by multiple factors, among which is the low economic level of the area [6], this has a poverty rate of 42.5%, the fifth highest in the country [7] Cajamarca has 16 of the 20 poorest districts in the country. This level of poverty prevents a large part of the population from having access to construction professionals. [8] This means that not only are the professionals in charge of building management not trained, but also those who provide the labour generally suffer from this lack. Cajamarca is one of the least favoured in terms of education, being the third department with the highest illiteracy rate, with 14.8% of its population illiterate. Of its 1,341,012 inhabitants, only 176,489 have higher education, or only 13.2%. 2%, so it can be concluded that most of the people involved in construction are not properly educated [9]. On the other hand, it is observed that self-construction is due to unskilled labour for the planning and execution of buildings, as well as the use of artisanal inputs to reduce investment costs [10]. The problem of self-construction is so serious and widespread that approximately 80% of housing in Peru is self-constructed, unsupervised and unlicensed [11].

This problem, added to the previous ones, leads to another, which is the lack of use of materials and techniques suitable for the area, which would allow us to have a better heat retention and limit heat loss due to its low conductivity, improving in turn the comfort of the person. [12] Traditionally, shingles or calamine are used as roofing, the latter being the most used due to its low cost and light weight; however, as this metallic calamine allows heat to flow from the outside to the inside (during the day) or vice versa (at night), causing high temperatures during the day and low temperatures at night inside the house. [13] To this must be added the situation of extreme poverty in which the inhabitants of these places live, which causes high levels of child malnutrition and makes them more vulnerable, in some cases, to death [14].

IEECP'23, July 11-12, 2023, 3rd European Conference

In the altiplano, measures are taken to combat the cold, such as heating systems that require electrical energy. This problem has been dragging on for years, so the need to implement heating systems without the need for direct, low-cost energy sources has arisen. The objective is to take advantage of available energy resources (renewable energies) to implement a prototype solar thermal system with flat plate collectors to improve the quality of life of the inhabitants of the high Andean areas, especially in cold weather [15],[16],[17] The bioclimatic design and the construction system of walls and roof of modular ferrocement panels and volcanic cement glass generate energy savings of 47% compared to a conventional house with cement block walls and a reinforced concrete roof lightened with polystyrene cassettes. [18] The use of local materials abundant in nature is much more sustainable [19], since it involves little energy to obtain them, having a lower environmental impact, since less fuel is used for transportation, the transportation time used is saved, greatly reducing the environmental impact. It considers the different factors that help to take advantage of the climate and the different conditions of the environment to reach or achieve thermal comfort inside a building [20].

In addition to the aforementioned factors, there is the limited accessibility of rural housing, which can only be accessed through roads, usually unpaved. The lack of roads represents 20% of the total infrastructure gap and the progress of paving in departmental and neighbourhood road networks is extremely slow (9.7% and 1.7%, respectively) [21].

The objective of this research is to propose an architectural design in the high Andean houses of Cajamarca, where it is intended to find solutions to the general problem of lack of comfort and how bioclimatic criteria influence the quality of life of the users [22].

II. METHODOLOGY

A. Methodologcal scheme

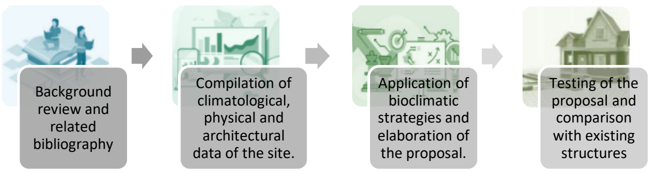


Figure 1. Methodological scheme of the research

B. Place of study

The study area is in the town of Ingatambo, district of Tumbaden, province of Cajamarca, department of Cajamarca, with coordinates 6°56'13.3" south and 78°39'41.2" west and 1.5 hours by car from the main square of the city of Cajamarca.

