The influence of the envelope in the preventive conservation of books and paper records. Case study: Libraries and archives in La Plata, Argentina

María de la Paz Diulio[a], Pilar Mercader-Moyano[b], Analía Gómez[a]

[a] Laboratorio de Arquitectura y Hábitat Sustentable (LAyHS-FAU), National University of La Plata.

[b] Departamento de Construcciones Arquitectónicas I, Universidad de Sevilla, Seville, Spain.

Corresponding author: Pilar Mercader-Moyano

Departamento de Construcciones Arquitectónicas I, Universidad de Sevilla, Seville, Spain.

E mail: pmm@us.es

Abstract

The common approach for libraries to preserve their paper-based collections from irreversible deterioration is by controlling quantitative parameters, such as temperature and relative humidity. Variations of these parameters for preventive conservation can be expressed by the "performance index" (PI) and the "amplitude index" (AI).

Building envelope is the first filter of the external climate, buffering the external weather fluctuations and maintaining the building's indoor climate stable. Its shape, window areas and envelope materials are the most influential parameters. As they capture the relationship of a few geometric and physical variables with the building's performance, the envelope characteristics can be expressed as certain passive envelope indexes.

This paper studies the relationship of certain passive envelope indexes and the preventive conservation indexes for books for several libraries and archives located in La Plata, Argentina.

The results show the impact of every passive envelope index upon the preventive conservation indexes. The compactness, heaviness, adjacency to spaces and adjacency to ground have a positive linear correlation meanwhile transparency and global transmittance are parameters with a negative correlation. In general, the most influential parameter is the relative area adjacent to other spaces, followed by global transmittance, transparency, heaviness, relative area adjacent to ground and compactness.

Highlights

- Definition of passive envelope indexes and caracterization of libraries in La Plata
- Environmental monitoring: achievement of preventive conservation indexes
- Correlation between passive envelope indexes and preventive conservation indexes
- Determination of the most influential passive envelope indexes for the achievement of preventive conservation indexes.

Keywords

Preventive conservation; building envelope; hygrothermal indoor environment; passive envelope indexes

1 Introduction

As well as functioning as meeting, study, work and discussion places for students and researchers, libraries lend books (use and reuse). Indeed, they often contain historical books which form part of the nation's cultural heritage. Due to their organic characteristics, books are vulnerable to both hygrothermal variations and contaminants [1].

Due to continuous, unremitting use, chemical deterioration, inadequate storage, and the effect of the environments in which they are kept [2], the general condition of books and paper records in most libraries and archives is not good. In order to extend the lifespan of books, a continuous temperature and relative humidity monitoring is necessary in order to register their oscilations and assess their adequacy to the conservation of paper records [3] [4] [5].

The International Council of Museums (ICOM) defines conservation as: "[…] all measures and actions aimed at safeguarding tangible cultural heritage while ensuring its accessibility to present and future generations" [6]. Three forms of conservation are mentioned specifically: "[…] conservation embraces preventive conservation, remedial conservation and restoration" [6]. These activities are aimed at "future", "current" and "past" deteriorations.

Preventive conservation is defined as "all measures and actions aimed at avoiding and minimising future deterioration or loss". These measures and actions are indirect – they do not interfere with the materials and structures of the items. They do not modify their appearance [6]. Preventive conservation is a combination of actions directed at reducing the exposed object’s risk of degradation and at identifying optimal environmental conditions for displaying the object in the most secure manner [7] [8].

The common approach for libraries to preserve their paper-based collections from irreversible deterioration is by controlling quantitative parameters, such as temperature and relative humidity. Environmental monitoring is necessary, therefore, in order to avoid fluctuations that may cause irreversible and unpredictable damage. Work on this activity started in the 1980s, with many experimental works being undertaken by the ISAC-CNR in Italy [9] [8].

In order to define the relationship between environmental conditions and heritage risks, the above studies involved both outdoor and indoor climates. In this context, each degradation phenomenon was investigated through monitoring and evaluating thermo-hygrometric parameters [10] [11] [12] [13] [14] [15].

The outcomes of these experiments contributed to the development of Italian [16] [17] [18] and European [19] [20] [21] standards which offered some recommendations concerning monitoring, processing, and summarisating procedures for taking the “historical climate” into consideration [8]. They also recommend temperature and relative humidity ranges in order to preserve paper records.

Therefore, providing such indoor climates, by controlling temperature fluctuations (T) and relative humidity (RH), as well as some synthetic parameters based on recommended T and RH levels, will extend the life of paper-based collections [7] [10] [22] [15].

The conditions recommended by Cunha [2] are a compromise between what is good for the books and paper records and what is comfortable for people. This compromise recommends temperatures between 19-21ºC and relative humidity between 45-55%, corresponding to the “20/50 standard” proposed by Thomson as Conservation Class 1 [23].

UNI standard 10586 [18] recommends a temperature range of 14-20ºC and a relative humidity of 50-60% for book depositories, with seasonal oscillations of 2ºC and 5%. For book consultation spaces the recommended temperature is 18-23ºC and a relative humidity of 50-65%.

UNI standard 10829 [17] for paper objects, recommends a temperature range of 18-22ºC and a relative humidity of between 40-55%. It also establishes a maximum daily amplitude of 1.5ºC and 6% RH.

Based on these standards, the scientific literature defined a synthetic "performance index" (PI) that identifies the percentage of time in which the parameter measured lies within the required ranges [24] [22] [25] [26]. In this way, hygrothermal quality was evaluated on the basis of medium/long-term monitoring and not on punctual data [11] [27] [22] [25].

With regard to the maximum daily amplitude, UNI standard 10829 [17] assesses the effect of the environment upon mechanical damage suffered by books and paper records due to the amplitude index (AI). This index can be defined as the percentage of days in which the amplitude of the measured parameter is lower than the maximum daily amplitude [28] [3].

In connection with these studies, several works analysed the contribution to passive climate control [29] [30] [31] of the original architectural features and their construction materials. Normally, collections are acclimatised to diurnal, seasonal and annual hygrothermal fluctuations thanks to the architectural features that house them [32] [33]. It is well-known that the building envelope is the first filter of the external climate, buffering the external weather fluctuations and maintaining the building's indoor climate stable [33], its shape, window areas and envelope materials being the most influential parameters [34].

As they capture the relationship of a few geometric and physical variables with the building's performance, these parameters can be expressed as certain building performance indexes [35] [36]. Shape-based indexes focus upon the relationship between the envelope surface area and the interior volume of the building [37] [38] [39] [40] [41] [42]. Window-based indexes, on the other hand, focus on the contribution of solar gains through the building's transparent envelope areas [43] [44].

This research focuses on establishing the relationship of certain building performance indexes and the indexes expressing the environmental adequacy for preventive conservation of books and paper records for several libraries and archives located in La Plata, Argentina.

2 Methodology

In order to study the influence of the thermal envelope upon the preventive conservation indexes for books and paper records, the following methodology was undertaken:

- Selection of the case studies
- Calculation of passive envelope indexes
- Environmental monitoring
- Calculation of preventive conservation indexes
- Analysis of the relationship between passive envelope indexes and preventive conservation indexes

2.1 Case studies and outdoor climate

The cases studied were selected from those conservation spaces whose predominant materials for conservation are paper books at the National University of La Plata (UNLP), Argentina.

The city of La Plata is situated 34º55 South and 57º57 West. It has a humid, subtropical climate (Cfa under the Köppen climate classification).

According to the hourly weather data obtained from the Astronomical Observatory of La Plata for 2015, in winter, temperatures are cool during the day and cold during the evening, possibly dropping to below freezing. Average temperature in the coldest month, July, is 8.9 °C. Snowfall in the city is extremely rare. Winters tend to be cloudier than summer, averaging around 10 overcast days from June to August, compared to 6 overcast days from December to February.

Summers are warm to hot, with a January high of 29 °C while nighttime temperatures are cooler, averaging 18 °C. Spring and fall are transition seasons, featuring warm daytime temperatures and cool nighttime temperatures. These temperatures can vary greatly, some days registering temperatures above 32 °C and below 0 °C.

Owing to its coastal location, the city is fairly humid and its average monthly humidity is higher than 75%. La Plata receives 1,092 millimetres (43 in) of precipitation annually, with winters being the driest months, and summer the wettest. On average, La Plata receives 2,285 hours of sunshine a year, or 51% of possible sunshine, ranging from a low of 41% in June and July to 62% in February.

