MICROCLIMATIC STUDY OF THE ICONIC CELLS IN THE SANTA CATALINA MONASTERY, AREQUIPA, PERU

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1. Introduction

Arequipa, a Peruvian city rich in history and culture, was recognized as a UNESCO World Heritage Site in 2000. This prestigious recognition is attributed, among other factors, to the preservation of buildings dating back to the vice-regal period which blend European and Andean knowledge. These structures, known as "Casonas," are scattered throughout the historic center, showcasing neoclassical and baroque-mestizo façades (Figure 1).

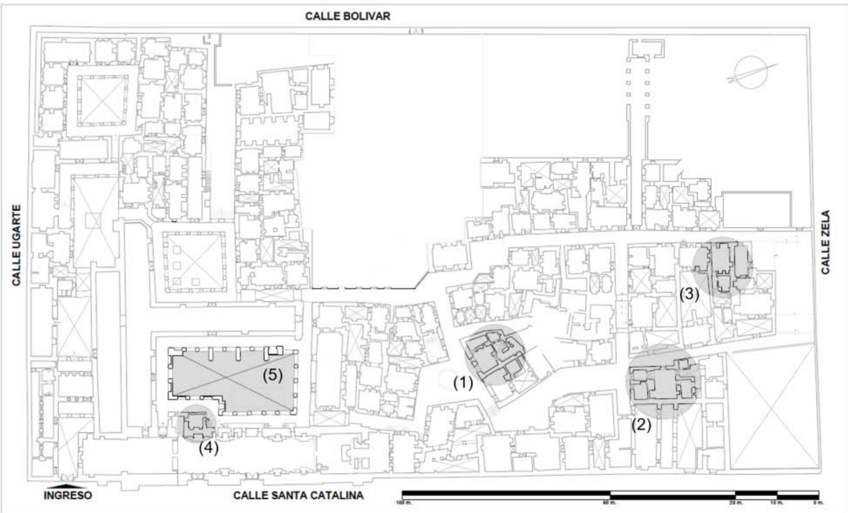

Figure 1. Location of the study areas on the base plan of the Santa Catalina Monastery in Arequipa. (1) Cell A; (2) Cell B; (3) Cell C; (4) Cell D; and (5) Main Cloister.

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The city's growth and the passage of time have created a need to understand these constructions and adapt them to new uses. A key material in Arequipa's architecture is ignimbrite, which is extracted using artisanal methods, and is an integral part of the city's popular culture. This material represents the core of Arequipa's architectural and construction heritage. According to Miceli's definition, its use in heritage architecture can be considered sustainable, as it meets design needs by creating spaces in harmony with the local environment and using natural resources to minimize environmental impact.

2. State of the art

In a local context, there is a study by José Andrew Zúñiga titled "Estabilidad térmica de un edificio centenario de sillar (ignimbrita) en clima desértico frío. Hospital Goyeneche" [1], in which he performs a thermal characterization of the Goyeneche Hospital in Arequipa. The study also includes measurements for temperature and relative humidity during two seasons of the year 2018.

The understanding of hygrothermal dynamics in historical buildings contributes to the conservation of heritage by preserving construction systems and facades that are highly susceptible to deterioration due to temperature and relative humidity [2,3]. Furthermore, its assessment allows for improving the energy performance of heritage buildings while preserving their historical and artistic values [4,5]. Other studies measure interior heat and humidity to assess their influence on the variability of the geometry and construction materials of historical buildings [6,7].

One of the tools used to analyze the interior temperature of the surfaces that make up spaces is thermographic cameras. Examples of current research utilizing thermography can be found in various fields. In the realm of architecture, it is employed for the analysis of installations and their proper functioning [8-10]. Methodological articles are also present in the literature, such as those by Bisegna [11] or Mulaveesala [12]. However, the most relevant to our study are those that refer to the analysis of entire walls of buildings, such as Quagliarini [13], Kordatos [14], or Nuzzo [15].

Comfort conditions are essential to ensure the proper development of activities in each of the spaces. Depending on the use of these spaces, the conditions will vary. There are various studies that have analyzed comfort conditions within indoor spaces such as Bravo-Morales [16], De Dear [17] or Bellizzi [18]. Comfort conditions, in addition to use, are greatly influenced by the climate of the location where the analyzed spaces are situated and the conductivity characteristics of the materials.

Studies have been conducted with the specific purpose of focusing on the thermal performance of vernacular constructions. For the measurement of comfort temperatures in indoor residential spaces, interior and exterior temperature and relative humidity monitoring were carried out, demonstrating better thermal performance in traditional architecture, as reported by Liu [19] or Basaran [20]. In comparison with contemporary constructions, vernacular solutions can maintain comfort standards more suitable to the environment in which they were developed [21].

Currently, in the context of global climate change and the desire to create more sustainable buildings, there are studies that analyze both historical buildings from an implicit sustainable perspective [22] and studies on energy retrofits using thermography as a tool [23]. Energy retrofit interventions in heritage architecture are diverse and depend on the degree of energy requirements and the structural conditions of the building [24]. Intervention solutions can be both active and passive, aimed at mitigating thermal bridges and optimizing energy consumption, as discussed by Etxepare [25].

Energy retrofit aims to adapt the conditions of historical buildings to new uses [26]. On the other hand, there are buildings that need to enhance the energy efficiency of their spaces to improve comfort conditions [27]. This has become a requirement to fulfill and justify both new constructions and rehabilitation.

3. Method

That is why the method used takes into consideration the interior and exterior hygrothermal environment of a characteristic heritage building such as the Convent of Santa Catalina. Environmental data including temperature, relative humidity, light, and sound were collected at the monument between February 13 and August 25, 2024. Temperature and relative humidity were recorded every hour, yielding 24 measurements per day. Light and sound were measured during visiting hours (9:00 a.m. to 6:00 p.m.), at variable intervals ranging from 30 to 45 minutes, depending on tourist activity. Table 1 shows the equipment used for measuring, along with specifications for its range and accuracy.

