2023 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Rome, Italy, October 19-21, 2023

Environmental tendency from the retrofit to current time: a case study in Rome, Italy

Beatrice Bartolucci[1], Francesca Frasca[2], Chiara Bertolin[3], Gabriele Favero[4], Anna Maria Siani[2]

[1] Department of Earth Science, Sapienza University of Rome (Italy), Piazzale Aldo Moro, 5, beatrice.bartolucci@uniroma1.it
[2] Department of Physics, Sapienza University of Rome (Italy), Piazzale Aldo Moro, 5, f.frasca@uniroma1.it, annamaria.siani@uniroma1.it
[3] Department of Mechanical and Industrial Engineering (MTP), Norwegian University of Science and Technology, Gløshaugen, Richard Birkelands vei 2b, chiara.bertolin@ntnu.no
[4] Department of Environmental Biology, Sapienza University of Rome (Italy), Piazzale Aldo Moro, 5, gabriele.favero@uniroma1.it

***Abstract* – This contribution presents the analysis of environmental data collected over the 2016-2022 period in the Hall of the historic building of Villa Blanc in Rome, Italy, with ceiling and walls hardwood paneling. Data related to three different sub-periods (during the retrofit, after 1 and 5 years from the retrofit) were analyzed in detail. Based on the ASHRAE 2019 Guidelines, it was found that thermo-hygrometric data differ among the sub-periods (specifically in the years 2016-2017, data are outside the limits of the 5th-95th multi-year band), however there is no marked risk of mechanical damage and mold germination in the prestigious wood. Finally, water vapour mixing ratio and carbon dioxide concentrations were studied as indoor tracers. Since the water vapor mixing ratio remains fairly constant while carbon dioxide concentrations have more variability, e.g., it can be assumed that people (as CO_2 source) may have a more visible effect than indoor/outdoor air exchanges.**

I. INTRODUCTION

In the field of cultural heritage, the knowledge of the environmental conditions affecting a cultural asset is relevant since the environment (the ensemble of the climatic conditions and air pollution surrounding the object of interest) can induce some types of deterioration (mechanical, biological, and chemical) [1,2]. The AHSRAE 2019 Handbook [3] defines six Types of Climate Control together with information on risk of degradation and benefits for the collections preserved in a building. The present contribution aims at analyzing microclimate (i.e., indoor temperature and relative humidity) and carbon dioxide data collected over the period 2016-2022 inside the Hall of Villa Blanc, a historic building located in Rome, Italy. Major focus is given to study the tendency of environmental time series from 2016 until 2022 and comparing three sub-periods (June 2016-May 2017, during the retrofit; June 2017-May 2018, after the retrofit; June 2021-May 2022, 5 years from the retrofit) since the Hall has ceiling and the walls hardwood paneling which is sensitive to microclimate changes. Indeed, indoor climate is strictly connected with wood conservation.

II. MATERIALS AND METHODS

A. Case study and environmental monitoring

Villa Blanc, as it appears nowadays, is the result of the transformation and expansion, wanted by Baron Alberto Blanc, of a building from the second half of the 19th century belonging to the *Lezzani*'s family (Figure 1a). In 1893 Blanc, bought the property formed by a small rustic building and a vineyard of about four hectares in the area surrounding the *Basilica of Sant'Agnese Fuori Le Mura*. He transformed the property into a particularly refined residence, representing a rare example of the eclectic art at the end of the 19th century in Rome, especially concerning the pictorial and the sculptural decorations. The architectural project was carried out by the architect Giacomo Boni while the structural aspects were designed by the engineer Francesco Mora. In carrying out the radical transformation of Villa Blanc, the architect Giacomo Boni experimented new techniques for working with traditional materials such as iron, cast iron, wood, ceramic, marble, granite, and leather. The decorative aspects were entrusted to the meticulousness and care of Alessandro Morani and Adolfo de Carolis, also helped by the painters Giuseppe Cellini and Guido Calori. Innovative techniques were mixed with traditional ones resulting in ceramics and painted glass and mosaics. After years in a state of disrepair, in 1997 the LUISS University of Rome bought Villa Blanc and the surrounding park in a public auction. Only in 2011 it was possible for the

