An index for the evaluation of microclimatic conditions inside museum showcases

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An index for the evaluation of microclimatic conditions inside museum showcases

Silvia Ferrarese[1*], Davide Bertoni[1†] and Alessio Golzio[1†]

[1*]Department of Physics, University of Turin, Via P. Giuria 1, Turin, 10125, Italy .

*Corresponding author(s). E-mail(s): silvia.ferrarese@unito.it;
Contributing authors: davide.bertoni@unito.it; alessio.golzio@unito.it;
†These authors contributed equally to this work.

Abstract

A new index useful in comparing microclimatic conditions inside museum showcases is here presented. The advantage of the index consists in its independence from thresholds that are usually fixed by the norms or by the experience of curators. The procedure to compute the index is described in detail and it is easily reproducible. Microclimatic conditions inside showcases have been compared using the proposed index in a library hall of the Museum of Physics, University of Turin, Italy, during two temporal periods longer than one year. The results show that the index correctly identifies the favorable or critical conditions for conservation.

Keywords: microclimate, museum showcase, microclimatic index, monitoring

1 Introduction

The aim of Museums is the conservation and exhibition of artworks. A common practice is the use of showcases that protect vulnerable exhibits from accidental shocks and dust deposition. Moreover, in consequence of showcase physical characteristics (thermal capacity and ability in absorbing humidity) the fluctuations in temperature and humidity in the room are mitigated inside the showcase. On the contrary, the radiation through the transparent parts of the case can generate increases in temperature [1–3].

The main method to define the microclimatic conditions in a museum hall and inside its showcases is the monitoring of microclimatic quantities, mainly temperature and relative humidity. In museums and libraries monitoring campaigns, the analysis of these physical quantities can be accompanied with the monitoring of particulate matter and its composition. The measurements can be performed inside the building rooms (as by [4]) or, more rarely, inside the showcases [5]. Usually, microclimatic analyses are performed collecting long time series typically longer than one year, and computing the daily averages and excursions, but which microclimatic conditions can be considered favourable to the conservation are actually object of debate in researcher community.

Some authors [6, 7] defined a Performance Index (PI), as the percentage of time in which the measured quantities lies within a specific range identified by the exhibit curators. PI was also applied within other four indexes in order to investigate the microclimatic conditions inside and outside showcases in an ancient building hosting a museum [8]. Other authors [9, 10] applied the same PI index, but they used the thresholds in norms to define the thermo-hygrometric quality level of an environment.

Recently, Ferrarese et al. [11] showed that the microclimate inside museum showcases depends not only by the microclimatic conditions inside the room and by the material composition of the showcases but also by the position of showcases in the room. The same authors proposed an index (IME, Index of Microclimatic Excursions) using the thresholds for temperature and relative humidity daily excursions in the normative [12] to compare microclimatic conditions in different showcases. The same method was applied outside the showcases, in museums rooms, at the Gallerie dell'Accademia in Venice [13].

The weak point of all the proposed procedures is the determination of the thresholds, that are applied to classify the microclimate conditions in acceptable or critical. Usually, the thresholds are fixed by the norms or by the experience of curators (amog others: [14]), but nowadays there is no general criterion for defining the allowed ranges.

In the present work a new index (IMV, Index of Microclimatic Variability), unrelated with the norm thresholds is presented and applied to the measured time series of temperature and relative humidity in a museum hall. The index considers the distribution of daily excursions in temperature and relative humidity weighted on their maxima values. The index is computed by an algorithm that is independent from fixed thresholds, and it can be easily used to compare and evaluate the microclimatic conditions inside different showcases.

The method is tested with two year datasets that were collected in some showcases at the Museum of Physics, University of Turin, where books, paper documents and scientific ancient instruments are exposed. The microclimate is here influenced by the natural meteorological conditions, by the heat system during winter, and by the presence of people, because the room is routinely used for meetings and lessons.

2 Procedure in computing IMV

A standard monitoring campaign consists in the measurement of temperature and relative humidity at the temporal frequency of one datum every 10 or 15 minutes. The monitoring period should be at least one year. Daily excursions in temperature and relative humidity (ΔT and ΔRH) can be compared with the norms thresholds [12], and the score n_1, n_2, n_3, n_4 (Fig. 1), representing the number of days when the two thresholds over daily excursions in temperature and relative humidity are exceeded or not, can be computed.