Table 1. Range and accuracy of the measurement equipment

MEASURING EQUIPMENT	*RANGE*	*ACCURACY*
Sensor HOBO UX100-003 Temperature/Relative Humidity 3.5% Data Logger ***S1 to S7 (interior spaces)***	*-20° to 70°C (-4° to 158°F)*	*±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F)*
	15% to 95% (non-condensing)	*±3.5% from 25% to 85% including hysteresis at 25°C (77°F); below 25% and above 85% ±5% typical*
Wired Sensor HOBO RH Smart Sensor (S-THC-M00x) ***S8 & S9 (exterior spaces)***	*-40°C to 75°C (-40°F to 167°F)*	*±0.20°C from 0° to 70°C (±0.36°F from 32° to 158°F)*
	0-100% RH at -40° to 75°C (-40° to 167°F)*	*±3.5% from 25% to 85% including hysteresis at 25°C (77°F); below 25% and above 85% ±5% typical*
Micro Station (H21-USB) ***(used with wired sensor)***	*-20° to 50°C (-4° to 122°F) with alkaline batteries*	*0 to 2 seconds for the first data point and ±5 seconds per week at 25°C (77°F)*
Center 32 Sound Level Meter	*30-90 dB / 50-110 dB / 70-130 dB*	*±1.4 dB (ref. 94 dB @ 1kHz)*
Light Meter (Lux/FC) 840020	*40.00 to 400,000 lux*	*± (3% rdg + 0.5% F.S.)*

For temperature and relative humidity measurements inside the cells, 07 HOBO brand temperature and relative humidity sensors, model U-series 1-800 - wireless Data Logger, were used. For temperature and relative humidity measurements outdoors, 02 HOBO brand temperature and relative humidity sensors, model S-THC- M00X, wired type, connected to a HOBO brand Data Logger, model Micro Station H21 - USB, were used. For light measurements, a SPER SCIENTIFIC brand Digital Luxmeter model 840020 in lux was used. For sound measurements, a CENTER 32 brand Digital Sound Level Meter model IEC 6672-1 class 2 in decibels was used. The 07 wireless temperature and relative humidity sensors were placed inside the cells, identifying two spaces, one main and one secondary, except for Cell D, which only has one space. The wired sensors and Data Logger were placed in the Main Cloister. The selected iconic cells belonged to important nuns who lived in the Monastery of Santa Catalina. Each of them represents a significant part of the monument's history. The cells were coded as follows: Cell A corresponds to the cell of Mother Rosa Cárdenas, Cell B to Mother Josefa Cadenas, Cell C to Mother Cipriana Centeno, and Cell D to Mother Juana Arias. For the purposes of this study, the terms main space and secondary space are used to distinguish functional and morphological subdivisions within each cell, which were historically occupied and used for daily life. The main space refers to the primary area where essential activities are presumed to have taken place, while the secondary space, typically smaller and adjacent, supported auxiliary functions. Environmental comfort conditions in both spaces were systematically monitored and comparatively analyzed to identify microclimatic variations. Cells A, B, and C consist of two distinct areas—main and secondary—whereas Cell D comprises a single, unified space. Although the original names of the cells are preserved in this study, they may not correspond to their historical occupants.Table 2 shows the distribution of sensors in the selected iconic cells and the main cloister.

Table 2. Distribution of sensors in emblematic cells

CELL	***Main space***	***Secondary space***
Cell A: Mother Rosa Cárdenas	*Sensor 1*	*Sensor 2*
Cell B: Mother Josefa Cadenas	*Sensor 5*	*Sensor 6*
Cell C: Mother Cipriana Centeno	*Sensor 3*	*Sensor 4*
Cell D: Mother Juana Arias	*Sensor 7*	*-*
Main Cloister	*Sensor 8 and Sensor 9 (wired)*	

For the placement of sensors, an average height of between 3.20 m and 3.50 m was established in interior spaces, except for Cell D, where the sensor was placed at 2.45 m, because the cell has a low ceiling with a flattened vault. For the exterior spaces, the sensors were placed at a height of 4.00 m, in the main cloister.

In all cases, the sensors were positioned so they did not receive direct sunlight in order not to alter the final measurements. Figure 2 shows photos of the sensors placed in the different study spaces. The sensors were mounted on the walls of the cells at a height ranging from 3.20 m to 3.50 m. The walls were constructed using the "cajón" system, which comprises two parallel ignimbrite walls filled with a composite material of lime, sand, and stone, with thicknesses between 1.20 m and 1.50 m. The thermal transmittance of the ignimbrite is 0.78 W/m²K [28], a value that does not affect the measurements taken by the sensors installed in each environment. Additionally, the methodology uses data obtained from the "La Pampilla" meteorological station in Arequipa, which was used to compare the indoor conditions of the studied spaces. Figure 3 shows a graph with the maximum and minimum temperatures from February to August 2024 in Arequipa, as well as the variation in relative humidity throughout the said period.

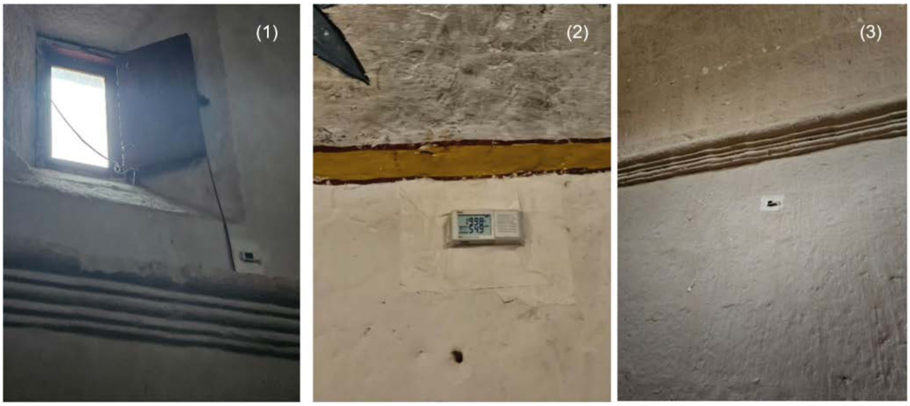

Figure 2. Placement of sensors in the study spaces. (1) Sensor 1 placed in Cell A at a height of 3.20 m; (2) Sensor 7 placed in Cell D at a height of 2.45 m; (3) Sensor 5 placed in Cell B at a height of 3.50 m.

