Thermal insulation as a strategy to improve comfort in high-altitude cold-region housing

Aislamiento térmico como estrategia de mejora del confort en viviendas de zonas frías a gran altitud

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ABSTRACT: *This research evaluates the improvement in thermal comfort in a home located in a cold region through the implementation of a thermal envelope with insulation, considering its economic viability and its impact throughout the building's useful life. An exploratory quantitative methodology is adopted, using the case study technique. A convenience non-probability sampling was used. The study was conducted over four months during the summer season and consists of four phases: regulatory analysis, assessment of the current state, implementation of a prototype envelope with thermal insulation, and analysis through monitoring. To this end, data loggers were used to measure temperature and relative humidity fluctuations in two comparable rooms: one intervening and one control. The results showed an average increase of 2°C in the interior temperature and a 10% reduction in relative humidity in the intervened room, allowing compliance with the EM110 standard, whose current minimum conditions do not guarantee interior thermal comfort. This evidence suggests the need to readjust the thermal envelope criteria in said regulation. Overall, the experience demonstrates the positive impact of passive strategies for improving thermal comfort in existing homes, proposing a replicable and low-cost approach that can be considered in future regulatory updates in the country.*

Keywords: *Bioclimatic architecture, environmental quality, housing construction, building regulations, temperature.*

RESUMEN: *Esta investigación evalúa la mejora del confort térmico en una vivienda ubicada en una zona fría mediante la implementación de una envolvente térmica con aislamiento, considerando su viabilidad económica y su impacto a lo largo de la vida útil del edificio. Se adopta una metodología cuantitativa de tipo exploratorio, utilizando la técnica del estudio de caso. La muestra es no probabilística por conveniencia, El estudio se desarrolló urante cuatro meses, en temporada de verano, y consta de cuatro fases: análisis normativo, evaluación del estado actual, implementación de un prototipo de envolvente con aislamiento térmico y análisis mediante monitorización. Para ello, se emplearon egistradores de datos que miden las fluctuaciones de temperatura y humedad relativa en dos habitaciones comparables: una intervenida y otra de control. Los resultados mostraron un incremento promedio de 2°C en la temperatura interior y una reducción del 10% en la humedad relativa en la habitación intervenida, permitiendo cumplir con la norma EM110, cuyas condiciones mínimas actuales no garantizan el confort térmico interior. Esta evidencia sugiere la necesidad de reajustar los criterios de envolvente térmica en dicha normativa. En conjunto la experiencia demuestra el impacto positivo de las estrategias pasivas en la mejora del confort térmico en viviendas existentes, proponiendo un enfoque replicable y de bajo costo que puede ser considerado en futuras actualizaciones normativas en el país.*

Palabras Claves: *Arquitectura bioclimática, calidad ambiental, construcción de viviendas, normas de construcción, temperatura.*

1. INTRODUCTION

Energy efficiency in buildings is one of the fundamental pillars for ensuring adequate conditions of habitability, comfort and environmental sustainability, especially in extreme climatic contexts. In Latin America, most countries lack specific and enforceable regulations regarding thermal design of homes, leading to inefficient construction and high exposure to thermal discomfort [1]. This problem is exacerbated in high mountain regions, such as the Peruvian highlands, where extremely low temperatures are persistent and directly affect the health and well-being of the population.

In the Peruvian context, the Ministry of Housing, Construction and Sanitation (MVCS) has introduced regulation EM.110 “Energy-efficient thermal and lighting comfort” [2], later reformulated as “Thermal envelope” [3], with the aim of promoting technical criteria for thermally efficient buildings. However, the effective application of this regulation in housing remains limited, both due to economic constraints and the lack of integration of thermal criteria into conventional architectural design.

Several studies [4], [5] in the country have demonstrated the positive impact of incorporating thermal insulation in walls, ceilings and windows, showing that the reduction of thermal transmittance using unconventional materials significantly improves thermal performance of living spaces. Several studies [6], [7] have proposed passive solutions based on local construction techniques and low-cost materials, with favourable results obtained through dynamic simulations. Likewise, other research [8], [9], have validated the use of bioclimatic envelopes in experimental homes located in Puno, highlighting their ability to achieve acceptable levels of thermal comfort even at high altitudes. For their part, [10] highlight that building energy simulation systems allow for the analysis of both the environmental quality and the energy demand of buildings. In the same vein, [11] show an energy-economic assessment that considers the predominant construction materials in the city under study. Similarly, [12] compared different material configurations considering variables such as orientation and shading. In [13], it is suggested that, in order to improve thermal comfort in housing developments, direct solar incidence should be reduced in warm climates and, conversely, favoured in cold climates. Finally,[14] carried out an energy assessment of homes during the period 1960–2011, managing to define a thermophysical model based on dynamic simulations.

From an adaptive comfort perspective, theories such as that of Fanger [15] serve as a reference for evaluating the thermal well-being perceived by users, considering not only physical parameters but also subjective, cultural and occupancy conditions. In high Andean areas, studies [16] have highlighted the specific sensitivity of inhabitants to draughts and sudden changes in temperature, with a comfort range slightly different from that of other latitudes.

Within this context, the purpose of this study is to analyse the effect of implementing a thermal envelope with insulation in a dwelling located in a cold high mountain area, in order to provide empirical evidence on its technical and economic viability. This work is part of a perspective of improving housing through passive strategies, proposing replicable alternatives that can be considered in future regulatory updates.

2. MATERIALS AND METHODS

2.1 Methodological approach

The study adopts a quantitative and exploratory approach, using the case study technique. The research is carried out from an empirical perspective with on-site measurements and energy simulation. The methodological choice is justified by the need to understand the actual thermal behaviour of an existing housing before and after a passive intervention in its envelope.

2.2 Location, population and sample

The case study is located in the city of Puno, Peru, at 3,827 metres above sea level, corresponding to the Bioclimatic Zone 6 – Very cold continental according to the classification of the National Building Regulations [3]. The selected housing was built in 1986, has four levels and handmade brick walls with cement plastering, without previous thermal insulation.