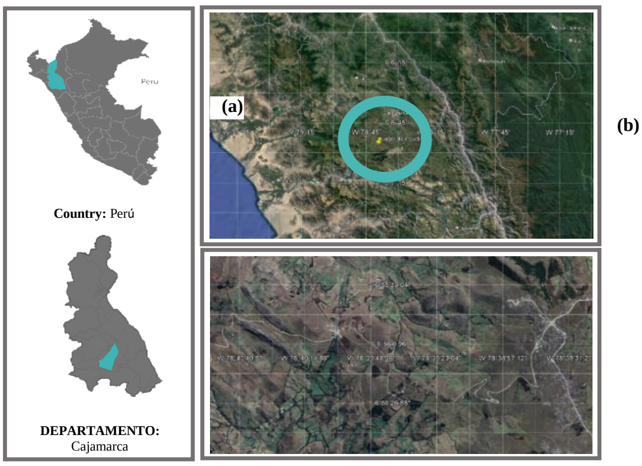


Figure 2. Study location

C. Cimate analysis

1) Solar radiation and sunshine hours

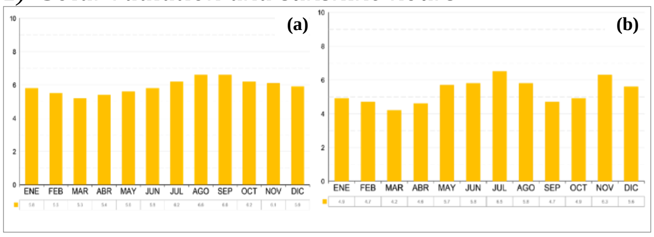


Figure 3. (a) Solar radiation (b) Sunshine hours

Figure 3 (a) shows that the brightest shows that the brightest period of the year lasts 2 months, from August 1 to September 30, with a daily average of incident shortwave energy per square meter of more than 6.5 kWh, and the darkest period least from February 2 to May 20, with an average of 5.6 kWh/m2. The difference between the darkest and brightest periods is not so significant. The figure 3 (b) shows that the hours of sunshine are not abundant, with an average of 5 hours per day, with a maximum average of 6.5 hours during the month of July and a minimum of 4.2 hours per day.

2) Temperature and relative humidity

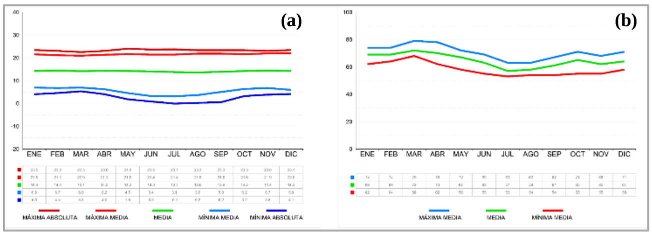


Figure 4. (a) Solar radiation (b) Sunshine hours

Figure 4 (a) shows that the cold season lasts 2.0 months, from June 3 to August 4, and the average daily maximum temperature is less than 21.4 °C. The coldest month of the year in Cajamarca is July, with an average minimum temperature of 3.1 °C and a maximum temperature of 21.4 °C. In addition, the maximum temperature remains stable throughout the year, while the minimum temperature varies slightly. Another constant factor in the climate of Cajamarca is the enormous thermal oscillation that exists, which can reach up to 18 °C between the hottest and the coldest point of the day. Figure 4 (b) shows that Cajamarca has a dry climate, oscillating on average between 60% and 70%.

3) Wind and precipitations

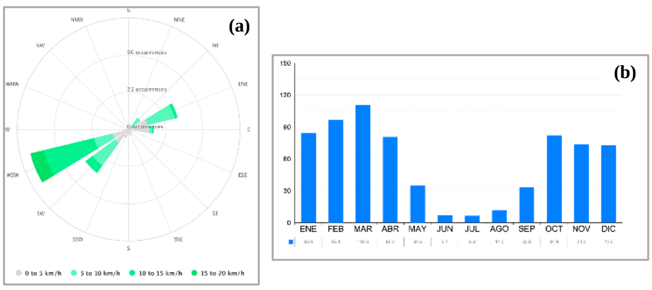


Figure 5. (a) Wind (b) precipitations

Figure 5(a) shows that the most frequent wind comes from the west for 6.0 days, from February 26 to March 4, and for 2.3 weeks, from November 20 to December 6, with a maximum percentage of 40% on December 2. The most frequent wind comes from the north for

4.0 weeks, from March 4 to April 1; for 1.1 months, from October 16 to November 20; and for 2.7 months, from December 6 to February 26, with a maximum percentage of 40% on October 30. The wind comes most frequently from the east for 6.5 months, from April 1 to October 16, with a maximum percentage of 80% on July 31. Figure 5 (b) shows that the hours of sunshine are not abundant, with an average of 5 hours per day, with a maximum average of 6.5 hours during the month of July and a minimum of 4.2 hours per day.

