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WIDESPREAD APPLICATION OF REHABILITATION STRATEGIES FOR WALLS OF PUBLIC HEALTHCARE CENTERS IN TUCUMÁN, ARGENTINA

ESTRATEGIAS DE REHABILITACIÓN DE APLICACIÓN GENERALIZADA EN MUROS DE CAPS EN TUCUMÁN, ARGENTINA

ESTRATÉGIAS DE REABILITAÇÃO DE APLICAÇÃO GENERALIZADA EM PAREDES DE CENTROS DE ATENÇÃO PRIMÁRIA À SAÚDE EM TUCUMÁN, ARGENTINA

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RESUMEN

Este trabajo aborda las deficiencias térmico-energéticas presentes en la envolvente vertical de los Centros de Atención Primaria de Salud (CAPS) en San Miguel de Tucumán, Argentina donde estudios previos revelan un desempeño inadecuado de sus muros, generándose una elevada demanda energética. Con el objetivo de proponer estrategias de rehabilitación masiva aplicables a los diversos tipos de soluciones constructivas existentes, se evalúan diferentes soluciones de aislamiento térmico que consideran sus prestaciones térmicas, costo económico y ciclo de vida. Mediante un análisis multicriterio con cálculo de ponderación, se seleccionaron las propuestas más convenientes. El análisis de la mejora en diez casos representativos evidencia un ahorro promedio de 21,32 %. en calefacción y 15,41 % en refrigeración. Se concluye que la implementación de las estrategias seleccionadas presenta un potencial significativo para optimizar el comportamiento térmico y reducir la demanda energética en los CAPS de la región.

Palabras clave
centros de salud, aislación térmica, muros, rehabilitación

ABSTRACT

This work addresses the thermal-energy deficiencies in the vertical envelope of Primary Health Care (PHC) Centers in San Miguel de Tucumán, where previous studies reveal inadequate performance of their walls, resulting in a high energy demand. Different thermal insulation solutions are evaluated based on their thermal performance, economic cost, and life cycle to propose widespread rehabilitation strategies for the diverse types of existing construction solutions. The most convenient proposals were selected using a multi-criteria analysis with a weighting calculation. The analysis of the improvement in ten representative cases shows an average saving of 21.32% in heating and 15.41% in cooling. It is concluded that implementing the selected strategies has a significant potential to optimize thermal behavior and reduce energy demand in the region's PHC Centers.

Keywords
health centers, thermal insulation, walls, rehabilitation

RESUMO

Este trabalho aborda as deficiências térmico-energéticas presentes na envolvente vertical dos Centros de Atenção Primária à Saúde (CAPS) em San Miguel de Tucumán, Argentina, onde estudos prévios revelaram um desempenho inadequado das paredes, gerando uma elevada demanda energética. Com o objetivo de propor estratégias de reabilitação em larga escala aplicáveis aos diversos tipos de soluções construtivas existentes, são avaliadas diferentes soluções de isolamento térmico que consideram suas performances térmicas, custo econômico e ciclo de vida. Por meio de uma análise multicritério com cálculo de ponderação, foram selecionadas as propostas mais convenientes. A análise da melhoria em dez casos representativos evidencia uma economia média de 21,32% em aquecimento e 15,41% em refrigeração. Conclui-se que a implementação das estratégias selecionadas apresenta um potencial significativo para otimizar o comportamento térmico e reduzir a demanda energética nos CAPS da região.