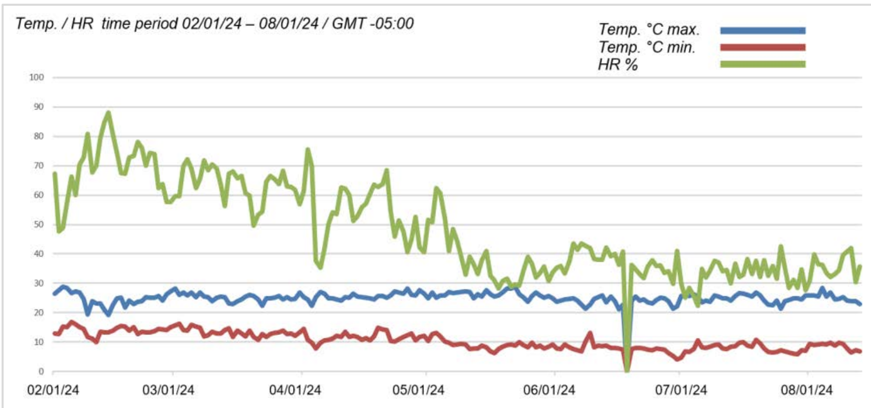

Figure 3. Temperature and Relative Humidity measurements of Arequipa between February and August 2024.

4. Temperature and Relative Humidity results

- *Cell A*

Figure 4 shows the measurements from sensors 1 and 2 placed in the main and secondary spaces of cell A, respectively. As can be seen, the temperature for sensor 1 fluctuates between 22°C and 17°C, with the lowest values recorded in August. The plot also illustrates significant variations in relative humidity, starting at high levels exceeding 63% in the initial months and gradually decreasing to a minimum of 15% in July and August. For sensor 2, the temperature remains within a range of 22°C to 20°C, also reaching its lowest levels in August. The plot shows a similar trend in relative humidity, with values exceeding 63% in the early months before dropping to around 15% in July and August. The measurements from sensors 1 and 2 indicate stable temperatures in the smaller space, while the larger space shows greater fluctuations. Relative humidity follows a similar pattern in both sensors, peaking in February and March and dropping in July and August. A minimum RH of 15% was detected, possibly due to sensor error, as “La Pampilla” station recorded variations of less than 10% in June.

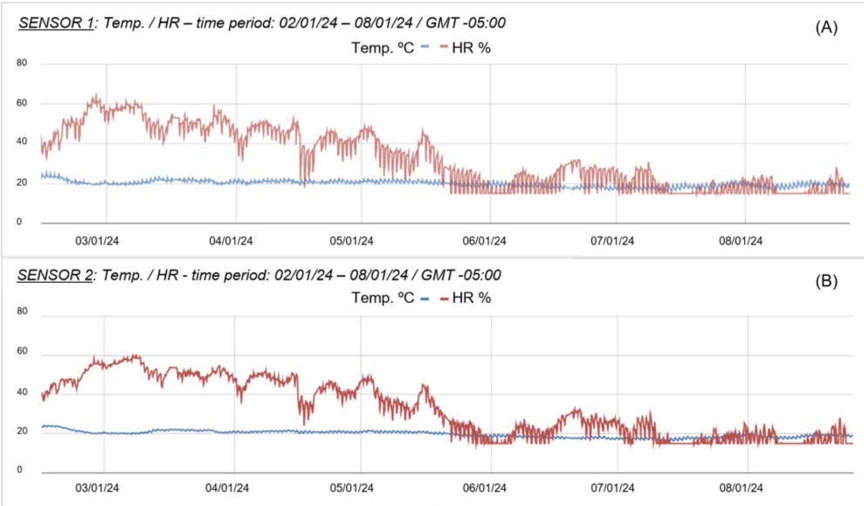

Figure 4. Temperature and Relative Humidity measurements from sensors 1 and 2 in Cell A. (A) main space; and (B) secondary space.

Based on the comparison of graphs (A) and (B) shown in Figure 4, it can be observed that the relative humidity percentages in the obtained measurements show clearly differentiated fluctuations between the months of February and March, and the months of July and August. In both sensors, February and March exhibit the highest levels of humidity, while July and August show the lowest. A minimum of 15% RH was detected in both sensors, which may be due to a sensor accuracy error, as the minimum relative humidity accuracy of the sensor is 15%. This is in contrast to the lowest peaks recorded at the “La Pampilla” station, which show a variation of less than 10% RH in June. At the “La Pampilla” station, maximum temperature levels exceeding 30°C and minimum temperatures close to 5°C were detected during July and August. These temperature levels, along with the relative humidity measurements, are consistent with the trends observed in the sensors, with very high humidity percentages recorded in February and March and lower percentages in July and August. The graph also shows an increase in humidity in August, with a peak near 50% RH. Overall, the comparison highlights the significant fluctuation in relative humidity between February and March and the months of July and August. The relative humidity is highest in February and March and lowest in July and August. The detected minimum of 15% RH in both sensors is likely due to the sensor’s accuracy limitation, as the “La Pampilla” station's measurements for June show a variation of less than 10%. Temperature records at the “La Pampilla” station also show extreme variations, with maximum temperatures exceeding 30°C and minimum temperatures near 5°C during July and August.

- *Cell C*

Figure 5 shows the measurements from sensors 3 and 4, placed in the main and secondary spaces of cell C, respectively. The time periods measured by sensor 3 indicate that the temperature remains within the range of 22.5°C to 15.5°C, with the lowest levels being in August and the highest between February and March. It is also evident that there was a marked difference in the temperatures between day and night in the months from June to August. The variation in relative humidity is very high during the first months, with peaks exceeding 60.2%, gradually decreasing to low levels of 15% in July and August. In addition, in the months of June, July, and August, humidity reached high levels of about 40% RH and low levels of 15% RH. During March and April, temperatures in some instances exceeded 23°C, further emphasizing the significant variation in both temperature and humidity levels during this period. The trend in the graph refers to the fluctuation in relative humidity, particularly in these months, where humidity levels show a clear pattern of highs and lows, showing the considerable changes in both climatic factors. To compare measurements with the generic meteorological conditions of Arequipa, the measurements of the "La Pampilla" station were applied. The temperature of sensor 4 remains within a range of 22.0 °C to 15.0 °C, with the lowest levels in August and the highest between February and March. It is also evident that in the months of June to August there was a more marked difference in the temperatures between day and night. The variation in relative humidity, which is very high in the first months with peaks of more than 65.2%, descending to low levels of 15% in the months of July and August. In addition, in the months of June, July and August, humidity reached high levels of about 40% RH and low levels of 15% RH.