LUISS to start a long and meticulous conservative restoration for the functional adaptation and redevelopment, bringing the Villa back to its former prestige [4]. Since 2017 Villa Blanc is the headquarters of the LUISS Business School. The complex includes a main villa, six dependencies and greenhouses immersed in a park where typically Mediterranean precious species are preserved. It is under architectural protection and cultural heritage constraints since 1922.

a)  b) 

Fig. 1. Villa Blanc, a) outdoor view and b) indoor Hall Source: photo by Bartolucci B., 2018.

Temperature, relative humidity, and carbon dioxide have been monitored in the Hall of Villa Blanc (Figure 1b) since December 2015. In this indoor space, internal walls are covered with boiserie of acacia and cedar wood, which have been known as durable and precious woods since ancient times. The room, as the whole Villa, has windows and impressive stained glass, which are peculiar from a decorative point of view even if they could favor air exchanges with the outside and making the environment sensitive to the external climate. The indoor monitoring campaign of thermo-hygrometric parameters and carbon dioxide at Villa Blanc has been conducted to track environmental conditions during and after the retrofitting and to study whether the environment may be favorable to wooden materials deterioration. The monitoring system consists of two sensors for measuring temperature (T, °C) and relative humidity (RH, %) installed at a height of 2.5 m and 4 m, and a carbon dioxide sensor for the measure of indoor concentration (CO_2, ppm). Technical specifications of the monitoring system are listed in Table 1. The instruments are connected to an acquisition system. Data sampling takes place every 5 minutes, and an average is processed every 30 minutes. Furthermore, to trace the air masses, from the thermo-hygrometric values the mixing ratio (MR, g/kg) is calculated considering the atmospheric pressure equals to 1013 hPa, according to EN 16242:2012 [5].

Before carrying out an exploratory statistical analysis, a data quality analysis was carried out, by determining completeness (CoI) and continuity (CI) indices at the annual level [6] on the entire dataset (from 2016 to 2022). Values outside measurement range of the instruments were discarded. For completeness of information, this contribution will focus on the analysis of data related to the sensor at 2.5m being the stability of the air (analyzing data of the sensors at 2.5m and 4m) out of scope.

Table 1. Technical specifications (name of sensor, type of transducer, measuring range, and accuracy) are provided for thermohygrometric (T, RH) and for carbon dioxide (CO_2) sensors, from the Rotronic and Vaisala manufacturers, respectively.

	T (°C)	RH (%)	CO_2 (ppm)
Name	Thermohygrometer "TTU 600"		GMW86P
Transducer	Pt100 thermo-resistance	Thin film capacitor	CARBOCAP
Range	- 40°C + 60°C	0 - 100%	0 - 2000 ppm
Accuracy	± 0.3°C	±1.5 %	±30 ppm

B. Identification of environmental reference band

Hourly data of temperature, relative humidity, and carbon dioxide were analyzed for the entire period. For each variable the band between the 95th and 5th percentiles related to the long-term period (2017-2022) was determined as the reference excluding both the 2016 (i.e., during the retrofit) and the three months of COVID lockdown (i.e., March, April, and May 2020). The percentiles were computed for each of the ith day based on hourly data collected for each of ith day of the year and smoothed out by the 30–days moving average centered on the ith day under investigation. The same procedure was applied to CO_2, but excluding the entire year 2020, as during the pandemic condition the lectures and activities were largely carried out on-line.

Then the daily average of each variable was compared with respect to the refence band to evaluate the occurrences of the departures from the percentiles (e.g., too warm, or too cool).

