IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Assessment of thermo-hygrometric indicators for preventive conservation inside museums: in field monitoring and passive microclimatic control strategies applied to “La Specola” museum of Florence

To cite this article: Fabio Sciurpi *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **364** 012023

IOP Conf. Series: Materials Science and Engineering **364** (2018) 012023 doi:10.1088/1757-899X/364/1/012023

Assessment of thermo-hygrometric indicators for preventive conservation inside museums: in field monitoring and passive microclimatic control strategies applied to "La Specola" museum of Florence

Fabio Sciurpi*, Cristina Carletti, Leone Pierangioli

Department of Industrial Engineering, University of Florence, Via di San Niccolò 93, 50125 Florence, Italy

*fabio.sciurpi@unifi.it

Abstract. The University of Florence has equipped one of the most representative Florentine historical Museum, "La Specola", of a specific microclimatic monitoring system installed in some rooms. The paper presents the results of one-year record of temperature and relative humidity, regarding a room and its showcases. The elaboration and analysis of the microclimatic data have been carried out according to the Italian Standard UNI 10829 and the Performance Index of the most important thermo-hygrometric parameters has been calculated and assessed. Moreover, a dynamic thermal simulation to assess the effectiveness of some passive refurbishment strategies has been carried out in terms of annual and monthly Performance Index and dry bulb temperature variations. The results can be extended to several historical buildings, where poor envelope performances and large windows or skylights imply not acceptable indoor environmental conditions that can even cause damage to the artefacts.

1. Introduction

Indoor environmental conditions play a fundamental role in the deterioration process of the objects exhibited inside museums, and can be strongly affected by the values of temperature and relative humidity, as well as their time and space fluctuations [1]. As a matter of fact, the attitude is oriented to preventive conservation; it implies both "passive" techniques, aimed to minimize the potential damage to the object from the exhibition environment, and environmental monitoring and management directed to minimize variations of indoor parameters and to reduce impacts from outdoor. In the absence of a heating, ventilating and air conditioning system (HVAC), showcases are very important for the artefacts conservation; in general, they work as a filter against environmental attacks due to microclimate variations, chemical pollution and action of micro-organism; moreover, they offer a protection against vandalism, robberies and any direct damage that could come from visitors. Microclimatic monitoring of museum rooms and showcases is fundamental to assess the museum environment suitability to conserve exhibits and to plan any action required to reduce degradation risk [2] [3] [4]. Italian and European technical regulations about cultural heritage conservation [5] [6] establish guidelines and methods to measure indoor temperature, relative humidity and lighting level. Moreover, Guidelines for the Museums operation and management have been drawn up by the Italian

Ministry for Cultural Heritage [7], giving information about quality standard and technical equipment inside Museums.

In Italy, as well as in the Florence district, there are many important museums located in historical buildings that were built with a different destination, so that their restoration, improvement, safety and accessibility is difficult to achieve and maintain. Bad conservation conditions of the museums are mainly due to: high humidity levels, water infiltration from roof and windows, absence of lighting and solar control systems, poor thermal performance of the building envelope. As concern the microclimatic control systems in the museums, most of all have only a heating system, only some museums, or their specific sections have a HVAC system.

To choose suitable retrofitting strategies many aspects must be considered, and a global comparative analysis has to be carried out to express a qualitative assessment associated to a particular strategy: effectiveness in terms of indoor climate improvement and reduction of the solar thermal loads, architectural integration, technical feasibility, management of the device in terms of easy maintenance, costs [8].

Aim of the research carried out by the University of Florence is to investigate microclimatic conditions inside museums in historical buildings in Florence by means of a long-term monitoring and the calculation of dedicated performance indices, such as PI_{θ} (%) and $PI_{\Delta\theta 24}$ (%). Moreover, the Research will outline the main problems for the exhibits related to poor climatic indoor conditions, assessing different strategies to refurbish them with a dedicated dynamic calculation code [9]. This research evaluated many different passive and active strategies to guarantee proper conservation on very peculiar and precious objects such as substitution of glasses and drapes, thermal insulation, ventilation.