III. RESULTS

A. Location of the Project and volumetric proposal

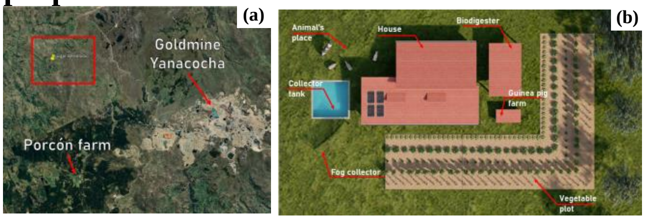


Fig. 6. (a)Satellite view of the project, (b)Plan and volume of the proposal

Figure 4(a) shows all the components of the proposal, the most important of which are the bio garden, the fog catcher, the water collection cistern and the house.

B. Project climatology

1) Solar Path and winds

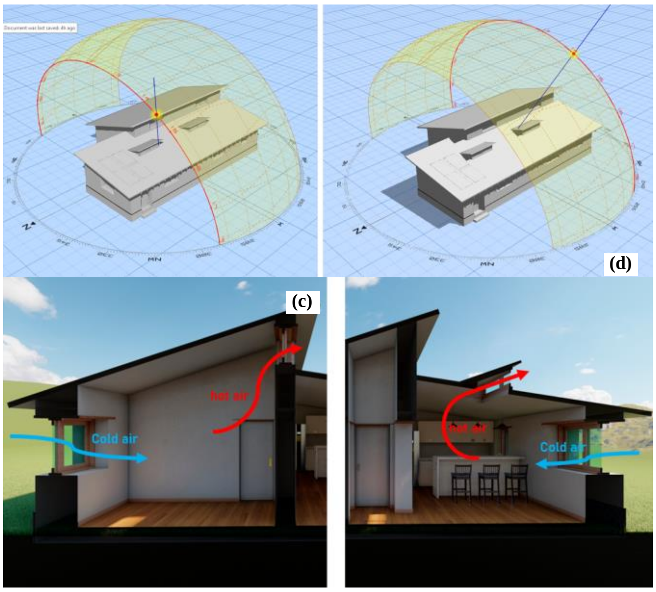


Fig. 5. (a) June 21 and B: December 21 at 2 pm, Air circulation in the proposal.

Figure 5(a), (b) shows the solar incidence on the most extreme dates: June 21 (winter solstice) and December 21 (summer solstice). Figure 5(c), (d) shows that, in order to avoid overheating the house during the hottest periods, multiple windows were designed to allow heat to escape at the user's will.

