ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.745

Energy Performance Design and Analysis of a Passive Collector System Applied to an Andean House

Francisco, Soto Holgado[1], and Rubén Alfredo, Salcedo Guillén[2]
[1,2]Universidad Tecnológica del Perú, Perú, arquitectofranciscosoto@gmail.com, rubensalcedo02@gmail.com

Abstract*– The study presents and analyzes a housing module design with a passive collector system that collects via thermal inertia and air convection. The aim is to find an optimal response to the climatic conditions of the meso- and high-altitude Peruvian Andes regions, which are located in the city, province, and region of Cusco. The analysis and comparison of the thermal responses of the proposal and the traditional module, whose data were obtained using Design Builder, are conditioned by average temperatures below 12°C, which reach below 0°C from June to August. The results show that the project outperformed the traditional module in terms of energy performance, with average solar gains of 95 kWh/day and increased average indoor and outdoor air temperatures of 6°C and 8°C, respectively. This demonstrates that the thermal comfort of buildings can be improved by properly establishing relationships between collector surface, habitable volume, inertia, and thermal material transmittance.

Keywords-- Andean House; Energy Performance; Thermal comfort; Passive Collector; Thermal inertia.

I. INTRODUCTION

The Peruvian land is characterized by being longitudinally crossed by the Andes. This geographic condition results in diverse climatic and altitudinal regions. Based on this, the National Meteorological and Hydrological Service of Peru (Servicio Nacional de Meteorología e Hidrología del Perú, SENAMHI) [1] categorizes the country's climates using the Thornthwaite methodology. As a result of analyzing the effective precipitation, seasonal humidity concentration, and thermal efficiency indexes from over 480 meteorological stations located across the country, 38 types of climates are identified.

Additionally, considering the orography of the land, and thus altitude as an essential factor, the National Building Regulation [2] uses this data as the primary factor to determine that the territories whose altitude varies between 3000 and 4800 MSL correspond to the meso- and high Andean regions. Around 6 million people live in these rural areas. Likewise, based on information from the National Center for Disaster Risk Estimation, Prevention, and Reduction [3] these regions are distributed in the departments of Puno, Cusco, Arequipa, Moquegua, Junín, Ayacucho, Apurímac, Cajamarca, and La Libertad.

Digital Object Identifier: (only for full papers, inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).
DO NOT REMOVE

These regions have an average annual temperature of 6°C in the high Andean region and 12°C in the meso-Andean region, with average minimum temperatures that can fall below zero. In the winter months, and even from May to September, these conditions are intensified by "frosts," a phenomenon that causes health problems such as respiratory tract diseases, the most common and with the highest mortality rate. According to the Ministry of Health, between 2013 and 2018, an average of 1200 cases and 14 deaths per year caused by pneumonia were reported in the departments mentioned.

Authors in [4]claims that the compact balcony, altarpiece, patio, or court, and the putuco types exist in the architectural field, in the building tradition developed in the referenced Peruvian regions, whose foundation is tradition and empirical knowledge. However, buildings and houses in such regions operate precariously in their autonomous thermal aspects. They are not prepared to counter the climatic conditions imposed by the region, partly owing to a lack of specialized technical advice or a lack of interest in studies on the subject.

In this regard, it appears that the proposals and research consulted share a common denominator of a particular concept of passive heating systems or their implementation in housing, which is conceptually or metaphorically similar to the operation of a type of prosthesis that allows reaching acceptable levels in the power operation of such buildings. Therefore, metaphorically speaking, the goal of this research proposal is not the development of a new prosthesis, but rather the amalgamation of the built and the prosthetic options in a single device that can be replicated not only in domestic uses, but also in other options that need autonomous heating during operating hours.

II. BACKGROUND

To begin research and diving into such topics, we must first determine which variables influence the energy performance of traditional Andean houses in Peru. Thus, it has been found that, among the main variables, we can list the climate, the social characteristics of the population or community, and the technical training of future house builders, as mentioned by [5], [6], The first author also includes sanitation and hygrothermal comfort; the second research study includes ventilation, material thermal inertia, and energy use; and the final study includes bioclimatic indexes and thermal problem-solving strategies.