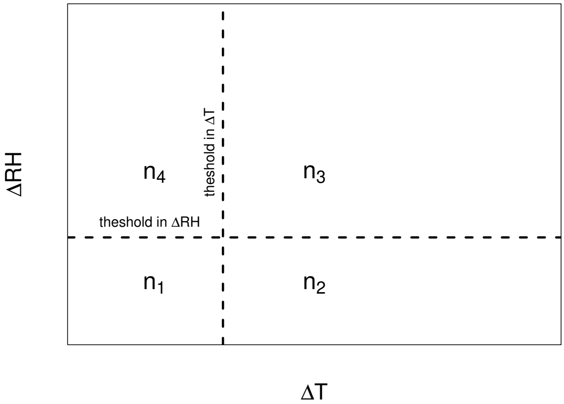

Fig. 1 Scheme showing the ranges where the number of intervals n_1, n_2, n_3 and n_4 are counted

The scores can be used to compute the IME index (equation 1) [11] that ranges from -1 (potentially dangerous conditions for conservation) to 1 (favorable conditions for conservation), and it is able to summarize the data variations in temperature and relative humidity. Its disadvantage lies in the use of the thresholds, in fact the scores do not take into account the proximity to the thresholds but only their exceeding or not.

$$IME = \frac{n_1 - n_3}{n_{tot}} + 0.5\frac{n_2 + n_4}{n_{tot}} \tag{1}$$

Here a new procedure and a new index are described according to the following steps.

1) The excursions in temperature and relative humidity (ΔT, ΔRH) are computed as difference between the daily maximum and minimum, so their number is equal to the number of days in the monitoring campaign multiply

with the number of sensors. The maximum value in temperature and relative humidity daily excursions during the whole monitoring period, are then computed considering all daily excursions:

$$\Delta T_{max} = max(\Delta T) \quad (2)$$

$$\Delta RH_{max} = max(\Delta RH) \quad (3)$$

2) Temperature and relative humidity excursions are then normalized respect to maxima, where ΔT_n and ΔRH_n are computed for each day and each sensor and they are expressed in percentage (the range is from 0 to 100 for both quantities).

$$\Delta T_n = \frac{\Delta T}{\Delta T_{max}} 100 \quad (4)$$

$$\Delta RH_n = \frac{\Delta RH}{\Delta RH_{max}} 100 \quad (5)$$

3) The following quantities Δ are then computed:

$$\Delta = \sqrt{\frac{\Delta T_n^2 + \Delta RH_n^2}{2}} \quad (6)$$

Δ can merge the excursions in temperature and relative humidity and are dimensionless as ΔT_n and ΔRH_n. Δ range is from 0 (favorable conditions for conservation) to 100 (potentially dangerous conditions for conservation). So, for each sensor, the number of Δ values is equal to the number of days. The comparison between the means and the distributions of Δ values gives information about the microclimatic variability in the showcases and it can be easily performed using box-plots.

4) In order to build a parameter that consider the Δ variability and that is able to give an information about the "goodness" of microclimatic conditions, the Δ values are weighted with a linear function (Fig. 2a), obtaining the index IMV (Index of Microclimatic Variability) in the linear form:

$$IMV_{linear} = \frac{\sum (1 - 2\, \frac{\Delta}{100})}{n_{days}} \quad (7)$$

where n_{days} is number of monitored days.

A similar expression, but using a function with a Gaussian shape (Fig. 2b), permits to obtain the index IMV:

$$IMV = \frac{\sum (2\, e^{-\frac{\Delta^2}{2a^2}} - 1)}{n_{days}} \quad (8)$$

where the parameter $a = 30$ in the present analysis. The weight function with Gaussian shape amplifies the differences between the IMV values relating to favorable and critical microclimatic conditions.