Figure 1 shows that the vertical enclosures and openings of the building are composed of handmade brick, cement mortar and Moduglass system glass.

The sample selection was convenience non-probabilistic, given the accessibility of the property and the willingness of the occupants to participate in the study. The unit of analysis was a thermally intervened room and a control room, both with similar construction conditions.

Figure 1. Exterior condition of the dwelling before the intervention.

Source: own elaboration.

Ethical Considerations

The study was conducted with the authorisation of the occupants and under the ethical principles of informed consent. No interventions were made that could compromise the health or safety of the residents during the study.

Phases of the study

The research was conducted over four months during the summer season and was structured in four methodological phases, according to the research model proposed by Wieser et al. [9]:

Phase 1. Synthesis

First, a regulatory review [3], [15] was carried out to identify the established criteria and their applicability in cold high mountain areas, a technical review of the theoretical framework of thermal comfort and a qualitative analysis of the dwelling.

Phase 2. Contrast

In the second phase, the current state of the dwelling was diagnosed through direct observation, architectural and thermal data collection through thermographic inspection, and energy simulation in DesignBuilder v7.3.1.003.

Phase 3. Exploration

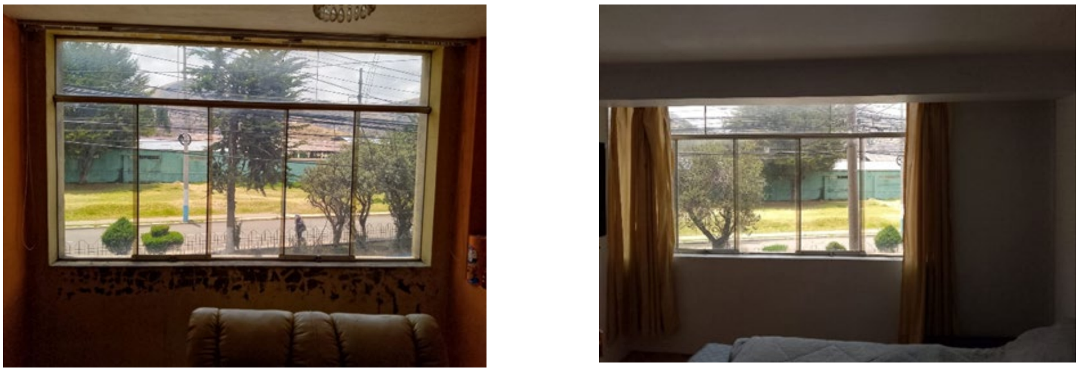
A prototype thermal insulation envelope was then implemented using accessible materials and construction techniques adapted to the local context: a system consisting of a wall clad with insulation, a ceiling with EPS, high-density fireboard (HDF) floating floor with 0.5 cm insulation, exterior cladding, and replacement of windows with a double-glazed Moduglass system with an air chamber.

Phase 4. Conclusion

Finally, a comparative analysis was carried out by monitoring thermal behaviour with MadgeTech RHTemp101A sensors to record temperature and relative humidity under three conditions: (1) no insulation, (2) partial insulation, and (3) complete insulation.

Figure 2 shows the interior condition of the case study before the intervention, where the walls are made of handmade brick, cement plaster, and the windows are Moduglass system with 6 mm thick single glazing.

Figure 2. Interior condition of the case study. a) Room to be intervened with thermal insulation, b) Control room.



a) b)

Source: own elaboration.

Instruments and materials

The instruments used were:

A FLIR i50 thermal imaging camera, with an accuracy of ±2% and thermal sensitivity of 0.1°C, as shown in Figure 3.

Figure 3. Flir I60 thermal imaging camera.

Source: own elaboration.

MadgeTech RHTemp101A sensors, with a measurement range of –40 °C to +80 °C with an accuracy of ±0.3 °C temperature and ±3 % relative humidity, as shown in Figure 4.

Figure 4. Madgetech Data Logger sensor.

Source: own elaboration.

DesignBuilder software for energy simulation and thermal performance analysis.

Finally, Python Jupyter in Google Colab was used for data processing.

Thermal insulation system and costs

The thermal envelope was designed using low-cost, easy-to-install materials adapted to local construction techniques. It was based on technical criteria proposed by [17], prioritising efficiency, availability and speed of implementation. The final system included:

- Exterior plastering: PEN 1,200.00
- Insulated wall cladding (internal panels): PEN 1,528.80
- 8.3 mm HDF flooring with insulation: PEN 600.00
- 1" EPS ceiling: PEN 160.50
- Replacement of windows with double glazing with air chamber: PEN 2,000.00

Analysis variables and indicators

The data were processed using Python (Pandas, Matplotlib). Anomalous thermal behaviour, interior thermal stability and level of compliance with regulatory thresholds were identified.

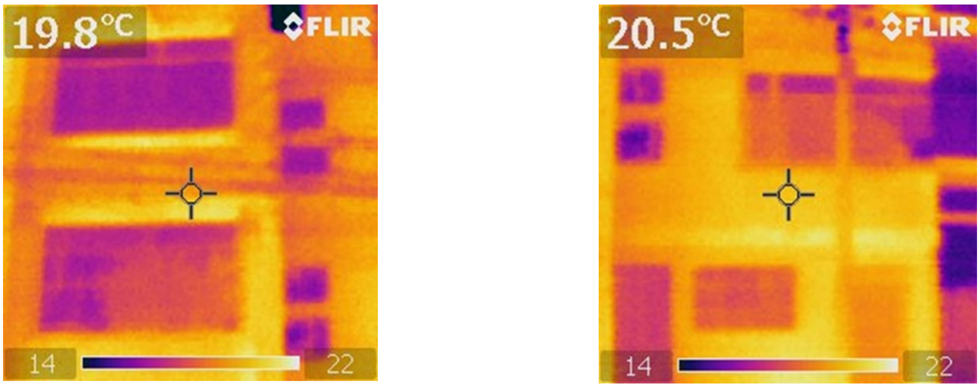
RESULTS

During the contrast stage, the initial thermal state was evaluated using thermographic inspection and energy simulation with DesignBuilder software. The most relevant findings are detailed below:

The thermographic image shows significant thermal differences between window frames, walls and construction joints, suggesting the presence of critical thermal bridges. Surface temperatures range from 14°C to 22°C. The cold areas, represented in violet and blue tones (approximately 14°C), correspond to surfaces with high heat loss, such as single glazing and uninsulated walls. In contrast, the warmer areas, shown in orange, red and yellow tones (up to 22°C), indicate heat accumulation on surfaces exposed to solar radiation or with high thermal inertia. The central cursor registers temperatures of 19.8°C and 20.5°C. These images allow the identification of deficiencies in the building envelope, especially in windows and joints between walls and structural elements, where the lack of insulation facilitates unwanted heat transfer, affecting indoor thermal stability. This analysis is key to establishing the baseline thermal behaviour prior to passive intervention.

Figure 5 shows significant thermal differences between frames, walls and construction joints, highlighting thermal bridges and areas with high heat loss.

Figure 5. Thermographic analysis of heat loss. a) Room to be renovated. b) Control room without intervention.



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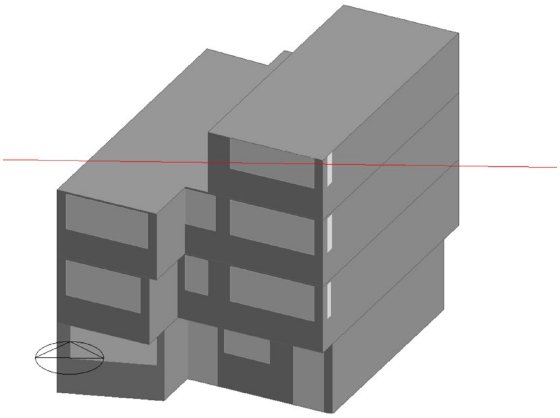
Source: own elaboration.

Figure 6 shows the digital representation of the dwelling modelled in DesignBuilder, used to analyse the initial thermal behaviour through energy simulation.

Figure 6. Energy simulation model in Design Builder.

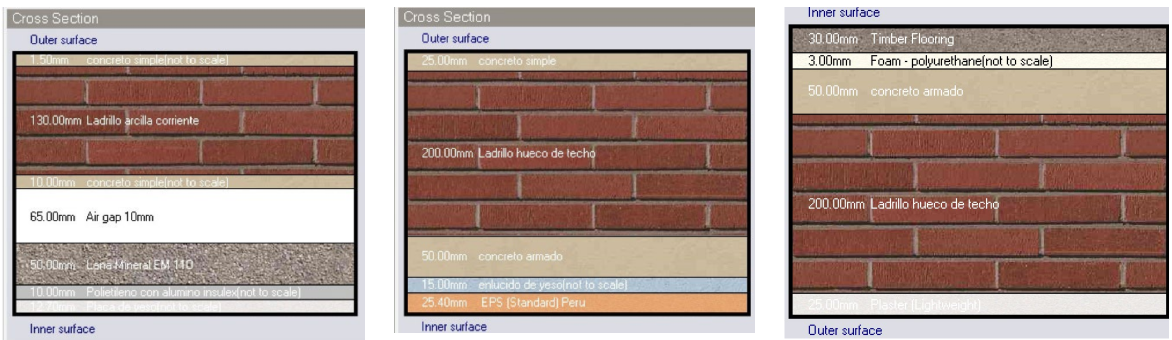


Source: own elaboration.

During the same analysis period, the energy model in DesignBuilder showed heat losses through walls, ceilings and floors, especially at night when the outside temperature drops. Cold discomfort was detected, with operating temperatures dropping to 16 °C, which is insufficient to ensure thermal comfort, especially when resting or wearing light clothing. At this altitude, sensitivity to cold is greater. Although indoor temperatures remain between 16 °C and 18 °C, according to Fanger's criteria, these conditions do not reach acceptable comfort levels.

The simulation showed a thermal transmittance of 2.96 W/m²·K in walls and 1.26 W/m²·K in floors. The EM.110 standard establishes maximum values of 2.7 W/m²· K for walls, 1.20 W/m²·K for floors and 0.8 W/m²·K for ceilings in zone 6 (very cold continental climate), as well as an acceptable range of indoor comfort from 18°C, a threshold that is not always reached according to the results of the simulation and monitoring. After the passive intervention, the thermal transmittance values improved significantly: walls with 0.44 W/m²·K, ceiling with 0.64 W/m²·K and floor with 0.78 W/m²·K, reflecting a substantial improvement in the thermal envelope and, therefore, in indoor comfort, as shown in Figure 7.

Figure 7. Thermal envelope. a) Wall. b) Ceiling. c) Floor.