Palavras-chave:
centros de saúde, isolamento térmico, paredes, reabilitação

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INTRODUCTION

There is a growing consensus on the importance of climate change and the role of anthropogenic greenhouse gas emissions (Recalde et al., 2018; Mora-Barrantes et al., 2021). Global energy consumption is recognized as a central cause (Gómez Cerdeiro, 2021; Mercado Burciaga, 2023). The building sector, recognized as a significant contributor to this crisis (Flores, 2021; Ortega-Díaz et al., 2023), currently accounts for approximately 40% of CO_2 emissions and one-third of the world's energy consumption (Muñoz-Rojas et al., 2023; Abdou et al., 2021). Air conditioning is a determining factor (Kuchen & Kozak, 2020; Galindo-Borbón et al., 2024) due to the increasing demand for thermal comfort (Daioglou et al., 2022; Andersen et al., 2019). The building envelope is responsible for a substantial part of the energy losses (Ascione et al., 2019; Bacelis et al., 2024), and offers considerable potential for consumption optimization and reduction (Wang et al., 2019; Costantini-Romero & Francisca, 2022). In this context, any action aimed at reducing energy demand through the rehabilitation of the envelope's materiality becomes relevant (Ré & Filippín, 2021). In Argentina, the building sector is responsible for nearly 37% of the final energy consumption, led by the residential sector, followed by the commercial and public sector, where the Health subsector is located, which accounts for 8.35% of this (Ministry of Economy, 2023). Although this subsector has a lower share of final energy consumption than other sectors, it is characterized as a public service of social interest (Urteneche et al., 2022).

The city of San Miguel de Tucumán (SMT), located in northwestern Argentina, has a subtropical climate characterized by a dry season, dry winters, and rainy summers, with annual rainfall exceeding 1000 mm and temperatures exceeding 40 °C (González & Ceballos, 2021; Giovino et al., 2022). There are 32 PHCs (Public Healthcare Centers) that constitute the health infrastructure for the local community. Previous studies conducted in these PHCs (Fernández & Garzón, 2023; Fernández & Garzón, 2024) have shown a significant energy inefficiency associated with thermal conditioning and deficiencies in the hygrothermal behavior of their vertical envelopes. This situation directly affects the comfort of patients and staff, generates high operating costs, and increases energy demand on the local grid. Therefore, improving the thermal performance of these buildings is relevant not only from a comfort and efficiency perspective, but also contributes to regional environmental sustainability.

This work aims to generate systematic rehabilitation strategies for the exterior vertical enclosures (EVEs) of Primary Health Care (PHC) centers in SMT, designed for their widespread application in the existing building stock. In this context, the term *systematic* refers to an evaluation and selection methodology based on defined and replicable criteria. At the same time, *mass application* focuses on its replicability potential in multiple buildings with similar typologies. The innovation of this research is based on the proposal of an original methodology for evaluating and selecting these strategies. This methodology is based on a weighting system that considers the economic cost, thermal performance, and life cycle analysis (LCA).

METHODOLOGY

This study proposes an analysis of rehabilitation strategies for the vertical envelope of the PHCs located in SMT. Initially, the thermal properties of the vertical envelope are analyzed, followed by the definition of proposals and their constructive feasibility for the context. Then, each proposal is evaluated from three perspectives: economic cost, thermal properties, and LCA.

In the thermal analysis, the thermal resistance of each rehabilitation proposal is calculated according to the procedure established in the IRAM 11601 (2002) standard. For this, equation 1 is considered, where the thermal resistance of a flat component, formed by several homogeneous layers (R_t), is equal to the sum of the resistances of each of those layers (R1, R2, ..., Rn) in m^2W/K. In turn, equation 2 is used to determine the resistance of the different layers (R), where R is equal to the ratio between the thickness of the layer (e) in meters and the thermal conductivity of the material (λ) expressed in W/mK.

$$R_t = R_1 + R_2 + \ldots + R_n + R_{c1} + R_{cn} \quad (1)$$

$$R = e/\lambda \quad (2)$$

To evaluate the LCA, the Design Assistance Tool for a More Sustainable Building (HADES) is used. HADES is an open-source software developed by the Industrial Construction Institute of Catalonia (ITeC), designed for the environmental analysis of materials and construction elements. It is based on the principles and methodological framework established in the ISO 14040 (2006) and ISO 14044 (2006) standards. The choice of HADES is based on its accessibility, intuitive interface, and extensive database of common construction materials in the Spanish and Latin American context, which facilitates the modeling of the rehabilitation proposals considered in this study. The indicators considered and evaluated in this case are embodied energy (MJ/m²), which indicates the non-renewable energy

