LIBRO DE ACTAS

IX Congreso Ibérico y VII Congreso Iberoamericano de Ciencias y Técnicas del Frío

CYTEF 2018

Valencia

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INDOOR AIR QUALITY ASSESSMENT OF A NATURALLY VENTILATED MUSEUM IN PORTUGAL: EVALUATION OF TWO HALLS OF PERMANENT EXHIBITION

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Abstract: *It is recognized worldwide that indoor air quality (IAQ) conditions in museums influence the preservation of the exhibited items. Recently, international guidelines towards environmental management in the field of conservation have been revised, leading to a different perspective on 'ideal/fixed' hygrothermal air conditions, namely EN 15757:2010.*

Herein, some results of the ongoing study of the IAQ conditions in the Science Museum of the University of Coimbra (UC) are discussed, following a continuous monitoring campaign recently implemented (since January 2017). These data are compared with those of a previous study on the environmental conditions of this museum, a XVI-XVIII century heritage building with no mechanical air conditioning and ventilation (HVAC) system, which was grounded on several non-consecutive monitoring campaigns conducted over more than one-year focused on the hygrothermal air conditions of two exhibition rooms of the Museum.

The obtained results reinforce the need for further investigation on the subject. HVAC might be required for proper control of the indoor conditions, e.g., for minimizing the impact of the identified risky conditions.

Keywords: Microclimate, Museum conservation, Hygrothermal analysis, Natural ventilation, Heritage building

1. **INTRODUCTION**

It is recognized worldwide that indoor environmental quality (IEQ) conditions in museums influence the state of the exhibited items [1]. Several environmental parameters namely the hygrothermal parameters (air temperature and relative humidity), particulate matter and other pollutants and/or radiation (IR illuminance levels and UV radiation) have a direct impact on the conservation of collections [2],[3]. At the same time, the difficulty of determining accurate optimal intervals of these parameters is well acknowledged since many museum halls contain different types of objects, which, in turn, are composed of different materials that have diverse behaviours under the same hygrothermal conditions.
Aiming at defining intervals of hygrothermal values for the optimal conservation of the exhibited collections of the Science Museum of the University of Coimbra (MCUC), it is proposed in this paper an assessment of such parameters. Some results of the ongoing monitoring campaign (implemented in January 2017) on the MCUC IEQ conditions are presented and compared with the first study on the subject [4], which was based on data from 2015/16.
Currently, the focus was addressed to the hygrothermal data and CO_2, a pollutant originated indoors by human activity which can be used as an indicator of the need for air renewal in buildings and to assess the visitors' impact and thus contribute to visitors' management.
Grounded on EN 15757:2010 [5] a range of 'sustainable values' of the hygrothermal parameters considered acceptable for an adequate conservation of the exhibited objects was defined. The obtained results reinforce the need for further investigation on the subject. HVAC might be required for proper control of the indoor conditions, *e.g.*, for minimizing the impact of the registered risky conditions.

2. METHOD AND OBJECT OF STUDY

The case study − the Science Museum of the University of Coimbra (MCUC) − is located in the heights of the University of Coimbra (UC), in the north-eastern area of the historic centre, Figure 1.*a)*. It was the first Portuguese university museum and it is housed in the ancient Jesus College, a XVI-XVIII century heritage building (started in 1547, and then reconstructed in 1773-1775) without any HVAC system.
The Museum houses a great variety of valuable collections, including a significant Natural History collection from the former Portuguese Colonies in Africa. A detailed description of the Museum collections and of the two analysed halls can be found in [6] and [4]. *'It is daily open, closing only on Mondays and other 5 holidays during the year. Between March 1st and September 30th it is open 7 days/week. The analysed exhibition rooms, located in the first floor of the building, are integrated in a carriage-type Gallery"* [4].

