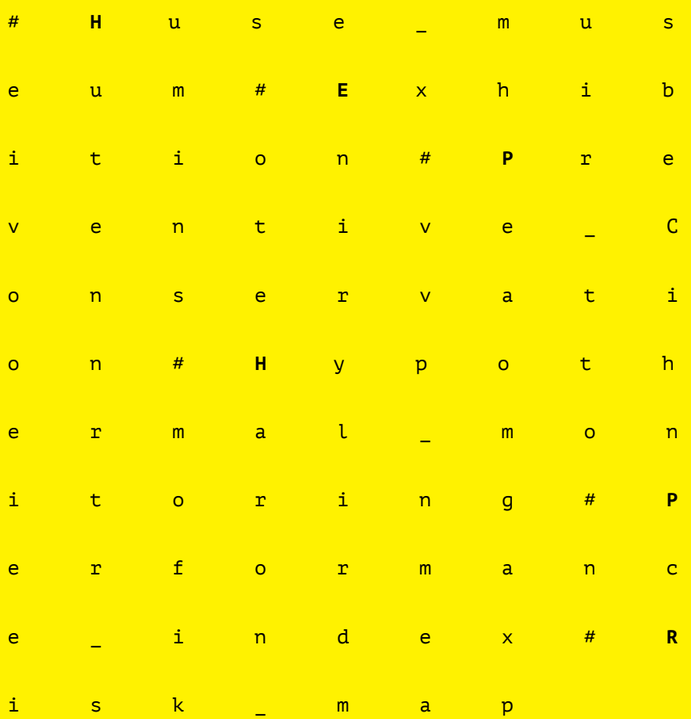

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The house museum environment: A methodology for evaluation of hygrothermal conditions

ABSTRACT

In recent decades, the obvious deterioration suffered by the collections exhibited in museum rooms has become alarming. A lack of hygrothermal control is one of the reasons for this. Herein, a methodology is presented to evaluate the degree of adequacy of environmental conditions for the exposed heritage in house museums. The data processing combines the Ashrae B criteria with the PI performance index to relate the conditions of exhibitions with the potential damage to collections. A risk map was created to detect the comfort zone and impact zones. It was found that the heritage was being exhibited in inadequate hygrothermal conditions, causing effects that would become visible over time if the conditions were not reversed. The application of this methodology together with the criteria of museum curators will help detect causes for damage without having to implement high-cost systems as an alternative solution.

KEYWORDS: *house museum, exhibition, preventive conservation, hygrothermal monitoring, performance index, risk map*

INTRODUCTION

In recent decades, the obvious deterioration suffered by the collections exhibited in museum rooms has become alarming. The lack of hygrothermal control is currently one of the most vulnerable aspects of exhibitions of objects and works of art in museums.

In historic cities, museums are usually located in old buildings and houses that were not created specifically for the preservation of heritage objects; therefore, the curators must adapt the collections to the hygrothermal conditions of their rooms to try to minimise the damage.

This adaptation requires knowledge of the collection (the state of conservation, restoration, historical exhibition conditions, etc.) and the current environmental conditions of the museum. The literature indicates that within the criteria of preventive conservation, the monitoring and control of hygrothermal conditions are essential practices to minimise damage to a heritage caused during the exhibition[1,2]. In this work, the hygrothermal aspect will be discussed.

The main damage to exhibits caused by inadequate levels of temperature (hereinafter T) and relative humidity (hereinafter RH) is physical and is mainly caused by the expansion and contraction of hygroscopic materials. This leads to a change in the size and shape of the object. In the most extreme cases, it can cause mechanical and irreversible damage when the cycle of contraction and dilation experienced by the object is very short and abrupt. T and RH can also accelerate processes initiated by other factors such as lighting and air pollution[3-6].