In this paper the result of this Research applied to a room (Room XIX) of one of the oldest museum in Florence, “La Specola”, are presented and discussed. As conservative problems of the exhibits mainly refer to elevated temperature, the paper focus on the analysis of temperature variation and temperature performance indices both in the Rooms XIX as well as in its showcase.

To evaluate the effectiveness of different strategies, the performance indices of air temperature and relative humidity have been calculated and assessed by means of a dynamic simulation tool and are compared to the base case.

Among the different rooms of “La Specola”, Room XIX has been chosen for applying the methodology of the Research for its critical issues also related to an event that occurred in August 2014 when a cloudburst causes the windows to break and severe water infiltrations.

2. Description of “La Specola” Museum of Florence

“La Specola” is one of the oldest Museum of Florence and is situated at the second floor of Palazzo Torrigiani in the historic centre of Florence.

In about 1520, many thirteenth-century houses were merged by transforming the property into a building that was acquired in 1771 by the Grand Duke Pietro Leopoldo of Lorraine to turn it into the first European scientific museum. After extensive expansion and adaptation works the museum was opened to the public on February 21, 1775.

At present, Palazzo Torrigiani, which is one of the locations of the University of Florence, hosts the museum of Natural History La Specola, the Institute of Zoology and the Institute of Comparative Anatomy, General Biology and Genetics. “La Specola” zoological collections are rich, but only a small portion of the over three million specimens is visible to the public. Inside “La Specola” Museum are collected objects with different conservative requirements; the rooms contain showcases, of great historic and artistic value, in which very different specimen are exposed, such as: Diorama, Protozoa, Mollusca, Insects, Worms, Echinoderms, Carnivores, “Count of Turin” hunting trophies, Rodents, Cetaceans, Monkeys, Birds, Reptiles, Fishes, Anatomic Waxes, etc. The zoological exhibits are particularly sensible to high temperature values that can cause biological growth and activate putrefaction. Relative humidity variations are particularly important for the mammals exhibited that have an inner filling made of gypsum instead of straw; this filling presents a different behaviour then the animal skin and can cause its break due to high temperatures that determine a quick and uncontrolled reduction of relative humidity values in summer periods.

"La Specola" Museum is a building with a stone and brick masonry, wooden floors and turned ceilings. The many enlargements of the Palace determine a great variability of envelope structures about the wall thickness and materials. Shading devices combined with the windows and the skylights respectively consist of external shutters and internal drapes. The Rooms of the Museum have different orientations and dimensions as well as technological and thermal characteristics [10].

3. Microclimatic monitoring campaign

Environmental monitoring inside historical buildings can contribute to prevent damages of the exhibits due to inadequate thermal and hygrometric conditions also suggesting the Curator strategies to carry out in order to improve climatic indoor conditions.

To investigate and control the indoor microclimatic conditions, the University of Florence has equipped "La Specola" of a specific microclimatic monitoring system installed on 2011 in some rooms, with fixed data loggers to collect values of dry bulb temperature (θ) and relative humidity (RH). The monitoring system (table 1), has been described in [4]. In general, the internal measuring positions have been chosen considering the fruition needs of the Rooms, the operating requirements of the instruments (avoiding proximity to heat sources, direct light, direct contact with local disturbance causes that may affect the proper functioning of the instruments), as well as the geometric characteristics of the environments and the wireless connectivity. The loggers, placed in 16 rooms, inside 4 representative showcases and outside the museum, send the measure every 15 minutes to a master connected to a PC thanks to a LAN network. Recordings of each data logger are displayed in the bookshop's PC and in the museum manager's PC, to perform a real-time control of the measured environmental parameters.

Table 1. Main characteristics of the sensors used (http://www. giorgiobormac.com).

