Evaluation of thermal insulation in rural dwellings for their natural bioclimatic conditioning at 3820 m.a.s.l.

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Research paper

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Avaliação do isolamento térmico em habitações rurais para seu condicionamento bioclimático natural a 3820 m.a.s.l.

Evaluación del aislamiento térmico en viviendas rurales para su acondicionamiento bioclimático natural a 3820 m.s.n.m.

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Contribuição dos autores

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Contribución de los autores

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JRHS, SFA, GMM: Supervisión, validación, revisión y edición.

Conflict of interest

The authors declare that they have no conflicts of interest

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Abstract

According to recent studies, about 19% of the population in Peru is at risk of suffering from respiratory diseases due to frost, which is a drop in temperature below 0°C and causes a decrease in thermal comfort inside homes. In addition to these respiratory diseases, frost also increases the risk of other cold-related health conditions, such as hypothermia and circulatory diseases. Therefore, it is important to implement measures to improve thermal conditioning and reduce the risks of these diseases in the affected population. For this reason, the purpose is to improve thermal conditioning through the use of natural insulation. An investigation was carried out in the district of Taraco, using a rural house as a sample. The internal and external temperatures of the house were measured every half hour for 24 hours, and plans of the house were drawn up to collect information. It is proposed to make a natural thermal insulator with quinoa, to increase the temperature by 2 °C inside the house during the night. The thermal conductivity of the material will be evaluated. This study seeks to promote the use of local materials and thermal comfort to achieve sustainable development in the affected population and can be replicated in other areas of the country.

Keywords:

Building materials
Energy efficiency
Environmental conditioning
Indoor microclimate

Resumo

De acordo com estudos recentes, cerca de 19% da população do Peru arrisca sofrer de doenças respiratórias devido à geada, sendo uma queda na temperatura abaixo de 0°C e causa uma diminuição no conforto térmico dentro de casa. Além dessas doenças respiratórias, a geada também aumenta o risco de outras condições de saúde relacionadas ao frio, tais como hipotermia e doenças circulatórias. Portanto, é importante implementar medidas para melhorar o condicionamento térmico e reduzir os riscos dessas doenças na população afetada. Portanto, o objetivo é melhorar o condicionamento térmico, utilizando isolamento natural. Foi realizada uma investigação no distrito de Taraco, utilizando uma casa rural como amostra. As temperaturas internas e externas da casa foram medidas a cada meia hora durante 24 horas, elaborados planos da casa para coletar informações. É proposto fazer um isolante térmico natural com quinoa, para aumentar a temperatura dentro da casa em 2 °C durante a noite. A condutividade térmica do material produzido será avaliada. Este estudo procura promover o uso de materiais locais e conforto térmico para *alcançar o desenvolvimento sustentável da população afetada, e é replicável em outras áreas do país.*

Palavras-chave:

Condicionamento ambiental
Eficiência energética
Materiais de construção
Microclima interno

Resumen

Según estudios recientes, cerca del 19% de la población en el Perú está en riesgo de padecer enfermedades respiratorias debido a las heladas, que son bajadas de la temperatura por debajo de 0°C y causan una disminución en el confort térmico dentro de las viviendas. Además de estas enfermedades pueden respiratorias, las heladas también aumentan el riesgo de otras afecciones de salud relacionadas con el frío, como hipotermia y enfermedades circulatorias. Por lo tanto, es importante implementar medidas para mejorar el acondicionamiento térmico y reducir los riesgos de estas enfermedades en la población afectada. Por tal motivo el propósito es mejorar el acondicionamiento térmico mediante el uso de un aislamiento natural. Se realizó una investigación en el distrito de Taraco, utilizando una vivienda rural como muestra. Se midieron las temperaturas internas y externas de la vivienda cada media hora durante 24 horas, y se elaboraron planos de la vivienda para recopilar información. Se propone la elaboración de un aislante térmico natural con quinua, con el objetivo de incrementar la temperatura en 2 °C en el interior de la vivienda durante la noche. La conductividad térmica del material elaborado será evaluada. Este estudio busca fomentar el uso de materiales locales y el confort térmico para lograr un desarrollo sostenible en la población afectada, y es replicable en otras zonas del país.

Palabras Clave:

Acondicionamiento ambiental
Eficiencia energética
Materiales de construcción
Microclima interior.