Starting from this point, it is deemed necessary to perform an initial classification of the identified research. The first point to mention is the energy performance of the architectural object and the use of passive heating systems. The second point will be to analyze the physical and typological characteristics that will determine the thermal behavior of the object.

Regarding the first point, [7] prepared a prototype using two main strategies: using materials with high thermal inertia (such as adobe reinforced with mesh, a plaster made with clay and hay) and using roof openings, such as skylights, to guarantee the thermal gain of specific living spaces at midday. This study also analyzes the thermal behavior of initial models and their improvement using the Design Builder software. The results of installing a direct thermal collector and improving insulation plaster materials show a thermal gain of 5°C inside the house.

During the second research stage, which included improving the prototype analyzed using Design Builder, the strategies applied were improved by increasing thermal insulation and changing the size of the skylight to increase its area and the resulting direct solar gain. Such improvements were subsequently confirmed with a thermal camera, which revealed that the temperature inside the prototype was 5°C higher. This means that the total temperature reached 10°C compared to a typical house in the area.

According to [8], roof span usage was complemented with greenhouses attached to the walls. In this project, which was developed in the village of Imata, they used the EnergyPlus software to analyze five experimental modules proposed. It was determined that "Experimental Module 5" had the best thermal performance. The authors concluded that skylights or greenhouses with skylights may cause an increase of up to 10°C between 6:00 p.m. and 8:00 a.m., when most activities will be carried out indoors. In this research study, the effectiveness of strategies to improve energy performance is tested experimentally with two modules. Data are collected using PT100 sensors. Results show that the attached greenhouse and the 2.4 m^2 skylights increased the temperature inside the house by 5.7°C.

Heat loss was limited in the research conducted by [9] by improving insulation methods, applying materials such as plaster and plastic on opaque surfaces and double-glazing windows to create an insulated air chamber, in addition to using strategies related to the use of materials with high thermal inertia, openings in certain surfaces, and adding high thermal-gain devices. The prototype was analyzed using M2M software. The research concluded that the improvements result in a significant thermal gain, with average temperatures of 15.8°C, 10.6°C, 14.4°C, and 12.8°C for bedrooms, living rooms, and kitchens, respectively.

Sensors are placed in such spaces to verify the thermal gain of the applied strategies, as well as that there was a slight difference between the temperatures determined by the simulations and the actual ones of up to 3°C in the worst case, corresponding to June 10.

However, research has been conducted on the first topic for urban settings. Among such studies, the one by [10] is highlighted. They analyzed a house in the city of Huaraz that had passive and low-cost strategies like replacing a patio with a greenhouse or installing double-glazing windows on vertical windows on the north side of the house. In 7 h, an average temperature increase of 3°C was achieved.

At this point, it is necessary to state that the passive strategies described in the preceding research are efficient and repeatable. The use of greenhouses, skylights, double-glazing windows and openings, or improving the insulation of closing elements should become a common denominator of housing projects in climates where this project is proposed. However, because these aspects have not yet been studied, the social and typological aspects of regions should also be considered.

On the second point of this text, the first research study that refers to material properties used in the type of housing that needs to be improved, [11] compared the thermal behavior of materials in two different rooms. They found that adobe has a thermal conductivity of 0.176 W/mK for walls, while brick has a thermal conductivity of 0.45 W/mK. They concluded that metallic materials have higher conductivity for roofs, with values of 235 W/mK for aluminum and 14 W/mK for steel. Regarding the floor, the study estimates that accumulation systems made of wood, stone, and guano can collect up to 8305 MJ of energy. This study also recommends using attached greenhouses because adobe, roof tiles, and an energy accumulation system are insufficient to ensure adequate temperatures inside houses in the high Andean region.

[7] stated that the traditional use of stone in house walls resulted in heat loss at night because of its thermal conductivity of up to 2.4 W/mK. Metal sheets were not recommended for roofs owing to their thermal conductivity of 50 W/mK and rather low insulation capacity at night.