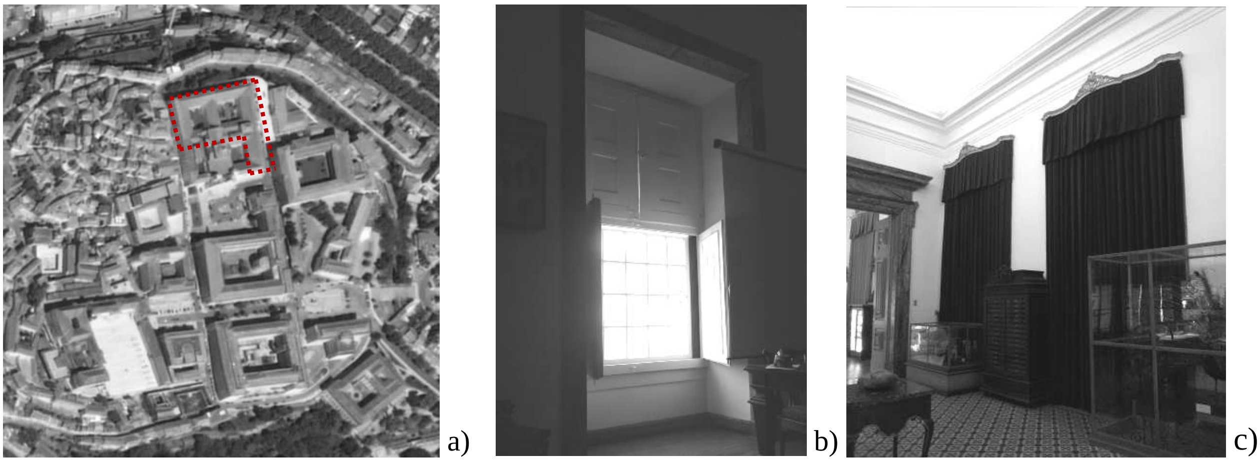


Figure 1 – *a)* Location of the MCUC, ArcGis (2017) [(originally published in [4])]; *b)* Sash type windows in the MCUC; *c)* Interior view of the windows with curtains in the Vandelli Hall.

2.1. The monitoring campaign

Between January and June 2017, indoor air temperature (T, ºC), relative humidity (RH, %) and carbon dioxide concentration values (CO_2, ppm) were continuously monitored in the MCUC. The equipment used in this monitoring campaign are listed in Table 1. Two HOBO UX100-003 sensors were placed in each exhibition room, one inside a display case and the other outside. A single HOBO MX1102 was used in the Vandelli Hall (VH).

Table 1 – List of the equipment used in the monitoring campaign.

Parameter	Period	Equipment	Monitoring interval
Temperature (T, ºC) Relative Humidity (HR, %)	4 January – 28 June	HOBO UX100-003 Data Logger	Every 10 min
Carbon dioxide (CO_2, ppm)	19 April – 7 May 12 July – 17 July	HOBO MX1102 Data Logger	Every 60 sec

2.2. Guidelines and recommendations

In terms of pollutants, CO_2 concentration levels were assessed according to the Portuguese legislation (RECS - Regulation of Energy Performance of Commercial and Service Buildings [7]), *'which currently defines a threshold limit for CO_2 in the indoor air equal to 2250 mg/m^3 (1250 ppm), average concentration value during the various occupancy periods'* [8].

Regarding the hygrothermal parameters, the international guidelines towards environmental management in this field have been updated, from a perspective beyond 'ideal/fixed' hygrothermal air conditions, namely EN 15757:2010 [5] (Conservation of Cultural Property - Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials) and ASHRAE's 2015 (ASHRAE Handbook - HVAC Applications: Chapter 23 Museums, Galleries, Archives and Libraries) [9]. Both procedures consider the historical climate of the spaces where exhibition objects have been kept. In [4], data collection of the MCUC was processed and analysed according to ASHRAE [9]. As suggested in this previous study, the authors opted to perform a subsequent analysis according to EN 15757:2010. By taking into account the historical climate of the exhibition spaces, the EN proposes an acceptable microclimatic variability, according to the acclimatization process of exhibited objects, which have developed *'an adaptation to "normal variability"'*. As such, data processing is framed *'to the "real season" effects'* [8] − in practice, *'analyses of seasonal cycles and the calculation of the central moving average (MA)'* [9].