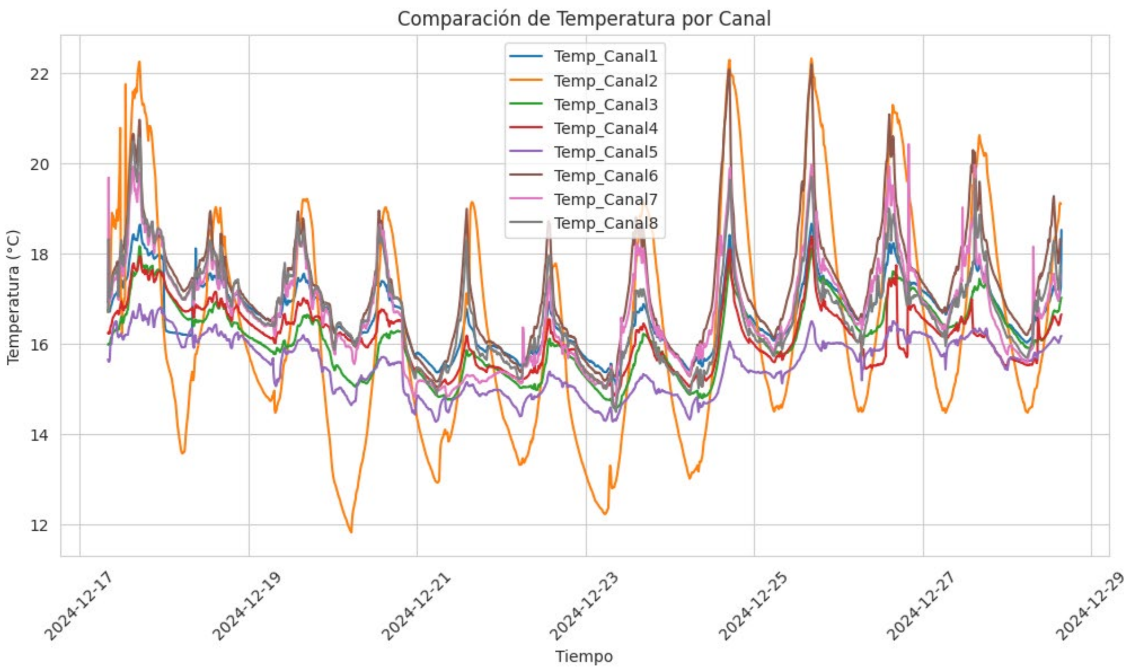
a) b) c)

Source: own elaboration.

In the conclusion stage, thermal behaviour was monitored using MadgeTech RHTemp101A sensors. In condition (1) without insulation, recorded in December 2024, outdoor temperatures ranged from 20°C (maximum) to -2°C (minimum).

The indoor temperatures in the control room fluctuated between 17°C and 10°C, while the relative humidity varied between 70% and 30%. Channel 2, located on the interior window sill of the main façade, showed the greatest thermal variability, indicating a less protected area or one with greater exposure to the environment, as shown in Figure 08.

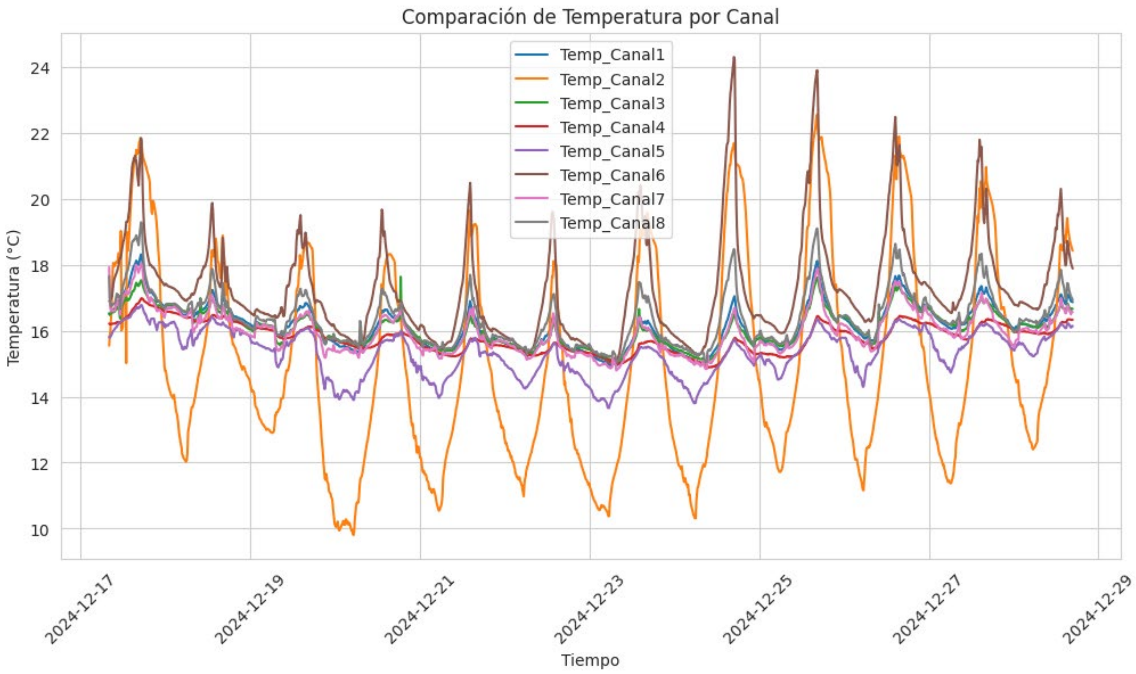
Figure 8. Temperature comparison by channel – Bedroom 03 (control room).



Source: own elaboration.

In the room to be renovated, average indoor temperatures ranged between 22 °C and 10 °C, with relative humidity between 70% and 20%, as shown in Figure 9. Also, channel 2 in this room showed greater thermal variability due to its critical location.

Figure 9. Temperature comparison by channel – Bedroom 02 (room to be refurbished).

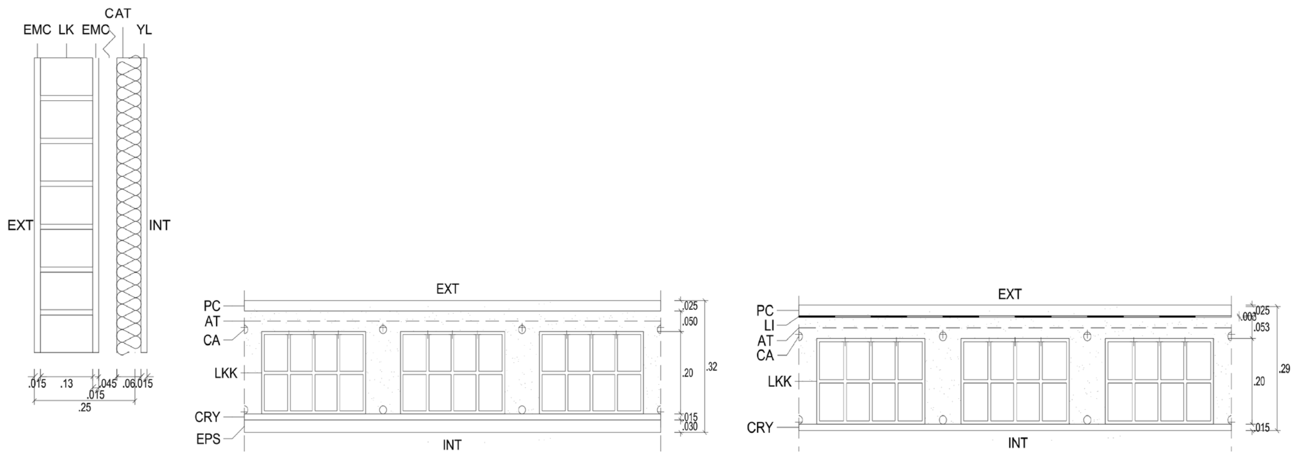


Source: own elaboration.