C. Bioclimatic strategies

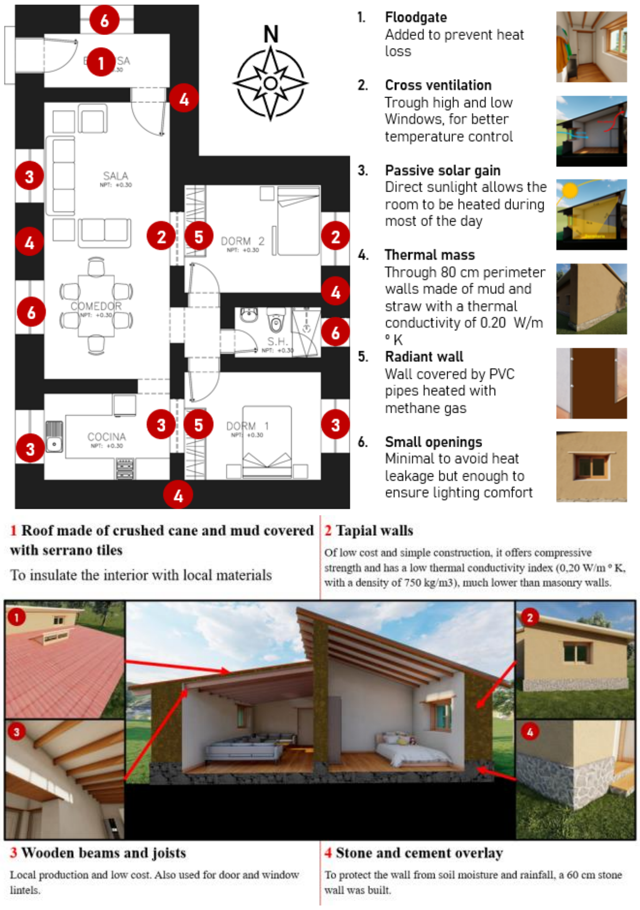


Fig. 6. (a) Summary plan of bioclimatic strategies, (b) Materials used in the project

Figure 6 (a) shows a resume of the bioclimatic strategies used in the project. Figure 6 (b) shows the use of materials such as crushed cane and mud, which serve to maintain adequate insulation inside the house; wood in the use of beams in the openings and joists for the ceiling; rammed earth for the walls, which mixed with straw provides tensile strength and helps store energy; and stone to protect the mud wall from humidity.

1) Passive solar gain and thermal mass

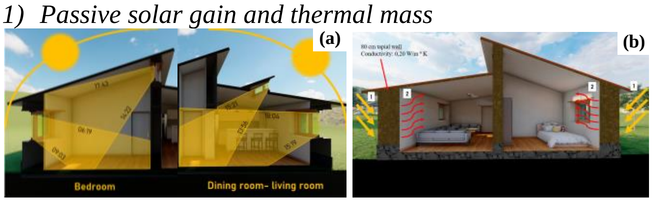


Fig. 7. (a)Window illumination ranges in proposal (b) Thermal mass operation

Figure 7(a) shows that, in order to heat the interior of the house, they will be placed strategically and with their respective solar protection, to allow the entry of sunlight in the coldest seasons and always keep booth bedrooms warm, in addition to always having sufficient lighting to achieve lighting comfort [23]. Figure 7(b) shows the operation of the thermal mass through a cross section of the building. The thermal mass system works through thick perimeter walls with low transmittance [24] in 2 stages, in stage 1 the walls are heated during the day by solar radiation. In stage 2, during the night, the walls release the accumulated heat, thus heating the interior of the building.

(b)

2) Radiant wall system

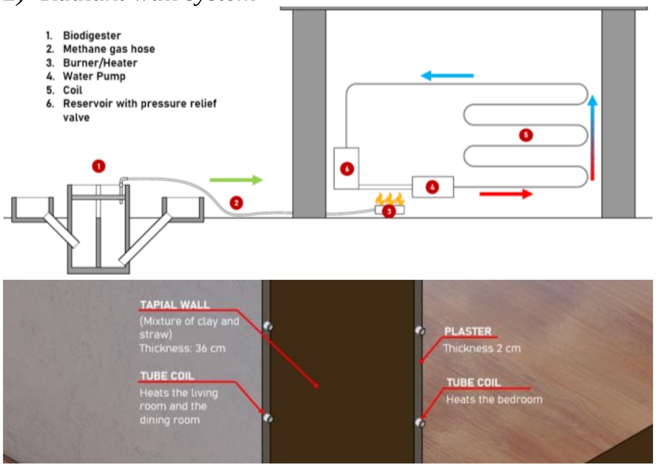


Fig.8. Radiant wall system, Detail of the radiant wall.

Figure 8(a), (b) shows the operation of the radiant wall and tube system and its component parts [25], modified and adapted to the project, thus taking advantage of the gas generated by the biodigester. Although the graphic shows a direct connection, between elements 2 and 3, tire chambers could also be used to store the methane gas and then feed the heater through them.