Technical standards, specific studies on damage to museum objects and recommendations offered by museums and institutes of conservation and restoration, are useful to relate optimal values with real physical values in exhibition spaces and to determine the most favourable climatic areas for collections. The American Society of Heating, Refrigerating and Air Conditioning Engineers (Ashrae) is one of these standards, and it suggests applying the Ashrae B criteria for historic buildings and house museums; this means keeping the T between 15°C and 25°C and the RH between 40% and 60% for general collections and, for the daily hygrothermal fluctuations, not exceeding 5°C and 10%. For storing chemically unstable collections, Ashrae recommends stable cold storage (-20°C and 40%RH), and for special metal collections, it recommends a dry room (0% to 30%RH)[7].

Additionally, a suitable indicator to evaluate the indoor climatic quality is the PI Performance Index proposed by Corgnati (2009). It is defined as the percentage of time in which the measured hygrothermal parameter lies within the required range and can be calculated for T and/or RH[8].

The purpose of this work is to present a methodology to evaluate the degree of adequacy of environmental conditions to the exposed heritage in a house museum through the measurement and analysis of the hygrothermal conditions (T and RH). The approach is based on a short-, medium-, and long-term field monitoring of the T and RH parameters and combines the Ashrae B criteria with the PI performance index to relate the hygrothermal conditions of the exhibition with the potential damage to works of art.

MATERIALS AND METHODS

Two experimental studies were carried out in the Historic House of Independence Museum in Tucuman (hereinafter MCHI; Phot. 1). This house museum (CA 1760-1780) is one of the most important museums in the history of the Argentine and has seven rooms built with brick and only one room (called the Room of Jura) built with adobe. Over time, the house suffered various interventions and was demolished in 1904, preserving only the Room of Jura, where the Independence of the country was declared. In 1941, the house was declared a National Historic Monument.

MCHI does not have mechanical systems for air conditioning, and the artificial lighting consists of incandescent 50W halogen lamps with a dimming system. In recent years, the building envelope of the museum has presented signs of humidity by capillarity and water leaks in some rooms. Generally, the doors and windows of each room remain closed.

In a preliminary study, eight rooms were analysed, and the three most representative ones were selected (Fig. 1):

- Room VIII, called the Room of Jura (93 m²), the only room built with adobe
- Room I, called Colonization (70 m²), which is in contact with the exterior and has the closest surface to room VIII
- and Room V, called Tucuman in 1816 (14 m²), which is located between two rooms and is the smallest in the museum

Study 1 analyses the evolution of hygrothermal conditions over time (2010–2014) in each selected room to understand the general behaviour of the museum. Study 2 evaluates the degree of adaptation of T and RH conditions for specific works of art in each selected room over a medium period (November 2013 to February 2014) to propose improvements that favour the preventive conservation of this heritage.

In each study, the calculation of the PI performance index will help to understand the evolution of the hygrothermal parameters.

DATA COLLECTION AND PROCESSING

The museum is located in Northwest Argentina in a subtropical climate, with a mean annual T of 21 °C (minimum mean: 15 °C and maximum mean: 26 °C) and a mean annual RH of 72% (minimum mean: 58% and maximum mean: 90%). The mean annual rainfall is 885 mm with a maximum daily rainfall of 70 mm (and 134 days with precipitation)[9].

PHOT. 1 *Historic House of Independence Museum, located in the city of San Miguel de Tucumán, Argentina*
MCHI' archive