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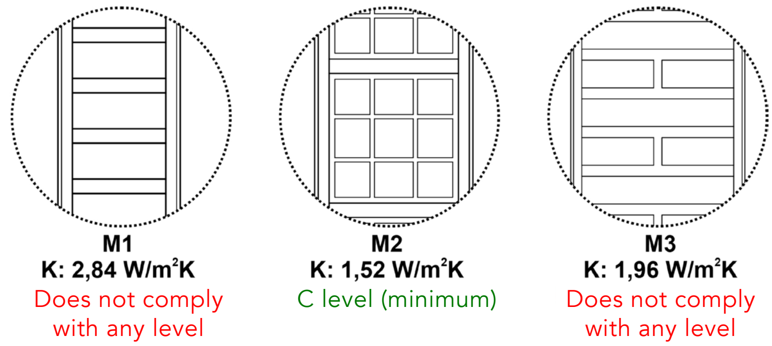

Figure 1. Wall construction solutions, thermal transmittance coefficients, and hygrothermal comfort levels. Source: Preparation by the Authors.

consumed during the materials' life cycle, and CO_2 equivalent emissions (kCO_2eq/m^2), which quantify the associated greenhouse gas emissions.

For the economic analysis, the direct costs of materials and labor necessary to implement each rehabilitation proposal were considered. Unit prices were established based on SMT's local market, averaging different points of sale in the city for the materials. Labor costs were based on up-to-date values from the UOCRA (Construction Workers Union of the Argentine Republic), corresponding to November 2024. The cost per square meter of each proposal was calculated in isolation, excluding specific completion details that may vary depending on the particular case. The values were expressed in US dollars.

Based on these analyses, the most relevant strategy was selected using our own numerical weighting methodology, which was designed to objectively determine the most effective one. To each of the mentioned criteria, the same percentage weight was awarded. In turn, within each criterion, a score from 1 to 10 was assigned to the different proposals, where 1 represents the worst performance and 10, the best. The assignment of scores was based on ranges of values defined for each indicator. The total score obtained for each proposal was calculated by adding the score obtained in each criterion. The proposal with the highest total score, which represents the best balance between the evaluated criteria, was considered the optimal option for rehabilitation.

Finally, the global seasonal thermal behavior of 10 existing PHCs in SMT was evaluated, selected using a non-probabilistic convenience sampling (Scharager & Reyes, 2001) to represent the diversity of construction typologies identified in the building stock. The selection criteria include the representativeness of the existing vertical envelope types, as well as variations in location and orientation. This selection was made to allow for a greater depth of analysis of the thermal behavior of a manageable number of cases. For each of these 10 PHCs, its existing vertical envelope is defined in the CIDEE-EA calculator (Elsinger et al., 2021), from the constructive details revealed *in situ*. Subsequently, the application of the selected rehabilitation proposal to the vertical envelope of each of the 10 PHCs was modeled, with the thermal transmittance values updated according to the properties of the rehabilitation solution. The annual heating and cooling thermal loads, as defined by IRAM 11604 and IRAM 11659-1 standards, were analyzed. The original case was compared with the rehabilitated case, and the percentage impact of the improvement in the overall thermal behavior was analyzed for each of the 10 representative PHCs.

RESULTS

CHARACTERIZATION OF PHCS' WALLS

The EVEs of all the PHCs in SMT are made from ceramic brick masonry. Three constructive solutions are distinguished: M1, solid 0.15 m ceramic brick masonry plastered on both sides with earthquake-resistant chaining; M2, hollow 0.20 m ceramic brick masonry plastered on both sides; and M3, solid 0.30 m ceramic brick masonry plastered on both sides. The most typical case is the M2, which is the constructive solution for 37.04% of the PHCs. It is followed by M3, with 33.3%, then the M1 wall with 18.52%. Finally, 11.11% of the buildings combine the M2 with M3, which are buildings that underwent later extensions (Fernández & Garzón, 2021).

