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To cite this article: Elisa Moretti *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **949** 012098

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ABSTRACT DEADLINE: DECEMBER 4, 2020



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Microclimatic monitoring for book heritage preservation in historic buildings: preliminary investigation on “Sala del Dottorato” in Palazzo Murena, Perugia, Italy

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Abstract. In order to ensure the proper conservation of the book heritage, the hygrothermal conditions of the rooms where the books are stored must respect precise ranges of temperature and relative humidity. The paper deals with the study and the optimization of the conservation conditions of the book heritage in historic buildings by a case study, namely “Sala del Dottorato”. This room is one of the University of Perugia most exquisite rooms, because of its decorations and the presence of rare and ancient books (27 incunabula; the oldest piece of the collection is an edition of St. Augustine, *De Civitate Dei*, printed in 1470). The room is located on the first floor of Palazzo Murena and it was originally the monastery library. From the Sixties and up to a few years ago, the room hosted the discussions of PhD final thesis, while now is used to host the most representative meetings of the University. This involves the presence of a significant number of people for a brief period of time, causing the alteration of the environmental parameters. The present study was carried out by an experimental campaign (temperature, relative humidity, CO₂) aimed to understand the microclimatic critical issues in order to develop a permanent monitoring system; this system should notify when the microclimatic conditions are out of the range for conservation and people comfort, giving information about the possible actions to restore the correct environmental conditions.

1. Introduction

Preventive conservation is essential to limit the damage processes and the subsequent restoration work, to increase cultural features, and enhance the economic values of the cultural heritage [1-2]. Indoor microclimatic conditions play an important key role in the conservation and maintenance of book heritage, especially in historic buildings [3–7]. In order to ensure the correct conservation of cultural heritage in libraries and museums, the hygrothermal conditions must respect precise ranges of temperature and relative humidity, according to literature and technical standards [8-13]. Several studies investigated the effects between cyclic variations of indoor conditions, environmental pollution and the related deterioration and biodegradation processes in materials [14-17].



Starting from the recent research works [18-20], the indoor microclimatic variations, linked to building thermo-physics conditions, were investigated in order to highlight unfavourable conditions for books conservation or people comfort.

The study was carried out in the “Sala del Dottorato” in Perugia (Italy), located on the first floor of the Palazzo Murena, the headquarter of the University of Perugia. The books heritage preserved inside the room consists about 10500 volumes and some of them have a very significant historical and artistic value. Anyway, even if inside the room a great number of books is preserved, it cannot be considered as a “standard” library for two main reasons: the room is basically closed to public visitors and consultation of books is permitted only by reservation. On the other hand, due to its charming atmosphere, the room is sometimes used for representation meetings of the University of Perugia attended by a significant number of people. The library has no cooling and mechanical ventilation systems, whereas the rooms are equipped with a heating system with radiators.

The aim of the research is to investigate how these conditions can allow unfavourable conditions for books conservation or people stay. The paper presents the results of more than 7 months of microclimate monitoring inside the “Sala del Dottorato” at different levels (floor level and mezzanine level). In addition to the microclimatic parameters, the concentration of carbon dioxide (CO₂) in the room was monitored as well, in order to evaluate the occupants comfort level, ventilation quality of the room and possible risks for frescoes painting on the vault [21, 27].

2. The case study

From 1810 to this day, Palazzo Murena houses the headquarters of the University of Perugia. The building was built starting from 1739 as an Olivetan Order’s male monastery and it is the result of the collaboration between architects Carlo Murena (hence the name of the building) and Luigi Vanvitelli.

The Sala del Dottorato (Hall of Graduates) is one of the University’s most exquisite rooms, by virtue of both its decorations and collection of rare and ancient books it stores. It is located on the first or *nobile* floor, currently hosting the Dean's office, and it was originally the monastery library. From the Sixties and up to a few years ago the hall hosted the discussion of thesis, so it owes the name to its former function. A smaller atrium introduces visitors to the main hall (Figure 1), that has a long inner balcony with a balustrade (mezzanine) in a marbled wood; it is possible to reach the second level using a ladder. The arched-ceilings were fresco-painted by two Perugian artists, Giovanni Bevilacqua and Vincenzo Monotti, and the walls of both rooms are covered by ornate and painted wooden bookcases, which hold about 10500 rare and ancient books of the University.