3. RESULTS AND DATA ANALYSIS

As proposed, the following results (section 3.2) were analysed following EN 15757:2010 [5]. It is noteworthy that according to this EN the concept of seasonality is applicable to a period of 395 days, so that the present study, despite applying this methodology to the collected data, is not applied in full compliance with it, and forthcoming data should follow future treatment after the indicated period.

3.1. CO_2 concentration

During both monitoring periods (April 19 – May 7 and July 12-17, Table 1), CO_2 levels indoors (registered only in VH) were within the recommended values: average values varied between 783 and 1111 ppm. During the first period the Museum was visited by circa 200 people/day (average), while in the second period it received more than 1500 people/day (almost 8 times more). Punctually, in the second period, the CO_2 levels exceeded 1250 ppm, but these values correspond only to 0.07% of the data. With so many visitors, low levels can be explained only by: (*i*) the significant volume of the room (circa 900 m^3) and (*ii*) the fact that the doors are always open and the exhibition rooms are all communicating in a carriage-type distribution. This second explanation effortlessly enhances air renewal, especially if considered also the poor insulation of the original wooden windows (weakly sealed, even if added indoor velvet curtains), Figure 1.*b)* and *c)*.

3.2. Indoor air temperature and relative humidity

The analysis of indoor air temperature and relative humidity data is presented in Tables 2 and 3, and in Figures 2 and 3. Moreover, in Table 2, current data are confronted with those obtained during the 2015-16 campaign, published in [4]. Relating these data, some explanations are due:

1) In [4], the sensor located in VH had been placed inside a display case. The Portugal Hall (PH) sensor was located outside a display case;

2) Herein, Table 2, data analysis and comparison was performed under the same circumstance, *i.e.*, considering the same sensor location;

3) Regarding 2017's data, temperature (T, ºC) differences between inside/outside sensors in VH were not significant ($\Delta T_{ave \pm st\ dev} = 0.2 \pm 0.2$ ºC). Relative humidity (RH, %) differences in VH were more expressive ($\Delta RH_{ave \pm st\ dev} = 1.4 \pm 6.5$ %). In PH, T differences between inside/outside sensor were more significant

($\Delta T_{ave \pm st\ dev}$ = 0.1 ± 1.1 ºC) than those of RH ($\Delta RH_{ave \pm st\ dev}$ = -1.2 ± 5.0 %).

Table 2. Summary table of the registered values in the exhibition rooms.

Room	Parameter	Period	Maximum	Average (± st dev)	Minimum
Vandelli Hall (VH) *VH values relate the sensor inside the display case*	T (ºC)	Jan – Jun 2017	28.7	18.2 ± 5.0	9.3
		2015/ 16 [4]	29.3	20.0 ± 5.1	11.1
	RH (%)	Jan – Jun 2017	69.1	57.2 ± 5.6	37.3
		2015/ 16 [4]	77.6	58.8 ± 5.8	50.1
Portugal Hall (PH) *PH values relate the sensor outside the display case*	T (ºC)	Jan – Jun 2017	**33.5**	18.4 ± 5.3	7.5
		2015/ 16 [4]	32.8	18.9 ± 4.8	9.2
	RH (%)	Jan – Jun 2017	**82.0**	57.6 ± 9.4	**27.3**
		2015/ 16 [4]	91.9	65.9 ± 9.2	30.1

Nonetheless, Table 2 evidences data of sensors located inside (VH) and outside (PH) display cases, some general comments are possible based on data collected from all the four sensors:
1) It was verified that the most extreme hygrothermal values were registered in PH – these values are signalled in bold in Table 2;
2) The lowest T record was registered in 2017/01/20 at 6:40, while the highest value, also in this room (PH), was registered in 2017/06/20 at 15:40. In these moments, the 'protective' effect of the display case was observed – when T_{PH} = 7.5 ºC, the sensor inside the display case registered 9.1 ºC, which means a 1.6 ºC difference (when outdoor T = 2.6 ºC), while when T_{PH} = 33.5 ºC, the 'inbox sensor' registered 29.1 ºC, corresponding to ΔT = 4.4 ºC (and outdoor T = 35.2 ºC). Hereafter, when summer data are available, further investigation should be addressed on this subject;
3) Relating RH, although the extreme values were registered also in PH, peaks seem to have improved in face of the past (2015/16s' data).