The thermal transmittance levels for each case are presented below (Figure 1), along with their verification against the hygrothermal comfort levels recommended by IRAM (A: ecological, B: recommended, and C: minimum). It is observed that in no case is the recommended level met, and only the M2 type wall complies with the minimum level.

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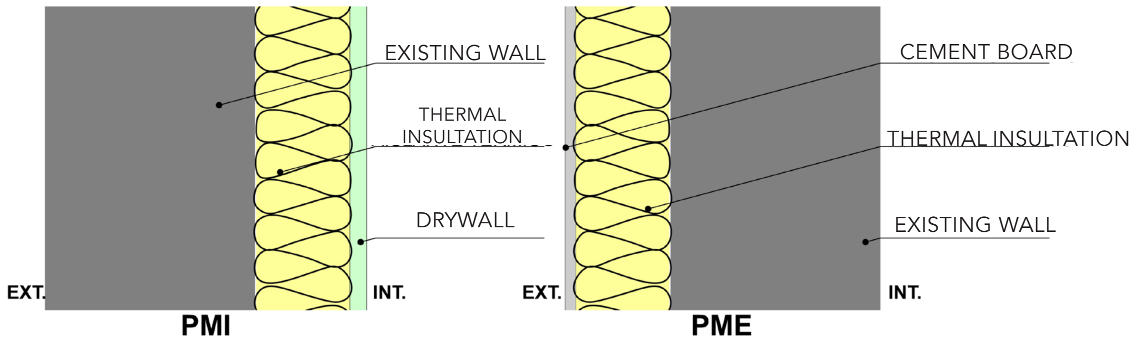

Figure 2. Outline of proposals for the rehabilitation of interior (PMI) and exterior (PME) EVE. Source: Preparation by the Authors.

Table 1. Main technical characteristics of insulation found in the local market. Source: Preparation by the Authors.

Characteristics	Expanded polystyrene (EPS)	Glass wool (GW)	Rock wool (RW)
Origin	Synthetic	Mineral	Mineral
Structure	Closed cells	Fibrous	Fibrous
Fire behavior	Self-extinguishing	Incombustible	Incombustible
Water vapor permeability	Low	High	High
Density	Low 16 to 19 kg/m3	Medium 30 to 70 kg/m3	Medium-high 35 to 160 kg/m3
Mechanical resistance	Low	Medium	Medium-high
Price	Medium	Medium	High

Table 2. Definition and assignment of nomenclatures in the six rehabilitation proposals. Source: Preparation by the Authors.

Proposal number	Location of the insulation	Type of insulation	Proposal name
1	Exterior	EPS	PME_1
2	Exterior	GW	PME_2
3	Exterior	RW	PME_3
4	Interior	EPS	PMI_1
5	Interior	GW	PMI_2
6	Interior	RW	PMI_3

PRESENTATION OF PROPOSALS

The rehabilitation strategies applicable to the walls are presented below. In all cases, they consist of incorporating an intermediate thermal insulation and a surface finishing material. For this, the incorporation of the insulation on the inner (PMI) and outer (PME) faces is proposed (Figure 2). The types of insulation are selected for their permanent availability in the SMT market, as well as for being materials that the local workforce can apply. It is essential to note that for the proposed system to be effective, it must be implemented appropriately. These are expanded polystyrene in sheets, glass wool with aluminum, and rock wool with aluminum. In Table 1, the main characteristics of the selected insulating materials are presented.