The libraries selected serve 88% of all Univeridad de la Plata library users and employ 85% of the University's library staff. They are the most representative spaces from the point of view of document collections and the population served. These spaces contain 91% of the University's monographs belonging to faculties that, together, account for 90% of the UNLP's lecturers and students.

Table 1 shows the selected cases that total 33 spaces in 9 libraries and 2 archives:

Table 1: Selected case studies

2.2 Passive Envelope indexes

A building's envelope acts as a filter to the external climate and its characteristics influence how indoor environmental conditions are achieved. Those characteristics that focus on minimising the building's energy demand are known as passive design.

Serra and Coch [36] describe several indexes that link the geometrical and physical characteristics of the envelope with its climatic repercussion. These are defined as natural ways of controlling the indoor environment via the envelope. In order to characterise the study cases, some of these indexes have been calculated. These are: compactness, heaviness, relative area in contact with adjacent spaces, relative area in contact with the ground, transparency and global transmittance value.

The compactness index establishes a relationship between the total surface of the building and its volume. It is dimensionless and it is defined in such way that the greatest compactness, which is a sphere, corresponds with the highest index value, the unit.

$$CI = (Seq/St) = 4{,}836\ (VT^{2/3}/St) \qquad \text{[Eq. 1]}$$

Where CI is the compactness index (dimensionless, 0-1); Seq is the equivalent surface, which is the surface of a sphere which has the same volume as the building; VT is the total volume of the building; and St is the sum of the surfaces of the envelope.

Heaviness is a physical quality that depends on the specific constructive composition of the envelope. The heaviness index (HI, kg/m^2) expresses the relationship between the total superficial mass of the wall (M, kg) and the wall surface area (S, m^2)

$$HI = M/S \qquad \text{[Eq. 2]}$$

This concept is usually associated with that of thermal inertia. Buildings which contain a large thermal capacity within the thermal envelope can store and progressively release large quantities of heat, thereby time-shifting and attenuating temperature excitations [45] [46]. In temperate climates, this behaviour leads to a great thermal equilibrium in a short period of time [8] [13]

The relative area in contact with adjacent spaces(Ad) is a dimensionless index that expresses the relationship between the surface of the envelope that is in contact with other spaces (Sad) and the total surface of the envelope (St).

$$Ad = Sad / St \qquad \text{[Eq. 3]}$$

Its climatic repercussion is directly linked to the fact that high values imply low envelope areas in contact with external conditions. This provides greater thermal protection against exterior climatic fluctuations, but it also implies greater problems in terms of capturing solar radiation and of ventilating the indoor spaces leading to an increase in relative humidity.

The relative area in contact with the ground (Ag) is a dimensionless index that expresses the relationship between the surface of the envelope in contact with the ground (Sag) and the total surface of the envelope (St).

$$Ag = Sag / St \qquad \text{[Eq. 4]}$$

This index is linked with an increase in the thermal inertia, a lower solar radiation capture and lower fresh air renewal rate, thus increasing relative humidity.

The concept of transparency provides an idea of the performance of the building in terms of capturing solar radiation. The transparency index (TI) is a dimensionless index expressing the relationship between the glazed area (Sgl) and the total surface of the envelope (St).

$$TI = Sgl/St \qquad \text{[Eq. 5]}$$

Its climatic repercussion is linked to the greenhouse effect. This effect is based on the fact that solar radiation, having passed through the glazing and having been absorbed by interior surfaces, is re-emitted in waves of a higher longitude that cannot now escape through the glazing, thus increasing the temperature.

As result, a building with a large glazed area can capture high levels of radiant energy, but the energy losses by transmission are also high. The indoor environment will, therefore, suffer high temperature oscillations.

A building's insulation provides an idea of the resistance of the envelope to heat transfers by conduction. This energy flux is based on the temperature diference between external and internal conditions. The building's global insulation can be expressed by the global transmittance value:

$$K_G=(\sum S_i\ U_i\ \alpha i)/S_G \qquad \text{[Eq. 6]}$$

Where Kg is the global transmittance value of the envelope of the case study (W/m^2K), defined as the weighted average of the U-values of each component of the envelope, Si is the surface of each component of the envelope (roof, walls and floor), Ui is the transmittance value (W/m^2K) of each component of the envelope, αi is a coefficient linked to the position of each component of the envelope (being 1 for the enclosing surface in contact with external air, 0'5 for the enclosing surface in contact with no heated spaces or in contact with ground, and 0'8 for roofs) and Sg is the sum of the surfaces of the envelope.

A highly insulated building has a low energy interchange between indoor and outdoor conditions; heat losses during winter are, therefore, low. A value of around 0.5 indicates a highly insulated envelope and a value higher than 4 indicates poorly insulated envelopes, resulting in higher energy interchanges with the outdoor environment and higher temperature oscilations according to climatic variations.

Table 2 shows the values calculated for each case study and also include information about the use of each space and the presence of HVAC systems:

Table 2: Characterisation of each case study

It can be seen that 45% of the above are spaces whose principal function is to house paper records (Deposit), the presence of people being occasional; 18% are reading rooms or working spaces, the presence of people is continuous and the paper records are kept in the same space; and 36% are of mixed use, the users can access to shelves but stay during short time; the afluence is of significance.

It has to be highlighted that all of the spaces whose function is reading room or mix have implemented a HVAC system, meanwhile only 4 of the 15 deposit spaces have HVAC systems.

Although internal gains and operation of HVAC systems have an influence on the indoor environment, the correlation between these parameters and the preventice conservation indexes has not been included in this article as the focus is to establish the correlation between passive envelope indexes and preventive conservation indexes.

2.3 Environmental monitoring

According to UNI 10829 Standard [17], the floor area of each case study is divided into a 5x5m grid and inner temperature and humidity are monitored at every node. Temperature and humidity sensors were placed at a height of 1.50 m, fixed at the surface of the shelves. During this procedure, particular situations, such as air stagnation or air speed change will be detected at certain nodes due to natural ventilation, mechanical ventilation and/or interaction with the air-conditioning system.

From the results of the punctual monitoring, the areas where the difference of temperature and relative humidity is lower than 2ºC and 5% were delimited, according to the protocol established by UNI 10829. The centre point of these areas are the points recommended for performing continuous environmental monitoring.

Wireless U-12-012 and U10-003 Onset Hobo data loggers with outdoor weather protection, belonging to the Laboratory of Architecture & Sustainable Habitat (LAyHS) were used. Temperature and humidity values were recorded with a time-step of 30 minutes. The characteristics of the measurement instruments are shown in Table 3.

Table 3: Measurement instruments

Monitoring began in March 2011 and ended in March 2013. As weather conditions do not change abruptly, these measurements are divided into four times [17], each one corresponding to central season periods. Figure 1 shows the table of the environmental monitoring of the 33 spaces under study.

Figure 1: Environmental monitoring schedule

2.4 Preventive conservation indexes

Once the monitoring phase was over, the indoor climate for preventive conservation of paper records was determined. This indoor climate is the reference interval that ensures the best conservation of paper records, consisting of establishing acceptable upper and lower temperature and relative humidity limits that are adequate for conservation purposes.

As stated in the introduction, there are several recommedations concerning the indoor climate. The proposed indoor climate is based on the arguments of the above recommendations regarding avoidance of distress of the paper records and on attaining an indoor climate similar to that monitored in La Plata, considering the passive thermal performance of these spaces and the ease of the existing HVAC systems to maintain the indoor climate within the conservative climate band.

The upper limit for relative humidity is determined by the fact that fungi proliferate when the relative humidity reaches 70% [32]. A value of 65% is therefore established, taking into consideration the external fluctuation, a margin of sensor error, and the recommended maximum value for book consultation spaces [18] [47]. In order to prevent dessication of the paper fibres, the lower proposed limit is 45%. According to a review of the literature and the analysis of the climate of Buenos Aires, a 10% fluctuation for relative humidity is proposed.

In terms of temperature limits, the recommendations combine the objectives of user comfort and avoiding condensation and chemical risk. A temperature range of 15-25ºC fulfils both objectives and is within the average range of Buenos Aires (19ºC ±5.5ºC). According to the recommedations of Thomson [23] and Bell and Faye [47], a 2-ºC temperature fluctuation is proposed.