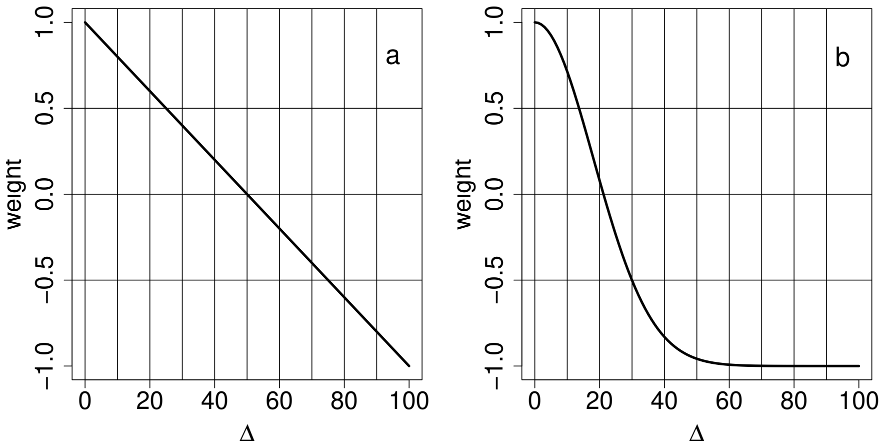

Fig. 2 a) Weight decreases linearly versus Δ, b) Weight decreases with a gaussian shape versus Δ

Both indexes range from -1 (worse value) to 1 (more favourable value to conservation).

IMV indexes are independent from the thresholds defined by the norms or suggested by curators and permit to compare the microclimatic conditions between different showcases.

3 Monitoring site

The proposed methodology has been tested using data from two microclimatic campaigns performed in the Museum of Physics, University of Turin, Italy, in the periods March 2016 - March 2017 and March 2017 - July 2018. A library hall has been monitored with 7 thermohygrometers in the first period and with 11 thermohygrometers in the second. A meteorological station on the building top provided the outdoor meteorological conditions.

The history of the building and the detailed description of the library hall is reported in the paper of Ferrarese et al. [11], here a brief and technical description of the monitoring campaign is presented. The library hall (9.4 x 7.2 meters) is furnished with closed wooden cabinets all around the walls dating in 1898. The cabinets are numbered from 1 to 23 (Fig. 3a) and are composed by an inferior part with wooden door, a central part with glass windows and a superior part with glass windows too (Fig. 3c and Fig. 3d).

The hall is heated in winter by a central heating system, whereas the room is not equipped with a summer air conditioning system. The radiators are located in the inferior part of cabinets 1, 2, 22, 23 (black rectangles in Fig. 3a). In the first period the heating system was not activated for the whole year, while during the second period the heating system was activated in winter following three regimes: a) turned on during the weekday daily hours and turned off during night and weekends, b) turned on every time, c) turned on during daytime and off during night. Moreover, the microclimate in the room can be influenced by the presence of people as the hall is usually used for academic lessons and meetings.

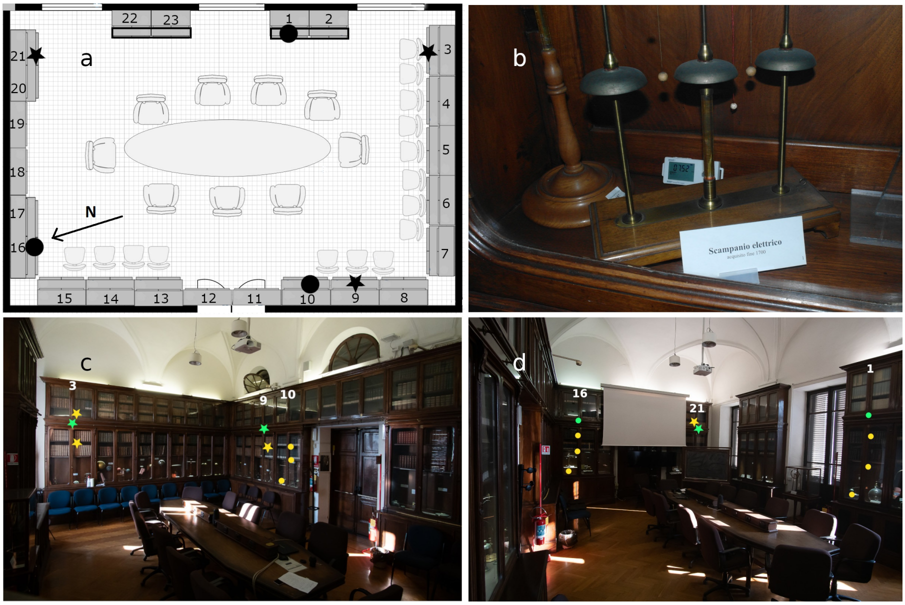

Fig. 3 a) A scheme of the library hall with the cabinet numbers, the black rectangles show the positions of the heat system, the stars are the positions of thermohygrometers from March 2016 to March 2017, the black points are the thermohygrometer positions from March 2017 to July 2018; b) Photo of a HOBO UX-100-011 thermohygrometer in a showcase; c) Image of the South-West side of the library hall, yellow (green) stars show the position of sensors inside (outside) the showcases 3 and 9 in the period from March 2016 to March 2017, yellow points show the position of sensors inside the showcase 10 in the period from March 2017 to July 2018; d)Image of the North-East side of the library hall, yellow (green) stars show the positions of sensors inside (outside) the showcase 21 in the period from March 2016 to March 2017, yellow (green) points show the positions of sensors inside (outside) the showcases 1 and 16 in the period from March 2017 to July 2018.