	Temperature Reading Resolution/ Accuracy	0,1°C/±0,5 °C
	Temperature Reading Range	- 30 to + 70 °C
	RH Reading Resolution/ Accuracy	0,1%/±2%
	RH Reading Range	0 to 100%

Optimal parameters for objects conservation can be defined both by the Conservators and by technical documents and UNI standards, such as DM 10.05.2001, UNI 10829, UNI EN 15757 and UNI 10969. Based on the climatic history of the exhibits, their material and structural characteristics, the recommended values for the artefacts by "La Specola" Conservators are the followings:

- for Anatomic Waxes: 20°C≤θ≤22°C; $\Delta\theta_{24} \leq 1.5$°C; 40%≤ RH≤60%; $\Delta RH_{24} \leq 5\%$
- for all other objects: 15°C≤θ≤24°C; $\Delta\theta_{24} \leq 1.5$°C; 40%≤ RH≤60%; $\Delta RH_{24} \leq 5\%$

4. Monitoring campaign analysis, results and discussion

The monitoring campaign in the Museum started on October 2011 and is still in progress. Data were collected, analyzed and discussed according to the methods for elaboration and analysis of data suggested by UNI Standard 10829. For each room and showcase monitored the temporal profile of temperature and RH, minimum, medium and maximum values of temperature and RH, daily gradients of temperature ($\Delta\theta_{24}$) and RH (ΔRH_{24}) were evaluated. Further on, the "Performance Index" (PI) was calculated; this index expresses a brief evaluation on the quality of the indoor environment in relation to the conservation of the object exhibited on it. It represents the percentage of time during which the measured parameters fall within their ranges considered as "acceptable" [1] [4]. At the moment, acceptable limits concerning different Performance Indices have not been established by Scientific Research on Cultural Heritage conservation.

Data monitored from a typical year have been analyzed and discussed for some air-conditioned and non-air-conditioned Rooms and for some showcases in a previous paper [4]. In the present paper, data monitored from March 2012 to March 2013 are analyzed and discussed for Room XIX and for the N/W showcase inside this room (XIXs), chosen on the basis of its importance and problems (exposition, great windows surfaces combined with not effective solar shadings).

Room XIX is without any HVAC system, has a not insulated opaque envelope, six large windows with internal drape and without external solar shadings (S/E, S/W and N/W oriented), and preserves relevant "large birds stuffed"; the showcases are placed against the three external walls. Tubular fluorescent lamps are used inside showcases and for artificial lighting of the room.

For one-year monitoring, the time profiles of mean daily temperature and RH measured in room XIX are presented and compared with the corresponding outdoor values (OUT), the showcase values (XIXs) and the accepted values (figure 1).