As expressed in the standards for preventive conservation, the values proposed are generic and do not contemplate particular materials or situations. In such cases, a specific investigation is required.

Once the indoor climate for preventive conservation is proposed, the preventive conservation indexes are calculated. These are the Performance Index (PI), the Amplitude Index (AI) and the Combined Index (CI). The Performance Index (PI) was developed by Corgnati, Filipi and Merino [49] and lately used for environmental assessment of museums and archives [25]. The Amplitude Index (AI) and the Combined Index (CI) are proposed by the authors. The Amplitude Index is based on the concept of the environmental stability of the paper records, as it helps to their conservation by minimizing the paper distress. The Combined Index (CI) allows to assess simultaneously PI and AI.

The Performance Index (PI) identifies the percentage of measurements in which the measured parameter lies within the required ranges:

$PI = M_{within}/M_{total}$ [Eq. 7]

Where PI is the performance index, M_{within} is the number of measurements within the indoor climate range and M_{total} is the total number of measurements.

The Amplitude Index (AI) assess the number of days in which the daily amplitude of the measured parameter lies within the máximum admited fluctuation:

$AI = D_{within}/D_{total}$ [Eq. 8]

Where AI is the amplitude index, D_{within} is the number of days with an oscillation lower than the maximum established and D_{total} is the total days of measurement.

The Combined Index (CI) assess the achievement of the Performance and Amplitude Indexes. It can be calculated as the average between both indexes.

$CI_i = (PI_i+AI_i)/2$ [Eq. 9]

0 is the mínimum value and it corresponds to the most unfavourable performance. The maximum value is 1 and corresponds to the best situation. Values near 1 are desirable, while values near 0 represent indoor climate conditions that are far from what is hoped for. The values of preventive conservation indexes for the study cases are shown in Table 4.

Table 4: Preventive conservation indexes for the cases of study

3 Results

The results of the impact of every passive envelope index upon the preventive conservation indexes are shown in this section. The Pearson correlation coefficient (r) is determined for every parameter studied. the Pearson correlation coefficient (r) is determined.

Table 5: r values for each passive envelope indexes and preventive conservation indexes

Figure 2: Pearson correlation coefficient for each passive envelope index and preventive conservation index

As seen in Figure 2, the compactness, heaviness, adjacency to spaces and adjacency to ground have a positive linear correlation, meaning that as these passive envelope indexes increase, the preventive conservation indexes also increase.

Transparency and Global transmittance are parameters with a negative correlation. As the relative glazed area increases and consequently thermal insulation decreases (higher transmittance), the conservation indexes decrease.

The Combined Index is the attainemnet of indoor climate ranges and the maximum allowed amplitude for temperature and relative humidity; the most influential parameter is the relative area adjacent to other spaces, followed by global transmittance, transparency, heaviness, relative area adjacent to ground and compactness.

The relative area in contact with adjacent spaces is linked to the fact that high values imply low envelope areas in contact with the external conditions, providing greater thermal protection against exterior climatic fluctuations.

Figure 3: Relative area in contact with adjacent spaces and Preventive Conservation indexes

As a consecuence of the envelope's lower exposure to external conditions, the Amplitude Index presents the highest value for the Pearson correlation coefficient. The Performance Index for this parameter is, however, relatively low. Therefore, the role of the adjacent spaces is that of attenuating external fluctuations by reducing exposure to them.

The Global transmittance value presents a negative correlation as higher transmittances imply lower thermal insulation, leading to minor differences between external and internal climate. CI values higher than 0.6 correspond to global transmittance values between 1 and 1.8 W/m^{2}K.

The Amplitude Index is higher than the Performance Index. This means that although the temperature and relative humidity inside spaces do not meet the ranges in more than 40% of the measurements, daily fluctuations were lower than the permitted maximum.

Figure 4: Global transmittance value and Preventive Conservation indexes

The transparency index is assessed based upon the hypothesis that the glazed area has a lower transmittance value than opaque envelope areas and that it allows solar radiation to be transmitted into the interior, affecting the indoor climate.

Figure 5: Transparency index and Preventive Conservation indexes

The results indicate that the best values are achieved for a transparency index lower than 6%, especially for the Amplitude Index. This corresponds to low solar captation, implying fewer temperature fluctuations. This correlation is negative, so as the transparency index increases, preservative conservation indexes decrease.

The heaviness index assesses the capacity of the envelope to absorb, store and release heat, attenuating daily and seasonal temperature excitations. Figure 6 reveals that there is a certain correlationship between the heaviness index and the Combined Index.

The Amplitude Index is observed to be that with the highest Pearson correlation coefficient, confirming the potential of heavy envelopes to cushion external climate conditions. The value of this coefficient is lower for the Performance Index, expressing that although the envelope is able to reduce the external climate fluctuations, the heaviness index has a lower influence on attatining an indoor climate within the thresholds.

Figure 6: Heaviness index and Preventive Conservation indexes

The analysis of the relative area in contact with ground takes into account only those spaces which have part of their envelopes in contact with the ground, so a small number of spaces are considered. The ground temperature is very stable, so a high contact percentage of the envelope with the ground implies an energy transmittance with a material with lower fluctuations than the external climate.

Figure 7: Relative area in contact with the ground and Preventive Conservation indexes

Although globally this parameter is almost the least influential, it can be seen that there is a strong correlation, especially in terms of the Performance Index.

Interest in the compactness index lies in the fact that the greater the compactness, the lower the contact of the building with the external conditions. This implies lower solar radiation capture and lower energy losses through the envelope.

Figure 8: Compactness index and Preventive Conservation indexes

For every preservative conservation index, the value of the Pearson correlation coefficient is nearly 0. This implies that there is no linear correlationship between the variables. It can therfeore be said that the compactness index does not have any influence upon the preservative conservation indexes.

4 Conclusions

Historical books are part of a nation's cultural heritage. They are vulnerable to hygrothermal variations and contaminants. In order to extend their lifespan and reduce risk of deterioration, preventive conservation is required.

In libraries preventive conservation measures are based on controlling temperature and relative humidity in order to avoid the irreversible deteriorarion of the paper-based collections and to display them in the safest possible manner.

While simultaneously providing hygrothermal conditioning, the characteristics of a building's envelope passively buffer variations in external temperature and relative humidity.

The novelty of this research is based on the correlation of envelope characteristics with some hygrothermal metrics associated to the preventive conservation of paper-based files. It has, therefore, been possible to determine the characteristics of the studied buildings' envelopes which exert the greatest influence upon attaining certain values and ranges of temperature and relative humidity that are in agreement with preservative conservation.

It has been demonstrated that the envelope has a greater ability to buffer variations in temperature and relative humidity, expressed by means of the Amplitude index (AI), than to attain specific temperature and relative humidity values, expressed through the Performance index (PI).

The results show that the most influential characteristics are the relative area adjacent to other spaces, meaning exposure to the external environment, followed by global transmittance, transparency, heaviness, relative area adjacent to ground and compactness. This prioritisation is helpful in order to take decisions when designing new libraries, always bearing in mind that there are other characteristics which were not studied in this research, yet which also influence preventive conservation. This prioritisation can be taken into account in existing libraries by reallocating the most sensitive activities, such as the archive, to the spaces which, in agreement with the results, are the most suitable for their specific function – especially in those buildings that contain different activities, such as the faculties of a university.

The optimisation of these characteristics, especially exposure to the elements, global transmittance and transparency, will allow reductions in the HVAC systems' energy consumption. Such systems are designed to maintain specific temperature and relative humidity values, suitable for preventive conservation. This optimisation will also reduce greenhouse emissions, thus contributing to improved energy efficiency in the libraries.

5 Acknowledgements

The authors are grateful for the collaboration of the staff of the libraries of the National University of La Plata that took part in this research.

The research was supported by the following Argentinian programs: National Council for Scientific and Technical Research, UNLP-PPID006 and Bec.Ar, Ministerio de Modernización, Argentina. It is the result of a doctoral thesis co-tutored by the National University of La Plata, Argentina, and Universidad de Sevilla, Spain.

The wording of this paper is part of the project "Rehabilitación Ecoeficiente de Edificios y Barrios" of the Universidad de Sevilla, Spain, financied by the following companies: GRUPO PUMA S.L. and MAPEI SPAIN S.A.