Figure 1. Picture of the “Sala del Dottorato”

The library houses books printed from the 15th to the 19th century. The oldest are 27 incunabula, items printed from movable type before 1501. The most antique is an edition of St. Augustine, *De Civitate Dei*, printed in Rome in 1470 by C. Sweynheym and A. Pannartz, the first printers who moved on to set up a press from Germany to Italy. The books have manuscript notes, exlibris and stamps of the previous owners, some of whom were professors of the University who donated their libraries. There are even about 800 volumes belonging to the Olivetan monks, part of their ancient library.

The collection contains a series of organic materials such as paper, tissue, animal hair and adhesive substances, these, together with ink for colour and graphics, may alter and perish in time, especially if they are preserved in inadequate environmental conditions and without any specific precautionary devices to protect them from damage provoked by diverse factors: chemical, biological, and physical (light, heat, humidity). So, in this context, the knowledge of the place of preservation and of its characteristics (insulation, lighting, ventilation etc.) are the prerequisites for the analysis of the potential risks and to draw up a maintenance plan. Furthermore, the direct periodic check of the books becomes fundamental to discover situations already problematic from the biological and chemical point of view and to propose and organize the more appropriate maintenance interventions.

3. Materials and methods

The first step of the research consists in monitoring (every ten minutes) the Sala del Dottorato indoor microclimatic parameters: temperature T ($^{\circ}\text{C}$) and relative humidity RH (%). In figures 2 and 3 the different monitored positions are shown: the first letter of each point specifies in which wooden bookcase is situated the logger, while the number specifies if the logger is in the floor level of the room (0) or above it, in the mezzanine level (1). The monitoring campaign started in May 2019 and it is still in progress.