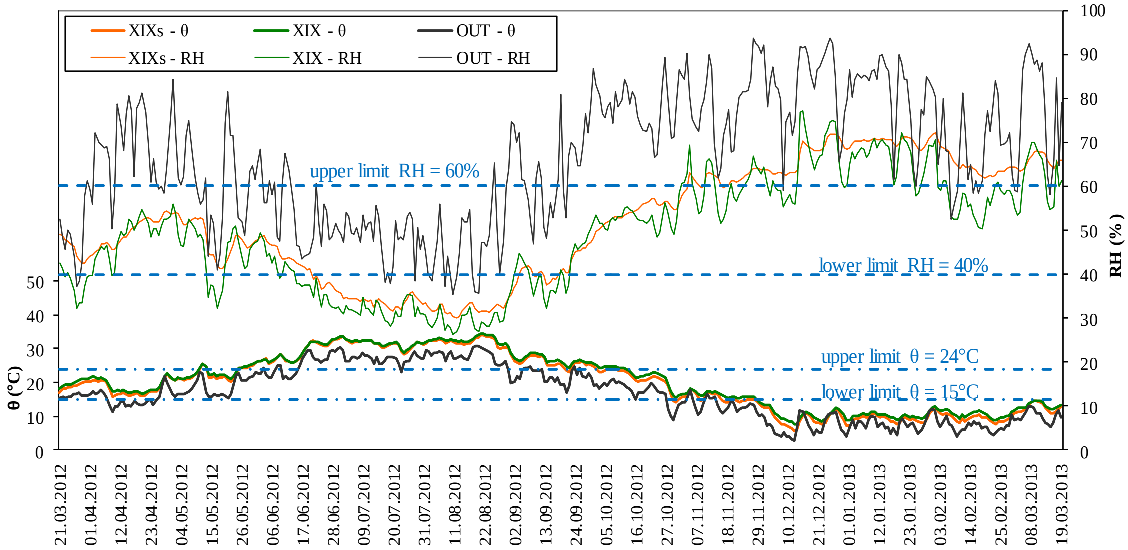

Figure 1. Time profile of mean daily temperature and RH values for one-year monitoring period for Room XIX, showcase XIXs and the outdoor compared with the accepted values.

From data collected it is clear that the temperature and RH trend for the Room XIX and the showcase XIXs follows the outdoor climate, although very dampened in sudden hourly and daily changes. In spring and autumn indoor temperature and RH are within the recommended range, whereas in summer and in winter temperature is respectively above and below the limits and RH is respectively below and above the limits. Particularly significant are the values of temperature inside the showcase that are maintained especially in winter below those of the room with a maximum value of about 3°C in February; as a matter of fact being this showcase placed against a not insulated and N/W oriented external wall, the lack of thermal insulation is reflected in lower temperatures inside the showcase. Faced with an external maximum daily gradient of temperature ($\Delta\theta_{24\ max}$) of 22.6°C, the maximum daily temperature variation in Room XIX is 4.7°C, while in the showcase XIXs is 3.6°C. The annual PI_θ is 32% for the room and 30% for the showcase, while the $PI_{\Delta\theta 24}$ is very low for the environment monitored (15% for the room and 26% for the showcase). Faced with an external maximum daily gradient of RH ($\Delta RH_{24\ max}$) of 63%, it is clear the stabilization of this parameter inside the monitored environments (18% for the room and 7% for the showcase). The annual PI_{RH} is 47% for the room and 41% for the showcase, while the $PI_{\Delta RH24}$ is quite high (65% for the room and 99% for the showcase). Although the showcase is not sealed, it reduces RH variations respect those of the room and guarantees a damping of RH changes greater then temperature ones. The RH trend inside the case is related to the indoor temperature trend rather than to the outdoor RH variations. The percentage of time during which the temperature and RH simultaneously fall within their acceptable ranges ($PI_{\theta,RH}$) is only the 26%.

The analysis of the microclimatic parameters measured shows that especially the temperature conditions were not reasonably acceptable for the preservation of the kind of objects exhibited. The most problematic period for the kind of objects appears to be the summer, during which temperatures and their variations are always outside the range recommended by the conservators and can cause important and permanent damages.

5. Microclimate control strategies for museum retrofitting

Aiming "La Specola" retrofitting and to control the temperature values and their variations inside the Rooms, both passive and active strategies have been selected.

For Room XIX passive strategies referring to the improvement of the thermal performances of the envelope and of the solar shading device have been selected and assessed [11]. Wall thermal resistance has been improved with the application of an internal layer of a good insulating material positioned between the showcase itself and the wall. As the windows in Room XIX are single glazed with wooden frame, they have been successfully replaced with more performing glasses such as double glass or solar control glass. Moreover, to guarantee a good uniformity of illumination and avoid overheating effective, internal drapes have been evaluated.

Active strategies applied to Room XIX mainly refer to the improvement of the indoor climate as well as air quality, and consist of a ventilation and air filtration equipment.

With the purpose of evaluating the different actions, a model of the museum was made in Energy Plus®, trough the Design Builder® interface, using the conduction finite difference solution algorithm [10]. The hourly values of the main climatic parameters for the Florence location are from Test Reference Year (TRY) data set developed by CTI (Italian Thermotechnics Comitee).