D. Clean technologies

1) Solar Panels

Due to the high radiation index in the area (5.93 kW/h/m2 annual average), it was decided to supply energy to the house by means of common solar panels installed on the roof of the building. These panels have an efficiency of 20.2% and a surface area of 2 m2, which would provide an average of 2395.2 w/h. However, they are limited to a maximum of 455 W/h. Assuming a maximum consumption of 698.5 w/h for 4 hours, an average consumption of 126.5 w/h for 12 hours, we would have a daily consumption of 4312 W. This demand could be supplied, considering an annual average of 5.3 hours of useful sunshine, with 2 panels, although it is suggested to add a third one to have a greater safety margin.

Table 1. Table of maximum daytime and nighttime consumption.

	Maximum daytime consumption			Maximum night consumption		
Element	Consumption/ hour	Quantity	Partial consumption	Consumption/ hour	Quantity	Partial consumption
Lights	30	7	210	-	-	-
Refrigerator	100	1	100	100	1	100
Microwave	1000	0.15	150	-	-	-
TV	50	1	50	-	-	-
Radio	10	1	10	10	1	10
Basic PC	100	1	100	-	-	-
Cell phone charger	5	3	15	5	1	5
Maximum consumption per hour:			635			115
Percent sec (10%).			63.5			11.5
Maximum consumption per hour:			698.5			126.5

2) Sewage Treatment

Due to the need to properly dispose of sewage, the use of PET ring biodigesters for sewage is proposed. Already commonly used in Peru, they are an excellent option; they do not pollute the environment or are not a possible source of pests as a septic tank would be; they provide gray water that can be used for irrigation; they do not require constant or complex maintenance; they provide odourless compost; they are inexpensive compared to other solutions; and they are easy to install [26],[27].

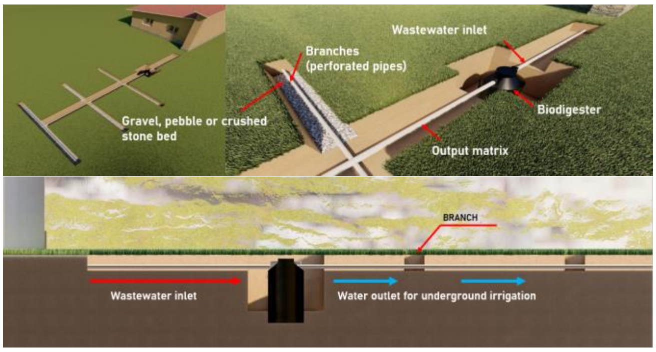


Fig. 9. Sewage treatment system

Figure 9 shows the waste processing in the project with the use of a biodigester and its parts. As can be seen, in addition to solving the wastewater problem, the biodigester also provides irrigation water for the subway, which is much appreciated in dry seasons.

3) Fog traps and Rainwater Collection

Due to the abundant amounts of fog that invade the area at dusk, it was decided to implement fog-catching elements in the project to provide the house with drinking water [28].Due to the water supply that exists in several places, specifically in rural areas, where there is no access to drinking water supply systems, it was decided to implement systems for the use of natural resources such as water, which is conducted through canals and pipes to a storage tank, and then used for one or more uses, either for irrigation, washing, toilets and urinals or even for human consumption [29],[30].

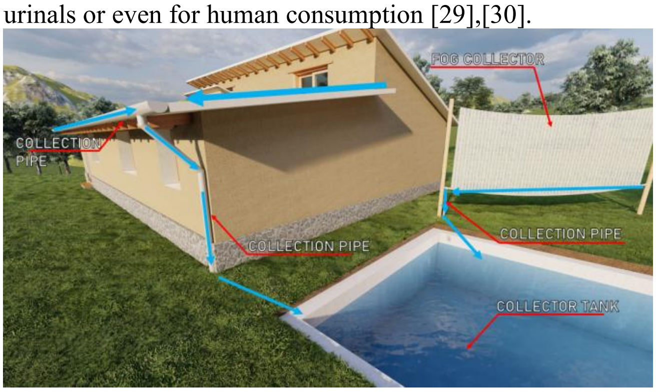


Fig. 10. Water collection systems

Figure 10 shows the location of the fog catcher in the project, which is located perpendicular to the wind direction to obtain as much water as possible. The collected water is stored in a covered cistern, along with the collected rainwater from the roof of the house [31]-[32].