C. ASHRAE 2019 Guidelines

ASHRAE Guidelines 2019 were applied to the thermo-hygrometric data of the three sub-periods, i.e., during the retrofit (June 2016 - May 2017), after the retrofit (June 2017 - May 2018), and 5 years from the retrofit (June 2021 - May 2022). The Type of Climate Control B was chosen as the reference target conditions based on the type of building and on the material preserved (details are reported in Table 2). Thermo-hygrometric data and the guidelines' limits related to the climate-induced risk for wooden ceilings and boiserie are displayed on the psychrometric chart. On this chart it is plotted the long-term outer limits (i.e., the boundaries beyond which the risk increases unacceptably for hygroscopic materials such as wood), the annual average (historic for permanent collection, i.e., the average to which the material has acclimatized to minimize the risk of mechanic degradation), the seasonal adjustments (i.e., the limits drawn from the annual averages and reported in Table 2), the short-term fluctuations (i.e., limits allowed beyond the long-term outer limits).

Table 2. ASHRAE 2019 Guidelines limits for wooden materials kept inside a building with Type of Climate Control B.

Type of Collection and Building	Museums, galleries, archives, and libraries needing to reduce stress on their building (e.g., historic house museums), depending on climate zone
Type of Control	B: limited control, seasonal changes in RH and large seasonal changes in T
Long-Term Outer Limits	30% ≤ RH ≤ 70% T ≤30°C
Annual Averages	For permanent collection: historic annual average of RH and T.
Seasonal Adjustments from Annual Average	±10% (RH) + 10°C, - 20°C (T)
Short-Term Fluctuations	±10% (RH) ±5 °C (T)

D. MR and CO_2 as indoor tracers

The water vapor mixing ratio (MR, g/kg) and the indoor carbon dioxide (CO_2, ppm) concentrations can provide information about the indoor/outdoor air exchanges, and the presence of people respectively and for this reason can be used as "indoor tracers". In this contribution, MR data and CO_2 concentrations were analyzed by considering the average hourly data over the four seasons (spring, summer, autumn, and winter), with their respective standard deviations, over the three selected periods.

III. RESULTS AND DISCUSSIONS

A. Data quality analysis

The determination of CoI and CI of the data series revealed that the completeness is close to 100% (i.e., indexes are close to the unity) for the entire dataset and for each year, both for T and RH data, and it is above 70% (i.e., index > 0.7) for CO_2 data. Before computing the 5^{th} and 95^{th} percentiles, the level of completeness of the dataset within each day of the years was verified, resulting in the data coverage always above 72%.

B. Analysis of environmental data with respect to the reference band

Figures 2 and 3 shows the time series of daily averages of T and RH for each year over the period 2016-2022 with respect to the 5^{th} and 95^{th} percentiles band calculated with respect to the reference period, i.e., 2017-2022.

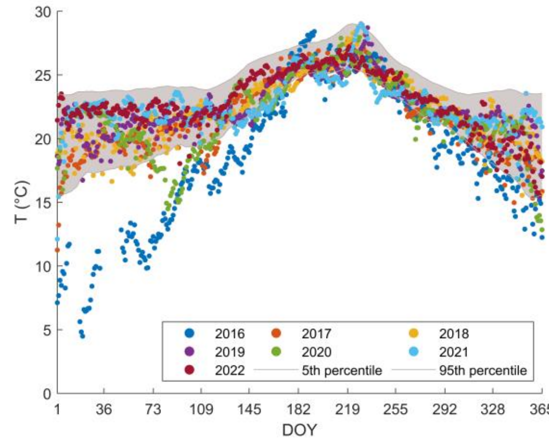

Fig. 2. Time series of T daily averages for each year over the period 2016-2022 with respect to the 5^{th} and 95^{th} percentiles of a reference period 2017-2022 (grey band), excluding the three months of lockdown (March, April, and May 2020).