The authors also want to thank the collaboration of Dr. Paula M. Esquivias, lecturer at the MSc Building and Neighbourhood Ecoefficient Retrofit: without her work it could not have been possible.

6 References

[1] L. Dias Pereira, A. Rodrigues Gaspar y J. J. Costa, «Assessment of the indoor environmental conditions of a baroque library in Portugal,» *Energy Procedia,* vol. 133, pp. 257-267, 2017.

[2] G. M. Cunha, «Methods of evaluation to determine the preservation needs in libraries and archives: a RAMP study with guidelines,» UNESCO, Paris, 1988.

[3] M. d. l. P. Diulio, M. García Santa Cruz y A. Gómez, «Preventive Conservation Plan for Library Buildings in La Plata, Argentina,» *Energy Procedia,* vol. 78, pp. 1293-1298, 2015.

[4] J. Tacón Clavaín, La Conservación en Archivos y Bibliotecas: Prevención y Protección, Madrid: Ollero y Ramos Editores, 2008.

[5] T. Coşkun, Ö. Gülhan, C. D. Şahin, Z. D. Arsan y G. G. Akkurt, «The effect of spatial interventions on historic buildings' indoor climate (Case study: Tire Necip Paşa Library, Izmir-Turkey),» *Energy Procedia,* vol. 133, pp. 358-366, 2017.

[6] ICOM-CC, «Terminology to characterize the conservation of tangible cultural heritage,» 2008. [En línea]. Available: http://www.icom-cc.org/242/about/terminology-for-conservation/#.WoQsOa7iYdU.

[7] E. Lucchi, «Review of preventive conservation in museum buildings,» *Journal of Cultural Heritage,* vol. 29, pp. 180-193, 2018.

[8] C. Camuffo, Microclimate for cultural heritage, Amsterdam: Elsevier, 1998.

[9] A. Bernardi, Conservare opere d'arte, Padova: Pleiadi, 2003.

[10] A. Bülow, *Preventive conservation for paper-based collections in historic buildings,* Leicester: DeMonfort University, 2002.

[11] V. D'agostino, F. R. d'Ambrosio Alfano, B. I. Palella y G. Riccio, «The museum environment: A protocol for evaluation of microclimatic conditions,» *Energy and Buildings,* vol. 95, pp. 124-129, 2015.

[12] E. Krüger y W. Diniz, «Relationship between indoor thermal comfort conditions and the Time Weighted Preservation Index (TWPI) in three Brazilian archives,» *Applied energy,* vol. 88, pp. 712-723, 2011.

[13] H. E. Silva y F. M. Henriques, «Preventive conservation of historic buildings in temperate climates. The importance of a risk-based analysis on the decision-making process,» *Energy and Buildings,* vol. 107, pp. 26-36, 2015.

[14] M. H. J. Martens, Climate risk assessment in museums : degradation risks determined from temperature, Eindhoven: Technische Universiteit Eindhoven, 2012.

[15] C. D. Sahin, T. Coskun, Z. D. Arsan y G. G. Akkurt, «Investigation of indoor microclimate of historic libraries for preventive conservation of manuscripts. Case Study: Tire Necip Pasa Library,˙Izmir-Turkey,» *Sustainable Cities and Society,* vol. 30, pp. 66-78, 2017.

[16] UNI (Ente Italiano di Normazione), «Beni culturali. Principi generali per la scelta e il controllo del microclima per la conservazione. Standard UNI 10969,» UNI, Milano, 2002.

[17] UNI (Ente Italiano di Normazione), «Beni di interesse storico artistico. Condizioni ambientali di conservazione. Misure ed analisi Standard UNI 10829,» UNI, Milano, 1999.

[18] UNI (Ente Italiano di Normazione), «Condizioni climatiche per ambienti di conservazione di documenti grafici e caratteristiche degli alloggiamenti. Standard UNI 10586,» UNI, Milano, 1999.

[19] CEN (European Committee for Standardization), «Conservation of cultural property. Indoor climate standard EN 15759,» CEN, Brussels, 2011.

[20] CEN (European Committee for Standardization), «Conservation of cultural property. procedures and instruments for measuring temperatures of the air and the surfaces of objects standard EN 15758,» CEN, Brussels, 2010.

[21] CEN (European Committee for Standardization), «Conservation of cultural property. specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials standard EN 15757,» CEN, Brussels, 2010.

[22] S. Corgnati y M. Filippi, «Assessment of Thermo-hygrometric quality in museums: method and in-field application to the “Duccio di Buoninsegna” exhibition at Santa Maria della Scala (Siena, Italy),» *Journal of Cultural Heritage,* vol. 11, pp. 345-349, 2010.

[23] G. Thomson, The Museum Environment, London: Butterworths, 1978.

[24] H. Entradas Silva, F. M. Henriques, T. A. Henriques y G. Coelho, «A sequential process to assess and optimize the indoor climate in museums,» *Building and Environment,* vol. 104, pp. 21-34, 2016.

[25] S. Corgnati, V. Fabi y M. Filippi, «A methodology for microclimatic quality evaluation in museums: application to a temporary exhibit,» *Building and Environment,* vol. 44, nº 6, pp. 1253-1260, 2009.

[26] M. Rota, S. Corgnati y L. Di Corato, «The museums in historical buildings: energy and systems. The project of the Fondazione Musei Senesi,» *Energy and Buildings,* vol. 95, pp. 138-143, 2015.

[27] E. Lucchi, «Multidisciplinary risk-based analysis for supporting the decision making process on conservation, energy efficiency, and human comfort in museum buildings,» *Journal of Cultural Heritage,* vol. 22, pp. 1079-1089, 2016.

[28] M. d. l. P. Diulio y A. Gómez, « Propuesta metodológica de evaluación higrotérmica para la conservación preventiva del papel,» *Revista Hábitat Sustentable,* vol. 4, nº 1, pp. 36-45, 2014.

[29] F. Toledo, The role of architecture in preventive conservation, Rome: ICCROM, 2006.

[30] M. Andretta, F. Coppola y L. Seccia, «Investigation on the interaction between the outdoor environment and the indoor microclimate of a historical library,» *Journal of Cultural Heritage,* vol. 17, pp. 75-86, 2016.

[31] C. M. Muñoz-González, A. L. León-Rodríguez y J. Navarro-Casas, «Air conditioning and passive environmental techniques in historic churches in Mediterranean climate. A proposed method to assess damage risk and thermal comfort pre-intervention, simulation-based,» *Energy and Buildings,* vol. 130, pp. 567-577, 2016.

[32] G. Pavlogeorgatos, «Environmental parameters in museums,» *Building and Environment,* vol. 38, pp. 1457-1462, 2003.

[33] S. Michalski, «The Ideal Climate, Risk Management, the ASHRAE Chapter, Proofed Fluctuations, and Toward a Full Risk Analysis Model,» de *Contribution to the Experts' Roundtable on Sustainable Climate Management Strategies*, The Getty Conservation Institute, 2007.

[34] G. Litti, A. Audenaert y K. Fabbri, «Indoor Microclimate Quality (IMQ) certification in heritage and museum buildings: The case study of Vleeshuis museum in Antwerp,» *Building and Environment,* vol. 124, pp. 478-491, 2017.

[35] V. Granadeiro, J. R. Correia, V. M. Leal y J. P. Duarte, «Envelope-related energy demand: A design indicator of energy performance for residential buildings in early design stages,» *Energy and Buildings,* vol. 61, pp. 215-223, 2013.

[36] E. Rodrigues, A. R. Amaral, A. Rodrigues Gaspar y Á. Gomes, «How reliable are geometry-based building indices as thermal performance indicators?,» *Energy Conversion and Management,* vol. 101, pp. 561-578, 2015.

[37] R. Serra Florensa y H. Coch Roura, Arquitectura y energía natural, Barcelona: Editions UPC, 1995.

[38] P. Depecker, C. Menezo, J. Virgone y S. Lepers, «Design of buildings shape and energetic consumption,» *Building and Environment,* vol. 36, nº 5, pp. 627-635, 2001.

[39] W. Pessenlehner y A. Mahdavi, «Building morphology, transparence, and energy performance,» de *Procedings of building simulation 2003*, Eindhoven, 2003.