Introduction

On average, in Peru, 19% of the population has a high probability of being affected by respiratory diseases (Ramirez and Enciso, 2019). In the Puno region, the most prominent climatological phenomenon is frost, which is a drop in temperature below zero degrees (Choque, 2018; Flores, 2017; Huanca, 2018). This is due to a frigid climate in the region, which generates problems of lack of thermal comfort in homes (Condori, 2014). In addition, rural areas in the high Andean regions suffer from very cold every year, resulting in the death of fragile people and animals (Barnet and Jabrane, 2015; Cruz, 2019). The most vulnerable population are children and the elderly, resulting in high mortality rates, respiratory diseases, and malnutrition (Choque, 2018).

Building energy consumption depends mainly on climatic conditions (Arboit, Arena, and Rosa, 2008). Achieving thermal comfort in homes and/or buildings involves worldwide until today the excessive use of technologies, but these have high costs and many times people or companies decide not to implement them (Saettone, Prutschi, and Seinfeld, 2014). In addition, many climates do not provide enough heat to feel comfortable or are too cold (Molina, 2017). If the exterior envelope is not adequate for the climate of the location, it presents a poor thermal-energetic performance (Martinez, 2015). Rural homes in the Sierra lose energy due to large temperature differences between the interior and exterior.

Built housing often does not take into account bioclimatic criteria to counteract the adverse effects of climate through the use of strategies and techniques (Molina, 2017). An adequate proportion of windows to the north can improve direct sunlight capture and decrease heating demand (Henriquez, 2014). However, in many dwellings, construction techniques have worsened, with less thermal insulation due to the use of materials such as roofs and doors of metal calamine, and inadequate orientation and design of dwellings (Espinoza, 2009). It is important to incorporate simple and low-cost environmental technologies that allow people to take advantage of their benefits and achieve human comfort without relying on polluting energies. For this reason, the purpose of the study was to evaluate the thermal insulation in rural houses for their natural bioclimatic conditioning at more than 3820 m.a.s.l., in the southern Andes of Peru.

Methodology

The present research work is quantitative (experimental) and consisted of monitoring temperatures inside and outside a rural house for 24 hours, from July 23 to 24, with a measurement every half hour. Two environmental thermometers were used to record temperatures and analyze them using a monitoring card. In addition, a survey of information on the rural house plans was carried out. To improve the interior temperature, four quinoa panels filled with barley fiber will be made to increase the temperature by 2°C during the night. To evaluate the thermal capacity of the natural insulation, a calculation of the thermal conductivity coefficient was performed using Fourier's law (Flores, 2017).

After evaluating the characteristics of the Taraco district, the Puquis community (15° 17′ 54″ S, 69° 48′ 44″ W, at 3819 meters above sea level) was selected because it is a rural area where natural binders can be easily obtained and present hostile environmental conditions. A neglected and inhabited house was selected, and a survey of information on its structure and initial conditions was carried out. The house is built with adobe walls with a thickness of 0.30 cm, an earthen floor, a calamine roof, and three openings (two doors and one window). A thermal measurement plan was drawn up to be carried out both inside and outside the house, resulting in a subsequent thermal diagnosis. During monitoring, the openings were kept closed and the measuring instrument was placed in the center of the room. Two types of simulation will be carried out: one of the dwellings without conditioning, and the other with natural thermal insulation (quinoa covered with barley fiber).

In the study, the indoor and outdoor temperatures of a rural house in Puquis, a rural area in the community of Taraco, Peru, were monitored to identify its thermal behavior. For this purpose, two environmental thermometers were used to record temperatures and a monitoring sheet was prepared. A survey of information was carried out and plans of the house were drawn up and the construction materials and initial conditions were recorded. In addition, quinoa panels stuffed with barley fiber were made to increase the interior temperature by 2°C. The thermometer used to record temperature data was an environmental analog thermometer with a range of -30 to 40°C and a 1°C margin of error. A pleximeter was used for the measurement of the dwelling and statistical analysis data tabulation was performed in Excel 2019. The selected dwelling was built with adobe walls 0.30 cm thick, an earthen floor, and a calamine roof, and had 3 openings: two doors and one window. Two simulations were carried out: one of the houses without conditioning and the other with natural thermal insulation. The thermal conductivity coefficient was calculated using Fourier's law to evaluate the thermal capacity of the natural insulation. The drawings were prepared in Revit 2017, as shown in Figure 1.