The single actions are the follow:

- substitution of single clear glass (SG, thermal transmittance of the glass U_g=5.84 W/m^{2}K, total solar energy transmittance of the glass g=0.87, light transmittance of the glass τ_v=0.90) with a new double glass (DG, U_g=1.61 W/m^{2}K, g=0.62, τ_v=0.79) and with a new solar control glass (SCG, U_g=1.61 W/m^{2}K, g=0.21, τ_v=0.40). Thermal transmittance of the frame (U_f) is 2.2 W/m^{2}K;
- substitution of dark internal drape (ID-D, solar transmittance τ_e=0.3, solar reflectance ρ_e=0.1) with s light internal drape (ID-L, τ_e=0.70, ρ_e=0.15);
- introduction of a Demand Controlled Ventilation (DCV) system equipped with filter to prevent pollution due to dust and micro-organisms, to provide night free cooling (air change rate n=h^{-1} from 10 pm to 8 am);
- thermal insulation of external walls with pellets of cellulose blown into the air gap between the showcases and the external walls (ITI, thickness s=0.08m, conductivity λ=0.038W/mK, density ρ=55 kg/m^3, specific heat c_p=2544 J/kgK, vapour resistance factor μ=2). Thermal transmittance of the wall decreases from U=1,53 W/m^{2}K to U=0,36 W/m^{2}K).

The single actions have been combined in 6 different strategies compared with the performance indexes of the base case (BC, single glass, dark internal drape):

- DG/ID-L: double glass with light internal drape;
- SGC/ID-L: solar control glass with light internal drape;
- DG/ID-L/ITI: double glass with light internal drape and internal thermal insulation;
- SGC/ID-L/ITI: solar control glass with light internal drape and internal thermal insulation;
- DG/ID-L/ITI/DCV: double glass, light internal drape, internal thermal insulation and demand controlled ventilation;
- SGC/ID-L/ITI/DCV: solar control glass, light internal drape, internal thermal insulation and demand controlled ventilation.

Room XIX (13m x 13.5m x 6.9m high) has been modelled with 4 external surfaces: 3 walls (s=0.63m; U=1.53W/m^{2}K) and the roof (s=0.05m; U =2.99W/m^{2}K). Since the present analysis focused on the performance of the showcase adjacent to the external NW wall, the heat exchanges are mostly affected by Room XIX and the external environment. The other adjacent thermal zones were considered at the same thermo-hygrometric conditions of Room XIX. The Room (Figure 2) has 6 windows (2 windows on each external wall) oriented to NW, SW and SE. Each window is about 6.3m^2 and has a wooden frame and a single clear glass.

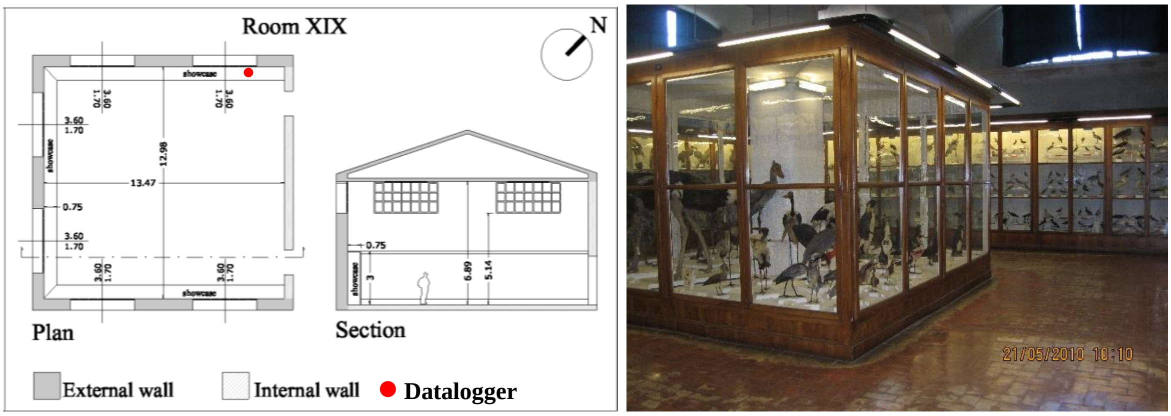

Figure 2. Plan and section of energy model and picture of the Room XIX

Each of the six strategies has been evaluated by means of the following indicators, referred to the air inside the N/W showcase: dry bulb temperature θ (°C), PI_{θ} (%) and $PI_{\Delta\theta 24}$ (%).