A slight downward trend in temperature was observed towards the end of the period, possibly due to a seasonal or climatic change, despite it being the summer season. The thermal waves in both rooms show divergent behaviour. In addition, discrepancies were identified between the simulation results and the data obtained through monitoring.

During the exploratory phase, a thermal envelope was implemented consisting of: insulated wall cladding, EPS ceiling, insulated HDF floating floor, exterior cladding and window replacement (from a Moduglass system to double glazing without thermal break), as shown in Figure 10.

Figure 10. Thermal envelope construction detail. a) Interior wall cladding, where: INT = Interior, YL = Plasterboard, AT = Glass wool thermal insulation with vapour barrier, C = Air chamber, EMC = Cement mortar plaster, EXT = Exterior. b) Ceiling, where: EXT = Exterior, PC = Floating floor, AT = Thermal insulation, CA = Reinforced concrete, LKK = King Kong brick for ceiling, CRY = Plaster ceiling, EPS = Expanded polystyrene. c) Floor, where: EXT = Exterior, PC = Floating floor, Li = Polystyrene foam, AT = Thermal insulation, CA = Reinforced concrete, LKK = King Kong brick for ceiling, CRY = Plaster ceiling.



a) b) c)

Source: own elaboration.

Figure 11 shows the implementation of the thermal envelope in exterior walls through cement plastering.

Figure 11. Implementation of the thermal envelope in exterior walls.

Source: own elaboration.

Figure 12 shows bedroom 02 refurbished with the thermal envelope in the floor, wall and ceiling.

Figure 12. Implementation of thermal insulation in the floor, interior walls and ceiling. a) Interior walls with drywall cladding consisting of EPS, glass wool, vapour barrier and plasterboard. b) Floor with insulating foam and HDF laminate flooring (8.3 mm, 19.3 x 1.20 cm); replacement of windows with aluminium double glazing (6 mm) with air chamber without thermal break; ceiling with EPS ceiling (1").


a)


b)

Source: own elaboration.

The total cost of implementing the thermal envelope is PEN 9,000.00, as shown in Table 1. According to Ipsos [18], the average monthly income in Peru ranges from PEN 12,000.00 for socio-economic status A to PEN 1,300 for socio-economic condition E. Therefore, the total cost would be less than one salary for class A and almost seven salaries for class E.

Table 1. Thermal envelope cost for interior renovation

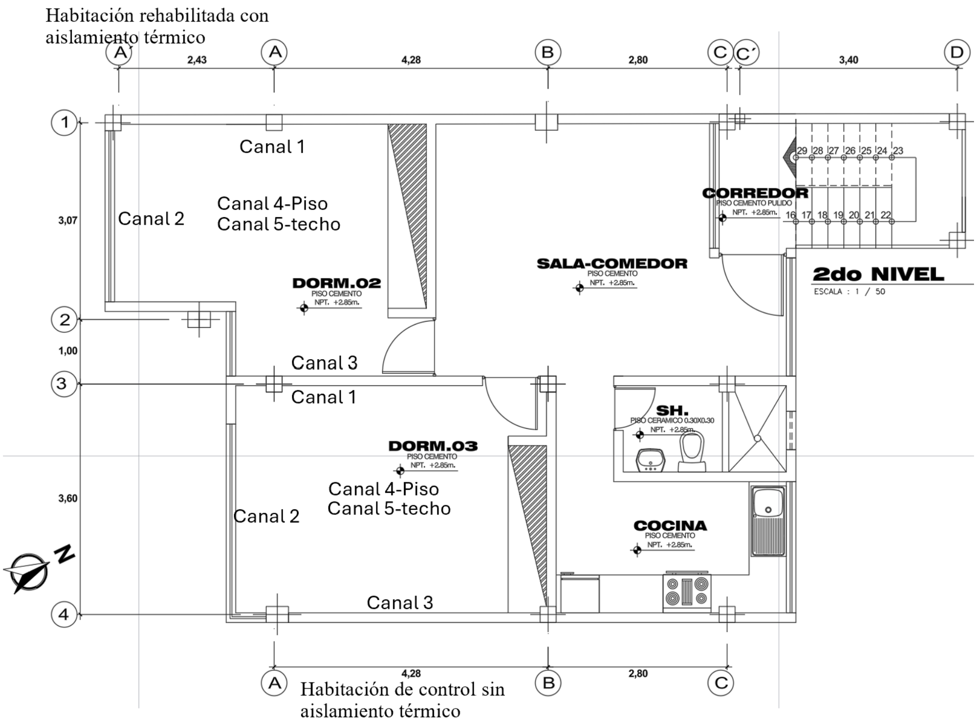
Thermal envelope	Area in sq.m.	Partial cost in PEN
Interior wall	22.00	1,528.00
Exterior wall of control room and insulated room	43.26	1,200.00
Floor	15.24	600.00
Ceiling	16.00	160.50
Window of control room and insulated room	8.60	2,000.00
Interior painting of insulated room		300.00
Installation labour and other transport costs		3,211.50
	Total cost in PEN	9,000.00

Source: own elaboration.

In **condition (3) with complete insulation**, sensors were placed at various points on the envelope to evaluate its thermal performance.