The thermohygrometers were manifactured by HOBO (model UX-100-011). The accuracy in temperature is 0.21°C in the range from -20°C to 70 °C and in relative humidity is 2.5% in the range from 1% to 95 %. Figure 3b shows one HOBO thermohygrometer positioned in one showcase.

The thermohygrometers were localized at three levels in the central showcases, and at one level in the superior showcase, other sensors were positioned outside the cabinets, in the room (Fig. 3c).

During the first period the analysis was devoted to the two opposite cabinets near the windows (number 3 and number 21) and one in the front of the windows (number 9), as shown in Fig. 3. The sensors were positioned in cabinet 3 in the superior and central showcases, in cabinet 21 in the superior and in cabinet 9 in central showcase. In Fig. 3c-d the yellow stars show the positions of sensors in showcases 3, 9 and 21. Two further sensors were located outside cabinets 3 and 21 (green stars in Fig. 3c-d). The sensors positions and the heights respect with the floor are shown in Table 1.

In the second period the sensors were located in cabinet 1 (over the heating system), 10 (in front of the windows), and 16 (in the North corner) as shown in Fig. 3a. The thermohygrometers were positioned in the central window at three different heights in cabinet 1 and 16, and at two heights in cabinet 10 (yellow circles in Fig. 3c-d). Two further sensors were positioned outside the cabinets numbered 1 and 16 (green points in Fig. 3c-d). Table 1 shows the positions and heights respect with the floor during the second period.

Table 1 Sensor positions in the periods March 2016 - March 2017 and March 2017 - July 2018. The height is referred to the floor.

March 2016 - March 2017			
Sensor	Cabinet	Height (m)	inside/outside
3-middle	3	2.00	in
3-top	3	2.85	in
3-out	3	2.54	out
9-middle	9	2.00	in
9-out	9	2.54	out
21-top	21	2.85	in
21-out	21	2.54	out
March 2017 - July 2018			
1-base	1	0.90	in
1-center	1	1.60	in
1-high	1	2.19	in
1-out	1	2.54	out
10-center	10	1.60	in
10-high	10	2.19	in
10-out	10	2.54	out
16-base	16	0.90	in
16-center	16	1.60	in
16-high	16	2.19	in
16-out	16	2.54	out

4 Results

Temperature and relative humidity were processed following the methodology presented in section 2. All datasets (7 in the first period and 11 in the second) were analysed and the daily excursions, ΔT and ΔRH, the normalized daily excursions ΔT_n and ΔRH_n, the Δ parameters, and finally IMV indexes were computed.

The results are discussed separately during the two periods as the microclimatic conditions in the room were influenced by the winter heating system that was turned off during the first period and turned on in the second following three regimes. The comparison was made between the showcase conditions during each single period.

4.1 Daily excursions

Daily excursions ΔT and ΔRH are computed for each dataset. Figure 4 shows, as examples, the two datasets during the first period in the showcase 21 and during the second period in the showcase 1. The two examples were chosen as they represent two very different situations: showcase 21 was characterized by limited daily fluctuations, while in showcase 1 the fluctuations were greater in consequence of the near heating system. The red lines represent the standards suggested by the norms [12] for printed volumes, while the percentages equal to the ratios $\frac{n_1}{n_{tot}}$, $\frac{n_2}{n_{tot}}$, $\frac{n_3}{n_{tot}}$, and $\frac{n_4}{n_{tot}}$ give a first information about the microclimatic conditions.