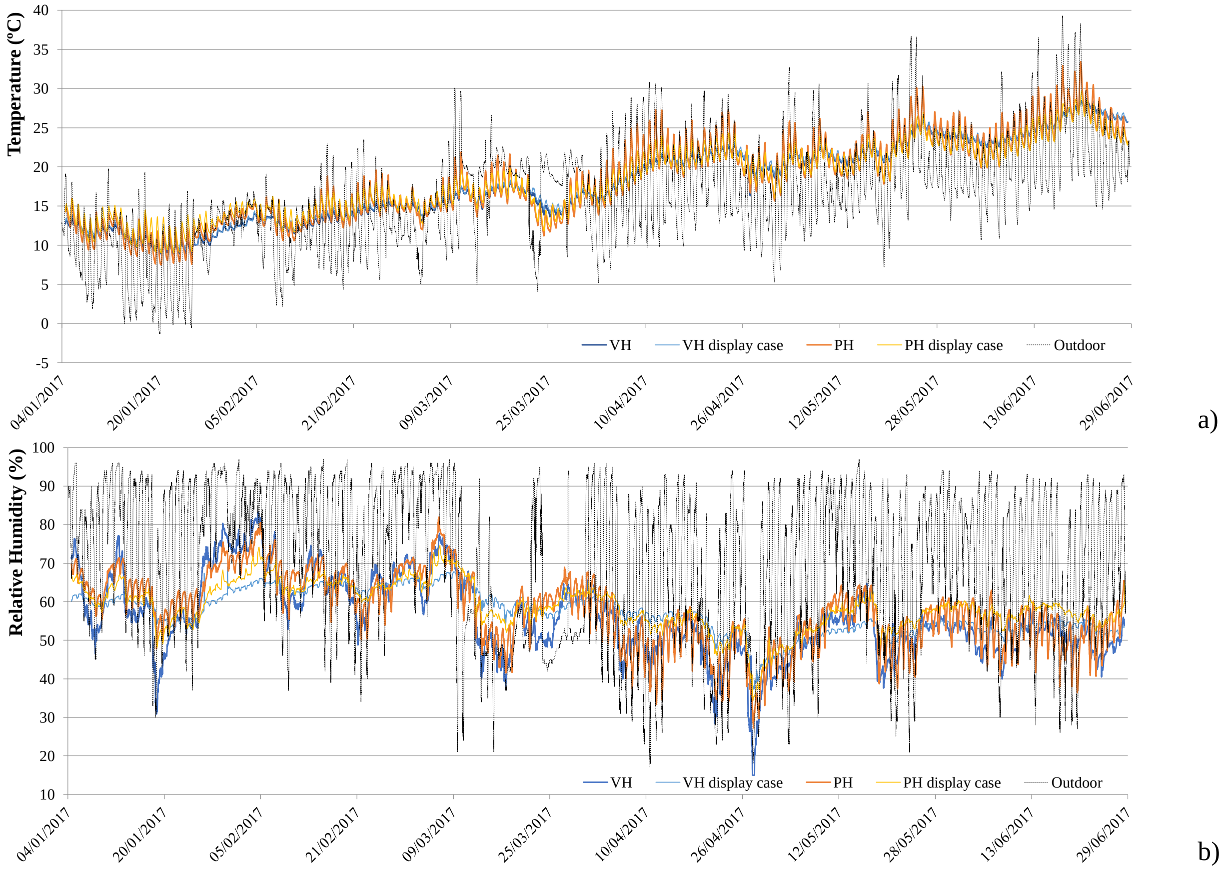