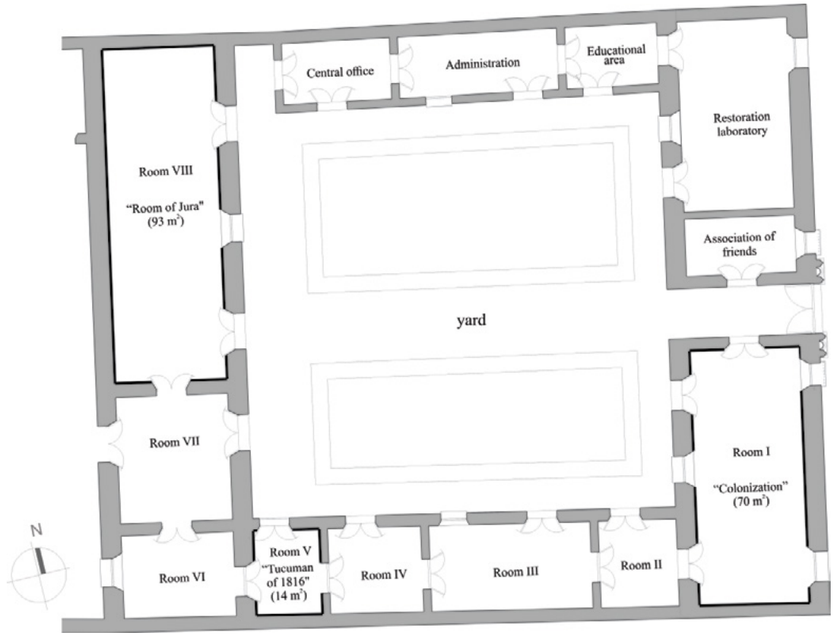


FIG. 1 *Planimetry of the MCHI. Location of rooms I, V, and VIII*
MCHI' archive

STUDY 1

The data were recorded by MCHI in the centre of each room at 8:00 a.m., 1:00 p.m., and 5:30 p.m., using a humidity T meter, TES-1365[10], previously calibrated in the ranges of 20°C to 60°C and 1% to 99% of T and RH, respectively (the nominal uncertainty of the sensors was ±0,8 °C for the T and ± 3,5% for the RH). The most relevant data in the processing of the T and RH conditions measured during 2010–2014 were[11,12]

- Mean yearly values (T_y, $RH_{y)}$
- Mean monthly values (T_m, RH_m)

STUDY 2

The data were collected by the authors every 5 minutes for a short period on the site where the selected work of art was located (from 25 November 2013 to 26 February 2014) using a HOBO T RH data logger[13] previously calibrated in the ranges of 20°C to 70°C and 5% to 95% of T and RH, respectively (the nominal uncertainty of the sensors was ±0,5 °C for the T and ± 2,5% for the RH). The same type of data processing used in Study 1 was applied while taking into account the material sensitivity of the works of art selected in each room. Further, the use of the PI performance index was extended (hereinafter PI_f) to analyse the daily fluctuations of T and RH.

The work of art that was more sensitive to hygrothermal conditions was selected in each room according to the criteria of the curators of the MCHI:

- Room I: An oil painting called *Coronation of the Virgin for the Holy Trinity* (S. XIX). Main materials: linen and wood.
- Room V: Set of saints called *St. Joseph and the Virgin* (S. XIX). Main materials: wood, silk, and gold threads.
- Room VIII: Oil painting called *Francisco Narciso de Laprida* (S. XVIII): Main materials: linen and wood.

In this case, the data were processed according to:

- Mean monthly and daily values (T_m, RH_m; T_d, RH_d)
- Mean daily fluctuation ($\Delta T_{d,} \Delta RH_d$): Calculated as the difference between the absolute maximum daily level and the mean level or the difference between the absolute minimum daily level and mean level (only the biggest difference between the two was considered).

The mean level corresponds to the mean of all the registered data in the period considered (year, month, or day).