As it can be noticed from both graphs, the daily average data of 2016, and part of 2017 (specifically from January to April 2017) are outside the limits of the reference band (the grey band determined by the 5^{th} and 95^{th} percentiles). This could be justified by the fact that during the year 2016 and part of 2017 (characterized by the end of the retrofit interventions) the Hall of Villa Blanc perhaps had the indoor air conditioning system not in operation and hence a higher air exchange rate because of the windows and doors maintained open during the retrofit intervention, thus highlighting the effect of external climate.

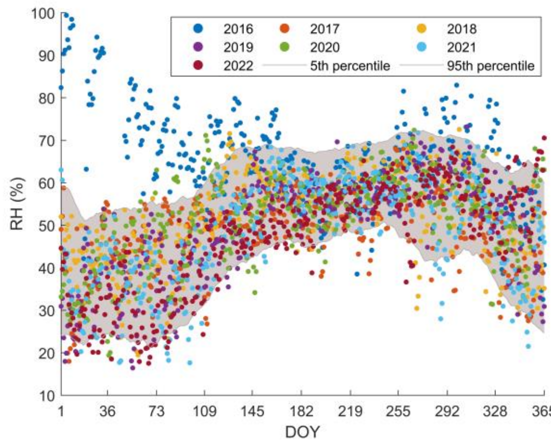

Fig. 3. Time series of RH daily averages for each year over the period 2016-2022 with respect to the 5^{th} and 95^{th} percentiles of a reference period 2017-2022 (grey band), excluding the three months of lockdown (March, April, and May 2020).

In addition, focusing on 2020, i.e., the year of COVID lockdown, the daily averages are distributed within the band limits, except for the months of March and April which have data below the 5th percentile (specifically for temperature) and few data above the 95th percentile (for relative humidity), highlighting a colder and wetter environment than the reference, probably for the indoor conditioning system switched off due to restrictions imposed by the COVID period.

Figure 4 shows the behaviour of carbon dioxide with respect to the reference band.

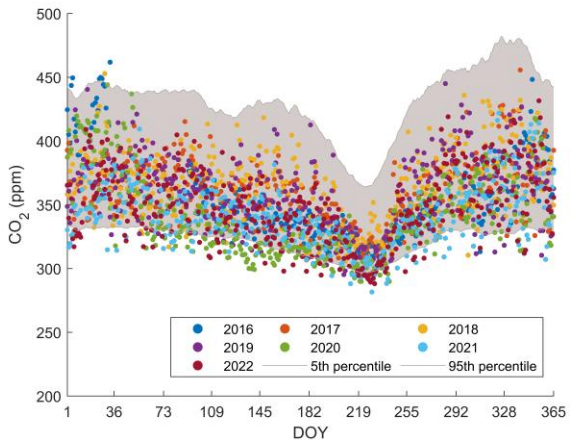

Fig. 4. Time series of CO_2 daily averages for each year over the period 2016-2022 with respect to the 5th and 95th percentiles of a reference period 2017-2022 (grey band), excluding the entire year 2020

From this graph we can notice that 2020, 2021, and 2022 have data below the 5th percentile. Therefore, we can assume that after 2020, the COVID period, the access to the Hall and to Villa Blanc was regulated by the limitations and restrictions that the post-Covid imposed.

C. Analysis of environmental data with respect to the Type of Climate Control B of the ASHRAE 2019 Guidelines

Hourly data (small colored dots) and monthly averages (bigger color dots) are plotted in the psychrometric chart for the three selected sub-periods (Figures 5, a, b, c). Moreover, hourly data and the monthly averages are colored according to the season: red for summer, orange for autumn, blue for winter, and green for spring. Climate specifications from ASHRAE 2019 are also reported: the black full line represents the long-term outer limits, the dashed line is the seasonal adjustments from the annual averages reported in Table 3, and the dotted line represents the short-term fluctuations.