[12]also stated that hygrothermal insulation for floors is required to avoid water entry and improve thermal exchange. They proposed using wood, stone, and air chambers over the rammed floor. Regarding energy loss,[8] found that ceramic tiles with a thermal conductivity of 0.625 W/mK contribute only 2.6% of the total energy loss in houses. Therefore, the greatest losses are registered for openings, accounting for 48.6% of the total loss. This was determined using M2M software.

Similarly, [13] reported in their research that the openings of houses in Kairahuiri, Cusco, were small to prevent interior temperature losses and provide adequate lighting and ventilation. However, the latter objectives were not always met. Likewise, they stated that the raised placement of doors in walls 0.30–0.40 m high prevents potential water entry into indoor spaces.

It should be noted that, because there is no intention of relying on active heating systems, as stated by [12], stoves or improved stoves inside houses produced a significant increase in indoor temperatures of up to 13°C.

Finally, it can be stated from the preceding statements that several aspects must be considered for an architectural object to achieve adequate energy performance. Naturally, the first factor is weather conditions. The second factor is the energy capture strategy to be used, as well as its direct relationship with building materials. Finally, there are factors that are closely related to design and prototype construction.

III. METHODOLOGY

To conduct this study, we have reviewed and used several studies that shared concerns about high altitude Andean housing as methodological and technical references. Among them are studies by [7], [8], [9], [11], [12], [14]. They demonstrated, to a greater or lesser extent, that passive solar heating is an effective and economically viable bioclimatic design strategy for high altitude, cold regions.

On this basis, this paper aims to present a new approach for the development of bioclimatic architecture in the Peruvian Andean region, with the goal of improving the thermal behavior of architectural objects via passive collector systems, improving the levels of comfort inside buildings, and mitigating the consequences of frost incidence and health problems caused by this phenomenon. To achieve this, the direct and indirect solar radiation gains and heat losses of traditional Andean housing modules as well as a proposed hybrid module are investigated and compared. The initial premise is that the new architectural object is not a fixed set comprised of a traditional building and its aggregates or prosthesis, but rather a hybrid artifact that will improve thermal comfort levels in indoor areas of the house.

For the comparison, the first task is to build virtual models of traditional and proposed modules, which will include a passive solar collector system. It will operate as a two-way system: as a direct collector with thermal inertia and as an air convection collector. The second task is to assign traditional materials for the walls and roofs of each module, as well as the materials for night insulation in openings and the collector system, using the Design Builder software. Temperature data from both objects are registered to compare them and determine internal thermal gains as well as the relationship between collector surfaces, livable volumes, and insulation coefficients to verify improvements in the thermal behavior.

All of this will be performed using the software's own weather data and compared to historical data from the Kayra Weather Station in Cusco. The cold period of the months of June, July, and August will be emphasized. After this, the fundamental material characteristics of traditional typologies are presented, based on the base module and the passive collector system module that are proposed. Subsequently, the dual operations of the latter will be described.

A. Regional Weather

The Cusco region is located in the southwestern region of Peru. It borders Junín, Ucayali, Madre de Dios, Puno, Apurímac, Ayacucho, and Arequipa. Based on SENAMHI data, this region has 16 of the 38 Peruvian climates based on Thornthwaite methodology. The predominating climate is rainy and temperate, with moisture deficiencies in autumn and winter.

According to Peruvian climate maps, Cusco has a semidry climate with dry autumns and winters. The maximum temperature ranges from 23°C to 27°C, and the minimum temperature ranges from 5°C to 11°C, with an annual rainfall of 500–900 mm. The Kayra Weather Station provided meteorological data for this climate study (for the reference period of 2015 to 2017). Its latitude is 13° S, and it is located at 3214 MSL in the district of San Jeronimo, southeast of Cusco.