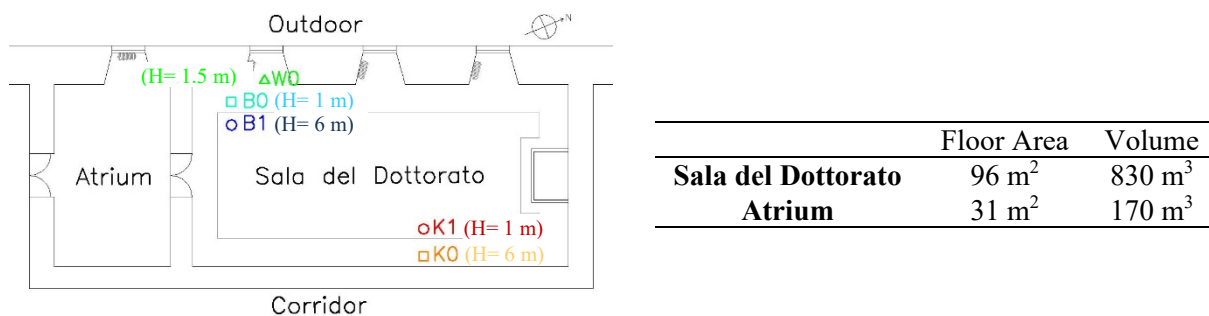


Figure 2. “Sala del Dottorato” plan and geometric features

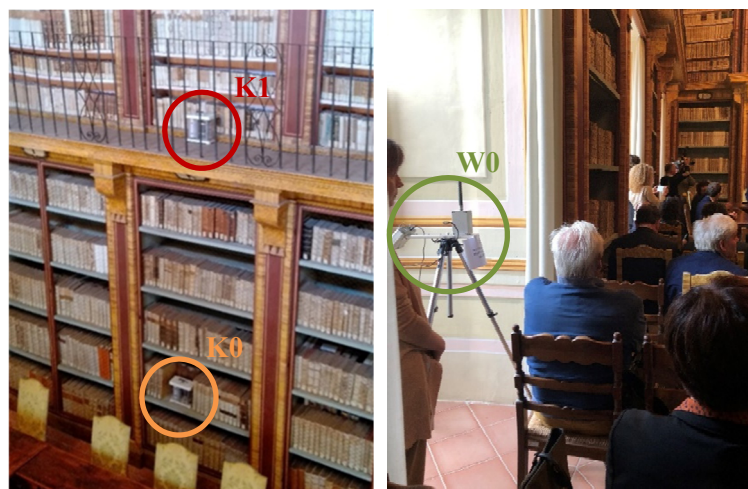


Figure 3. Position of the two thermo-hygrograph (K0 and K1) and the data logger M-Log with the CO₂ probe (W0).

Furthermore, the CO₂ concentration was monitored (every five minutes) for one week (from October 23rd 2019 to October 29th 2019), in the point called *W0*, 120 cm above the floor, in front of the first window of the room. In *W0* the instrument does not interfere with room activities and is at the sitting breathing height. CO₂ monitoring is important not only for the comfort of human beings but also for optimal conservation of books collections and frescoes (high level of RH and CO₂ concentration may cause surface dissolution of frescoes [27]); in fact, the presence of people can be considered as an additional alteration factor of microclimate of historic libraries (increase in temperature, hygrometric degree and pollutants) [24]. Therefore, the aim of this monitoring is to assess the fluctuations of this indoor air pollutant, related to the degree of occupation of the room; to investigate this aspect it was important the inauguration ceremony of the new Dean on October 24th 2019, in which there were about 70 people.

In Table 1 are summarized the monitoring positions, the monitoring period and the instrumentation.

Table 1. Monitoring Campaigns.

| Measured parameters | Instruments | Monitoring period | Position of the instrument | Logging interval |
|--|---|--------------------------|----------------------------|------------------|
| Temperature and relative humidity | Thermo-Hygrograph (Salmoiraghi) | from 07/05 to 26/05 | K0 | continuous |
| | | from 07/05 to 26/05 | K1 | logging |
| | Data logger Tinytag Ultra 2 (Gemini) | from 07/05 to 30/05 | B0 | every 10 minutes |
| | | from 30/05 to 12/06 | K1 | |
| | | from 12/06 to 09/07 | B1 | |
| | | from 06/09 (in progress) | K1 | |
| Carbon dioxide | Data logger M-Log with CO ₂ probe (LSI LASTEM) | from 23/10 (in progress) | K0 | every 5 minutes |
| | | from 23/10 to 29/10 | W0 | |

4. Results and discussion

4.1. Indoor Air Temperature and Relative humidity

The books conserved in the room are made of different organic materials: paper, wood, leather, parchment and some of them are stored in the same place since 1810. The standards for conservation [12-14] report different suggested ranges depending on the material, therefore for this study, the optimal ranges cannot be strictly defined. The UNI 10829 suggests values included in the 13-18°C range for paper materials and 19-24° C for parchment, whereas the MIBAC guidelines suggest the 19-24°C range for paper and books to prevent from physical damages and a maximum temperature of 21°C and a maximum daily temperature variation (ΔT daily) of 3 °C to prevent microbiological grow. As regards relative humidity, the UNI 10829 suggests values included in the 50-60% range for paper materials and 45-55% for parchment, whereas the MIBAC guidelines suggest the 50-60% range for paper and books to prevent from physical damages and 45-55% range and a maximum daily variation (ΔRH daily) of 5 % to prevent microbiological grow. However, a multidisciplinary analysis to determine the previous history and values of microclimatic parameters in which the books have been preserved should be carried out considering that they must be kept in environmental conditions to which they have adapted and by which they have been affected. In the specific case of the Sala del Dottorato, the present study is the first methodological survey related to continuous monitoring of the microclimatic conditions. Previous studies investigated specific issues such as the potential fungal biodeterioration effects and included spot measures of temperature and humidity [22] and highlighted the correlation between high temperatures and book embrittlement [23].