4) Biodigester

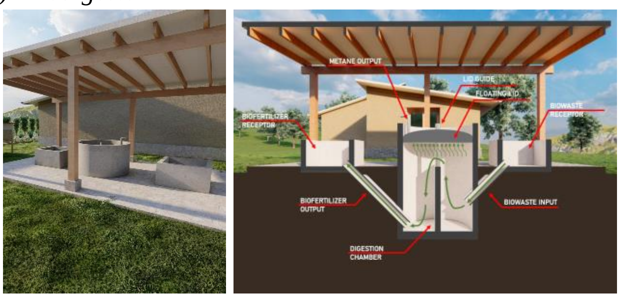
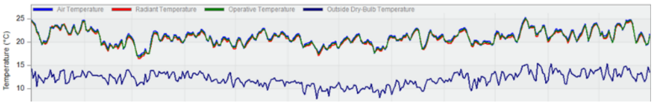


Fig. 11. Location and detail of the biodigester in the project.

A biodigester was chosen to make use of the solid organic waste resulting from day-to-day life and guinea pig husbandry. Among the available biodigesters, the floating dome biodigester was chosen because it is cheaper and easier to manufacture compared to other models [33].

E. Test



Once the strategies and technologies to be used in the proposal were selected, the data were introduced in a simulation software (Design Builder), providing us with the following temperature results:

Fig. 12. Graph of temperatures inside and outside the dwelling.

As can be seen in the graph, the proposal manages to maintain, for most of the time, a comfortable temperature range, well above the outdoor temperatures (in deep blue). The lowest indoor temperatures (17.2 °C) are reached in early March and mid-June and July, and the highest (24.8 °C) at times between mid-October and early January. Although these temperatures fall outside the comfort range, they can be counteracted using the radiant wall system (in the case of minimum temperatures) and cross ventilation (in the case of low temperatures) to maintain the desired 18 °C and 24 °C.

IV. Discussion

The design of the bioclimatic housing for the high Andean zones of Peru is innovative and ecologically sustainable, as shown in the results, the housing takes advantage of natural resources such as the sun, the materials of the area and others, making it ecologically sustainable, also proposes the use of clean technologies such as a passive conditioning system for thermal comfort, a biodigester. [34], [35]

V. Conclusions

The consideration of bioclimatic criteria in the architectural design of a rural dwelling has a positive impact on the quality of life of its inhabitants, since it provides a state of general comfort, which in turn contributes to a state of physical, mental and material well-being.

The use of local building materials, thanks to their physical characteristics (especially their insulating capacity), have a positive impact on the correct application of bioclimatic criteria in rural housing in Cajamarca, in addition to being affordable and leaving a minimal carbon footprint.The use of design strategies, due to the improvement in user comfort in a passive and active way, has a positive impact on the quality of life of the rural inhabitant of Cajamarca, since it allows a high degree of environmental protection without requiring periodic expenses.We want to express our special thanks and gratitude to the colleagues who gave us the golden opportunity to carry out this wonderful project on the subject of bioclimatic criteria and quality of life in high Andean rural homes in Cajamarca - Peru.

VI. REFERENCES

[1] A. Brügger, R. Tobias, Monge-Rodríguez (2021). Public Perceptions of Climate Change in the Peruvian Andes, Sustainability, 13, 2677 (2021)

[2] R. L. Espinoza Paredes, G. Saavedra, F. Huaylla, A. Gutarra, J. O. Molina, R. Barrionuevo, L. Lau, Experimental evaluation of constructive changes to achieve thermal comfort in a High Andean dwelling in Peru. Advances in Renewable Energies and the Environment, 13 (2009)

[3] J. L. Poma, L. Garay, K. Romero, Climatic study in the high-Andean region and analysis of bioclimatic indicators of potential application in architectural design. XIII International Conference on Virtual Cityand Territory: “Challenges and paradigms of the contemporary city”: UPC, Barcelona, Centre de Política de Sol i Valoracions, CPSV/Universitat Politècnica de Catalunya, UPC (2019)

[4] S. Arribasplata, J. Yamali, Application of insulation techniques to achieve thermal comfort in the design of the I.E. secondary and technical - farm porcon, (2018)

[5] SENAMHI, Warning of increased acceleration of glacier retreat. SENAMHI (2016)

[6] Peruvian Institute of Economy, Cajamarca: the fifth poorest region in 2020, (2020)

[7] INEI, Press release N°194 - Censuses 2017: Cajamarca, (2018)

[8] National University of Cajamarca, Cajamarca and the basic concepts, (2022)

[9] The Ministry of Education (2021). Literacy and Educational Continuity Program serves more than 46 thousand people.