[40] T. Catalina, J. Virgone y V. Iordache, «Study on impact of the building form on the energy consumption.,» de *12th conference of international building performance simulation association*, Sydney, 2011.

[41] R. Albatici y F. Passerini, «Bioclimatic design of buildings considering heating requirements in Italian climatic conditions. A simplified approach.,» *Building and Environment,* vol. 46, nº 8, pp. 1624-1631, 2011.

[42] S. Bekkouche, T. Benouaz, M. Hamdani, M. Cherier, M. Yaiche y N. Benamrane, «Judicious choice of the building compactness to improve thermo-aeraulic comfort in hot climate,» *Journal of Building Engineering,* vol. 1, pp. 42-52, 2015.

[43] T. L. Hemsath y K. A. Bandhosseini, «Sensitivity analysis evaluating basic building geometry's effect on energy use,» *Renewable Energy,* vol. 76, pp. 526-538, 2015.

[44] M.-L. Persson, A. Roos y M. Wall, «Influence of window size on the energy balance of low energy houses,» *Energy and Buildings,* vol. 38, nº 3, pp. 181-188, 2006.

[45] A. Stegou-Sagia, K. Antonopoulos, C. Angelopoulou y G. Kotsiovelos, «The impact of glazing on energy consumption and comfort,» *Energy Conversion and Management,* vol. 48, nº 11, pp. 2844-2852, 2007.

[46] S. Verbeke y A. Audenaert, «Thermal inertia in buildings: A review of impacts across climate and building use,» *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 2300-2318, 2018.

[47] G. Evola, L. Marletta, S. Natarajan y E. M. Patanè, «Thermal inertia of heavyweight traditional buildings: experimental measurements and simulated scenarios,» *Energy Procedia,* vol. 133, pp. 42-52, 2017.

[48] L. Bell y B. Faye, La concepción de los edificios de archivos en los países tropicales, Paris: Unesco, 1980.

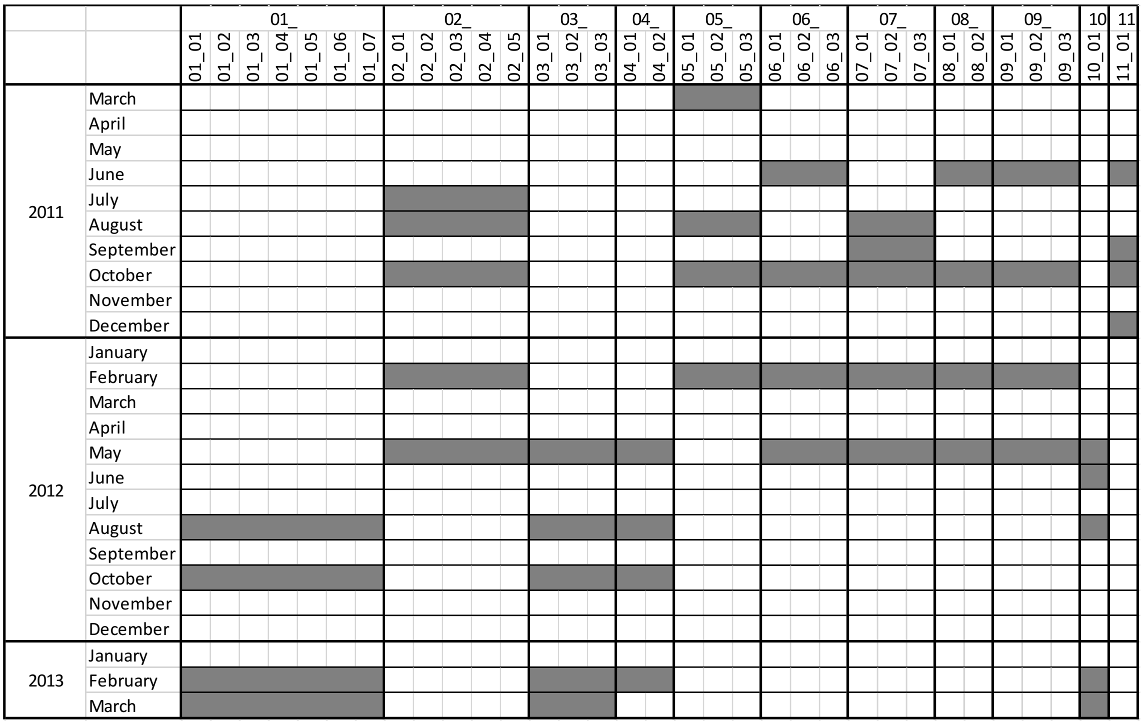


Figure 1: Environmental monitoring schedule

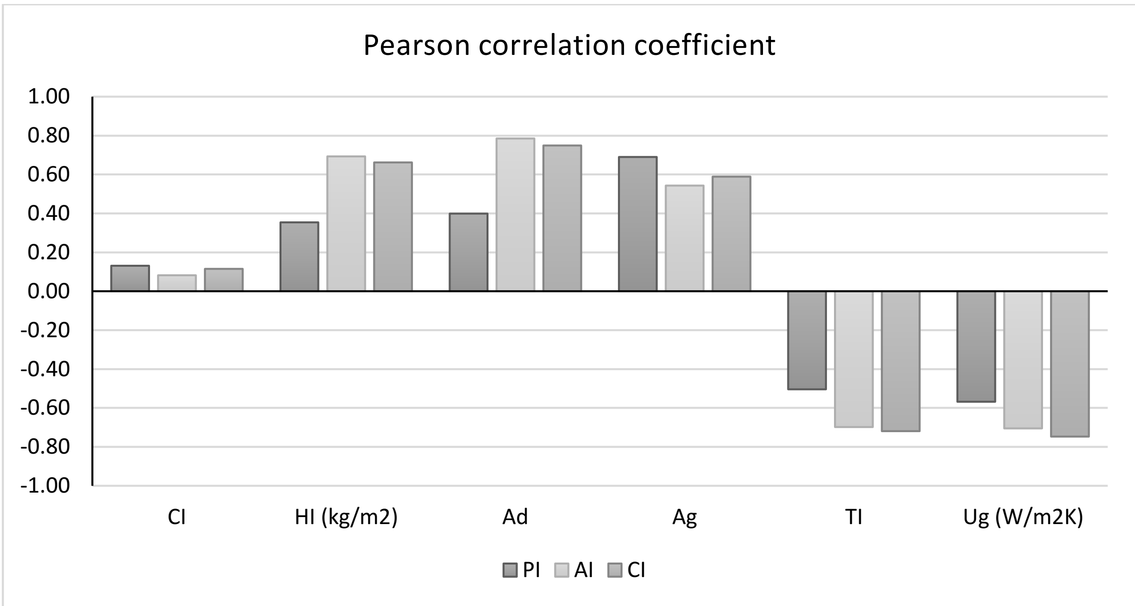


Figure 2: Pearson correlation coefficient for each passive envelope index and preventive conservation index