In figure 4 the trend of indoor air temperature in the different periods and positions is reported and a strict correlation with the outdoor daily values is shown. In particular, regarding “K1”, the daily peaks

are due to the direct sunlight coming from three windows above the mezzanine wooden bookcase West oriented. Further confirmation of that is given by the monitoring in B1: in this point, where the sunlight does not hit directly the probe, the peaks are absent and the temperature is rising yet.

During the summer, the temperature reaches high values (about 29°C, Table 2), which can accelerate the rate of degradation processes; for instance, the physical and chemical effects are doubled for each 10°C rise in temperature [8]. Indeed, some books in the mezzanine floor show desiccation and embrittlement process, especially those hit directly by sunlight. In addition, the high temperature, coupled with RH values greater than 50%, has created a conducive environment for borers, which have infested some books.

The last two campaigns show that between two points in the same wooden bookcase but at different height (K0 and K1) there is a vertical temperature gradient of about 0.5°C. From the October 15th, during the weekdays, is visible the effect of the heating made by the radiators. This cause daily fluctuations over the references limit [14], especially in November.

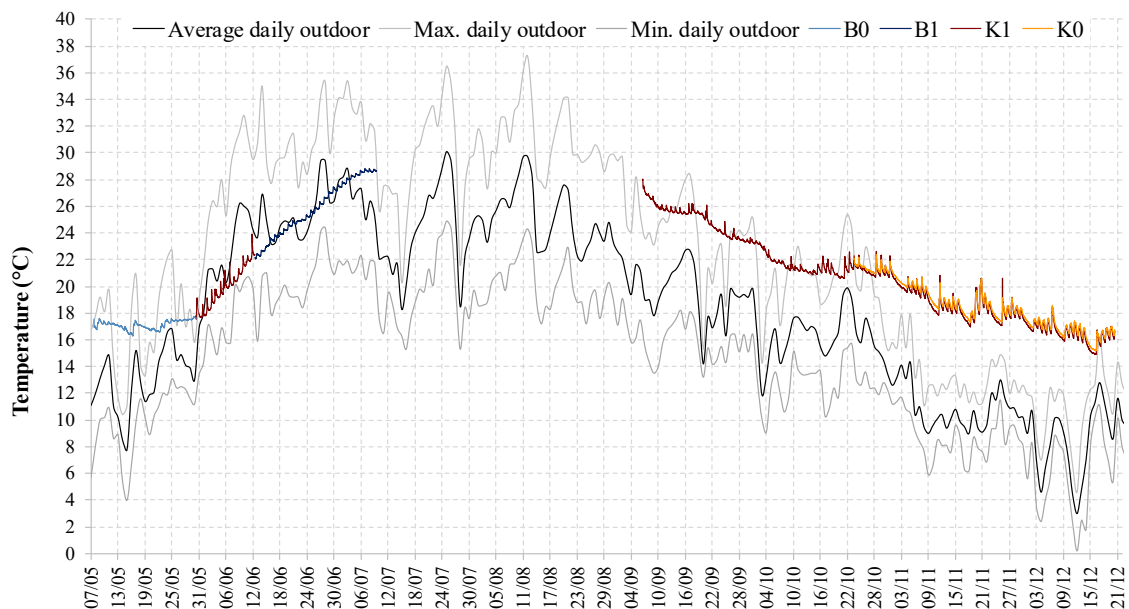


Figure 4. Indoor air temperature and daily outdoor air temperature

Table 2. Analysis of the results of monitoring campaigns.