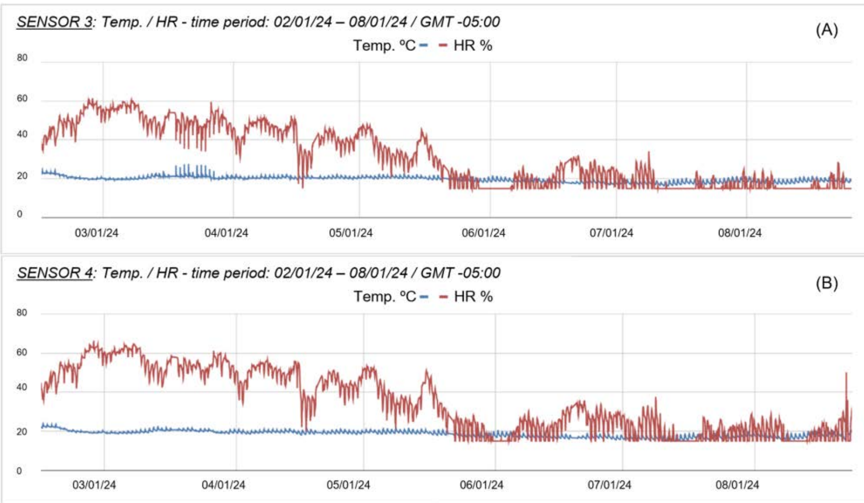

Figure 5. Temperature and Relative Humidity measurements from sensors 3 and 4 in Cell C. (A) main space; and (B) secondary space.

- *Cell B*

Figure 6 shows the measurements from sensors 5 and 6, placed in the main and secondary spaces of Cell B, respectively, indicating that temperatures ranged from 22°C to 20°C for sensor 5 and from 23.5°C to 16°C for sensor 6, with the lowest values recorded in August and the highest between February and March; additionally, both sensors recorded high relative humidity levels above 65% in the first months of the year, descending to low levels of 15% in the months of July and August, additionally, in June, July and August, humidity reached peaks of around 40% RH and dropped to low levels of 15% RH. Sensor 6, placed in a larger space, shows a more pronounced fluctuation in both temperature and relative humidity, as shown in graph (B), however, it does not drop to levels below 15 °C despite the fact that when compared with the lower temperatures captured at the "La Pampilla" station, temperatures below 10 °C are evident. As for the percentage of Relative Humidity, the measurements obtained show a very differentiated fluctuation between the months of February and March and the months of July and August. The months of greatest humidity are February and March and the months of least humidity are July and August, both sensors detected that there is a minimum peak of 15 % in the RH, this is possibly due to an error in the sensor, given that the lower peaks measured at the "La Pampilla" station show a variation of less than 10 % in the month of June. At the "La Pampilla" station, maximum temperature levels exceeding 30 °C and minimum temperatures close to 5 °C were detected in the months of July and August. The relative humidity percentages are also consistent with the measurements taken in the cells, with very high percentages in February and March and lower percentages in the months of July and August.

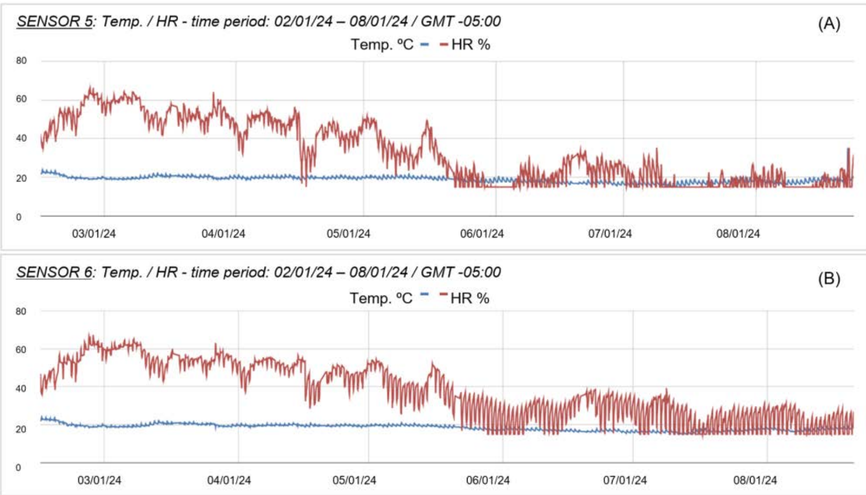

Figure 6. Temperature and Relative Humidity measurements from sensors 5 and 6 in Cell B. (A) main space and (B) secondary space.

- *Cell D*

Figure 7 presents the temperature data recorded by Sensor 7, which range from 14.0 °C to 21.0 °C, with minimum values observed in August and maximum values between February and March. A greater diurnal temperature variation is observed from June to August, whereas February and March exhibit more thermally stable conditions throughout the day. These thermal patterns exhibit a consistent correlation with the external environmental data recorded at the “La Pampilla” meteorological station, where maximum temperatures exceeded 30 °C and minimum temperatures approached 5 °C during the same period. The variation in relative humidity is significant throughout the year. During February and March, RH levels peak above 65.2%, while in July and August, they drop to lows of around 15%. In June, July, and August, fluctuations are observed with intermediate peaks reaching up to 40%, although the graph shows only a slight increase in August, not exceeding 30%. Overall, February and March are the most humid months, and July and August the driest. Sensor 7 recorded a minimum of 15% RH, which may be attributed to a sensor error, as data from the "La Pampilla" station showed a variation of less than 10% in June. The RH percentages are consistent with the cell measurements, confirming higher humidity in February and March, and lower values in July and August.