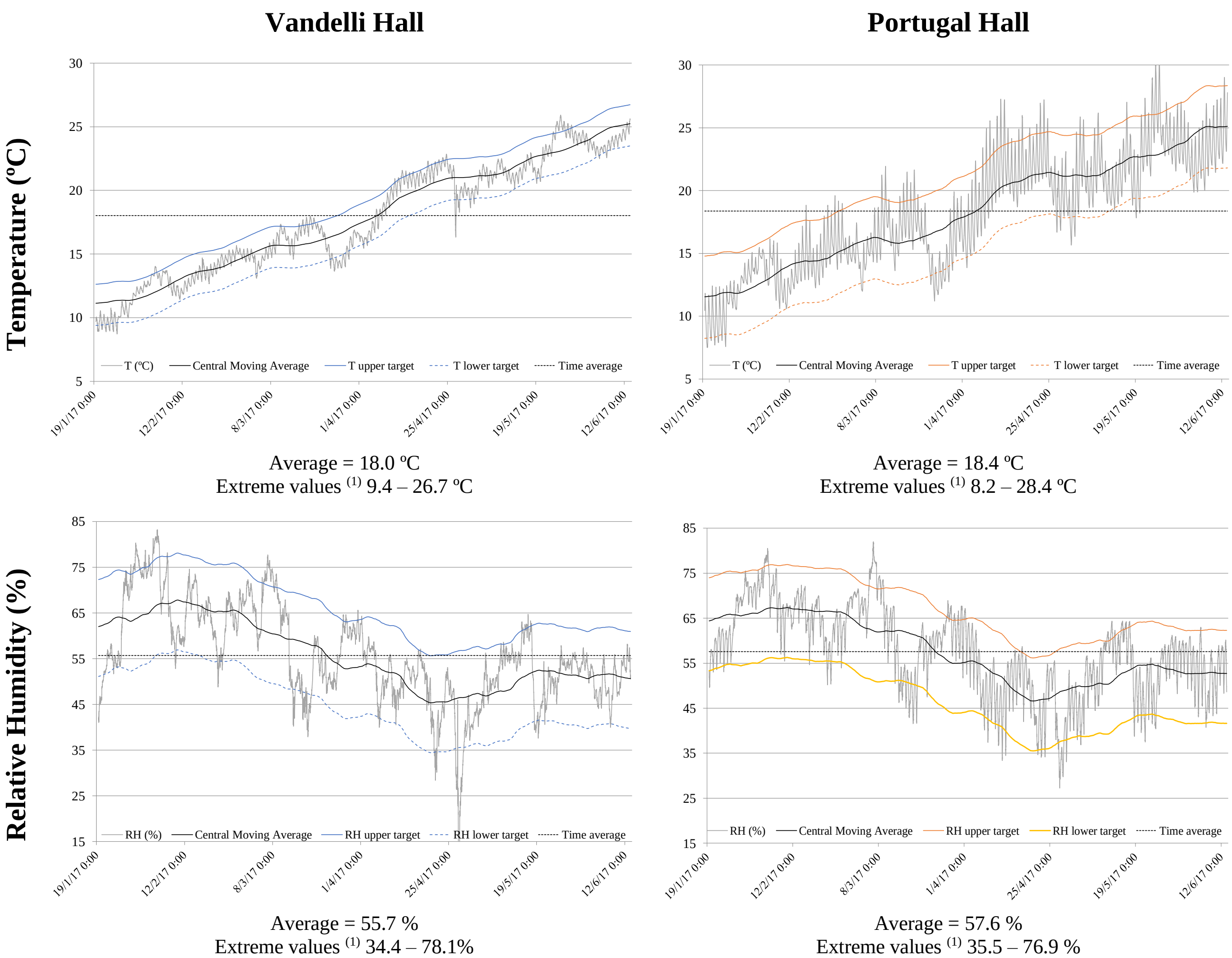