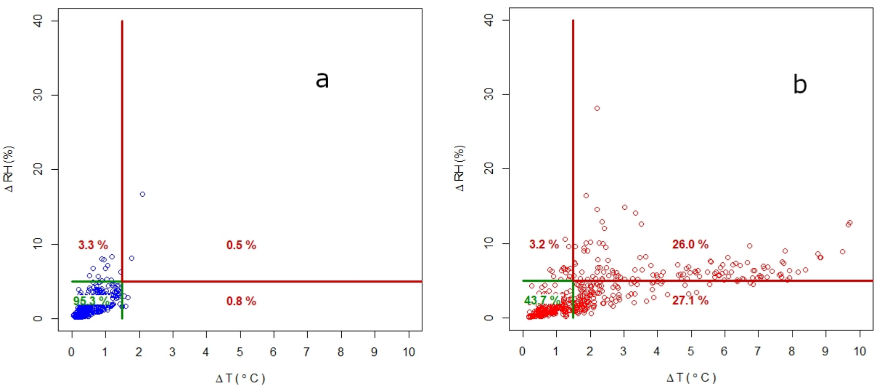

Fig. 4 a) Daily fluctuations inside showcase 21 in the period March 2016 - March 2017 and b) inside showcase 1 base position in the period March 2017 - July 2018

Using measured data at all sites, the IME index is computed (Table 2). IME index values are lower than 0.2 for the collected dataset outside the showcases (3-out, 21-out, 1-out, 16-out), while inside the showcases its values are always higher in consequence of the thermal capacity and the ability in absorbing humidity of the showcases. In the first period, inside showcases, IME value is always higher than 0.9 with the exception of the showcase 3-top that is sometimes lighted by a beam of natural radiation through the windows in the morning.

In the second period, IME index has values lower than 0.6 in showcase 1 (base and center positions) as consequence of the near heating system and

Table 2 Indexes in the periods March 2016 - March 2017 and March 2017 - July 2018

March 2016 - March 2017			
INDEX	IME	IMV_{linear}	IMV
3-middle	0.93	0.79	0.76
3-top	0.79	0.76	0.68
3-out	-0.08	0.52	0.01
9-middle	0.96	0.88	0.88
9-out	0.18	0.61	0.19
21-top	0.96	0.89	0.88
21-out	0.16	0.61	0.18
March 2017 - July 2018			
1-base	0.33	0.64	0.31
1-center	0.53	0.73	0.46
1-high	0.81	0.83	0.73
1-out	0.08	0.54	0.09
10-base	0.61	0.79	0.62
10-center	0.42	0.74	0.52
10-high	0.71	0.82	0.70
16-base	0.60	0.79	0.63
16-center	0.61	0.80	0.66
16-high	0.77	0.82	0.72
16-out	0.14	0.63	0.24

in the showcase 10 (center position) as sometimes it was lightened by direct radiation through the windows. All other dataset have IME values higher than 0.6, here the microclimatic conditions seem to be more favourable.

4.2 Normalized daily excursions

The daily excursions are then normalized respect to the maximum value of the microclimatic quantities measured by all sensor (see equations 4 and 5). In the two episodes the maximum values were ΔT_{max} equal to 8.7 °C in the first period and 9.7 °C in the second, while ΔRH_{max} was equal to 51% in the first period and 43% in the second.

For the two selected examples, ΔT_n and ΔRH_n are shown in Fig. 5. Plots in Fig. 4a and 5a have a similar shape, and the same for the couple of plots in Fig. 4b and 5b, in fact, Fig. 4a-b show daily excursions ΔT and ΔRH and Fig. 5a-b show the same excursions but normalized with the maximum values ΔT_{max} and ΔRH_{max} and re-scaled in the interval 0-100 (ΔT_n and ΔRH_n computed by equations 4 and 5).

4.3 Δ distributions

Δ values are then computed for each sensor, and their values are plotted as box-plots (Fig. 6 and 7). As mentioned in section 2, Δ values are daily data, and they can vary from 0 (favourable condition) to 100 (potentially dangerous