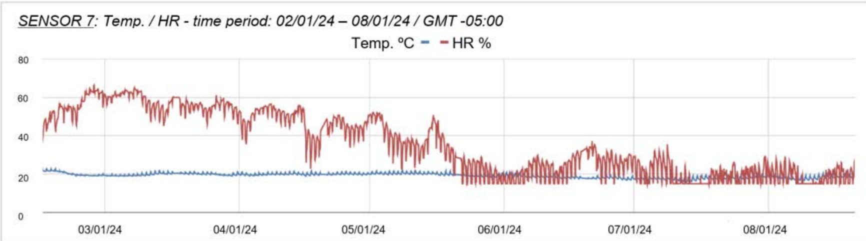

Figure 7. Temperature and Relative Humidity measurements from sensor 7 in Cell D. Main space.

- Main cloister

Figure 8 shows the temperature and relative humidity measurements from sensors 8 and 9, placed around the main cloister. The data collected from these sensors show that the temperature fluctuates between 25.0°C and 10.0°C. The months with the greatest variations between day and night temperatures are June, July, and August. In contrast, in February and March, temperatures range from a maximum of 22.0°C to a minimum of 15.0°C. At the “La Pampilla” station, maximum temperatures exceeding 30°C and minimums close to 5°C were recorded during June, July, and August. These data are consistent with the measurements obtained from both sensors. The relative humidity recorded by both sensors is highest in the early months of the year, with peaks exceeding 65.2%, and drops to lower levels around 15% during June, July, and August. In these months, humidity reached peaks of approximately 40% RH and dropped to as low as 15% RH. This trend is clearly reflected in the graph. Additionally, the graph in Figure 8 reveals an irregularity in June and July, where the values do not follow the expected trend. This irregularity is due to improper handling of the sensors. A comparative analysis between the data from the meteorological station "La Pampilla" and the relative humidity measurements obtained from sensors 8 and 9 shows a consistent pattern. Elevated RH levels were recorded in February and March, while significantly lower values were observed in July and August. These relative humidity readings align with those obtained inside the cells, confirming a seasonal trend characterized by high moisture levels at the beginning of the year and a marked decrease during the mid-year months.

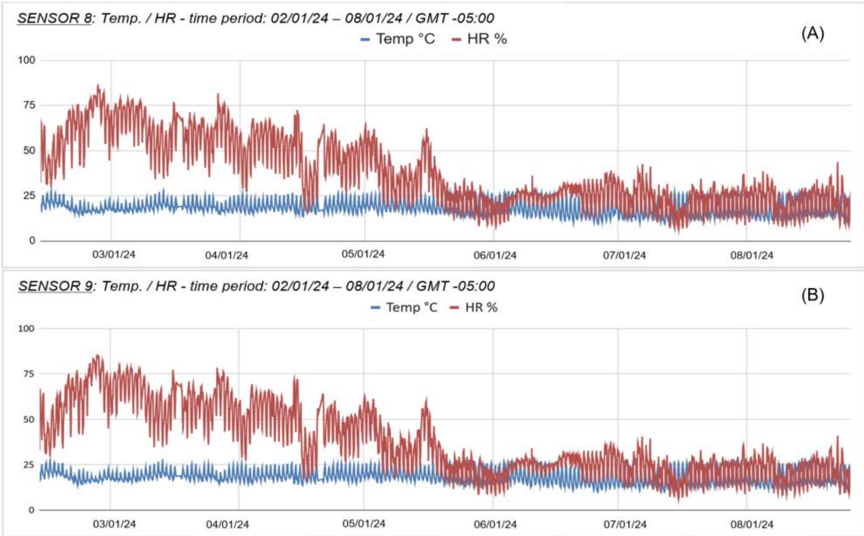

Figure 8. Temperature and Relative Humidity measurements from: (A) sensor 8; and (B) sensor 9 placed around the main cloister.

5. Light and acoustic results

Lighting and sound measurements were made in all the studied environments with a digital luxmeter and sound meter, the measurement intervals were between 30 and 45 minutes between 9:00 and 18:00 hours. For lighting measurements, lux was used and for sound, decibels. For lighting, the instrument was placed in the central area of the space, at a height of no more than 0.70 m, avoiding direct sunlight. For sound, the instrument was placed in the middle area of the space at a height of 1.60 m. For these measurements an attempt was made to avoid the flow of tourists who come to the monument. In addition, an audio was played with a prayer emulating the usual use of the space. The results are expressed in Lux and decibel graphs, highlighting the maximum and minimum in both cases. For lighting, a range of 0 to 150 lux was considered, except for the main room of Mother Rosa Cárdenas' cell where lighting levels close to 200 lux were reached. For sound, a range of 0 decibels to 60 decibels was considered. Data collection was done in the center of the spaces to avoid direct sunlight, considering both direct (artificial indoor lighting, excluding sunlight) and indirect (diffusion and reflection) contributions to the final measurements. All measurements were performed in environments devoid of artificial lighting sources. Indirect light sources in the environment featured ignimbrite walls coated with whitewash, along with paintings, furniture, and other furnishings composed of non-reflective materials. The flooring consisted of brick, while the solid wood doors exhibited antique, matte finishes. Figure 9 shows how the sensors were positioned on tripods at a height of 0.70 m above the finished floor level to ensure consistency in data acquisition. Figure 10 shows the sound level meter mounted on a tripod at a height of 1.80 m in the centre of each environment. The cells are rectangular, with dimensions ranging from 16.00 to 30.00 m². The minimum distance to the walls is 1.50 m.

Figure 9. Lux Meter placement in interior spaces, mounted on tripod at 0.70 m height; (1) position of equipment in Cell A; (2) position of equipment in Cell B; (3) position of equipment in Cell C; (4) position of equipment in Cell D.

Figure 10. Sound Level Meter placement in interior spaces, mounted on tripod at 1.80 m height. (1) position of equipment in Cell A; (2) position of equipment in Cell C; (3) position of equipment in Cell D; (4) position of equipment in Cell D.

- *Cell A*

The lighting in Cell A in the main space fluctuates during the day, with peaks between 12:00 and 14:00 hours, the highest lighting level is 171.4 lux at 13:00 hours and the lowest is 20.22 lux at 16:48 hours. In the secondary space of the cell, the lighting is more uniform than in the main space, with a peak of 78.1 lux at 13:40 hours and a low point of 3.85 lux at 12:42 hours. The higher and lower lux measurements correspond directly to the size of the study spaces and the number of openings in the cell. The sound levels in Cell A remain homogeneous throughout the day with a maximum peak of 164.3 decibels and the lowest point being 7.63 decibels. Both readings correspond to times close to 1:00 p.m. In this case, the measurements were carried out in silence and with prayer sounds. It should be noted that the minimum measurements correspond, in most cases, to 40 decibels, due to the configuration of the equipment. From the light and sound measurements of Cell A, it appears there is a direct relationship between the size of the room and the level of illumination, as well as the openings in the measured space. Regarding sound, the measurements show that there is no direct relationship between the size of the space and the decibels. Figure 11 shows the lux and decibel measurements in cell A.