The following data will be used for practical purposes of the research: an altitude of 3300 MSL, a latitude of 13° S, an average annual temperature of 13°C, an average annual rainfall of 589 mm, an annual relative humidity of 55%, and an average annual radiation of 4.80 kWh/m^2/day. Likewise, there are two seasons: the rainy season (October to March) and the dry season (April to September). The coldest months are June, July, and August, with an average maximum temperature of 22°C, an average minimum temperature of 0°C, and an average mean temperature of 11°C.

B. Traditional Typologies

As previously stated, traditional typologies in the meso- and high Andean regions include: the compact balcony type, which is characterized by its rectangular base and is usually a closed block with openings toward the road or courtyard and a balcony on the second level; the altarpiece type, which is a combination of a Quechua huairona and a Spanish gallery, whose side walls protrude and confine galleries; the patio and court types, which are configured as an urban system with a central patio; the putuco type, characterized by the use of turf as construction materials, a block floor, and a roof topped in a cone shape [4]; and the so-called high Andean alpaca-type housing, characterized by adobe or stone walls, wooden or zinc sheets, and thick and compressed layers of Andean thatch or ichu [14].

Two key characteristics are shared by various typologies. The first is regular, mainly rectangular floor plans, and the second is the gable roof. Depending on scale, buildings generally have a single space, or they may have several indoor spaces. An indoor courtyard surrounded by a bay and three walls, two bays and two walls, three bays and one wall, or four bays exists to a lesser extent.

B. The Base Module (MB)

The base housing module, hereafter MB, is located on an ideal site in Cusco. It has an area of 28.50 m^2 and a livable volume of 63 m^3. Their four walls are made of 40 cm-thick, sun-dried mud blocks or adobe, with 1.5 cm-thick mud plaster, and a thermal transmittance of U = 1.40 W/m^{2}K. The roof has a structure made of sawn timber trusses, reed roofing, mud tiles, traditional Andean tiles, and a fake interior ceiling made of reed roofing and gypsum plaster with a thermal transmittance of U = 04 W/m^{2}K. The floor is made of a 10 cm-thick stone bed over compacted soil and a simple, 5 cm-thick concrete subfloors with a thermal transmittance of U = 2.42 W/m^{2}K. The openings have a 0.90 x 2.10 m, south facing, wooden door with a thermal transmittance of U = 2.80 W/m^{2}K. Two windows face east and west and are 1 x 1.20 m^2 in size, with double-glazed glass, wooden frames, and wooden folding doors, as well as a thermal transmittance of U = 2.50 W/m^{2}K.

C. Module with Passive Collector System (MSCP)

The designed architectural object, called “passive-Andean housing module,” is located in an ideal site in Cusco. Its area is 26.50 m^2, with a livable volume of 62 m^3, and a passive collector system in the shape of a triangular prism facing N 20° E. It operates in two ways: as a direct collector with thermal inertia, its surface is 14 m^2, with an inertial element of 8.9 m^3 of cyclopean concrete, and as an air convection collector, its surface is 28 m^2 (see Figure 1). Three of the four walls are made of 40 cm-thick adobe with a 1.5 cm-thick mud plaster, and a thermal transmittance of U = 1.40 W/m^{2}K. The roof has a structure made of sawn timber trusses, reed roofing, mud tiles, traditional Andean tile, and a ceiling made of reed roofing as well as gypsum plaster, with a thermal transmittance of U = 1.04 W/m^{2}K.

The collector is located on the wall facing N 20° E, which has a wooden structure with a system of sliding wooden doors painted black that can be opened and closed, an air chamber of 15 cm, and on the outside, a double glazing that rests on the wooden structure with a thermal transmittance of U = 0.80 W/m^{2}K. The floor is made of a 10 cm-thick stone bed with a simple 5-cm-thick concrete subfloor and has a thermal transmittance of U = 2.42 W/m^{2}K. The south-facing openings are equipped with a 0.90 x 2.10 m^2 wooden door with a thermal transmittance of U = 2.80 W/m^{2}K. Two windows face east and west and are 1 x 1.20 m^2 in size, with double-glazed glass, wooden frames, and wooden folding doors, and have a thermal transmittance of U = 2.50 W/m^{2}K.