Figure 2 – Time variations of air (a) temperature and (b) relative humidity during 2017 monitoring campaign in both rooms. (VH/PH = air T/RH; $VH/PH_{display\ case}$ = T/RH registered inside the display case in each room).

Though T (ºC) differences between inside/outside sensors in the exhibition rooms were not very significant (considering the average values), both measurements in each room are shown in Figure 2.*a)*. It is graphically readable how T_{PH} values are less stable and inside/outside sensors' readings vary much more than T_{VH}. Curiously, air RH_{VH} values fluctuate much more and deviate from the values inside the display case more than RH_{PH}. As suggested by [10] (*in* [11]), in terms of conservation, the control of RH is more determinant than T, and that is why Figure 2.*b)* was looked in more detail. Herein, the buffering effect of the display cases is clearly observed during critical moments. For example, on January 18th afternoon, air RH_{VH} reached a low peak (31%) similar to the outdoor conditions (30%), while the sensor inside the display case in the same room registered 55%. The same remark could be appointed to data on April 27th: on this day RH_{VH} reached a very low peak (15%) for more than 8 hrs (between 16h-24h), probably due to the outdoor climate conditions (17 < RH (%) < 30); nonetheless, during this period, RH inside the display case only varied between 37-40%. Concerning RH values in PH, a significant difference between inside/outside sensor values can also be observed between January 25th and February 5th (Figure 2.*b)*) and March 13th – 19th.
Figure 3 and Table 3, which present data handled according to EN15757:2010, relate both sensors located outside the display cases. Data processing presented in Figure 3 shows acceptable seasonal fluctuation bands of both hygrothermal parameters.



Note: (1) *Safety targets were defined by the upper and lower limits, defined by the 7th and 93rd percentiles excluding 14% of the more dangerous fluctuations.*

Figure 3 – Target values of the hygrothermal parameters (signalled by the two lines parallel to the Central Moving Average) for this sample of recordings (monitored data relates sensors outside the display cases).

The target ranges for short-term fluctuations of both hygrothermal parameters were also estimated by the difference between the instantaneous values and the seasonal cycle (30-day moving average), limited by the 7th and 93th percentiles [5]. The sustainable intervals for these variations are shown in Table 3 − for the sake of brevity, these variations are not represented graphically. This approach reinforces the previous impression caused by Figure 2: (*i*) T values oscillate much more in PH than in VH (this factor leads to a tighter target range); (*ii*) generically, RH values oscillate more than T values in both rooms; (*iii*) RH fluctuations require control; controlling RH variations will enhance T fluctuations control as well.

Table 3 – Short-term fluctuations of the hygrothermal parameters determined according to EN15757:2010.

	Vandelli Hall	**Portugal Hall**
T (ºC)	$-1.7 \leq \Delta T$ (ºC) ≤ 1.5	$-3.3 \leq \Delta T$ (ºC) ≤ 3.2
RH (%)	$-10.9 \leq \Delta RH$ (%) ≤ 10.3	$-11.1 \leq \Delta RH$ (%) ≤ 9.6

3.3. Discussion

During the first semester in 2017, the general impressions anticipated in [4] were reconfirmed: PH was the exhibition room unveiling more alarming values – presenting more extreme values, showing to be more dependent on the outdoor conditions and presenting more significant fluctuations. Moreover, the overall mean values of VH were closer to the international guidelines for conservation in Museums [9], [13]–[15].

Despite the accurate estimation of the target values of the hygrothermal parameters according to EN 15757:2010 (which mostly addresses RH), some considerations/enlightenments are required, namely:

1) lower T values equal to 9.4 ºC (VH) or 8.2 ºC (PH) cannot be considered acceptable, either because T values lower than 10 ºC can lead to condensation, or due to thermal discomfort. Besides the conservation aspect, the MCUC is also a place of enjoyment of visitors’. Under the analysis of the presented data, authors’ propose the same lowest T value as ASHRAE’s [9], *i.e.*, 15 ºC (though lower values could be considered in museum storage rooms);
2) as the highest determined T value was 28.4 ºC (PH), and this also complies with ASHRAE’s [9] suggestion (T < 30 ºC), an acceptable interval could be defined as 15 < T (ºC) < 28.4;
3) concerning RH, the lowest determined value was 34.4 % (VH), which is somehow a low value;
4) moreover, as the upper determined value was very high (78.1 %, PH), it should not be accepted – some guidelines determine 70% as the limit against fungal growth [15]; ASHRAE’s [9] upper limit (critical value) is 75% instead. As such, one possible RH acceptable interval would be 40% < RH (%) < 70% (determined by $RH_{average} \pm 15$ %, also grounded on VH and PH average values, ≈ 55%).