In figure 3 the monthly values of PI_{θ} for the analyzed strategies are reported. In figure 4 the monthly values of $PI_{\Delta\theta 24}$ for the analyzed strategies are reported. In figures 5 and 6 the hourly dry bulb temperature values respectively for a typical summer (19 June) and winter day (28 January) for the analyzed strategies are reported. From the analysis of annual values of the above-mentioned indicators, the following general observations can be made: the substitution of current single glasses with solar control glasses implies a significant improvement of $PI_{\Delta\theta 24}$, while the introduction of the Demand Controlled Ventilation system produces a light improvement of PI_{θ}. In particular:

- double glass combined with light internal drape (DG/ID-L) does not change annual PI_{θ} and makes $PI_{\Delta\theta 24}$ worse (from 48% to 39%); the introduction of internal thermal insulation further worsens $PI_{\Delta\theta 24}$ up to 25%;
- solar control glass combined with light internal drape (SCG/ID-L) does not change annual PI_{θ} and enhances $PI_{\Delta\theta 24}$ up to 78%); the introduction of internal thermal insulation does not modify the values of indicators referred to the Base Case (BC);
- double glass and solar control glass further combined with light internal drape, internal thermal insulation and demand controlled ventilation (DG/ID-L/ITI/DCV and SCG/ID-L/ITI/DCV) significantly enhance PI_{θ}, respectively up to 37% and 43%, and deeply worsen $PI_{\Delta\theta 24}$, respectively up to 18% and 26%.

Solar control glass combined with light internal drape is the most effective passive strategy in terms of enhancement of the percentage of time during which the daily variation of the temperature (Δθ24) inside the N/W showcase is less than 1,5°C. This strategy further combined with internal thermal insulation and demand controlled ventilation is the most effective passive action in terms of enhancement of the percentage of time during which the temperature inside the N/W showcase falls within the range of the acceptable values (from 15°C to 24 °C).

The results of the monthly simulations of PI_{θ} (%) and $PI_{\Delta\theta 24}$ reported in figures 3 and 4 agree with the results of the annual simulations.

The results of simulation in term of hourly temperature trend in a typical summer day (figure 5) and winter day (figure 6) confirm that solar control glass combined with light internal drape, internal thermal insulation and demand controlled ventilation (passive cooling active only in summer) is the most effective passive action in terms of summer dry bulb temperature reduction and winter and dry bulb temperature rise in comparison with the Base Case.