Figure 13 shows the location of the channels: Channel 1 in the dividing wall with the neighbour, Channel 2 in the window sill of the main façade, Channel 3 in the dividing wall with bedroom 03, Channel 4 on floor level 02, Channel 5 on the ceiling. Control room without thermal insulation: Channel 1 on the dividing wall with bedroom 03, Channel 2 on the main façade window sill, Channel 3 on the dividing wall with the neighbour, Channel 4 on floor level 02, Channel 5 on the ceiling.

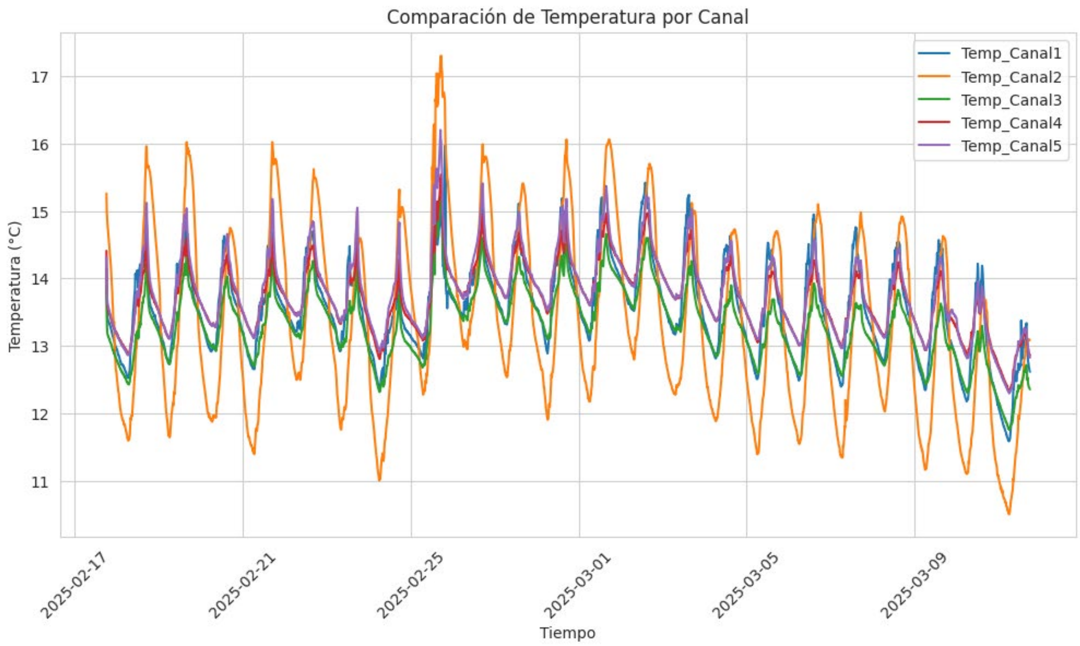
Figure 13**.** Floor plan of the house – location of the sensors (channels).



Source: own elaboration.

In February and March 2025, outdoor temperatures ranged from 18 °C (maximum) to 3 °C (minimum). The indoor temperatures in the control room fluctuated between 17°C and 11°C, while the relative humidity varied between 75% and 55%. Channel 2, located on the interior window sill of the main façade, showed the greatest thermal variability, indicating a less protected area or one with greater exposure to the environment, as shown in Figure 14.

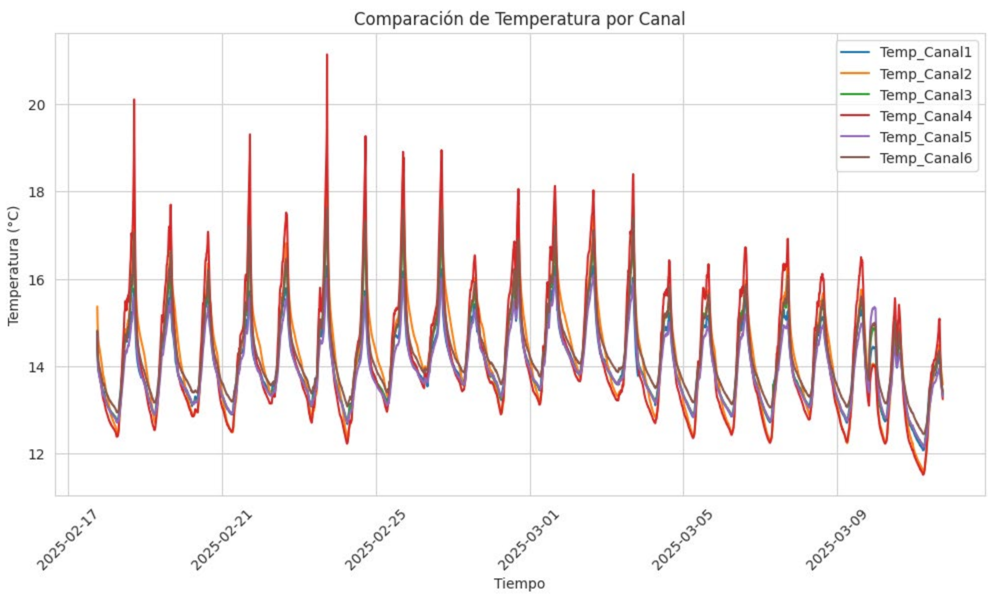
Figure 14. Temperature comparison by channel – Bedroom 03.



Source: own elaboration.

In the room refurbished with interior thermal insulation, indoor temperatures ranged from 20°C to 12°C, with relative humidity between 70% and 45%. Also, channel 2 in this room showed greater thermal variability due to its critical location. However, the temperature waves remain uniform in the other channels, demonstrating that thermal comfort has increased inside the room, as shown in Figure 15.

Figure 15 Temperature comparison by channel - Bedroom 02.



Source: own elaboration.

DISCUSSION

The results of this research are largely consistent with previous studies conducted in similar cold Andean climates, but in different settings. In [7], they demonstrated in a rural setting that a double adobe wall with interior insulation can increase the interior temperature by up to 3 °C. This finding is consistent with the average increase of 2 °C obtained in this research in an urban environment, following the renovation of the thermal envelope in [6], where significant thermal improvements were also demonstrated using lightweight earth panels in homes in southern Peru, validating the effectiveness of low-cost construction solutions.