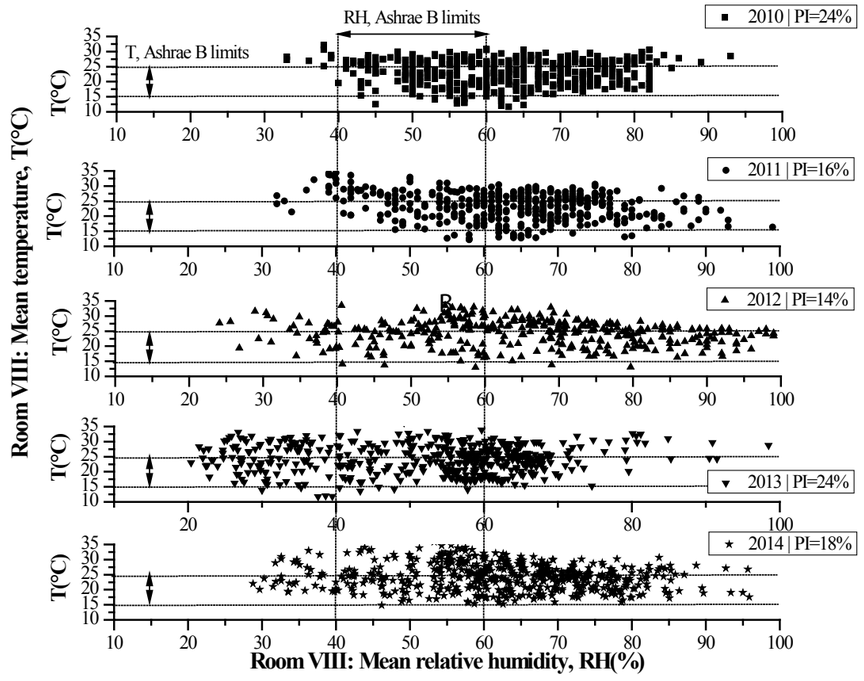
RESULTS

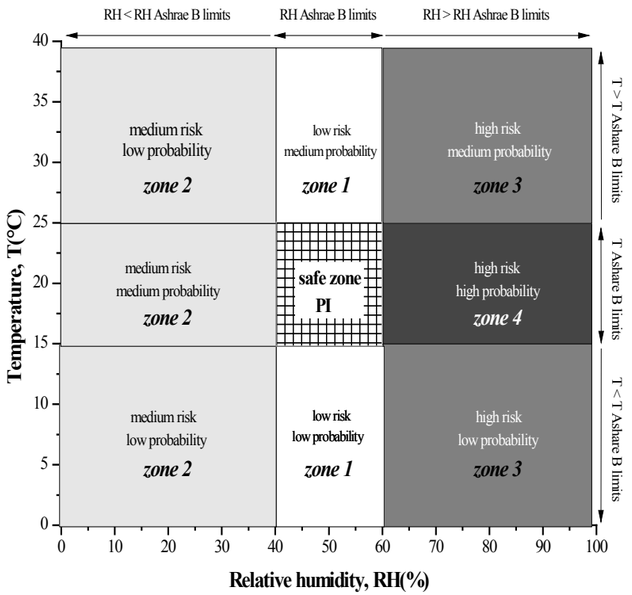
STUDY 1

The processed data were plotted according to the Ashrae B criteria to calculate the PI performance index. Graph. 1 shows the mean levels of T and RH during the 2010–2014 period in room VIII.

This type of graph allows one to quickly visualise how hygrothermal conditions are displaced from the theoretically safe zone. During 2010–2014, the mean PI performance index remained below 25%.

GRAPH. 1 *Evolution of PI performance index according to Ashrae B criteria (dotted lines), per year, in room VIII of MCHI. The x-axis corresponds to the mean levels of RH, and the y-axis corresponds to the mean levels of T,*
Maria Zamora





GRAPH 2. *Impact zones according to risk and probability. The darkest areas represent the worst exhibition conditions for the general collections in the MCHI,*
Maria Zamora

Year 2013	Safe zone (PI%)	Zone 1 (%)	Zone 2 (%)	Zone 3 (%)	Zone 4 (%)
Room I	23	20	24	12	21
Room V	22	22	24	13	19
Room VIII	24	20	23	16	17
Outside	16	20	11	24	29
Year 2014	Safe zone (PI%)	Zone 1 (%)	Zone 2 (%)	Zone 3 (%)	Zone 4 (%)
Room I	22	26	2	22	28
Room V	15	21	6	32	26
Room VIII	18	18	6	24	34
Outside	16	17	2	21	44

TAB. 1 *Comparison of mean Plyear performance index between room I, V, and VII, outside of MCHI, and between the four impact zones,*
Maria Zamora

Based on the historical hygrothermal conditions (Graph. 1), a hygrothermal risk map was developed as a risk analysis tool for the collection of MCHI; with this map, the evolution of the climate and the most critical hygrothermal levels of any museum could be easily evaluated.