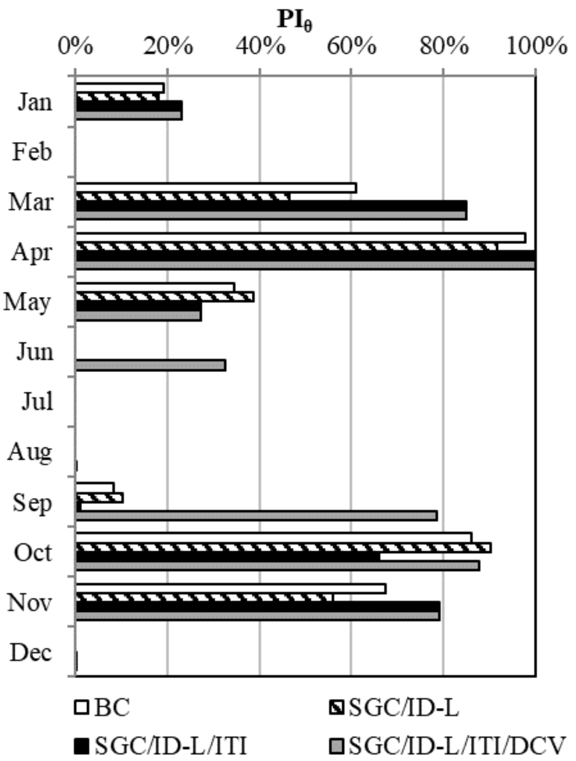

Figure 3. Monthly values of PI_θ for the analysed strategies.

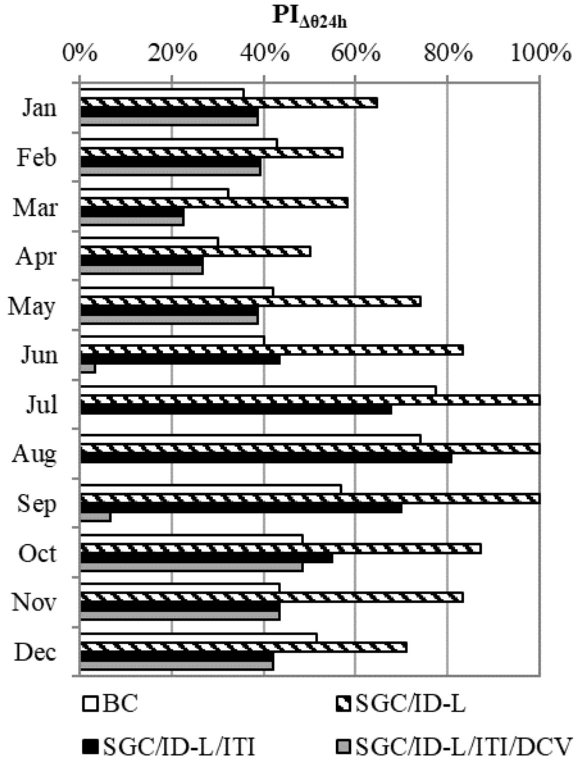

Figure 4. Monthly values of $PI_{\Delta\theta 24}$ for the analysed strategies.

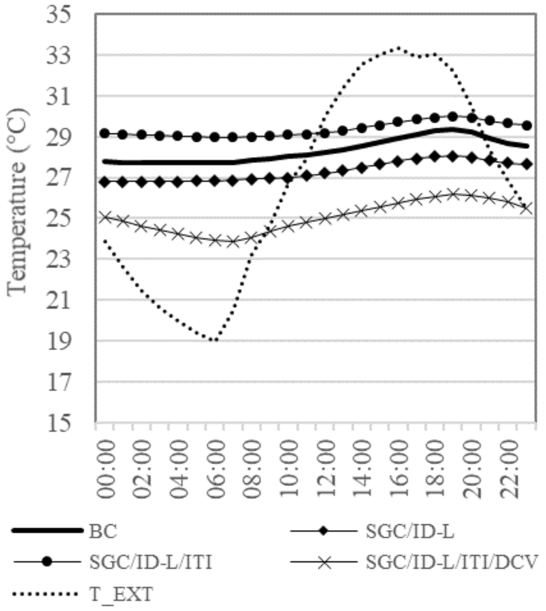

Figure 5. Hourly temperature values in a typical summer day for the analysed strategies.