Curiously, daily fluctuations determined according to EN 15757:2010 in VH are quite restrictive: $-1.7 \leq \Delta T$ (ºC) ≤ 1.5. This range width is practically the double of that recommended in UNI 10809:1999 [13], 1.5 ºC maximum T variation is accepted. Since ASHRAE’s [9] short-term variation for category B *(‘the best that can be done in most historic buildings’*) allows a higher variation (± 5ºC), the value determined in PH was taken as a reference: $-3.3 \leq \Delta T$ (ºC) ≤ 3.2. Regarding RH, as the difference between rooms was not very significant and short-term variations were close to the ASHRAE’s [9] recommendation, the range $-10.0 \leq \Delta RH$ (%) ≤ 10.0 is proposed by the authors in face of the collected data.

4. CONCLUSIONS AND OUTLOOK

As stated by Michalski [1], *‘creating climate specifications for collections is like buying a suit: a one-size-fits-all outfit is very precise, but looks awful on almost everyone; an off-the-rack suit in one’s own size is pretty good and works for most of us, but a tailored suit looks best, usually lasts longer, and costs less in the long run. However, the initial costs and time required are high, and there will always be naysayers who cannot see the difference’*.

Having this reasoning in mind, but being aware of the current conditions of the MCUC (no HVAC systems and communicating halls), the authors aligned the analysis of the present work with EN 15757:2010 [5], aiming at defining a range of ‘sustainable values’ for the indoor hygrothermal conditions of the MCUC in view of an acceptable conservation of the exhibited objects and of visitors’ thermal comfort; namely:

1) Target tolerance ranges for the hygrothermal conditions: 15 < T (ºC) < 28.4 and 40 < RH (%) < 70;
2) Target tolerance for short-term fluctuations: $-3.3 \leq \Delta T$ (ºC) ≤ 3.2 and $-10.0 \leq \Delta RH$ (%) ≤ 10.0.

In the light of these targets for the indoor hygrothermal conditions, the percentage of compliance of each parameter, also designated as a performance index (PI) – *the percentage of time in which the measured parameter lies within the required (tolerance) range’* [12], would be: (*i*) in VH, $PI_T = 63.9\%$, $PI_{RH} = 85.2\%$, combined $PI_{T,RH} = 59.4\%$; and (*ii*) in PH, $PI_T = 64.6\%$, $PI_{RH} = 87.8\%$ and simultaneous compliance $PI_{T,RH} = 56.3\%$.

As anticipated, further continuous monitoring data are required to fully implement the methodology suggested in EN 15757:2010. Moreover, as pointed out above, a proper control of the indoor conditions is required, namely the minimization of the extreme risky values (highest/lowest peaks) and smoothing of the acceptable target values, aiming at approaching other international guidelines, *e.g.*, approximating the upper limits of RH closer to 65% and/or of T closer to 25 ºC. T values lower than 10 ºC should also be strictly avoided. It would also be highly recommended improving the performance index (PI) according to the proposed/achieved target values. Under these reasoning, aiming at improving the stability of relative humidity, it is plausible the future suggestion of: (*i*) dehumidification systems in the exhibition rooms (this could also enhance a beneficial slight increase of air temperature, especially in winter); (*ii*) enhancing the hygroscopic inertia of such spaces through passive measures (*e.g.*, adding a layer of hygroscopic materials to the walls or ceilings); (*iii*) improving the built environment, namely through the sealing of windows and/or placing a windbreaker in the entrance/exit doors of the museum.

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