| Measured values | Position of the instrument and monitoring period | | | | |
|---------------------------------|--|------------------------------|------------------------------|---------------------------------|---------------------------------|
| | B0 from 07/05 to 30/05 | K1 from 30/05 to 12/06 | B1 from 12/06 to 09/07 | K1 from 06/09 in progress | K0 from 23/10 in progress |
| Max. Temperature (°C) | 17.7 | 23.9 | 28.8 | 28.0 | 22.4 |
| Average temperature (°C) | 17.1 | 19.9 | 25.9 | 20.6 | 18.5 |
| Min. Temperature (°C) | 16.3 | 17.5 | 22.1 | 14.9 | 15.2 |
| Max. ΔT daily (°C) | 1.6 | 2.0 | 0.7 | 3.5 | 2.4 |
| Average ΔT daily (°C) | 0.4 | 1.2 | 0.4 | 0.9 | 0.9 |
| Max. RH (%) | 53.8 | 54.8 | 55.6 | 57.1 | 56.8 |
| Average RH (%) | 51.6 | 53.3 | 54.7 | 52.5 | 54.4 |
| Min. RH (%) | 48.4 | 47.9 | 52.5 | 42.9 | 49.2 |
| Max. ΔRH daily (%) | 2.8 | 7.4 | 1.8 | 8.5 | 5.3 |
| Average ΔRH daily (%) | 0.7 | 3.1 | 1.2 | 1.9 | 1.4 |

During the whole monitored period, relative humidity values (Figure 5) does not exceed the suggested maximum value (60%) and the fluctuations of indoor RH are limited (Table 2). The few rapid decreases of RH are due to the increase of temperature caused by the direct sunlight (K1) and the radiators (K0 and K1). During the event of October 24th 2019, the RH trend has increased by 3 points along with the temperature, both in the floor lever (K0) and in the mezzanine level (K1).

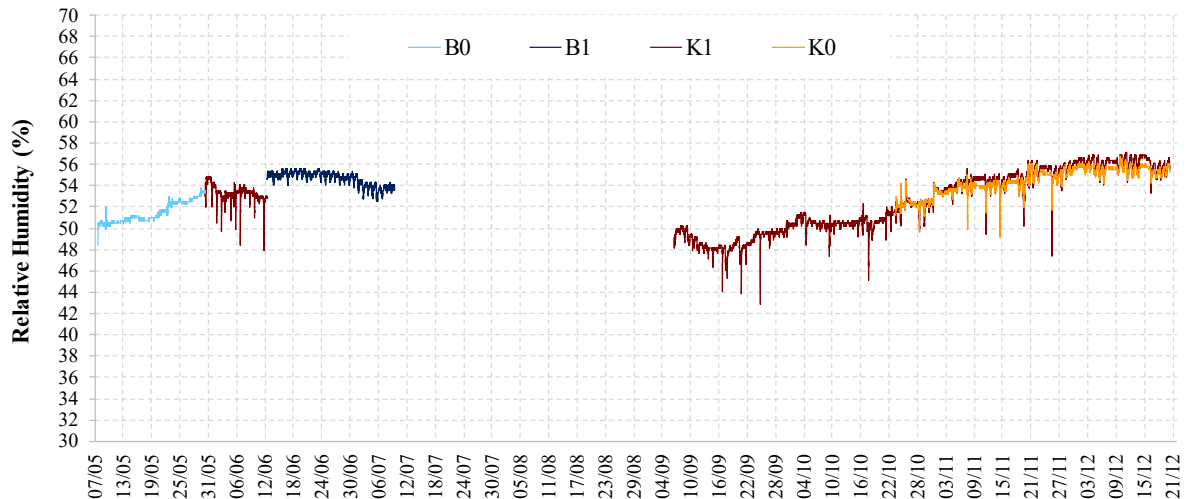


Figure 5. Indoor air relative humidity

4.2. CO₂ concentration

Figure 6 shows the value of CO₂ concentration measured during a week which includes a significant event, the ceremony of the new Dean. During the ceremony, on October 24th, which lasted about 20 minutes, the value of the concentration of CO₂ raises quickly the value of about 1100 ppm even if the opening of the windows. This value can cause uncomfortable conditions for people who attend the event. The CO₂ it took several hours (about two days) to reduce the concentration to the background level. In particular, the opening of the three windows for about two hours does not imply an appreciable effect.