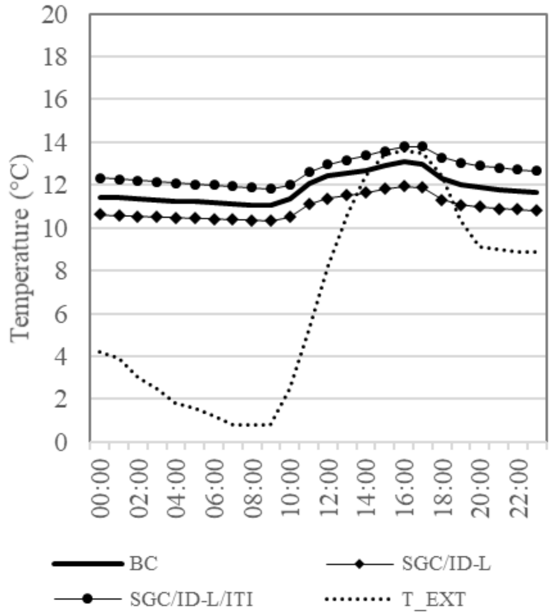

Figure 6. Hourly temperature values in a typical winter day for the analysed strategies.

6. Conclusions

One-year monitoring campaign carried out in “La Specola” Museum of Florence pointed out some critical aspects: temperature and relative humidity conditions were not reasonably acceptable for the preservation of the kind of objects exhibited (15°C<θ<24°C; 40%<RH<60%). Different refurbishment passive strategies have been selected and applied to a room of the Museum (Room XIX). Some combinations have been analyzed and discussed on the basis of the results of dynamic simulations in term of PI_{θ}, $PI_{\Delta\theta 24}$ and dry bulb temperature inside the showcases. Solar control glass combined with light internal drape is the most effective passive strategy in terms of enhancement of $PI_{\Delta\theta 24}$ while further combined with internal thermal insulation and demand controlled ventilation (passive cooling) is the most effective passive action in terms of enhancement of PI_{θ}. This methodology that combines long term environmental monitoring and dynamic simulation results expressed in terms of Performance Index seems to be suitable when the aim of the refurbishment is the optimal exhibits conservations.

References

[1] Corgnati S P, Fabi V and Filippi M 2009 A methodology for microclimatic quality evaluation in museums: Application to a temporary exhibit *Building and Environment* **44** 1253–60
[2] Pavlogeorgatos G 2003 Environmental parameters in museums *Building and Environment* **38** 1457–62
[3] La Gennusa M, Rizzo G, Scaccianoce G and Nicoletti F 2005 Control of indoor environments in heritage buildings: experimental measurements in an old Italian museum and proposal of a methodology *Journal of Cultural Heritage* **6** 147–55
[4] Sciurpi F, Carletti C, Cellai G and Pierangioli L 2015 Environmental monitoring and microclimatic control strategies in “La Specola” museum of Florence *Energy and Buildings* **95** 190–201
[5] UNI - Ente Nazionale Italiano di Unificazione 1999 UNI 10829. Beni di interesse storico artistico. Condizioni ambientali di conservazione. Misure ed analisi (In Italian). (Milan:

UNI)
[6] CEN - European Committee for Standardization 2010 EN 15757. Conservation of Cultural Property. Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials (Brussels: CEN)
[7] Ministry of Cultural Heritage and Activities and Tourism 2001 Ministero per i beni e le attività culturali. 2001. Ministerial Decree 10.05.2001. Atto di indirizzo sui criteri tecnico-scientifici e sugli standard di funzionamento e sviluppo dei musei (in Italian).
[8] Cellai G, Carletti C, Sciurpi F and Secchi S 2014 Transparent Building Envelope: Windows and Shading Devices Typologies for Energy Efficiency Refurbishments *Building Refurbishment for Energy Performance* Green Energy and Technology ed A Magrini (Springer International Publishing) pp 61–118
[9] Sciurpi F, Carletti C, Cellai G, Muratore V, Orsi A, Pierangioli L, Russo G and Schmidt E D 2017 Environmental monitoring and building simulation application to Vasari Corridor: preliminary results *Energy Procedia* **133** 219–30
[10] Carlucci S 2013 Thermal Comfort Assessment of Buildings (Milan: Springer)
[11] Carletti C, Sciurpi F and Pierangioli L 2014 The energy upgrading of existing buildings: Window and shading device typologies for energy efficiency refurbishment *Sustainability (Switzerland)* **6** 5354–77