In all three psychrometric charts (Figure 5), T is never above 30°C, i.e., the long-term outer limit. Comparing the period “during” and the periods “after” (1 and 5 years), it can be noted the increase in the minimum temperature value, while the maximum temperature always remains stable around 29°C.

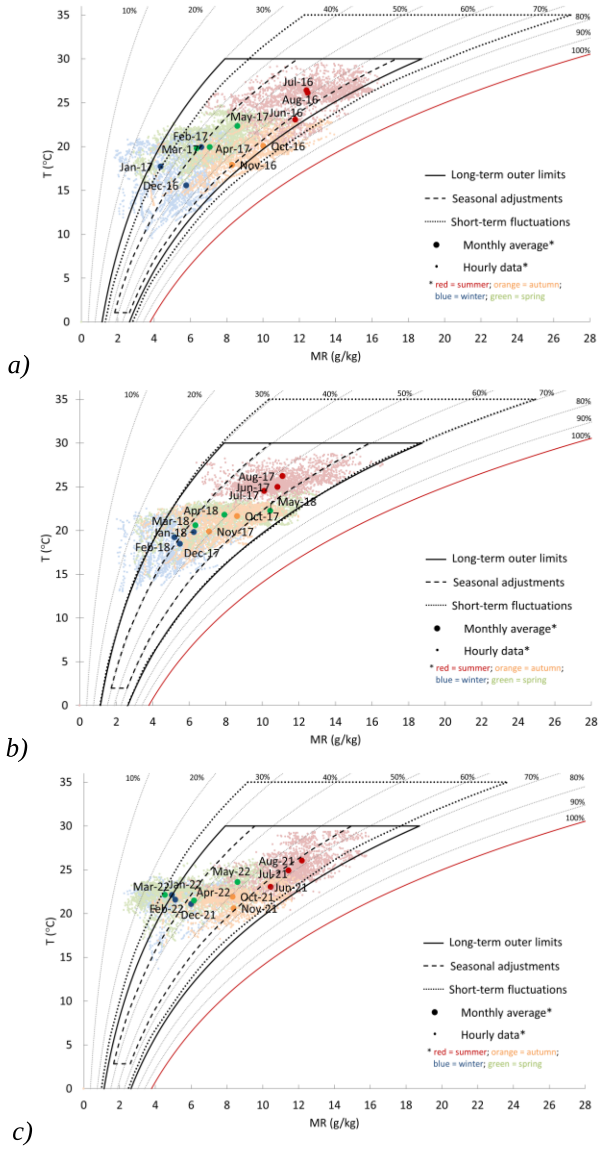

Fig. 5. Psychrometric chart representing the a) During retrofit (first period, 2016-17), b) 1 year after the retrofit (second period, 2017-18), and c) 5 years after the retrofit (third period, 2021-22).

The comparison among the three different sub-periods highlights the passage between the "during" and "after" retrofitting, as the data in figures 5b and 5c are distributed in an increasingly smaller cloud of points, highlighting a reduction in the indoor climate variability. Despite this, some relative humidity values exceed the long-term outer limits of 30% and 70% in winter and spring, especially 5 years after the retrofit (Figure 5c). RH data below 30% during the spring, could be attributed to the rise of the average monthly temperatures, as visible from the three psychrometric charts. This slight increase is also visible at annual level, and, at the same time, it is also characterized by a decrease in RH (Table 3). The decay effect of the lowering of RH on a hygroscopic material (such as wood) could be visible in the long term, but since most data are within the annual limits and short-term fluctuations allowed by the Type of Control B, and being the monthly averages within the aforementioned limits, sudden damages could not occur.

Table 3. Annual averages of Temperature (T, °C) and Relative Humidity (RH, %) for each period.