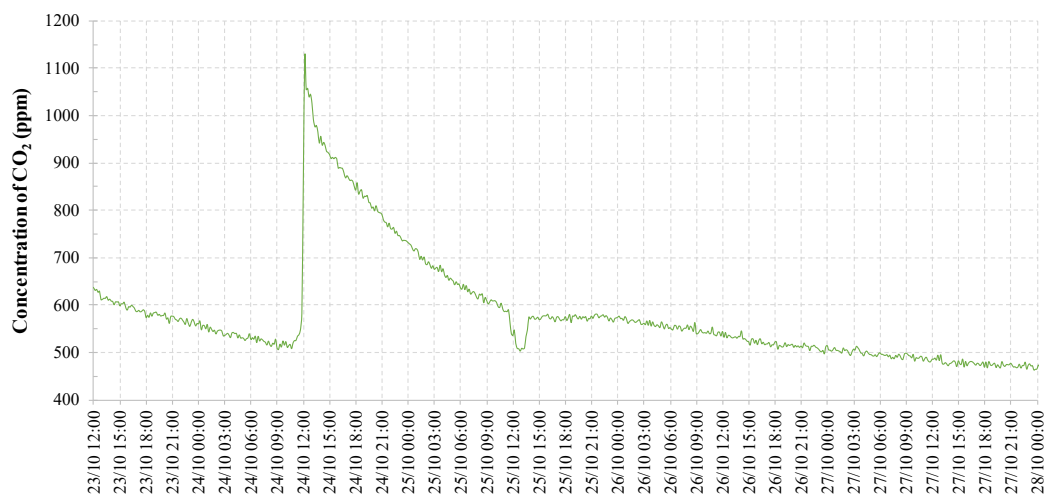


Figure 6. Indoor concentration of CO₂

5. Conclusion and future developments

The paper shows the preliminary results of the investigation on Sala del Dottorato, a historical room where rare and ancient books are stored and where prestigious events are organized by the University

of Perugia. The results of the monitoring campaigns showed that relative humidity is adequate for books conservation (43% - 57%). However, depending on the outdoor weather conditions, temperature values are in summer outside the ranges suggested by the national and international standards for the proper conservation of books. In winter, the quick fluctuations of temperature, caused by the heating system, are not suitable to correct conservation of volumes, especially on Monday when the radiators restart after the weekend stop.

Therefore, in sunny days of June and September, the direct sunlight coming from the windows above mezzanine wooden bookcase causes some papers to bleach and others to yellow or darken; it can also cause media and dyes to fade or change colour, altering the legibility and appearance of books [8-10].

The concentration of CO₂, even if it is not so dangerous to the books, can cause uncomfortable conditions for the attendance during the more crowded events and it could be dangerous to the frescoes painting along with high values of RH [19].

For these reasons, a continuous monitoring system for indoor and outdoor thermo-hygrometric parameters should be designed. The system can be controlled by a specific algorithm which should notify when the microclimatic indoor conditions are out of the range for conservation or for people comfort; it should also inform the staff people when the outdoor conditions are suitable for windows opening in order to mitigate these unfavourable situations. This is of fundamental importance because the hall is in a listed building (by the Superintendence) for its high historical value and a conventional HVAC system could not be planned (only a heating system with radiators is present).

The design of an MVHR system (Mechanical Ventilation Heat Recovery System) based on the future monitoring system represents a better solution which can solve the problems related to the current heating system and also the problems linked to the high concentration of CO₂, especially during the crowded event. However, the ventilation system should not strictly modify the indoor microclimatic conditions, because this could lead to worse conditions for conservation.

Also important is the planning of an accurate monitoring campaign of lighting parameters in order to investigate the level of artificial and natural lighting, especially on shelves in the mezzanine floor hit by the sunlight. Finally, actions to mitigate the damage caused by UV radiation have to be taken: for instance, the installation of UV filter films or shutter on the three upper windows.

6. Acknowledgements

The authors would like to thank Maria Giulia Proietti for her assistance during the experimental analysis.

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