- *Cell B*

Figure 12 shows the lux and decibel measurements in Cell B. In this Cell, the lighting in the main space fluctuates during the day, with peaks of light between 12:00 and 14:00 hours, the highest level of illumination being 62.1 lux at 13:00 hours and the lowest level being 7.19 lux at 16:49 hours. In the secondary space, illumination is variable, with the highest peak of 57.2 lux at 13:18 and the lowest reading of 2.05 lux at 9:27 hours. These higher and lower lux measurements directly correspond to the size of the study spaces and the number of openings in the cell. The sound levels in Cell B remain homogeneous throughout the day with a maximum of 51.7 decibels and a minimum of 40.0 decibels. Both measurements correspond to times around 12:00 and 14:00 hours. In this case, the measurements were made in silence and with prayer sounds. It should be noted that the minimum measurements correspond, in most cases, to 40 decibels, due to the configuration of the equipment. Of the two spaces measured in Cell B, it is noteworthy that the lighting level is balanced in both rooms, regardless of their size. The sound level is kept at levels that do not exceed 60 decibels.

- *Cell C*

Figure 13 shows the lux and decibel measurements in Cell C. The light in the main space of Cell C fluctuates throughout the day, with light peaks occurring between 3:00 p.m. and 5:00 p.m. (Figure 13). The highest illumination level is 140.1 lux at 9:55 a.m., and the lowest is 12.94 lux at 12:06 p.m. In the secondary space, illumination is variable, with the highest peak of 39.6 lux at 1:18 p.m. and the lowest reading of 1.04 lux at 4:38 p.m. These higher and lower lux measurements directly correspond to the size of the study spaces and the number of openings in the cell.

The sound levels in Cell C remain homogeneous throughout the day with a maximum peak of 58.8 decibels and a negative peak of 40.0 decibels (Figure 13). Both peaks correspond to times close to 12:00 hours. In this case, the measurements were carried out in silence and with prayer sounds. It should be noted that the minimum measurements correspond, in most cases, to 40 decibels; this is due to the configuration of the equipment. According to the results obtained, there is a direct relationship between the size of the measured spaces and the amount of illumination measured. Regarding sound, the measurements show that there is no direct relationship between the size of the space and the decibels, even though the peak of the highest sound is in the secondary space.

- *Cell D*

The lighting in Cell D, shown in Figure 14, which consists of a single space, fluctuates between 34.16 lux at its highest peak at 2:03 p.m. and 2.55 lux at its lowest level at 9:58 a.m. The cell does not receive direct sunlight at any time of the day due to its location within the Main Cloister. The sound levels in Cell D range from 59.2 decibels at 2:03 p.m. to 40.0 decibels for the rest of the day. Unlike the other cells, this single-room space is small and due to its location as part of the main cloister, is more prone to higher noise levels. The lighting levels in Cell D are low because it does not receive natural lighting throughout the day. As for sound, the levels are low but are affected by the music coming from the Main Cloister.

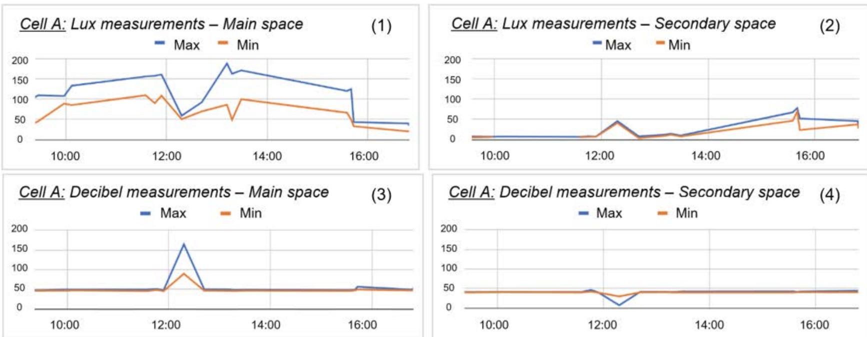

Figure 11. Lux and decibel measurements in Cell A. (1) and (2) Lux measurements, (3) and (4) Decibel measurements in the main and secondary spaces, respectively.

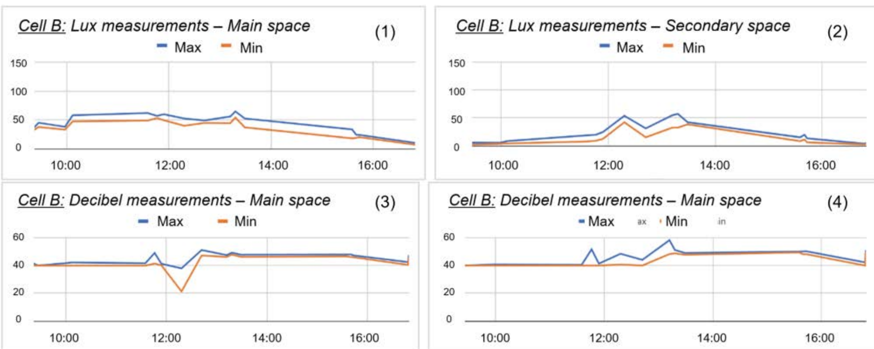

Figure 12. Lux and decibel measurements in Cell B. (1) and (2) Lux measurements, (3) and (4) Decibel measurements in the main and secondary spaces, respectively.