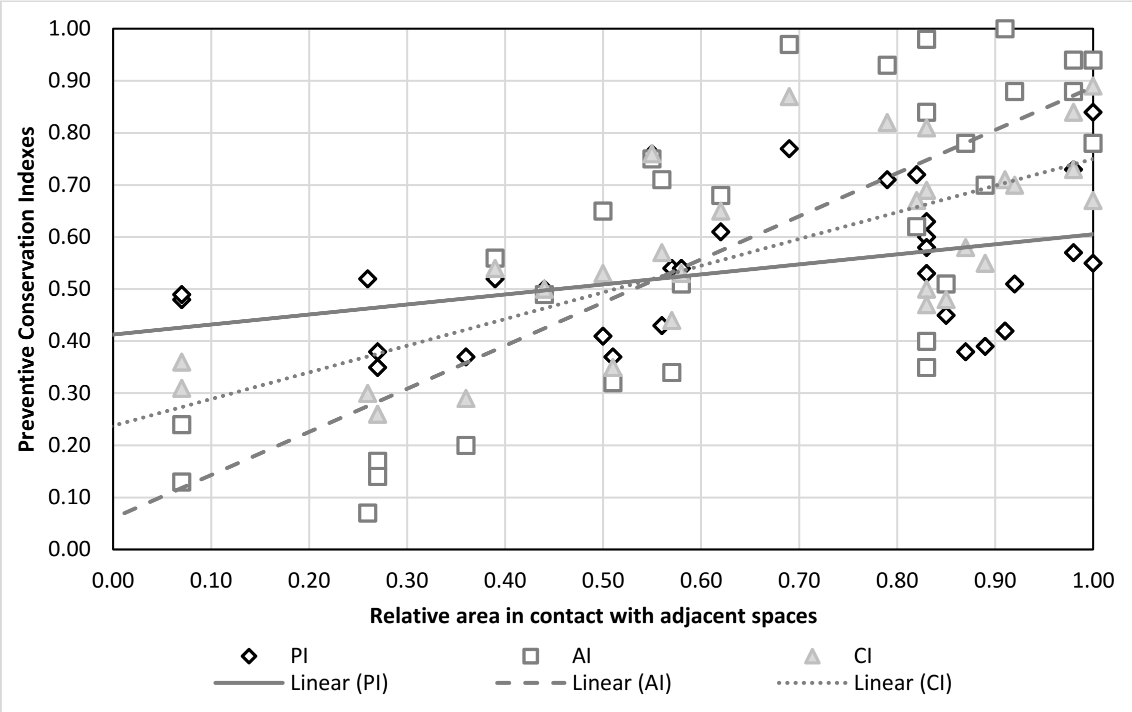


Figure 3: Relative area in contact with adjacent spaces and Preventive Conservation indexes