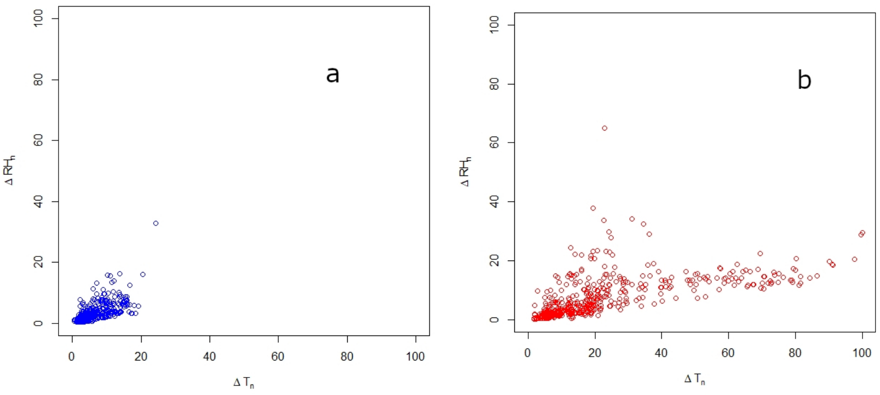

Fig. 5 a) Scaled daily fluctuations inside showcase 21 in the period March 2016 - March 2017 and b) inside showcase 1 base position in the period March 2017 - July 2018

conditions) giving a synthetic information about the microclimatic situation inside or outside the showcase.

In the period from March 2016 to March 2017 the three datasets relative to sensors outside the showcases, in the room, have higher Δ medians and wider distributions (3-out, 9-out and 21-out in Fig. 6). Δ box-plots at high positions (3-top and 21-top) are comparable as regards medians and whiskers but the number of outliers is greater in showcase 3. The inspection of time peaks in measured data and the room exposure suggests the presence of a direct solar radiation beam through the glass windows to the showcase 3 that can be the cause of the outliers. The same consideration is valid comparing the dataset 3-middle and 9-middle that have similar means and whiskers, but more outliers are present in 3-middle dataset. As conclusion the microclimatic conditions are better in showcases 21 and 9 respect to showcase 3.

In the period from March 2017 to July 2018 (Fig. 7), Δ distributions show high variations in the datasets that were collected outside the room and also inside the showcase 1 that is near the heating system (1-base, 1-out and 16-out). Other sensors with moderate variability were located in showcases 1 and 10 in central positions (1-center and 10-center), in fact showcase 1 is still influenced by the variations due to the heating system and showcase 10 is sometimes lighted by a blade of light through the blinds. All other sensors (1-high, 10-base, 10-high, 16-base, 16-center and 16-hight) have similar distributions and their differences are not easly appreciable in the plot. The use of the IMV index, as described in the next section, should help in distinguishing the differences in their microclimatic conditions.

4.4 IMV indexes

Following equations (7) and (8) the index $\text{IMV}_{\text{linear}}$ and IMV have been computed in the two periods (Tables 2). As mentioned in section 2, the two indexes

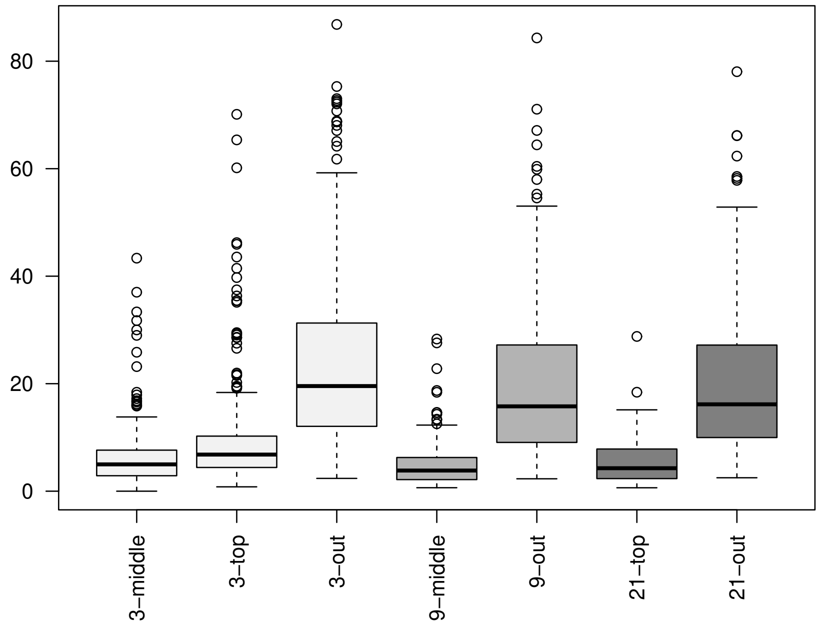

Fig. 6 Δ distributions in the period March 2016 - March 2017 in the showcases 3, 9 and 21

use Δ values to obtain a single value that would be representative of the microclimatic conditions and that is useful in comparing different microclimate conditions. The difference between the two indexes lies in the two weight functions that are respectively linear and gaussian shaped.