Likewise, [4] identified windows as the most critical elements in terms of thermal transmittance, which coincides with the initial phase of this study, where these components showed the greatest heat loss. However, unlike these studies, this work implements a progressive and comprehensive intervention in all enclosures (walls, ceilings, floors, and windows), allowing for a more complete analysis of thermal behaviour.

Thermographic analysis revealed significant heat loss in walls and windows, as well as the presence of thermal bridges and air leaks, in line with the findings reported by [19]. This evidence supports the validity of the methodological approach adopted, which seeks to obtain empirical data under real living conditions. Unlike studies focused on simulations or experimental prototypes, this research offers a methodology that can be replicated in contexts of high socio-economic vulnerability, using accessible materials and techniques compatible with local construction.

From a practical perspective, the findings show that improving the thermal envelope not only increases comfort but also contributes to energy efficiency by reducing dependence on active heaters. The indoor temperature in the intervened room increased from 16 °C to 18 °C, with a 10% reduction in relative humidity. With the use of an electric heater, a temperature of 20 °C was achieved, meeting the 90% thermal comfort threshold. In addition, greater stability of the daily thermal wave was observed, which reduces night-time heat loss.

However, the results also show that in areas with extreme climates such as Puno, passive insulation, although effective, may not be sufficient on its own. The incorporation of complementary heating systems, preferably low-consumption ones, continues to be necessary. This highlights the need for combined strategies that integrate passive design, efficient thermal insulation and active technologies adapted to the socio-economic reality of Peruvian social housing.

Despite the improvements achieved, structural limitations inherent to the existing housing were identified, such as the difficulty of incorporating continuous insulation without substantially modifying the original construction elements. This reinforces the importance of integrating thermal insulation from the architectural design phase [20], ensuring its correct execution during construction. The rehabilitation applied in this study proved to be technically feasible, low-cost and effective, as highlighted in [21] and [17], presenting itself as a practical solution to reduce the impact of the cold and improve the health of the occupants.

Finally, this research has implications that go beyond the improvement of a specific dwelling, as it highlights the urgency of strengthening public policies aimed at the thermal efficiency of the housing stock. It is recommended to promote passive design strategies, encourage the use of thermally efficient materials, and establish government incentives for thermal refurbishment in cold areas. Future research could evaluate the long-term impact of these improvements on energy savings, indoor air quality, and occupant health, especially in contexts of high climate vulnerability such as the Peruvian Andes.

CONCLUSIONS

Thermal rehabilitation of the building envelope in homes located in cold areas significantly improves indoor thermal comfort, allowing for an average increase of 2 °C in the average temperature and a 10% reduction in relative humidity according to the intervention conditions evaluated. The application of thermal insulation makes it possible to comply with the minimum requirements established in standard EM110, demonstrating that its current parameters are insufficient to guarantee indoor thermal comfort, and therefore its readjustment is recommended. The strategy employed proves to be both technically and economically viable for implementation in social housing, offering an effective solution to mitigate the effects of extreme cold in high Andean regions. The results obtained underscore the importance of incorporating insulation criteria from the architectural design stage in new buildings, as well as promoting public policies aimed at thermal rehabilitation. Finally, it is recommended that government incentives, technical training and awareness campaigns be promoted to facilitate the adoption of these strategies in low-income housing in Peru.

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REFERENCES

[1] CALVO, Rubén, ÁLAMOS, Nicolás, BILLI, Marco, URQUIZA, Anahí and CONTRERAS LISPERGUER, Ruben, 2011. Desarrollo de indicadores de pobreza energética en América Latina y el Caribe 207 RECURSOS NATURALES Y DESARROLLO. In: *CEPAL - Serie Recursos Naturales y Desarrollo,* vol. 207, pp. 1-88, 2011, [online]. Available at: www.cepal.org/apps

[2] M. Ministerio de Vivienda Construcción y Saneamiento, 2014. *Norma EM.110 Confort Térmico y Lumínico con Eficiencia Energética», Lima, 2014* [online]. Available at: https://waltervillavicencio.com

[3] M. Ministerio de Vivienda Construcción y Saneamiento, 2022. *Norma Técnica EM.110, Envolvente Térmica del Reglamento Nacional de edificaciones, Lima, jul. 2022* [online]. Available at: https://cdn.www.gob.pe/uploads/document/file/3453611/Texto%20EM110%20Norma%20vCPARNE%20VF%2026.07.2022.pdf.pdf [accessed: 30 March 2025].

[4] ESPINOZA CASTILLO, Luis, 2020. *Envolvente arquitectónica para la mejora del confort térmico en edificios multifamiliares certificados de la ciudad de Piura (2016-2019)* [online]. Tesis de maestría. Universidad Ricardo Palma, [accessed: 22 March 2024]. Available at: https://repositorio.urp.edu.pe/handle/20.500.14138/3212

[5] MORO PALOMINO, Maycol Jhorbin, 2020. *Propuesta de materiales ecológicos no tradicionales para construcciones según la norma EM.110* [online]. Bachelor's Thesis. Universidad Privada del Norte, [accessed: 23 March 2024]. Available at: https://repositorio.upn.edu.pe/handle/11537/24794

[6] WIESER, Martín, ONNIS, Silvia and MELI, Giuseppina, 2019. Desempeño térmico de cerramientos de tierra alivianada Posibilidades de aplicación en el territorio peruano, *Revista de Arquitectura*, vol. 22, n.o 1, dic. 2019, doi: 10.14718/revarq.2020.2633.

[7] MOLINA FUERTES, Juan Omar; HORN MUTSCHLER, Manfred Josef; GÓMEZ LEÓN, Mónica Marcela, 2020. Evaluación sistemática del desempeño térmico de un módulo experimental de vivienda alto andina para lograr el confort térmico con energía solar, *TECNIA*, vol. 30, n.o 1, pp. 70-79, may 2020, doi: 10.21754/tecnia.v30i1.841.