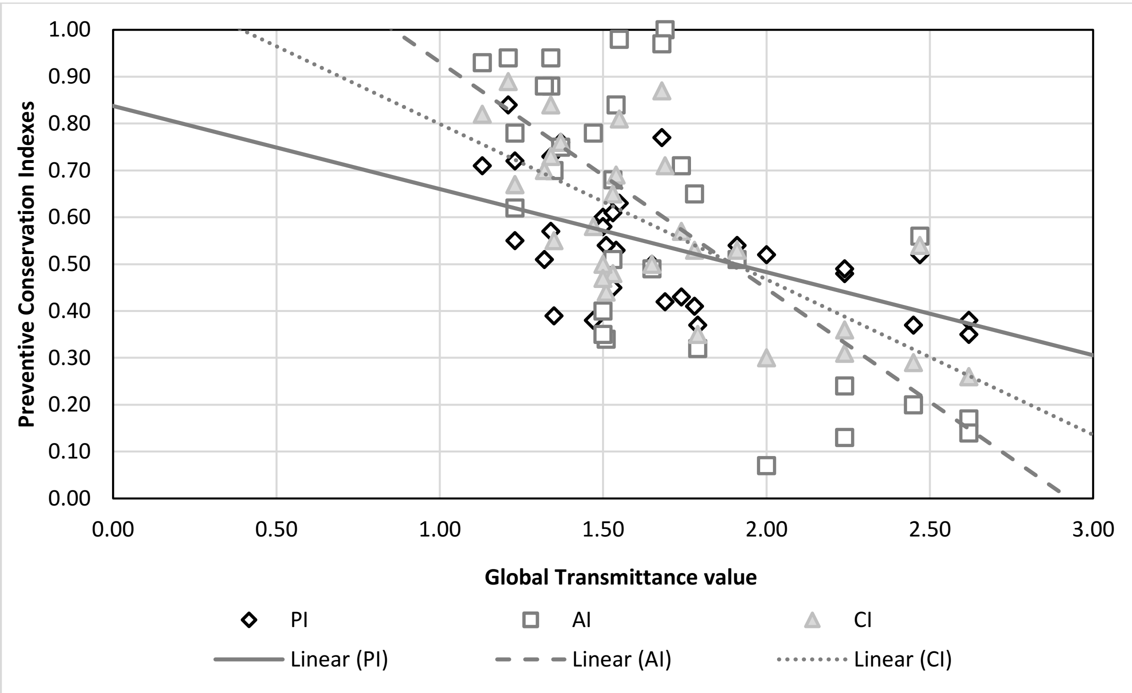


Figure 4: Global transmittance value and Preventive Conservation indexes

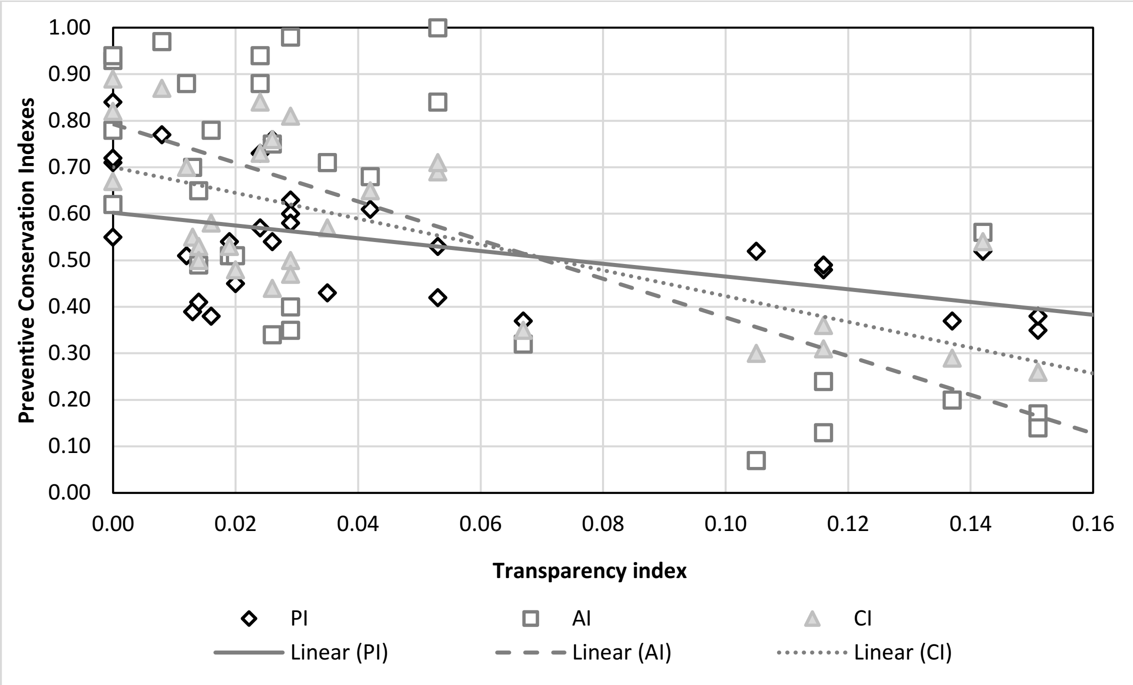


Figure 5: Transparency index and Preventive Conservation indexes

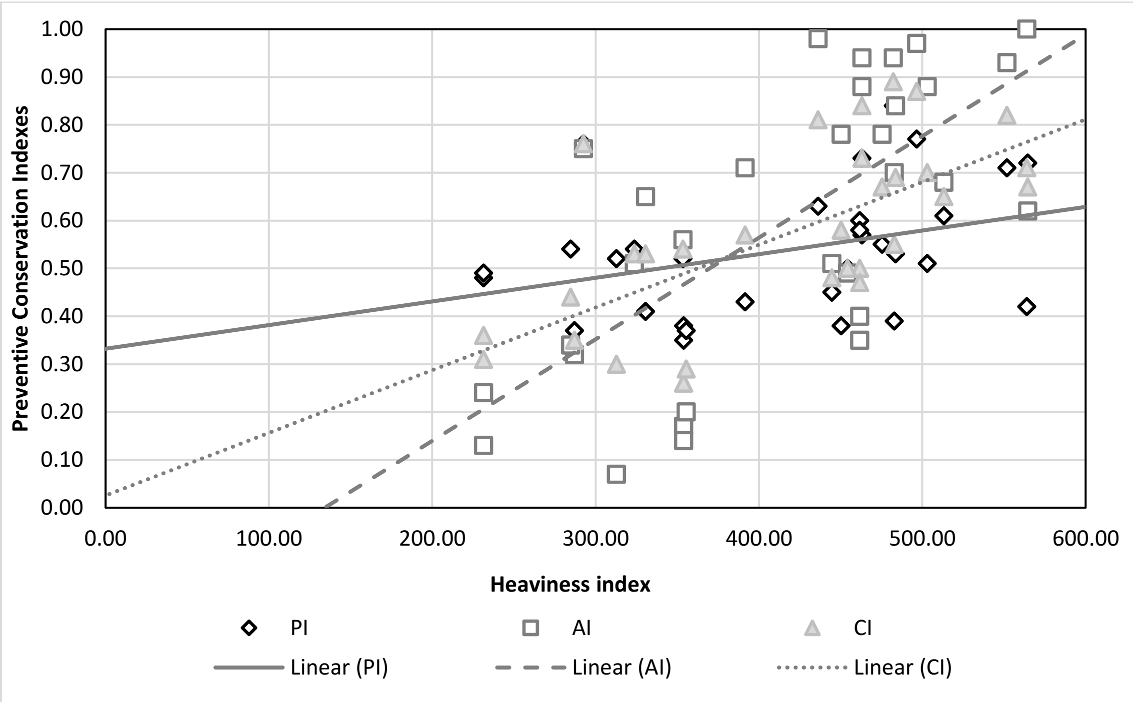


Figure 6: Heaviness index and Preventive Conservation indexes

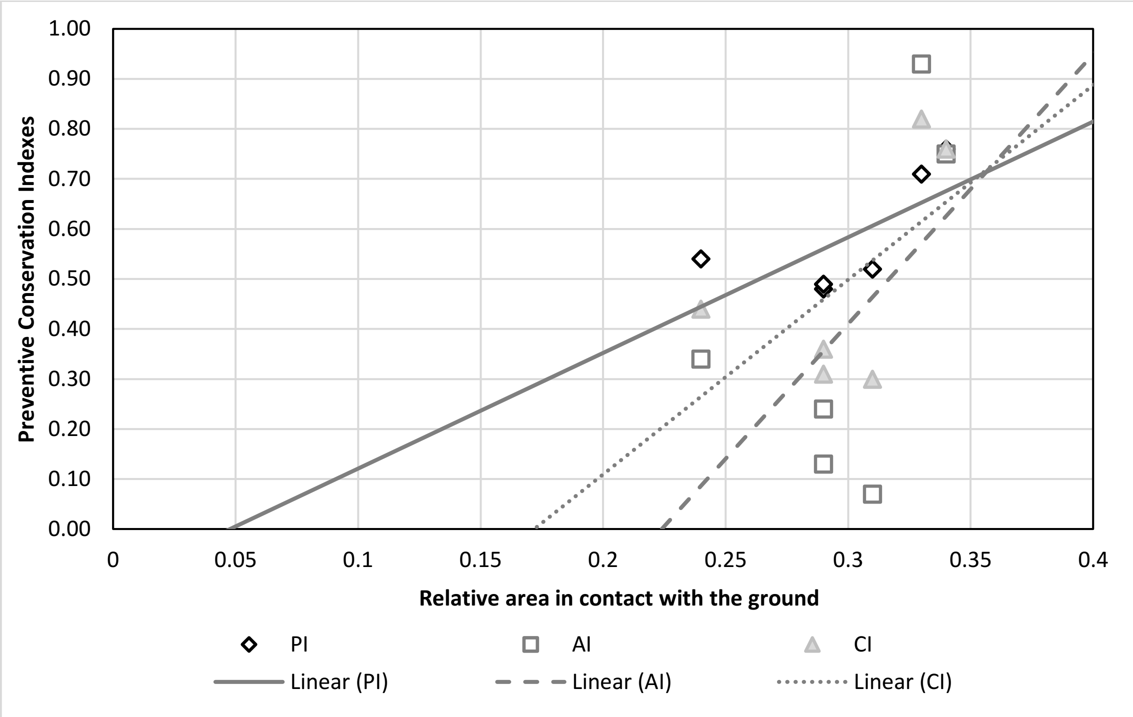


Figure 7: Relative area in contact with the ground and Preventive Conservation indexes

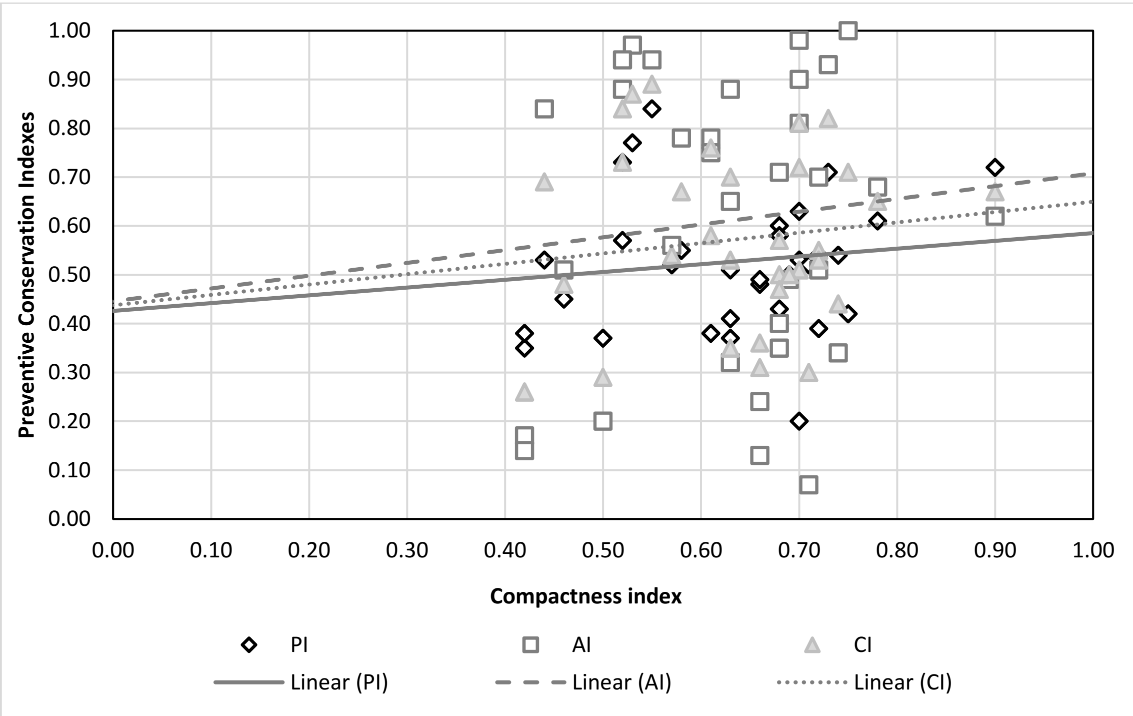


Figure 8: Compactness index and Preventive Conservation indexes

Table 1: Case studies

Buildings	Spaces selected	Envelope_ U-value (W/m²K)					Notes
		Exterior wall	Interior wall	Floor	Roof/ ceiling	Glazing	
01_ Public Library (1935)	01_1_VITRI	_	2,05	2,58	2,31	_	Completely interior
	01_2_DEP	1,53	2,05	2,58	2,58	5,88	
	01_3_LECT	1,53	2,05	1,38	2,31	5,88	Contact with ground External roof
	01_4_SAN	1,53	1,53	2,58	2,58	5,88	
	01_5_FAR	1,53	2,05	2,58	2,31	3,20	
	01_6_JVG	1,53	2,05	2,58	2,31	5,60	
	01_7_COSTA	1,53	2,05	2,58	2,58	5,88	
02_Humanities, Education and Psychology Library (1969-1984)	02_1_DEPO2	_	2,05	2,58	2,58	_	No external wall Contact with ground
	02_2_REF	2,11	2,11	2,58	2,58	5,88	
	02_3_COL	_	2,11	2,58	2,58	1.34	No external wall External roof
	02_4_COL	_	2,11	2,58	2,58	1.34	No external wall External roof
	02_5_DEP	2,11	2,39	2,58	2,58	5,88	
03_ Social and Legal Sciences Library (1969-1984)	03_1_COL	_	2,39	2,58	2,58	5,88	No external wall External roof
	03_2_DEPO	_	2,58	2,58	2,58	_	No external wall. Contact with ground
	03_3_MUSE	_	6,05	2,58	2,58	_	Completely interior.
04_ Architecture and Urban Planning Library (2007)	04_1_SALA	1,64	1,64	2,58	2,60	5,88	Almost completely exterior contact
	04_2_DEPO	1,64	1,64	1,38	2,58	5,88	Contact with ground
05_Engineering Library (1968)	05_1_ADMI	2,39	2,39	1,38	2,03	5,60	Contact with ground
	05_2_ESTA	2,39	2,39	1,38	1,98	5,60	Contact with ground
	05_3_ESTA	2,39	2,39	1,38	1,98	5,60	External roof.
06_ Economics Library (1969-1984)	06_1_DIRE	2,39	2,39	2,58	2,58	5,88	