Annual average	T (°C)	RH (%)
2016-17	21.1	55.0
2017-18	22.0	49.6
2021-22	22.8	46.2

D. MR and CO_2 as indoor tracers

Hourly average data of MR are displayed in Figure 6 on seasonal basis over the three sub-periods. It can be seen that the average values always remain stable within each season within each sub-period except in summer. Furthermore, in the winter and autumn seasons, data are distributed with a slight decrease in the morning hours, to then increase from the early afternoon, while in the spring and summer data seem to decrease in the middle of day. It is worth noticing that in summer 2017-18 MR values reached the minimum. It can be observed that during the retrofit the MR was generally higher (except in winter and spring); while 5-years after the retrofit the MR values decreased with respect to the retrofit period especially during the winter season and also in the spring months.

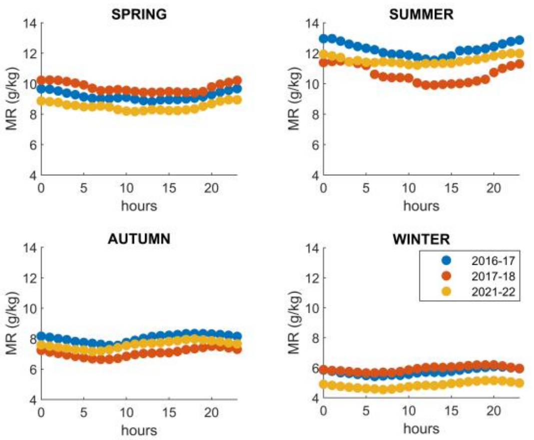

Fig. 6. Hourly data of water vapor mixing ratio (MR, g/kg), during the retrofit (2017-17, blue dots), 1 year after the retrofit (2017-18, orange dots), 5 years after the retrofit (2021-22, yellow dots) for the four seasons

Carbon dioxide was also studied in the same way. The hourly averages of carbon dioxide related to the three sub-periods by season are displayed in Figure 7. Specifically, the three sub-periods have consistent decrease in CO_2 in the summer season, and in part also in the afternoon hours of the spring season, that can be assumed as both a shorter use of the Hall, and/or a continuous opening of the windows with a consequent CO_2 sink effect caused by the presence of vegetation in proximity of the building [7]. This can also explain the CO_2 decrease during the hours 9-20 in summer or during the afternoon hours in late spring.

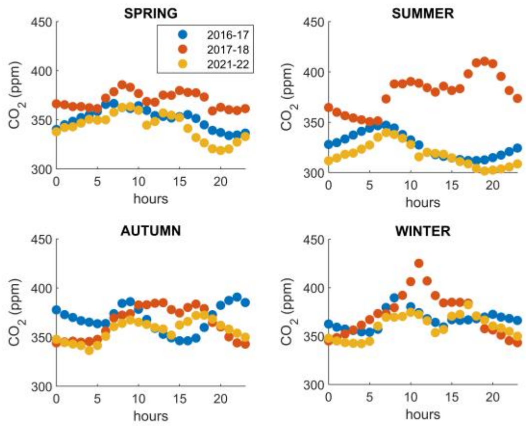

Fig. 7. Hourly data of carbon dioxide (CO_2, ppm), during the retrofit (2016-17, blue dots), 1 year after the retrofit (2017-18, orange dots), 5 years after the retrofit (2021-22, yellow dots) for the four seasons.

IV. CONCLUSIONS

This contribution presents the analysis of the environmental data collected in the Hall of the historic building of Villa Blanc. Conclusions can be outlined on the preliminary analysis of environmental data of T, RH and CO_2, based on the ASHRAE 2019 Guidelines to reduce the risk of climate-induced decay for wooden material. In addition, the analysis of the MR and CO_2 used as indoor tracers allow to highlight the use of opening of the Hall and the presence of visitors.

The daily average data of the 7 years considered in the analysis (2016-2022) show that T and RH data for the year 2016 and part of 2017 were outside the reference band of the 5^{th}-95^{th} percentiles, and this can be attributed that the Hall was kept open during the retrofit interventions, as expected. As for CO_2, the years 2020, 2021 and 2022 partially fall outside the limit of the fifth percentile, assuming that during the lockdown and subsequent years the restrictions to limit the COVID spread have caused the minimum access of visitors and staff to the Hall.