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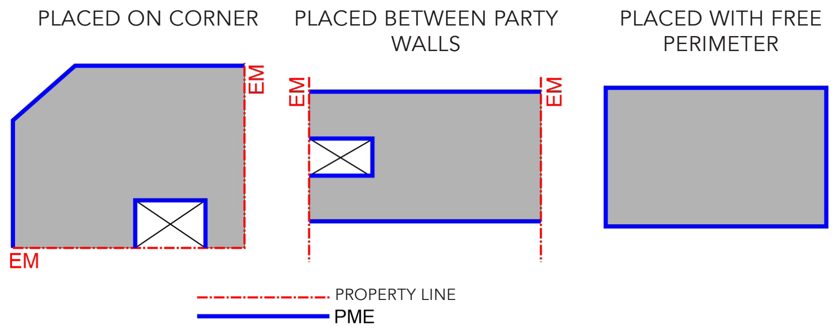

Figure 3. Layout of the PME application depending on the type of site. Source: Preparation by the Authors.

Table 3. Comparative analysis of the main characteristics of each of the proposals made. Source: Preparation by the Authors.

Proposal nomenclature	Thermal resistance [m2W/K]	Embodied energy [MJ/m2]	CO2 equivalent [kCO$_2$eq/m2]	Economic cost in [U$S/m2]
PME_1	1.93	30,660	3491	60.59
PME_2	1.74	26,621	2185	58.94
PME_3	2.16	21,884	1773	78.52
PMI_1	1.95	30,419	3450	32.36
PMI_2	1.77	26,381	2144	30.71
PMI_3	2.18	21,644	1733	50.30

It is proposed to incorporate insulation through galvanized sheet profiles available on the market, which are of standard sizes, along with drywall for the interior and fiber cement for the exterior. The measurement adopted for the profile and insulation is 70 mm thick. As a result of these combinations, three types of insulation with two placement possibilities yield six wall rehabilitation proposals. The acronyms PME are assigned for exterior wall proposals and PMI for interior ones; in turn, number one is assigned for those with expanded polystyrene, number two for glass wool, and number three for rock wool. The nomenclature assigned for each proposal considered is shown in Table 2.

CONSTRUCTIVE FEASIBILITY

The geometric configuration and location of each building condition the implementation of the PMEs. Three types were detected: between party walls (42.3%), corner supported by two party walls (42.3%), and free perimeter (15.38%). Although these solutions offer the advantage of being able to be implemented without interrupting the health center's activities, their application is limited in cases where the building is attached to walls. In these situations, intervention on a global scale is only viable within the walls that adjoin the public road or with internal patios (Figure 3). This is because the application of this system requires a sufficient workspace for the placement of the constructive elements and the subsequent finishing. In the case of buildings located in free perimeters, the constructive feasibility is total, allowing for the intervention on all exterior walls.

On the other hand, the PMIs, although they require the temporary interruption of PHC activities, have the advantage of being applicable in all indoor spaces without restrictions. By being executed inside the building, the need to consider external factors, such as weather protection, is eliminated, which simplifies logistics and reduces the execution costs and risks of future pathologies. To minimize the impact on public attention, it is recommended to carry out the work in stages, where each environment is intervened upon independently.

DETAILED ANALYSIS OF THE PROPOSALS

The main characteristics of the proposals made are presented below (Table 3). Initially, the thermal insulation is analyzed. To do this, on the one hand, the thermal resistance of each solution is studied in isolation. Secondly, the LCA of each proposal is studied using the HADES tool, considering the indicators mentioned in the methodology. Finally, the

Table 4. Comparison of total score between thermal insulation, economic cost, and environmental impact for wall rehabilitation proposals. Source: Preparation by the Authors.

Proposal nomenclature	Thermal insulation	LCA	Economic cost	TOTAL
PME_1	8.85	7.06	5.07	20.98
PME_2	7.98	8.13	5.21	21.32
PME_3	9.91	9.89	3.91	23.71
PMI_1	8.94	7.12	9.49	25.55
PMI_2	8.12	8.20	10.00	26.32
PMI_3	10.00	10.00	6.11	26.11