D. Energy operation of the House Collector Systems

The house collectors work in two ways: as direct collectors with thermal inertia, the sliding doors open and the sun enters directly via the glass to the inertial element and environments, and as convection collector. The doors close at night, insulating the environment (see Figure 2). The collector surface is 14 m^2. As an air convection collector, the doors are closed during the day while the upper and lower door openings of the inertial elements are opened. Windows are kept closed to exchange the cold environment air with the warm system air. At night, the upper and lower openings of the sliding door, as well as the inertial elements, are closed to isolate the environment (Figure 3). The surface area of the collector is 28 m^2.

Fig. 1 Module with Passive Collector System. The figure shows a prototype module design with a passive collector system.

D. Energy operation of the House Collector Systems

The house collectors work in two ways: as direct collectors with thermal inertia, the sliding doors open and the sun enters directly via the glass to the inertial element and environments, and as convection collector. The doors close at night, insulating the environment (see Figure 2). The collector surface is 14 m^2. As an air convection collector, the doors are closed during the day while the upper and lower door openings of the inertial elements are opened. Windows are kept closed to exchange the cold environment air with the warm system air. At night, the upper and lower openings of the sliding door, as well as the inertial elements, are closed to isolate the environment (Figure 3). The surface area of the collector is 28 m^2.

Fig. 2 Passive Collector System Operating as a Direct Collector with Thermal Inertia. The figure shows a passive collector system working as a direct collector based on thermal inertia.

Fig. 3 Passive Collector System Operating as a Collector with Air Convection. The figure shows a passive collector system working as a direct collector based on air convection.

E. Simulations

Base Module (MB) and passive collector system module (MSCP) simulations with the direct collector operating with thermic inertia were performed with Design Builder. The location chosen for the simulations was Cusco, Peru. The period of simulations was from June 1 to August 31. Air temperature in °C, operating temperature in °C, radiant temperature in °C, and outdoor air temperature in °C were obtained every hour inside such modules. To understand the process better, from June 17 to June 23, a seven-day approach was performed for the same temperature data, but every 30 minutes (Figure 4 and 5), along with solar gains in kWh/day (Figure 6). Temperature and solar gain data were downloaded to an Excel file. Figures of each module were developed along with graphs to compare the two modules.

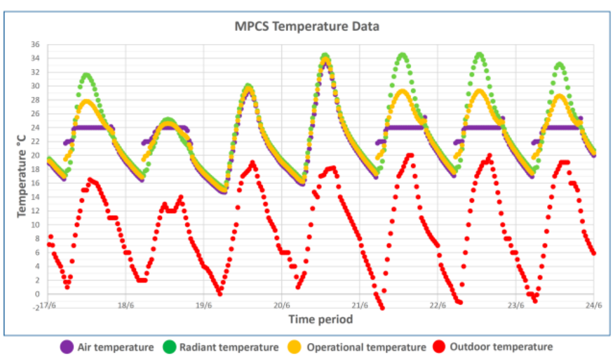

Fig. 4 Temperature Data Module with a Passive Collector System. In the figure, air temperature data is listed, with radiant and operative temperatures in °C. There was a seven-day approach to the module with a passive collector system compared to the outdoor temperature in °C.

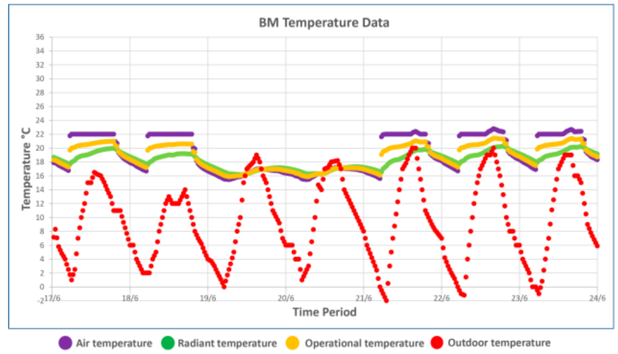

Fig. 5 Base Module Temperatures. In the figure, air temperature data is listed, with radiant and operative temperatures in °C. There were seven days of approach to the module with a based module compared to the outdoor temperature in °C.