For general collections, the map was divided into quadrants according to Ashrae B limits, probability level, and risk (Graph. 2). It can be adapted to other limits according to special collections or what the curators of museum consider appropriate.

The greater damage to collections is given by inadequate levels of RH and not by inadequate levels of T; therefore, the risk map considers the RH as the most critical parameter[14].

Graph. 2 clearly shows the safe zone and four impact zones for general collections. For example, if there is a high risk for the collections and a high probability that the risk causes damage, the impact will be greater than if there is high risk and medium probability. The probability level is based on Graph. 1, and it is typical of museums in Northern Argentina.

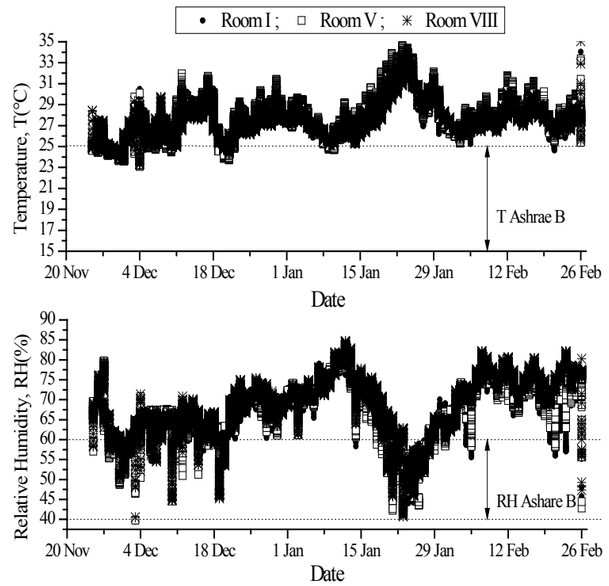
Tab. 1 shows the mean percentage of time for which hygrothermal conditions were maintained in the safe zone (PI performance index) and impact zones (1, 2, 3 and 4) for each room and outside the MCHI over the last two years.

For this type of museum, it is difficult to reach the ideal hygrothermal conditions. Therefore, attention must be paid to the control of the most critical areas (zone 3 and 4).

A basic statistical analysis (ANOVA) of three factors (year, month and room) indicated that the year is a highly significant factor in the behaviour of T and RH: there are great differences between 2013 and the rest of the years. Additionally, the month is moderately significant because of the influence of the external climate. Finally, the room is the least significant factor: there are small differences of T and RH between rooms I to VIII and room V, and there are no significant differences between rooms I to VIII (differences less than 1 °C were recorded).

STUDY 2

The measured data of T and RH were plotted in Graph. 3 from 25 November 2013 to 26 February 2014 in rooms I, V, and VIII. The dotted lines indicate the Ashrae B limits for each parameter.



GRAPH. 3 *Behaviour of T and RH from 25 November 2013 to 26 February 2014 in rooms I, V, and VIII. The dotted lines indicate the Ashrae B limits for T and RH,*
Maria Zamora

The monthly analysis indicated that, during the summer months (94 consecutive days), T_m and RH_m remained on average at 27,7°C and 67,3% in room I; 27,8°C and 67,2% in room V; and, 27,6°C and 68,4% in room VIII. The mean levels abroad remained at 26,1°C and 62%.

The daily analysis indicated that, during the 94 consecutive days, the T_d in room V was maintained 32% of the time above T_d in room VIII (only 1°C). There were no differences in T between rooms I to V and rooms I to VIII. Regarding RH, room VIII presented higher RH levels than rooms I and V (differences of up to 10% were detected 17% of the time).

Finally, Graph. 4 shows the risk map for each selected work of art with the mean levels of T and RH during the period analysed. Tab. 2 indicates the PI performance index and the dwell time of T and RH in the impact zones. Graph. 5 shows the extension of the performance index (PI_f), used to analyse the daily fluctuations of T and RH (ΔT_d and ΔRH_d).

The points represented in Graph. 5 correspond to the hygrothermal fluctuations suffered by each work of art (room I, V, and VIII) over 94 consecutive days.