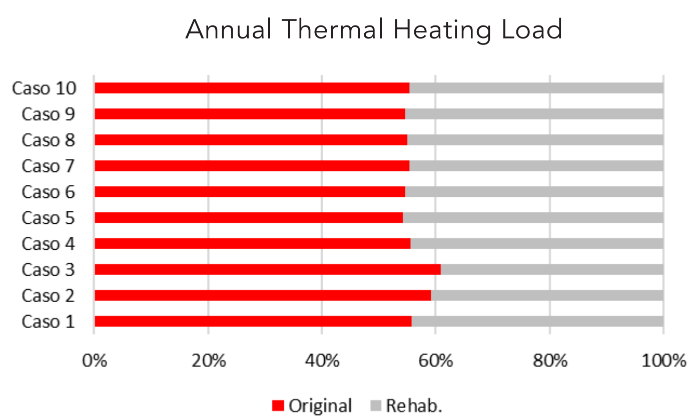

Figure 4. Annual thermal heating load, expressed in percentage for 10 existing PHCs in SMT in its original version and with the EVE rehabilitation proposal. Source: Preparation by the Authors.

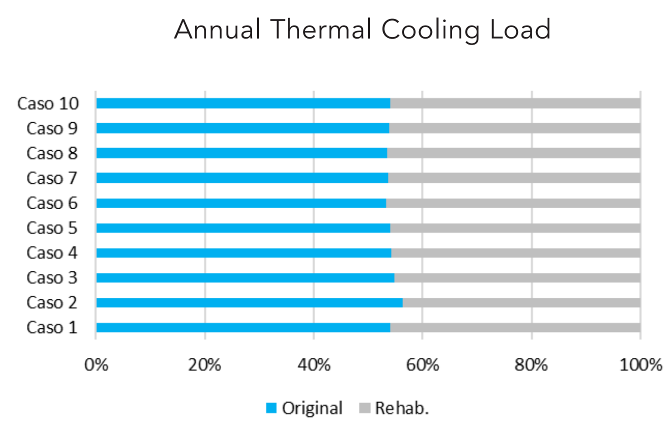

Figure 5. Thermal cooling load, expressed as a percentage for 10 existing PHCs in SMT in its original version and with the EVE rehabilitation proposal. Source: Preparation by the Authors.

unit economic cost is evaluated in US$/m² for each of them. In Table 3, these properties are expressed for each of the proposals made.

WEIGHTING AND SELECTION OF THE PROPOSAL

To select the most appropriate proposal in terms of cost-benefit ratio, a score is assigned to each proposal based on its performance in each considered criterion, and these scores are then added together. This score ranges from 1 to 10; the highest score is awarded to the proposal that performs best in each specific criterion. For example, in economic cost, a score of 10 is given to the one with the lowest price. The rest of the proposals will be evaluated proportionally, that is, the closer a proposal comes to the best performance in a factor, the higher its score will be. This assignment of scores is based on a simple rule of three, which allows an objective quantification of the performance of each proposal compared to the others.

The proposal with the highest score for walls is the PMI_2 (Table 4). In this comparative analysis, it is seen that the variation between proposals in terms of thermal insulation is 20%. In contrast, the economic cost variation is more significant, approaching 50%, and the environmental impact variation is 30%. Moreover, the interior proposals have a better cost-benefit ratio, as they are more cost-effective and sustainable than the exterior ones.

APPLICATION OF THE PROPOSAL TO EXISTING CASES

Finally, the thermal behavior of the selected rehabilitation proposal applied to ten existing PHC cases in the city of SMT is analyzed globally. The variants considered are the annual heating thermal load (kWh) and the cooling thermal load (W). The graphs shown below (Figure 4 and Figure 5) present a comparative analysis of both variants, for each case in its original version and with the proposed wall rehabilitation.

In both variants, a significant improvement in the overall thermal performance is observed across the

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different cases. For the annual heating thermal load, the improvement ranges from 17 to 30%, with an average value of 21.32%. In the case of the cooling thermal load, this ranges from 13 to 22%, with an average of 15.41%.