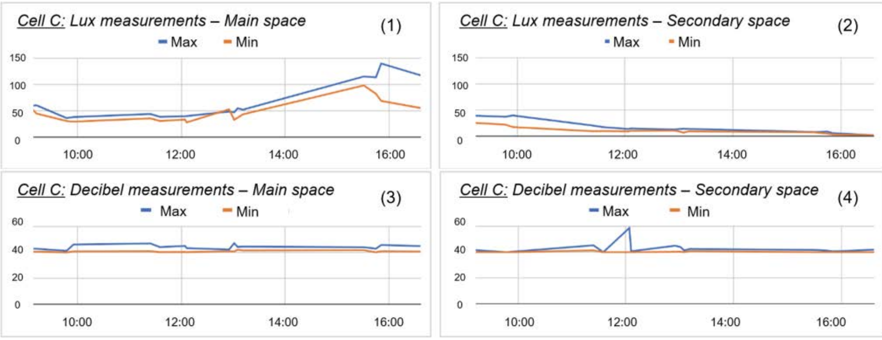

Figure 13. Lux and decibel measurements in Cell C. (1) and (2) Lux measurements, (3) and (4) Decibel measurements in the main and secondary spaces, respectively.

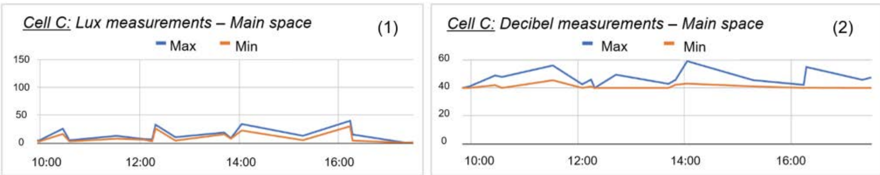

Figure 14. Lux and decibel measurements in Cell D, (1) Lux measurements, and (2) Decibel measurements in the main space.

6. Discussion

Given the significant number of ranges and results applied in the study, it is essential to construct a table containing the maximum and minimum values of temperature and relative humidity recorded by each sensor, along with their respective dates. Table 3 is a summary that will subsequently enable an evaluation to be made of the studied spaces based on Fanger's comfort scale.

Table 3. Summary table of maximum and minimum temperature and Relative Humidity values with corresponding dates

N° Sensor	Location	Space	T. Max. (C°)	Date / Hour	T. Min. (C°)	Date / Hour	HR Max. %	Date / Hour	HR Min. %	Date / Hour
Sensor 1	**Cell A**	*Main space*	*25.409*	*15-02-24 14:00*	*15.703*	*12-07-24 9:00*	*64.328*	*27/02/24 12:00*	*15*	*24-06-24 13:00*
Sensor 2		*Secondary*	*24.175*	*15-02-24 20:00*	*16.18*	*13-07-24 9:00*	*60.208*	*8-03-24 14:00*	*15*	*4-06-24 10:00*
Sensor 3	**Cell C**	*Main space*	*27.659*	*21-03-24 8:00*	*16.347*	*12-07-24 9:00*	*60.994*	*27-02-24 12:00*	*15*	*14-06-24 18:00*

Sensor 4		*Secondary*	*34.924*	*22-08-24 13:00*	*14.891*	*13-07-24 7:00*	*65.868*	*27-02-24 12:00*	*15*	*28-05-24 7:00*
Sensor 5	**Cell B**	*Main space*	*35.057*	*22-08-24 13:00*	*14.963*	*12-07-24 9:00*	*65.879*	*26-02-24 18:00*	*15*	*31-05-24 21:00*
Sensor 6		*Secondary*	*24.055*	*15-02-24 14:00*	*14.891*	*12-07-24 10:00*	*66.909*	*27-02-24 12:00*	*15*	*19-07-24 19:00*
Sensor 7	**Cell D**	*Main space*	*22.997*	*15-02-24 14:00*	*16.085*	*13-07-24 7:00*	*66.314*	*27-02-24 12:00*	*15*	*11-08-24 21:00*
Sensor 8	**Main Cloister (exterior measurements)**	*Outer space*	*28.089*	*16-08-24 13:00*	*9.408*	*12-07-24 6:00*	*86.212*	*26-02-24 20:00*	*6.296*	*15-07-24 12:00*
Sensor 9		*Outer space*	*27.66*	*16-08-24 13:00*	*9.966*	*12-07-24 6:00*	*85.086*	*26-02-24 19:00*	*6.328*	*15-07-24 12:00*

Table 4 shows the collected data that were analysed using the CBE Thermal Comfort Tool from Berkeley (https://comfort.cbe.berkeley.edu/EN) to compute the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices, in strict adherence to international standards ASHRAE Standard 55-2023 and EN-16798. The analysis determined that of the four evaluated cells, Cells A, B, and C meet the comfort thresholds outlined by both standards. Conversely, Cell D fails to meet the thermal comfort requirements of ASHRAE 55 but satisfies those of EN-16798.

Table 4. Microclimatic Determination of PPD and PVD values according to ASHRAE – 55 and EN 16798 in the evaluated spaces

					ASHRAE - 55		***EN 16798***		
	Location	***Space***	***T° Max. (C°)***	***HR Max. %***	***PMV***	***PPD (%)***	***PMV***	***PPD (%)***	***Category***
Sensor 1	***Cell A:***	*Main space*	*25.409*	*64.328*	*0.11*	*5*	*0.04*	*5*	*I*
Sensor 2		*Secondary*	*24.175*	*60.208*	*-0.36*	*8*	*-0.22*	*6*	*II*
Sensor 3	***Cell C:***	*Main space*	*27.659*	*60.994*	*-0.35*	*8*	*0.43*	*9*	*II*
Sensor 4		*Secondary*	*24.175*	*65.868*	*-0.18*	*6*	*-0,18*	*6*	*I*
Sensor 5	***Cell B:***	*Main space*	*23.886*	*65.879*	*-0.41*	*9*	*-0.23*	*6*	*II*
Sensor 6		*Secondary*	*24.055*	*66.909*	*-0.35*	*7*	*-0.19*	*6*	*I*
Sensor 7	***Cell D:***	*Main space*	*22.997*	*66.314*	*-0.72*	*16*	*-0.39*	*8*	*II*
Sensor 8	***Main Cloister***	*Outer space*	*28.089*	*86.212*	*1.28*	*39*	*0.77*	*17*	*IV*
Sensor 9		*Outer space*	*27.66*	*85.086*	*1.11*	*31*	*0.67*	*14*	*III*