Each point was calculated according to the difference and, and each point was plotted in the matrix ΔT_d versus ΔRH_d to determine the performance index for hygrothermal fluctuations (PI_f).

On average, the fluctuations suffered by the three works of art (PI_f) were maintained 92% of the time between the acceptable limits recommended by Ashrae B. Only some fluctuations of RH above the allowed limit (10%) were detected.

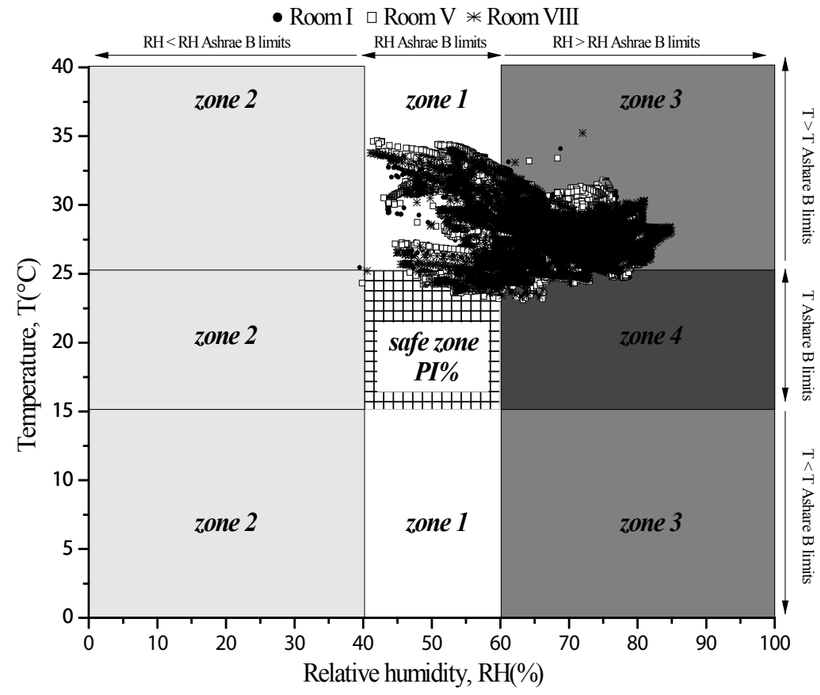
DISCUSSION

A methodology was presented to evaluate the degree of adaptation between the hygrothermal conditions of a house museum and the type of collection exposed; this involved the hygrothermal survey and diagnosis of the MCHI rooms. In this work, the class B criteria of the Ashrae Standard, suitable for heritage buildings and historical houses, was used. The methodology was based on the mean levels of T and RH recorded for short and long periods of time, based on which a hygrothermal risk map of MCHI for general collections was designed.

The risk map has a comfort zone given by Ashrae B (PI performance index) and four impact zones (zone 1, zone 2, zone 3, and zone 4) based on the MCHI records for five years. Each impact zone is weighted according to the probability that T and RH reach certain levels and according to the risk of deterioration in a certain hygrothermal range. It allows one to visualise how far away the hygrothermal conditions are from the comfort zone (PI performance index) and how long the collections are exposed to inappropriate hygrothermal conditions.

Study 1 allowed analysis of the history of hygrothermal conditions of the MCHI in 2010–2014. The year 2013 presented an important shift for the MCHI from the rest of the years, probably due to the influence of the external climate. The annual analysis of the 2010–2014 period of the external climate indicated that 2013 was, on average, 10% less humid than the rest, in accordance with the ANOVA. This behaviour favoured the stability of the hygrothermal conditions of MCHI, increasing the level of the PI and decreasing the dwell time in the most critical zones (zone 3 and zone 4). In contrast, in 2014 (Tab.1), the PI index decreased and the time of T and RH stay in zones 3 and 4 increased ($PI_{room\ I}$ = 22% is considered a reference because there are records only until June 2014).