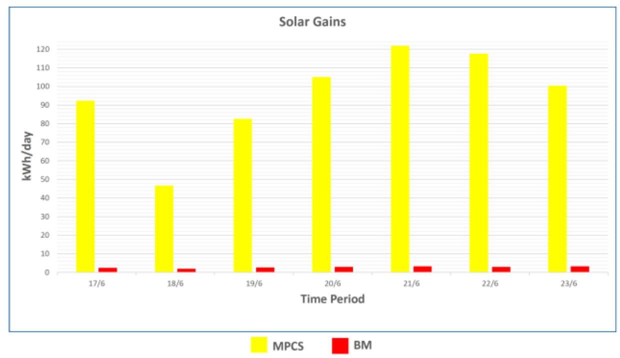

Fig. 6 Solar Gains Based on Span Radiation. The figure shows comparative data of solar gains from modular radiation in kWh/day for a passive collector system and the base module.

IV. RESULTS

The results of processing the MSCP data, with a direct collector with thermal inertia for a 14 m^2 collector surface are as follows:

MSCP attains temperatures greater than MB each day during the three months of the study. Regarding solar radiation gains based on direct collection, June 21 had the highest radiation, with gains of 121 kWh/day, and June 18 had the least, with gains of 43 kWh/day. Average gains of 95 kWh/day were achieved over the course of the seven-day study.

MSCP reaches air, radiant, and operating temperatures of 15°C–36°C. Nevertheless, during the three months of the study, MB experienced temperatures of 15°C–23°C. This shows that the MSCP is up to 13°C higher than the MB and up to 16°C higher than the outdoor temperature during the day. The night temperature difference between the two modules decreases considerably, but it remains at 16°C in relation to the outdoor temperature.

The following results were obtained for a shorter-period study corresponding to June 17–24 using the one-week approach.

On days with high radiation, the difference in air, radiant, and operating temperatures between MSCP and MB is 16°C, 17°C, and 15°C, respectively. MSCP had the highest temperatures. However, on days with less radiation, the differences decreased to 2°C, 6°C, and 4°C, respectively. (Figures 7, 8, and 9)

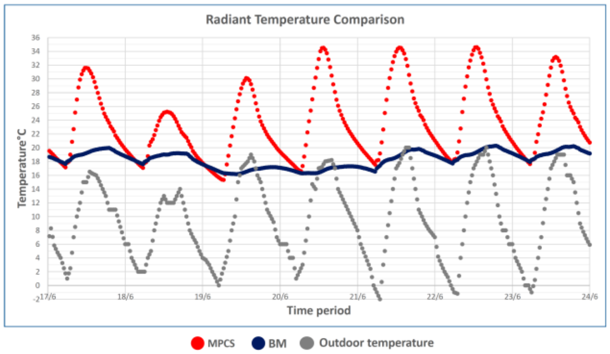

Fig. 7 Comparison of Radiant Temperature between the Base Module and the Passive Collector System Module. This figure shows comparative radiant temperature data in °C to compare the base module and the passive collector system.

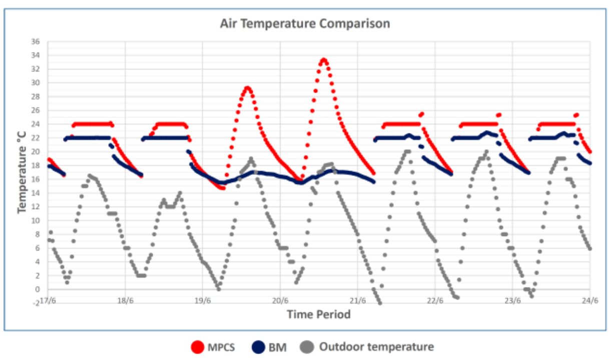

Fig. 8 Comparison of Air Temperature between the Base Module and the Passive Collector System Module. This figure shows comparative air temperature data in °C to compare the base module and the passive collector system.