Furthermore, ASHRAE 2019 Guidelines have been applied on three different sub-periods to verify the differences among the "during the retrofit", " 1 year after the retrofit ", and "5 years from the retrofit". By using the psychrometric chart, it was possible to extract information on conservation benefit and risks associated to the Type of Climate Control. In this case study, the Type of Climate Control B has taken as the reference, with the category of the material to be preserved being hardwood present on the ceilings and boiserie of the Hall. Within the climate specifications suggested by Type of Climate Control B for this type of hygroscopic material, we can conclude that the mold germination or proliferation is avoided. Moreover, there is no risk of mechanical degradation, and, as visible from psychrometric charts, the retrofit carried out seems to limit and/or eliminate sudden drops in temperature which could damage the prestigious wooden materials. However, with respect to relative humidity, a very small part of data is detected outside the lower limit in all three sub-periods and the annual average RH value is detected to be lower of about 9% with respect to the "during retrofit period". Therefore, it is necessary to monitor these data in order not to incur into risky situations of dryness for the conservation of wooden materials.

As regards the indoor tracers, both MR and CO_2 can give information on the influences of the external climate and of the close vegetation of the park of Villa Blanc on the internal environment and/or on the presence of users inside the building Hall. Analyzing the data, the carbon dioxide seems to have a major variability with respect to the mixing ratio during the summer season, and this may suggest a closer connection with the presence of people and the opening of the Hall kept open thus enhancing the air exchange between inside and outside.

Finally, the present contribution has as final aim to present the environmental tendency of Villa Blanc, considering the data of the entrance Hall, from the time of the retrofit until today. This approach highlights the importance of monitoring the microclimate and carbon dioxide, especially in historic buildings in order to evaluate whether the microclimate conditions depart from the historic climate to which the wooden materials is acclimatized. This is also important when the building has undergone (or is undergoing) a retrofit and restoration process, as the case study here presented. The results obtained through the methodological approach of this study could be better supported by information, such as opening and closing times to the public, switching on and off times of the indoor conditioning system, number of users per hour per day.

ACKNOWLEDGMENTS

Frasca F. acknowledges fellowship funding from MUR (Ministero dell'Università e della Ricerca) under PON "Ricerca e Innovazione" 2014-2020 (ex D.M. 1062/2021).

REFERENCES

[1] F.J García-Diego, E. Verticchio, P. Beltrán, A.M. Siani, "Assessment of the Minimum Sampling Frequency to Avoid Measurement Redundancy in Microclimate Field Surveys in Museum Buildings", 2016, Sensors, pp 1-17.

[2] D. Camuffo D, "La misura dell'umidità relativa nel campo dei beni culturali", 2014, Elsevier, Journal U&C, pp 6-7

[3] American Society of Heating, Refrigerating and Air-Conditioning Engineers "ASHRAE Handbook—HVAC applications. Chapter 24: museums, galleries, archives, and libraries.", 2019, Inc., Atlanta.

[4] VILLA BLANC - SAC s.p.a. Available online https://www.sacspa.eu/portfolio-item/villa-blanc/ (accessed on 04/09/2023)

[5] EN 16242:2012, "Conservation of cultural heritage - Procedures and instruments for measuring humidity in the air and moisture exchanges between air and cultural property"

[6] F. Frasca, A.M. Siani, G.R. Casale, et al., "Assessment of indoor climate of Mogiła Abbey in Kraków (Poland) and the application of the analogues method to predict microclimate indoor conditions", 2016, Environ SciPollut Res

[7] S. Fares, E. Paoletti, C. Calfapietra, T.N. Mikkelsen, R. Samson, D. Le Thiec, "Carbon Sequestration by Urban Trees", 2017, Chapter 4, in Urban Forest