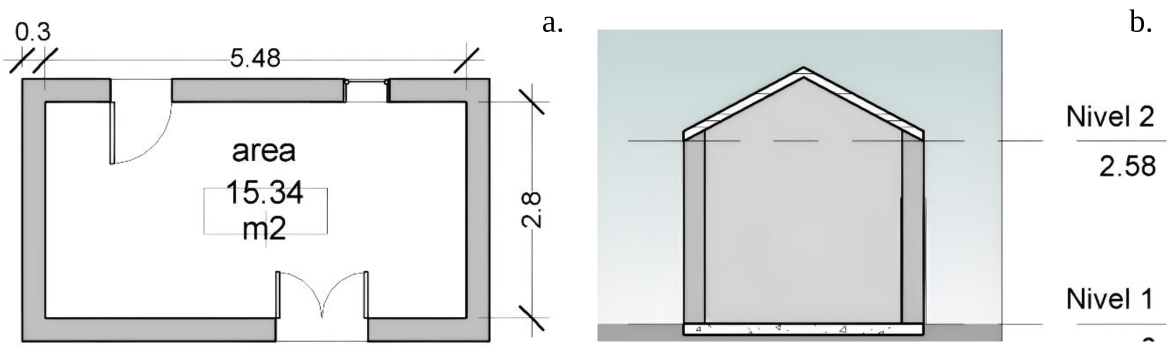

Figure 1.

The interior volume of 46.5 m^3 and the area of 15.34 m^2. In (a) the measurement of the dwelling and (b) the cut-off of the height of the dwelling.

Results

For the selection of the study site, the characteristics of the area and an analysis of the temperatures recorded in the coldest month of the year in July 2021 were considered. A detailed survey of the house plan was carried out to evaluate its condition, which made it possible to identify the characteristics that influenced the daily and nightly thermal gains and losses. During monitoring, a minimum indoor temperature of -2°C and a minimum outdoor temperature of -5°C at 5:00 am were demonstrated. This evidence indicates that people have been sleeping in cold environments and need to wrap up warmer, as the temperature is not adequate for their well-being.

As a result of the thermal diagnosis carried out, the need to raise the ambient temperature inside the home was verified, which implies generating thermal insulation. It is important to note that inadequate temperatures can have negative effects on people's health and well-being, so it is important to take measures to correct this situation.

In the research conducted on the description of the dwelling, it was identified that most of the dwellings present an adequate distribution of the thermal zones, without obstacles that impede the thermal flow since they are mainly composed of a single habitable piece. Regarding the enclosures, it was observed that the houses are built directly on the ground and their walls are made of adobe with an average thickness of 0.30 cm, which results in an estimated thermal conductivity of 0.65 m2K/W. In addition, it was found that the roof is constructed with metal calamine sheets, with an average thickness of 1 mm. These results are consistent with previous research in which it has been shown that houses built with traditional materials and local construction techniques have better thermal performance than those built with modern materials. For example, according to Givoni (1994), houses built with traditional materials such as adobe and stone have better thermal performance, since these materials have a high thermal storage capacity and can regulate the interior temperature of the house. In addition, metal calamine is a material with high thermal conductivity, which contributes to rapid heat transfer between the exterior and interior of the dwelling (Chauhan et al., 2016). It is shown that dwellings built with local materials and techniques present an adequate distribution of thermal zones and good thermal performance, suggesting the importance of valuing and preserving traditional construction methods in the region.

Figure 2.
(a) house analyzed and characteristics of materials, (b) condition of window, (c) roof, and (d) floor.

The enclosure elements of the house include wooden doors and metal sheet, as well as an entrance door of 1.20 m x 1.70 m in the front wall, a small door of 0.80 m x 1.40 m, and a window of 0.60 m x 0.50 m with a single glass of 3 mm thick, which allow natural ventilation (Rodriguez, 2018). The roof of the house, of the gable type and without a ceiling, is built with sheet metal (Salvador, 2015). Enclosure elements are important in a dwelling as it improves the quality of the indoor environment, energy efficiency, and safety of the occupants (Kavgaci & Ozcan, 2020). Natural ventilation is an effective means of controlling temperature and humidity in indoor spaces and improving air quality (Nazaroff & Alvarez-Cohen, 2019). The roof is one of the most important elements of the housing envelope and its design influences the amount of energy required to heat or cool the interior space (Haghighat & Godoy-Shimizu, 2016). The studied dwelling has enclosure elements that allow natural ventilation and the entry of natural light, which is improving the indoor environment. The roof, on the other hand, is of gable type and is built with metal sheets, which can affect the energy efficiency of the house. These aspects should be preferred in future housing projects to improve the quality of life of the occupants. Experimental measurements: Measurements taken inside and outside the house using an ambient thermometer are shown. Although the house was kept closed during monitoring, air leaks were observed through small cracks near the openings.