Microclimatic assessments within the interior environments revealed PMV values ranging from -0.19 to 0.11, signifying near-neutral thermal perception, consistent with the comfort zone. Corresponding PPD percentages (excluding Cell D) ranged from 5%

to 8%, averaging 6.5%, categorizing these spaces under Categories I and II of thermal comfort as per ISO 7730 guidelines. However, Cell D exhibited a PPD of 16%, exceeding the thresholds defined by ASHRAE 55, indicating non-compliance with acceptable indoor comfort levels. For the main cloister, an open-air environment, the recorded microclimatic conditions presented PMV values ranging from 0.67 to 1.28, with PPD percentages spanning 14% to 39%. These results position the cloister outside the defined thermal comfort zones of both standards, highlighting its unsuitability for extended occupancy or activity. The architectural analysis revealed that Cells A, B, and C benefit from two zones with direct solar exposure during the day, enhancing passive heating and contributing to compliance with thermal comfort standards. In contrast, Cell D, despite being constructed with ignimbrite, lacks solar incidence, resulting in suboptimal thermal performance and failure to meet the ASHRAE 55 standard. The main cloister, fulfilling its role as an open-space architectural and spatial organizer, demonstrates substandard microclimatic conditions, rendering it unsuitable for prolonged use without additional environmental controls or adaptations. Lighting for interior spaces is defined by the technical standard EM-0.10 'Interior Electrical Installations of the National Building Regulations,' published by ICG-Peru [29]. According to this standard, the minimum lighting comfort level for private residential spaces should be between 50 lux and 100 lux. In this regard, the cells of the Santa Catalina Monastery do not meet the minimum lighting requirements. However, Espinoza [30] describes spaces dedicated to worship, which aim to foster a connection between the user and their inner self, emphasize how low light levels, or twilight, support worship. In these spaces, lighting levels range from 0 lux to 65 lux, and the studied cells fulfill the purpose of providing the necessary dim lighting for introspection and worship. The regulations governing acoustic comfort in buildings are diverse. It is necessary to mention the regulations from the Ministry of Development: NBE-CA-88 'Acoustic Conditions of Buildings' [31] and the WHO Guidelines for Community Noise at the international level [32], as well as the 'Regulation of National Environmental Quality Standards for Noise' in Peru [33]. Regarding acoustic comfort, in general, the standard considers that levels below 45 dB are considered a zone of well-being, levels above 55 dB are perceived as annoying noise, and levels exceeding 85 dB are associated with harmful health effects. The cells studied in the Monastery of Santa Catalina show constant levels ranging from 40 to 60 decibels, maintaining acoustic comfort, conducive to religious introspection.

7. Conclusions

Measurements were conducted in four emblematic cells of the Monastery of Santa Catalina in Arequipa, evaluating four main variables: (i) ambient temperature, (ii) relative humidity, (iii) lighting levels, and (iv) sound levels. The results for temperature and relative humidity confirmed that the cells consistently remain within the comfort range of 18°C to 22°C. The relative humidity measurements, which fluctuated between 60% and 15%, align with those obtained inside the cells, revealing a seasonal trend characterized by high moisture levels at the beginning of the year, followed by a significant decrease during the mid-year months. However, the measured lighting levels were found to be below the comfort range of 500 to 750 lux, with levels ranging from 0 to 150 lux. These low lighting levels are consistent with the cell's use, which was intended to promote worship. Regarding sound, the measured levels were within the comfort zone, below 45 dB. Exterior measurements were carried out in the Main Cloister of the historic monument, obtaining data that was later compared with the measurements provided by the “La

Pampilla" Meteorological Station. The graphs showed that the thermal behavior of the cells was consistent with the outdoor temperatures, maintaining comfort temperatures in all cases. This is due to the use of ignimbrite in their construction.
From the results obtained it is clear that, generally, in the main environments, a direct relationship is observed between temperature, relative humidity and lighting and the size of the space. On the other hand, the data collected on sound show that the size of the environment does not necessarily affect the number of decibels quantified. The results obtained from the measurements show that Cell D (Sor Juana Arias's cell) does not have the characteristics of a residential cell, suggesting that it may have had a different function during the operational period of the Monastery of Santa Catalina. The dimensions, openings, and spatial relationships, as well as the cell's thermal behavior, indicate that it was likely used as a space for "meditation." The elevated windows and the door with an opening for receiving food reinforce this hypothesis.

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Summary

The Monastery of Santa Catalina in Arequipa is among Peru's most significant and well-preserved historical monuments. It comprises primarily residential cells occupied by cloistered nuns of the Dominican order. This study conducts a microclimatic assessment of four emblematic cells and the main cloister, focusing on thermal, lighting, and acoustic characterization to evaluate habitability based on international standards. Environmental conditions were monitored from February to August 2024 using temperature and relative humidity sensors, along with digital lux and sound level meters. The data were analysed according to Fanger's thermal comfort model. Results indicated PMV values between -0.19 and 0.11, corresponding to near-neutral thermal perception within the comfort zone. PPD values (excluding Cell D) ranged from 5% to 8%, with an average of 6.5%, aligning with Categories I and II of ISO 7730. Cell D, however, recorded a PPD of 16%, exceeding ASHRAE 55 thresholds, indicating non-compliance with acceptable thermal comfort standards.

Riassunto

Il monastero di Santa Catalina ad Arequipa è uno dei monumenti storici più significativi e ben conservati del Perù. È composto principalmente da celle residenziali occupate da suore di clausura dell'ordine domenicano. Questo studio conduce una valutazione microclimatica di quattro celle emblematiche e del chiostro principale, concentrandosi sulla caratterizzazione termica, illuminotecnica e acustica al fine di valutare l'abitabilità in base agli standard internazionali. Le condizioni ambientali sono state monitorate da febbraio ad agosto 2024 utilizzando sensori di temperatura e umidità relativa, insieme a misuratori digitali di lux e livello sonoro. I dati sono stati analizzati secondo il modello di comfort termico di Fanger. I risultati indicano valori PMV compresi tra -0,19 e 0,11, corrispondenti a una percezione termica quasi neutra all'interno della zona di comfort. I valori PPD (esclusa la cella D) variavano dal 5% all'8%, con una media del 6,5%, allineandosi alle categorie I e II della ISO 7730. La cella D, tuttavia, ha registrato un PPD del 16%, superando le soglie ASHRAE 55, indicando la non conformità con gli standard di comfort termico accettabili.