[10] D. Chalco, How serious is the problem of self-construction in the country?, (2021)

[11] Y. Sanches 80% of homes in Peru are self-built, (2022)

[12] Ministry of Housing, Construction and Sanitation, Constructive solutions to raise the interior temperature in rural homes located in high Andean areas, (2013)

[13] E. Ramos, (2015). Thermal conditioning for high Andean rural buildings, (2015)

[14] Eduardo, Daniel, Juan, Juan, & Rafael (2018). Pobreza extrema.

[15] O. Facho, T. Cama, D. Esenarro, J. Livia, C. Cuetoand, D. Ramos, Recovery of residual public spaces to improve the quality of life of the inhabitants of San Borja, Lima, Journal of Physics: Conference Series (2021)

[16] K. Hinojosa, D. Esenarro, L. Brigite M. Morales, W. Vasquez, Urban green areas to improve the quality of life in the San Juan de Miraflores district, (2021)

[17] C. Moncloa, (2017). Thermal comfort: a waterproofing system for high Andean housing made with recycled materials. CUC Architecture Module, (2017)

[18] S. Mecott, Bioclimatic house with modular ferrocement panels and alternative insulating materials, (2014)

[19] G. Gamez, J. Franz Prototype of sustainable and productive rural housing for the use of ecotourism in Cajamarca Tolima, (2019)

[20] L. Garay, Proposal for a scientific refuge in the Huaytapallana – Huancayo regional conservation area, (2018)

[21] Diario Gestión, The lack of roads represents 20% of the country's total infrastructure lag, (2016)

[22] D. Esenarro, C. Rodriguez, J. Arteaga, G. Garcia, F. Flores, Sustainable Use of Natural Resources to Improve the Quality of Life in the Alto Palcazu Population Center, Iscozazin-Peru International Journal of Environmental Science and Development, Vol. 12, No. 5 (2021)

[23] L. Guzman, Collection and use of rainwater, through collection systems, (2018)

[24] B. Yuste - Earth architecture characterization of building types.

[25] O. Molina, M. Horn, (2016) - Systematic evaluation of the thermal performance of an experimental module of high Andean housing to achieve thermal comfort with solar energy, (2016)

[26] G. Álvarez, R. Dorantes, Sustainable energy in buildings and houses, (2016)

[27] D. Aldana, J. Viera, Project for the implementation of biodigester systems for the use of organic waste generated by residential users in the Piura region, (2017)

[28] L. Céspedes, Fog water capture for family consumption, (2018)

[29] M. Cristina, J. Rubio, Description of rainwater collection and use systems, (2014)

[30] F. Agudelo, Design and construction of a rainwater collection system for the eco-sustainable module of the kyrios foundation, (2016)

[31] B. Palacios, Harnessing rainwater in architectural projects, (2020)

[32] J. Larrota, E. Gómez, D. Rodríguez, Design a rainwater and gray water collection system called "ecotank" to reduce the use of drinking water in secondary activities in the municipality of Girardot, Cundinamarca., (2021)

[33] J. Perez, Study and design of a biodigester for application in small farmers and dairy farmers, (2018)

[34] G. Álvarez, R. Dorantes, Sustainable energy in buildings and houses, (2016)

[35] D. Esenarro, K. Malpartida, L. Silvana, V. Raymundo and W. Morales, "Use of Renewable Energies Applied in Design Strategies for User Comfort in a House in Iquitos-Belen," 2022 11th International Conference on Power Science and Engineering (ICPSE), Eskisehir, Turkey, 2022, pp. 135-141, doi: 10.1109/ICPSE56329.2022.9935461.