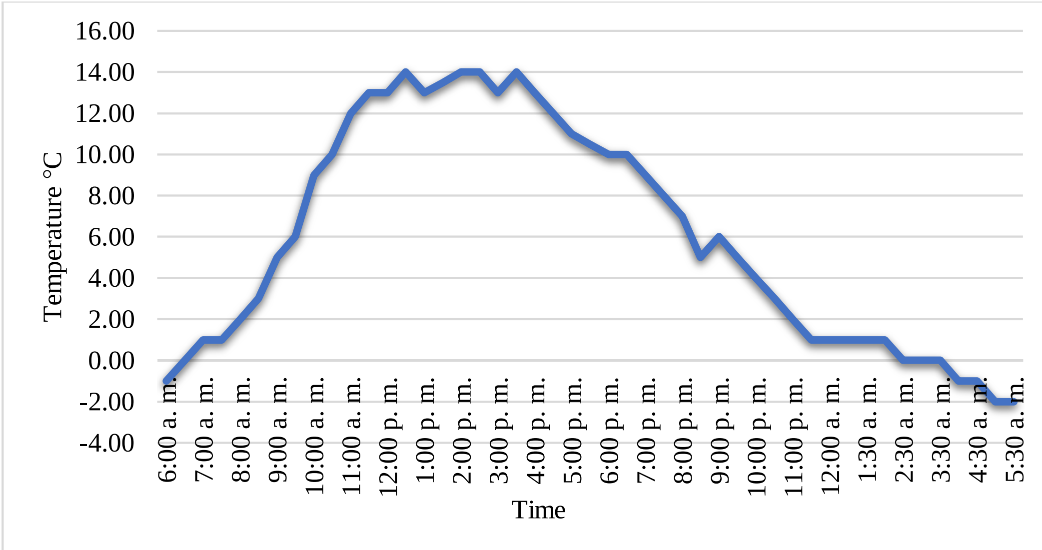

Figure 3.

Thermal behavior inside the house daily average per hour, in addition, there were strong winds with clear skies.

The indoor thermometer was placed in the center of the room, while the outdoor thermometer was placed at the side of the house. The data collected indicate that the minimum temperature inside the dwelling was -2°C, while the maximum was 14°C. In contrast, the minimum temperature recorded outside the house was -5°C, while the maximum was 21°C. The graphs obtained show a decrease in the indoor temperature after 4:00 p.m., as well as in the outdoor temperature.

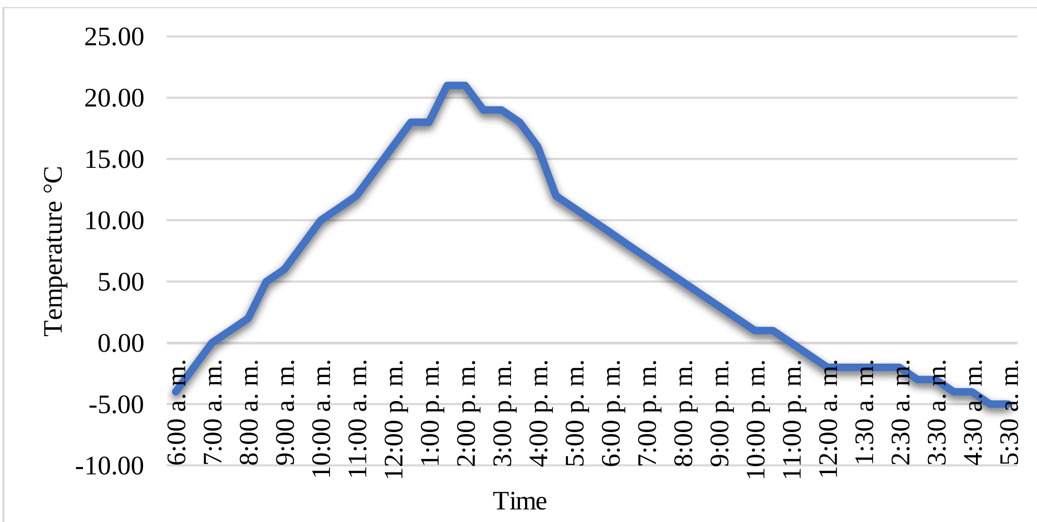

Figure 4.

Average daily hourly outdoor thermal behavior of the house, in addition to strong winds with clear skies.

These results are consistent with previous research that has shown that air leakage can have a significant impact on the thermal comfort of indoor spaces (Mendonça et al., 2017). Also, the findings of this research may be useful for designing more effective insulation and ventilation systems to control the indoor temperature of dwellings and improve the quality of life of their inhabitants.