[8] ENDARA ÁLVAREZ, Christians Paul and JIMÉNEZ LICONA, Mario Arturo, 2019. *Evaluación de las transmitancias Térmicas de la casa ecológica andina PUCP del distrito de Langui, provincia de Canas-Cusco, según los parámetros de la norma Técnica peruana EM. 110, para mejorar las condiciones de confort térmico de las viviendas de la zona bioclimática alto andina en el Perú* [online]. Bachelor's Thesis. Universidad Andina del Cusco. Available at: https://renati.sunedu.gob.pe/handle/renati/2727892

[9] WIESER, Martín, GARAYCOCHEA, Antonio and PRADA, Varinia, 2023. Improving the thermal performance of schools in the high andean region of Perú. The case of

"PRONIED's prefabricated frost-type modular classrooms", *Habitat Sustentable*, vol. 13, n.o 1, pp. 56-67, jun. 2023, doi: 10.22320/07190700.2023.13.01.05.

[10] GARCÍA-ALVARADO, R., GONZÁLEZ, A., BUSTAMANTE, W., BOBADILLA, A., and MUÑOZ, C., 2025. Características relevantes de la simulación energética de viviendas unifamiliares, *Informes de la Construccion*, vol. 65, n.o 533, 2014, doi: 10.3989/ic.12.108.

[11] MACAS-ESPINOSA, Vicente, PORTILLA-SANCHEZ, Israel, GOMEZ, David, HIDALGO-LEON, Ruben, BARZOLA-MONTESES, Julio. and SORIANO, Guillermo, 2025. Assessment of the energy efficiency and cost of low-income housing based on BIM considering material properties and energy modeling in a tropical climate. *Energies (Basel)*, vol. 18, n.° 6, mar 2025. DOI: 10.3390/en18061500.

[12] TREJO-TORRES, Betzabeth., 2020. Simulación energética de prototipo de vivienda de interés social para evaluar el confort térmico / Energy simulation of a social interest housing prototype to evaluate thermal comfort. *Revista de Ingeniería Civil*, vol. 4, n.° 11, pp. 16–21. DOI: 10.35429/JCE.2020.11.4.16.21.

[13] BONILLA Salazar, Carlos Mauricio and VELASCO BENAVIDES, Juan Carlos, 2017. *Estudio y simulación de la respuesta térmica de dos modelos de vivienda de interés social en las ciudades de Esmeraldas e Ibarra*. Quito, junio 2017. [online]. [accessed: 27 June 2025]. Available at: https://bibdigital.epn.edu.ec/bitstream/15000/17405/1/CD-7906.pdf

[14] MAZZOCCO, Maria Pia, FILIPPÍN, Celina, SULAIMAN, Halimi and FLORES LARSEN, Silvana, 2018. Performance energética de una vivienda social en Argentina y su rehabilitación basada en simulación térmica. *Ambiente Construído*, vol. 18, n.° 4, pp. 215–235, octubre 2018. [online]. DOI: 10.1590/s1678-86212018000400302..

[15] MANGUM, B. W. and HILL, J. E., 1977. *Thermal analysis – human comfort – indoor environments*. Gaithersburg, MD: National Bureau of Standards. [online]. DOI: 10.6028/NBS.SP.491.

[16] MINO-RODRIGUEZ, Isabel, KOROLIJA, Ivan and ALTAMIRANO, Hector, 2018. *Thermal comfort in dwellings in the subtropical highlands: case study in the Ecuadorian Andes*. Windsor, agosto 2018. [online]. [accessed: 27 June 2025]. Available at: https://discovery.ucl.ac.uk/id/eprint/10123813/7/Altamirano_red2018_Mino-RodriguezKorolijaAltamirano_ThermalcomfortindwellingsinthesubtropicalhighlandsCasestudyintheEcuadorianAndes.pdf

[17] CANETTI, Rocío Belén, 2016. *Aislantes térmicos alternativos para vivienda adecuada: una propuesta de diseño, social y ambientalmente sustentable*. Buenos Aires, 2016. [online]. [accessed: 27 June 2025]. Available at: https://host170.sedici.unlp.edu.ar/server/api/core/bitstreams/f12089a6-0b7a-49cd-b3ca-d52b72c33d03/content

[18] IPSOS – Investigación de Medios y Comunicación de Marca, 2020. *Perfiles socioeconómicos de Lima Metropolitana 2020*. Innovación y Conocimiento: Investigación de Medios y Comunicación de Marca, n.° especial, p. 12. [online]. [accessed: 27 June 2025]. Available

at:https://www.ipsos.com/sites/default/files/ct/publication/documents/2021-01/nse_2020_v2.pdf

[19] APARCO RAMOS, Jhordy Jhorman, 2019. *Patologías térmicas de origen físico en la envolvente del Pabellón "O" correspondiente a la Escuela Profesional de Ingeniería Civil, mediante termografía infrarroja* [online]. Bachelor's Degree. Universidad Nacional de Huancavelica [accessed: 27 June 2025]. Available at: https://apirepositorio.unh.edu.pe/server/api/core/bitstreams/c3a201b7-ebe5-40d9-9f6c-99e36141cfa6/content

[20] ARENAS CORUJO, Romina, 2014. Potencial de ahorro de energía térmica en el sector de la vivienda en España, según las directrices establecidas por las políticas energéticas comunitarias y nacionales. Aplicación a un edificio de viviendas de catorce plantas de Gijón (Asturias). *Congreso Nacional del Medio Ambiente*, 2014, pp. 1–16. [online]. [accessed: 27 June 2025]. Available at: https://www.conama.org/conama/download/files/conama2014/CT%202014/1896711520.pdf

[21] SANTA MARÍA, Rosario, 2008. *La iniciativa de vivienda saludable en el Perú*. *Revista Peruana de Medicina Experimental y Salud Pública*, vol. 25, n.° 4, pp. 419–430.