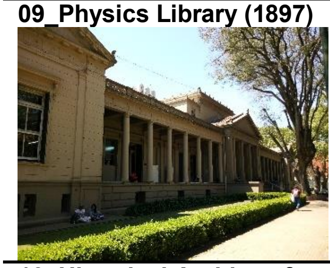
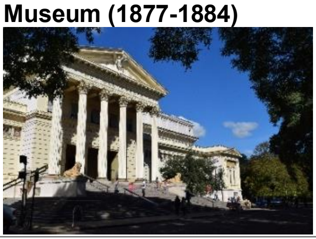
	06_2_ESTA	2,39	2,39	2,58	2,58	5,88	
	06_3_SUBS	_	2,39	2,58	2,58	_	No external walls
07_Agrarian and Veterinarian Sciences Library (2010) 	07_1_ESTA	1,64	1,64	2,58	2,60	5,88	
	07_2_OFI	1,64	1,64	2,58	2,60	5,88	
	07_3_ESTA	1,64	1,64	2,58	2,60	5,88	
08_ Fine Arts Library (1905) 	08_1_ESTA	2,05	2,39	2,58	2,58	5,88	
	08_2_OFI	2,05	2,39	2,58	2,58	5,88	
09_Physics Library (1897) 	09_1_SALA	1,53	1,53	2,58	2,31	5,88	
	09_2_REVI	2,05	2,05	2,58	2,58	5,88	
	09_3_REVI	2,11	2,11	2,58	2,31	5,60	Almost completely exterior contact
10_Historical Archive of the Presidency of the UNLP (1884) 	10_1_ARC	1,53	2,05	2,58	2,31	5,60	External roof
11_Historical Archive of the Natural Sciences Museum (1877-1884) 	11_1_MUS	_	1,53	2,58	2,31	_	No external walls External roof

Table 2: Case studies: Passive Envelope indexes

Spaces	CI	HI (kg/m^2)	Ad	Ag	TI	Kg (W/m^{2}K)	Use	HVAC
01_1_VITRI	0.70	-	1.00	-	0.000	1.60	Deposit	Yes
01_2_DEPO	0.44	483.62	0.83	-	0.053	1.54	Deposit	No
01_3_SALALEC	0.71	312.84	0.26	0.31	0.105	2.00	Reading	Yes
01_4_SANCHEZ	0.75	563.95	0.91	-	0.053	1.69	Deposit	No
01_5_FARINÍ	0.70	436.22	0.83	-	0.029	1.55	Deposit	No
01_6_JVGON	0.68	391.49	0.56	-	0.035	1.74	Deposit	Yes
01_7_COSTAAL	0.53	496.60	0.69	-	0.008	1.68	Deposit	No
02_1_DEPO2	0.73	551.87	0.79	0.33	0.000	1.13	Deposit	No
02_2_REF	0.72	482.87	0.89	-	0.013	1.35	Reading	Yes
02_3_COL	0.52	463.12	0.98	-	0.024	1.34	Mix	Yes
02_4_COL	0.52	463.12	0.98	-	0.024	1.34	Mix	Yes
02_5_DEP	0.61	450.33	0.87	-	0.016	1.47	Deposit	No
03_1_COL	0.63	287.14	0.51	-	0.067	1.79	Mix	Yes
03_2_DEPO	0.55	482.23	0.55	0.36	0.000	1.21	Deposit	No
03_3_MUSE	0.70	-	1.00	-	0.000	2.41	Deposit	No
04_1_SALA	0.57	353.49	0.39	-	0.142	2.47	Reading	Yes
04_2_DEPO	0.61	292.57	0.55	0.34	0.026	1.37	Deposit	No
05_1_ADMI	0.74	284.82	0.57	0.24	0.026	1.51	Reading	Yes
05_2_ESTA	0.66	231.38	0.07	0.29	0.116	2.24	Mix	Yes
05_3_ESTA	0.66	231.38	0.07	-	0.116	2.24	Mix	Yes
06_1_DIRE	0.72	323.83	0.58	-	0.019	1.91	Mix	Yes
06_2_ESTA	0.46	444.71	0.85	-	0.020	1.53	Mix	Yes
06_3_SUBS	0.58	475.45	0.85	-	0.000	1.23	Deposit	No
07_1_ESTA	0.42	353.99	0.27	-	0.151	2.62	Mix	Yes
07_2_OFI	0.42	353.99	0.27	-	0.151	2.62	Mix	Yes
07_3_ESTA	0.50	355.51	0.36	-	0.137	2.45	Mix	Yes
08_1_ESTA	0.68	461.70	0.83	-	0.029	1.50	Deposit	Yes
08_2_OFI	0.68	461.70	0.83	-	0.029	1.50	Reading	Yes
09_1_SALA	0.78	513.26	0.62	-	0.042	1.53	Reading	Yes
09_2_REVI	0.63	503.07	0.92	-	0.012	1.32	Deposit	No
09_3_REVI	0.63	330.68	0.50	-	0.014	1.78	Deposit	No
10_1_ARC	0.69	454.24	0.44	-	0.000	1.65	Mix	Yes
11_1_MUS	0.90	564.66	0.82	-	0.000	1.23	Mix	Yes

Table 3: Measurement instruments

SENSOR	**U10-003**		**U12-003**	
VARIABLE	T (°C)	HR (%)	T (°C)	HR (%)
RANGE	-20° to 70°C	25% to 95%	-20° to 70°C	5% to 95%
ACCURACY	± 0.53°C from 0° to 50°C	± 3.5% from 25% to 85% over the range of 15° to 45°C	± 0.35°C from 0° to 50°C	± 2.5% from 10% to 90%
RESOLUTION	0.14°C at 25°C	0.07% @ 25°C and 30% RH	0.03°C at 25°C	0.05%

Table 4: Preventive conservation indexes for each case study

	PI	AI	CI

01_1_VITRI	0.53	0.90	0.72
01_2_DEPO	0.53	0.84	0.69
01_3_SALALEC	0.52	0.07	0.30
01_4_SANCHEZ	0.42	1,00	0.71
01_5_FARINÍ	0.63	0.98	0.81
01_6_JVGON	0.43	0.71	0.57
01_7_COSTAAL	0.77	0.97	0.87
02_1_DEPO2	0.71	0.93	0.82
02_2_REF	0.39	0.70	0.55
02_3_COL	0.57	0.88	0.73
02_4_COL	0.73	0.94	0.84
02_5_DEP	0.38	0.78	0.58
03_1_COL	0.37	0.32	0.35
03_2_DEPO	0.84	0.94	0.89
03_3_MUSE	0.20	0.81	0.51
04_1_SALA	0.52	0.56	0.54
04_2_DEPO	0.76	0.75	0.76
05_1_ADMI	0.54	0.34	0.44
05_2_ESTA	0.48	0.24	0.36
05_3_ESTA	0.49	0.13	0.31
06_1_DIRE	0.54	0.51	0.53
06_2_ESTA	0.45	0.51	0.48
06_3_SUBS	0.55	0.78	0.67
07_1_ESTA	0.35	0.17	0.26
07_2_OFI	0.38	0.14	0.26
07_3_ESTA	0.37	0.20	0.29
08_1_ESTA	0.60	0.40	0.50
08_2_OFI	0.58	0.35	0.47
09_1_SALA	0.61	0.68	0.65
09_2_REVI	0.51	0.88	0.70
09_3_REVI	0.41	0.65	0.53
10_1_ARC	0.50	0.49	0.50
11_1_MUS	0.72	0.62	0.67

Table 5: r values for each passive envelope indexes and preventive conservation indexes

Parameter	PI	AI	CI
Compactnes	0.131	0.082	0.115
Heaviness	0.354	0.693	0.662
Adjacent	0.399	0.785	0.749
Ground	0.690	0.543	0.589
Transparency	-0.504	-0.698	-0.719
Transmittance	-0.568	-0.705	-0.747