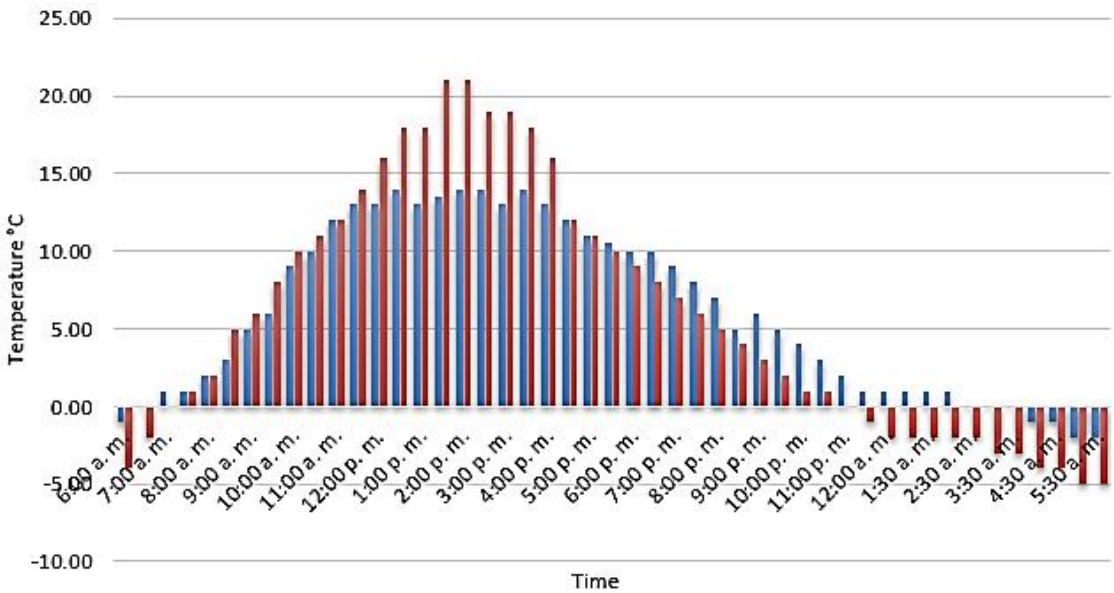

Figure 5.
Thermal comparison, red: outside temperature and blue: inside temperature.

After monitoring temperatures in a high Andean dwelling, minimum and maximum variations were found within 24 hours, especially during the night. These variations should be considered when determining the effectiveness of the proposed insulation (Fisher, 2016). The results also revealed the instability of temperatures both inside and outside the dwelling, which is consistent with Filippín's (2005) demonstrations of temperature variations in high Andean dwellings. These conclusions are considered a scientific contribution to improving high-Andean housing in the country. The addition of temperatures is an important factor in the energy efficiency of a dwelling since it can affect the effectiveness of thermal insulation. According to Fisher (2016), monitoring temperatures is essential to ensure that the proposed insulation works properly. The results of this study support this contention and provide a deeper understanding of temperature instability in high Andean dwellings. The evidence presented in this study suggests that the results of temperature monitoring are essential for designing and constructing energy-efficient study houses. The results can also be used to evaluate the effectiveness of improvements to existing dwellings. Consequently, this study contributes significantly to the improvement of high-Andean housing in the country.
After analyzing the insulation materials, it has become evident that both quinoa and barley are not effective in heat retention. On the other hand, local materials such as totora reeds and wood have favorable characteristics for use in housing construction. Totora has been widely

used as a construction material in the region due to its high strength and flexibility (Mamani, 2018). In addition, key terms have been identified in the research, such as "thermal conductivity" and "Hot Plate Method with Guard", which have been employed to measure the thermal conductivity of these materials (Cruz, 2019). Quinoa and barley are not effective insulation materials, while cattail and wood are viable options for use in housing construction. The key terms identified and the use of the Guarded Hot Plate Method in measuring thermal conductivity are important for the understanding and application of the results of this research.

Conclusions

This study presents a simple and low-cost experimental system to analyze the temperatures of a conventional rural house and to determine the thermal variations with and without insulation. It was shown that the lack of thermal insulation of the construction elements and the infiltration of outside air are the main causes of cooling in the house. The research highlights the importance of managing more temperature sensors and carrying out constructive modifications, such as thermal insulation of the roof and sealing of cracks, to improve energy efficiency and ensure a warmer indoor environment. Finally, this work proposes a technical solution to the serious problem of cold in homes in the high Andean areas, which every year has deadly consequences for children and the elderly.

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