As regards the first period (Table 2) $\text{IMV}_{\text{linear}}$ ranges from 0.52 to 0.89 whereas IMV is from 0.01 to 0.88, so IMV is more able than $\text{IMV}_{\text{linear}}$ in distinguish the different conditions. In particular IMV detects the worse conditions for outside sensors (IMV values lower than 0.25), best conditions in showcases 9 and 21 (IMV values are higher than 0.85), and intermediate conditions in showcase 3.

In the second period (Table 2) IMV values have more variability than $\text{IMV}_{\text{linear}}$ as in the first period. Low values of IMV are obtained by sensor outside the showcases and inside showcase 1 near the heating system. Intermediate values (0.4 - 0.6) are reached in showcases 1 and 10 in central positions that are respectively influenced by the heating system and direct radiation. All sensors in high position registered IMV values higher that 0.7, whereas in

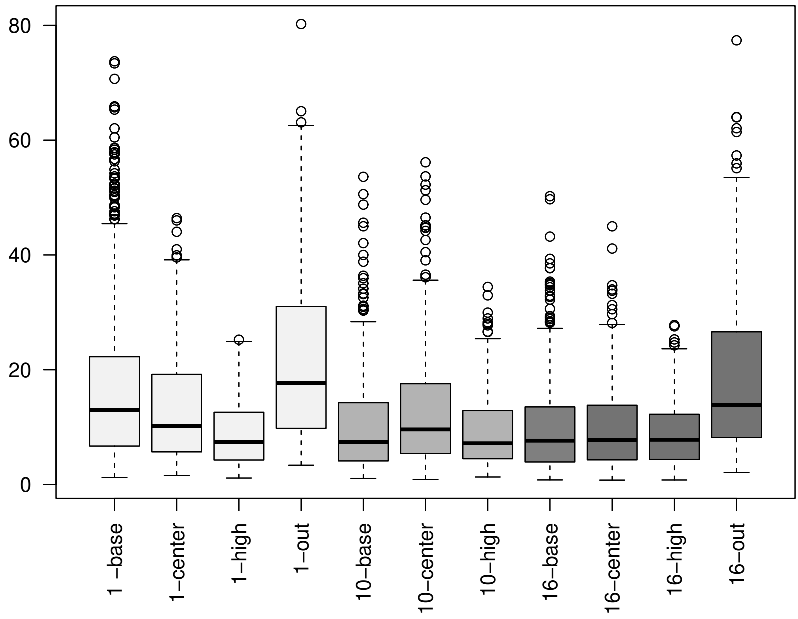

Fig. 7 Δ distributions in the period March 2017 - July 2018 in the showcases 1, 10 and 16

showcase 10 and 16 at base and center positions the IMV values are about 0.6-0.7. IMV values suggest that the better showcases in terms of microclimatic conditions are far from the floor, in high position.

Considering both monitoring campaigns, IMV index gives some practical advises in order to promote favorable microclimatic conditions inside the library hall:

a) the heating system should be off during the whole year;

b) the more ancient book and scientific instruments should be exposed inside the cabinets;

c) the showcases should not be exposed to direct radiation;

d) high positions should be preferred respect to low positions.

5 Conclusions

The microclimatic conditions can vary inside a museum room and they can be different inside showcases in the same room. As a matter of fact, the thermal and hygrometric quality of the showcases and their positions in the room can determine different microclimatic conditions. Microclimatic indexes can be applied in order to detect the showcases with the more favourable conditions for artworks conservation. They have the aim to give to curators important information about the best position where the more precious artworks should be exhibited.

In the present study a new microclimatic index (IMV Index of Microclimatic Variability) is presented and the procedure for its computation is described in detail. Its advantages lie in its independence from standards that are usually taken from norms or curators experience and in its easiness in computation. IMV has two main disadvantages: it needs almost one year-long dataset and it is able to compare different conditions but it does not give absolute information about the “goodness” of microclimatic conditions. However, these disadvantages are common to other indexes.

IMV has been applied at two case studies in order to test its ability in describing the microclimatic conditions inside showcases. The procedure has been applied and each step has been described and discussed.

The results showed that IMV can give practical suggestions to exhibition organizers, in particular it can indicate the showcases where the more precious artworks should be conserved.

Data Availability Statement. The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

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