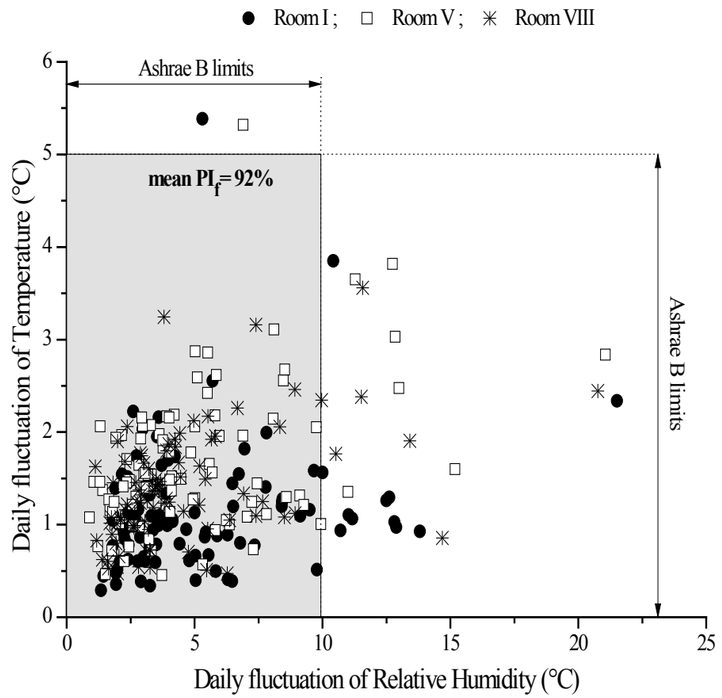
Study 2 allowed in-depth analysis of the hygrothermal behaviour in the rooms of the MCHI; the analysis of T and RH in each room allowed to analyse both the daily behaviour and the fluctuations, which are absorbed by the exposed collections. In this case, three works of art were selected according to their sensitivity to T and RH levels. The mean monthly analysis indicated, as in Study 1, that there were no significant differences of T and RH between the rooms; this could, in principle, rule out the effect of adobe on hygrothermal behaviour. However, the daily analysis indicated that, during the 94 consecutive days recorded, the RH in room VIII was up to 10% higher than in room I and room V; the maximum differences of T between the rooms was 1 °C.



GRAPH. 4 *Mean daily levels of T and RH for each work of art from 25 November 2013 to 26 February 2014. The shaded areas indicate the hygrothermal risk map of MCHI for general collections,*
Maria Zamora

November 25, 2013 to February 26, 2014	Safe zone (PI %)	Zone 1 (%)	Zone 2 (%)	Zone 3 (%)	Zone 4 (%)
Room I	3	13	0	79	5
Room V	4	13	0	77	6
Room VIII	3	12	0	82	3
Outside	8	33	0	28	31

TAB. 2 *PI performance index and time of permanence in the impact zones (1, 2, 3 and 4) for each work of art in rooms I, V, and VIII from 25 November 2013 to 26 February 2014,*
Maria Zamora



GRAPH. 5 *Performance index applied to the daily fluctuations of T and RH (PIf) from 25 November 2013 to 26 February 2014 in rooms I, V y VIII of MCHI,*
Maria Zamora

Thus, although the annual and monthly analyses did not find significant differences in the type of construction material, based on daily analysis, room VIII (93 m²) is the wettest room in the MCHI. This result can be attributed to the adobe, which, in subtropical climates where dryness is alternated with intense rains, absolves atmospheric humidity when the air is saturated[15]; it can also be attributed to a lesser extent to room VIII's orientation within the museum, which causes it to receive less solar radiation in comparison to rooms I and V. The influence of the adobe on the hygrothermal behaviour of the MCHI should be compared to the influence in other museums with similar characteristics to achieve greater precision in the result.