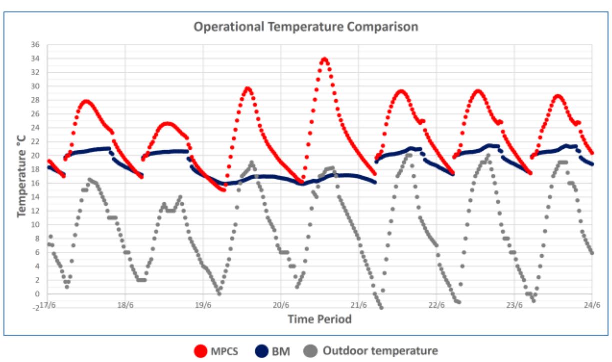

Fig. 9 Comparison of Operational Temperature between the Base Module and the Passive Collector System Module. This figure shows comparative radiant temperature data in °C to compare the base module and the passive collector system.

A. Analysis of results

On June 18, MSCP attained solar gains on direct collection of 47 kWh/day. This represented an increase in air, radiant, and operating temperatures of 2°C, 6°C, and 4°C, respectively, compared to those of MB. Nevertheless, on June 21, MSCP attained solar gains on collection of 121 kWh/day were attained. They represented increases in air, radiant, and operating temperatures of 16°C, 18°C, and 17°C, respectively, compared to those of MB.

On average, over a seven-day period, gains of 95 kWh/day were attained. They represent an average increase in air, radiant, and operating temperatures of 6°C, 12°C, and 9°C, respectively, compared to those of MB. It is relevant to mention that such temperature increases occurred in a module of 26 m^2 and a livable volume of 65 m^3.

We are aware of the fact that MSCP and MB have similar thermal transmittance in almost all elements except the collector system, because MB does not have one. We saw that, during the day, MSCP reaches higher temperatures. Nevertheless, at night, both modules attain almost the same temperature. This shows that MSCP loses more heat because of the thermal bridge produced by the collector.

V. CONCLUSIONS

In this study, MSCP reaches temperatures higher than those of MB every day of the study, implying that the direct collector with thermal inertia works. For a livable volume of 65 m3, a 14 m^2 direct collector surface facing N 20° E achieves an average increase in air, radiant, and operative temperatures of 6°C, 12°C, and 9°C, respectively. Thus, it is confirmed that heating a housing module with a passive collector is feasible in a climate like Cusco's.

Based on improved insulation at night, the MSCP thermal behavior can be improved to avoid losses, especially at nighttime, when the heat accumulated during the day is lost to the greatest extent.

The MSCP construction is recommended for a more thorough analysis, along with an analysis of the collector system when used as an air convection collector in a constructed model because of the complexity of the collector system, it will be important to register temperature and radiation data as well as manipulate their operation in the constructed building. Thermal transmittance should be improved in all enclosures using materials that are easily available and manufactured in the Andean Peruvian region for future research.

REFERENCES

[1] A. Castro *et al.*, "Climas del Perú - Mapa de clasificación climática del Perú," Lima, Aug. 2021. Accessed: Dec. 26, 2022. [Online]. Available: https://www.senamhi.gob.pe/load/file/01404SENA-4.pdf

[2] Ministerio de Vivienda Construcción y Saneamiento, *Norma EM.110 Confort Térmico Y Lumínico Con Eficiencia Energética*. 2021. Accessed: Dec. 26, 2022. [Online]. Available:

https://www.gob.pe/institucion/vivienda/informes-publicaciones/2309793-reglamento-nacional-de-edificaciones-rne
[3] P. y R. del R. de D.-C. Centro Nacional de Estimación, “Manual para la Evaluación de Riesgos Originados por Fenómenos Naturales – 2da Versión,” Lima, 2014. Accessed: Dec. 26, 2022. [Online]. Available: https://www.cenepred.gob.pe/web/wp-content/uploads/Guia_Manuales/Manual-Evaluacion-de-Riesgos_v2.pdf
[4] J. Burga, *Historia de la arquitectura peruana. Tomo I : arquitectura popular*. Lima: Universidad Nacional de Ingenierías. Facultad de Arquitectura, Urbanismo y Artes , 2018.
[5] X. Liang, Y. Wang, M. Royapoor, Q. Wu, and T. Roskilly, “Comparison of building performance between Conventional House and Passive House in the UK,” in *Energy Procedia*, 2017. doi: 10.1016/j.egypro.2017.12.570.
[6] L. I. Fernández Gutiérrez, “Un edificio para combatir la pobreza energética,” *Revista + Calidad*, pp. 20–23, 2021. Accessed: Jan. 31, 2024. [Online]. Available: https://socialasturias.asturias.es/web/revista-calidad/-/un-edificio-para-combatir-la-pobreza-energ%C3%A9tica?redirect=%2Fweb%2Frevista-calidad%2Fexperiencia-de-inter%25C3%25A9s%3Fp_p_id%3Dcom_liferay_asset_publisher_web_portlet_AssetPublisherPortlet_INSTANCE_Mg4jqpEKjzVy%26p_p_lifecycle%3D0%26p_p_state%3Dnormal%26p_p_mode%3Dview%26p_r_p_tag%3Deficiencia%2Benerg%25C3%25A9tica
[7] M. Wieser, S. Rodríguez-Larraín, and S. Onnis, “Estrategias bioclimáticas para clima frío tropical de altura. Validación de prototipo de vivienda. Puno, Perú.,” *Estoa*, vol. 10, no. 19, pp. 9–19, Jan. 2021, doi: 10.18537/est.v010.n019.a01.
[8] J. O. Molina, G. Lefebvre, M. Horn, and M. M. Gómez, “Design of an experimental bioclimatic module obtained from the analysis of thermal simulations for the community of Imata (4519 m A.S.L.), located in Arequipa, Perú,” *Informacion Tecnologica*, vol. 31, no. 2, pp. 173–185, Apr. 2020, doi: 10.4067/S0718-07642020000200173.
[9] J. R. Molina, G. Lefebvre, R. Espinoza, M. Horn, and M. M. Gómez, “Bioclimatic approach for rural dwellings in the cold, high Andean region: A case study of a Peruvian house,” *Energy Build*, vol. 231, Jan. 2021, doi: 10.1016/j.enbuild.2020.110605.
[10] M. Silva Lindo, R. Depaz Blácido, and O. Alva Villacorta, “Mejoramiento del confort térmico de vivienda en uso en la ciudad de Huaraz con el aprovechamiento de la energía solar pasiva,” *APORTE SANTIAGUINO*, vol. 9, no. 1, p. 37, Dec. 2017, doi: 10.32911/as.2016.v9.n1.211.
[11] K. U. Escobar Copa and A. Holguino Huarza, “Confort térmico en una habitación de adobe con sistema de almacenamiento de calor en los andes del Perú,” *Revista de Investigaciones Altoandinas - Journal of High Andean Research*, vol. 20, no. 3, pp. 289–300, Jul. 2018, doi: 10.18271/ria.2018.393.
[12] M. M. Gómez, R. Espinoza, J. Molina, and M. Horn, “Conceptos bioclimáticos y su aplicabilidad a la zona rural altoandina: caso comunidad San Francisco de Raymina (SFR)-Ayacucho,” *Revista Cientifica TECNIA*, vol. 25, no. 2, p. 5, Feb. 2017, doi: 10.21754/tecnia.v25i2.45.
[13] A. Mendoza Yauli, “Estudio y Análisis Térmico-Energético de la Vivienda Rural Andina con la Aplicación de Programas de Simulación Energética 3D en El Sector Poblado de Kairahuiri-Cusco,” UCSM, Arequipa, 2015.
[14] M. del P. Carranza Gayozo and O. C. Pacheco Zuñiga, “Vivienda alpaquera altoandina. Caso de estudio tipológico en Puno, Perú,” *Arquitectura de Tierra: Patrimonio*, pp. 88–94, 2016.