DISCUSSION

The evaluation of the thermal behavior of the EVE existing in the PHCs reveals, in general, high thermal transmittance values (K). Values of up to 2.84 W/m²K are recorded, which significantly exceed the value recommended by the IRAM standard of 1.10 W/m²K for warm areas. These high values have a direct impact on user thermal comfort, as they make it difficult to maintain a stable and comfortable indoor temperature. Additionally, it has a significant impact on the energy consumption of buildings, increasing the demand for HVAC systems to compensate for heat losses or gains through the envelope, which in turn translates into higher operating costs and a larger carbon footprint.

In this work, it is concluded that the most suitable proposal for the rehabilitation of walls in PHCs in SMT is PMI_2 (application of glass wool as an insulating material on the inner face). An additional factor that reinforces the desirability of the internal proposals is their feasibility of application in all the cases of PHCs analyzed, as detailed in the Feasibility section. This characteristic of universal applicability, added to its favorable performance in the evaluated criteria, makes it an optimal constructive intervention for generalized rehabilitation.

The analysis of the rehabilitation solutions evaluates each proposal in isolation. Although this allows an objective comparison in terms of thermal properties, cost, and sustainability, the specific constructive implications for each PHC are not considered in detail. The actual application of these solutions could lead to a greater use of materials, and consequently, an increase in environmental impact and total economic cost of the intervention.

Regarding the risks and uncertainties associated with the proposed solutions, it is essential to acknowledge that the long-term durability of insulating materials, particularly in indoor applications, may be influenced by factors such as humidity and temperature fluctuations. Inadequate maintenance could compromise the rehabilitation's efficiency over time. Therefore, it is essential to have specific installation and maintenance protocols to guarantee the effectiveness and durability of the implemented solutions.

CONCLUSIONS

This study addresses the problem of energy deficiency in SMT's PHCs and proposes rehabilitation strategies for its widespread application in the vertical envelope. The main result shows that incorporating thermal insulation on the inner faces of the walls is the most appropriate rehabilitation strategy from an economic, sustainability, and feasibility perspective. Likewise, glass wool is identified as the most suitable product on the local market due to its cost-thermal performance ratio and environmental impact. The implementation of this strategy demonstrates a significant improvement in the overall thermal energy behavior of the analyzed PHCs, with an average reduction of 15% in the cooling thermal load and 20% in the heating thermal load.

The rehabilitation of vertical envelopes in PHCs yields multiple benefits. The reduction of energy consumption and improvement of thermal comfort contribute to the sustainability of health services by minimizing their environmental footprint and optimizing the quality of life for both users and healthcare personnel. These results are aligned with the growing need to implement energy efficiency measures in the building sector, specifically in its envelope, as pointed out by several authors cited in this work (Ascione et al., 2019; Bacelis et al., 2024; Wang et al., 2019; Costantini-Romero & Francisca, 2022; Ré & Filippín, 2021).

This research contributes a methodology for evaluating envelope rehabilitation strategies based on the application of IRAM standards, as well as technical, economic, and environmental criteria. Its replicability potential allows addressing energy efficiency challenges in various types of buildings, public and private. In this sense, the results and the methodology offer valuable information for the formulation of public policies. These should focus on the sustainability of the health infrastructure at both the local and national levels by promoting the adoption of energy rehabilitation solutions that consider technical and life-cycle criteria. For future lines of research, it is suggested to explore the implementation on a larger scale, the impact of user behavior, and the integration of active HVAC systems for comprehensive energy optimization. Finally, it is concluded that the energy rehabilitation of the envelope in PHCs is a concrete and practical step towards the sustainability of public health infrastructure.

CONTRIBUTION OF AUTHORS CRediT

Conceptualization, A.F., B.S.G.; Data curation, A.F., B.S.G.; Formal analysis, A.F., B.S.G.; Acquisition of financing, not applicable; Research, A.F.; Methodology; A.F., B.S.G.; Project management, B.S.G.; Resources, A.F., B.S.G..; Software. A.F., B.S.G.; Supervision, B.S.G.; Validation, A.F., B.S.G.; Visualization, A.F., B.S.G.; Writing - original draft, A.F., B.S.G.; Writing - revision and editing, A.F., B.S.G.

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