During this period, the selected works of art were exposed to impact zone 3 80% of the time. This means RH levels above 60% (up to 85%) and T levels above 25 ° C (up to 35 ° C) were recorded. In the specific case of the works of art under study, and in the case of most museum collections, the most important parameter to control is the RH. The great water content in the environment can be absorbed by materials such as silk and wood that are present in the selected works of art, permanently expanding the material and creating internal tensions that could crack the material. Further, high levels of RH lead to the proliferation of microorganisms which, combined with atmospheric contamination, can create highly dangerous conditions for the materials under study, especially the silk of *St. Joseph and the Virgin*.

The performance index[9] was also used to analyse the daily fluctuations of T and RH faced by the selected works of art, which were maintained 92% of the time within the limits established by Ashrae B. This implies that, fortunately, the contraction and dilatation experienced by the works of art were produced slowly. At the same time, the lowest Ts recorded during the 94 consecutive days were higher than the dew point, so no condensation risk was detected. However, the period analysed (summer) and the winter period, are the most stable periods of the year, so we should analyse both the hygrothermal fluctuations and the risk of condensation in periods of greater instability (autumn and summer).

Finally, the studies indicated that mean levels do not provide enough information about the actual behaviour of the hygrothermal conditions of an exhibition space; the influence of adobe on the moisture content of room VIII was only detected during the daily analysis. Although a museum of this type cannot easily reach ideal hygrothermal conditions, it is important to control the most critical zones (zone 3 and zone 4); otherwise, the effects of the high levels of RH will be visible in the short term.

Different goals can be set over the years – taking into account the season of the year and the technical facilities of the museum – to make gradual changes that assist in the preventive conservation of the exposed heritage.

Study 2, conducted on the other seasons of the year, will help to take some actions to assist in the preventive conservation of the exposed patrimony; these actions will aim to progressively raise the PI performance index of the rooms:

First, the building envelope needs to be repaired to reduce infiltration, and the original climate control features of the building should be preserved as much as possible[16].

Second, because controlling T and RH is technically difficult and costly in this type of museum, efforts must be placed to control the most critical variable (RH) by maintaining the environment at less than 65% RH and varying T. The biggest threat to collections in hot and humid regions is biodeterioration and fungal and bacterial attacks. They can be prevented by using dehumidifiers in the wettest months of the year to control the level of RH. This in turn will provide greater comfort to museum visitors.

Third, the opening of doors and windows in the MCHI should be controlled and, as far as possible, minimised; if natural ventilation is necessary, it should be provided when the weather is mild to avoid unnecessary hygrothermal fluctuations. Permanent monitoring of the conditions of T and RH will indicate when this practice must be carried out.

Finally, the objective is not to reach a PI of 100%, but to avoid damage from environmental conditions during exhibitions.

These results are a part of a more general methodology of a doctorate thesis that also examines the influence of electromagnetic radiation and air pollution to provide more complete tools for achieving preventive conservation of heritage in museums.

CONCLUSIONS

The methodology presented in this study involved using a risk map to evaluate the impact of T and RH conditions on exposed collections based on historical hygrothermal records (2010–2014) and the recommendations of the Standard Ashrae. Changes in climatic conditions and the most critical hygrothermal levels of any museum can be easily evaluated using this methodology. During the summer months of 2014, the works of art under study remained exposed 80% of the time to a hygrothermal zone, impact zone 3, with levels of up to 85% of RH and T of up to 35 °C. Fluctuations and the risk of condensation were controlled.

The importance of recording daily the levels of T and RH was evident: the influence of the adobe on the moisture content of room VIII was only detected in the daily analysis and not in the monthly

and annual analyses. Although a museum of this type cannot easily reach ideal hygrothermal conditions, it is essential to control the most critical zones (zone 3 and zone 4); otherwise, the effect of high levels of RH will be visible in the short term. In this case, for example, a reduction of 5% in the levels of RH (allowing T to vary naturally) can increase up to 5% the dwell time in the comfort zone and reduce up to 20% the dwell time in the most dangerous zones.

Finally, this methodology can help museum curators gradually improve their exhibition conditions as much as possible by studying in detail the hygrothermal behaviour of their rooms in the different seasons of the year and adapting museography design to assist in preventive conservation of a heritage.

ACKNOWLEDGEMENTS

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