EVALUATION OF THE EFFECTIVENESS OF HUMIDITY CONTROL STRATEGIES IN PRESERVING A HERITAGE LIBRARY

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Keywords: Climate control systems; Dehumidifiers; Hygrothermal conditions; Long-term monitoring; Paper moisture; Heritage buildings

Abstract *Ensuring an appropriate and stable indoor environment is of the utmost importance when the preservation of historic heritage buildings and collections is at stake. As hygrothermal conditions are one of the determinant parameters of the indoor environment for safeguarding these valuable assets, their long-term monitoring is imperative in attempting to achieve the requirements established by different guidelines through a process of analysis and consequent implementation of mitigation strategies.*

The present study addresses the continuous monitoring and assessment of the hygrothermal conditions to evaluate the effectiveness of a humidity control strategy, which was implemented in a case study to meet its environmental needs for the preservation of collections. The case study is the 18th-century Baroque Library of the University of Coimbra, where air dehumidifiers were installed to help reduce extreme peaks in relative humidity.

The approach consists of surveying the data collected from two different types of loggers, thermo-hygrometers placed inside the Noble Floor of the heritage library and a paper hygrometer directly placed inside the collections. In this way, the comparative analysis of the hygrothermal data before and after the implementation of the new strategy indicated its level of effectiveness for this type of building. Moreover, the evaluation of the data according to the threshold ranges recommended by most guidelines was contested over the monitoring period.

From the results, it was possible to assess the quality of the hygrothermal environment concerning the thresholds proposed by preservation guidelines and to evaluate the effectiveness of the implemented strategy on both the indoor environment and the collections.

1. INTRODUCTION

As library collections inevitably embark into the digital era, preservation stands as the guardian of cultural heritage, ensuring that the stories within the collections retain their authenticity and remain accessible for future generations. However, preserving these valuable assets is a complex endeavour that requires a multidisciplinary approach and collaboration among stakeholders. It involves assessing the collections' conditions, interviewing staff and curators, conducting long-term monitoring of indoor conditions and analysing the collected data [1], [2]. In an attempt to meet preservation requirements, the study of environmental control strategies and implementation of mitigation measures depend on the particularities of each heritage building and its context. It is, therefore, important to study in more detail the impact of using active measures to control the indoor climate in this type of building.

Library collections consist of diverse organic and inorganic materials that naturally undergo an inevitable ageing process. The deterioration rate is dependent on the properties of constituent materials, and it is significantly influenced by the indoor microclimate [3]. Among all indoor microclimate parameters, the degradation of collections is highly influenced by the levels and time fluctuations of temperature (T) and relative humidity (RH) [4]. For the specific case of hygroscopic materials, particularly paper, the hygrothermal balance is achieved by the continuous absorption and release of moisture, in response to the surrounding hygrothermal fluctuations [5]. Consequently, paper collections may undergo dimensional changes (shrink/expand) due to the release/absorption of moisture, which can be associated with significant hygrothermal fluctuations, resulting in a decrease in mechanical strength [6]. Furthermore, the moisture content can directly affect the chemical and physical properties of paper and high moisture levels favour risks of microbiological growth [2]. To address and prevent the deterioration of collections from these moisture-induced risks, it is fundamental to evaluate and control the humidity content inside the building where the collections are kept. Historic buildings housing collections without any HVAC systems are particularly vulnerable to the outdoor environment and, consequently, to high levels of indoor humidity [7]. It is therefore crucial to investigate which humidity control strategies might be suitable for each case study.

The literature reveals three humidity control strategies commonly applied and studied, explained in Wessberg [8] with greater detail: conservation heating, dehumidification, and adaptive ventilation. Conservation heating involves adjusting the temperature to control the relative humidity levels at the desired levels while maintaining absolute humidity levels constant. Dehumidification consists of directly removing the indoor air moisture content, thus decreasing the absolute humidity. Finally, the principle of adaptive ventilation consists of ventilating fresh air inside when absolute humidity is lower outside. Among the existing literature, Wessberg [8] and Napp & Kalamees [9] tested these three strategies in their case studies, where dehumidification stood out as an effective and low-cost solution. Thomson [10] and Larsen & Broström [11] tested only dehumidification, which successfully minimized the high levels and fluctuations of RH in both case studies.

Monitoring is usually a recurrent tool to assess the effectiveness of humidity control strategies within the indoor environment [10]. However, there are few studies on monitoring and analysing the hygrothermal conditions directly within collections. Among the existing research, Bülow [2] monitored the hygrothermal conditions both indoors and directly inside dummy books to identify relationships between collections and their surrounding environment, thereby understanding their buffering capabilities.

Against this backdrop, the present study focuses on assessing the effectiveness of dehumidification in controlling the RH levels within the indoor environment and collections of a historic library. Also, a detailed analysis of hygrothermal conditions within books is carried out to fill the identified gap in the literature. As evidenced, dehumidification is a reliable method for controlling relative humidity levels in historic buildings. However, given the uniqueness of each case study, further investigation needs to be conducted to ascertain its effectiveness in the historic building under study.

2. METHODOLOGY

2.1. Case study

The case study is the Joanina Library of the University of Coimbra, a unique Baroque Library from the 18th century, considered a World Heritage Site by UNESCO. It is composed of three floors, the upper one – the so-called Noble Floor – being the focus of this study. It consists of three contiguous spaces interconnected by archways and a common hall, each one with double-tired bookshelves separated by a balcony, inaccessible to tourists [12]. It houses around 40,000 books about diverse subjects. The Noble Floor has no HVAC systems; it is naturally ventilated by infiltrations and the intermittent opening of the main door, which gives direct access to the "School Courtyard".

Recently, spikes in relative humidity were observed in previous studies [13]. Therefore, on 16 November 2023, six identical dehumidifiers were installed on the ground level of the Noble Floor. Each of the three spaces was equipped with two: one positioned close to the north facade and the other on the south. The selected equipment (Argo Platinum 41) is a domestic condensing dehumidifier with a dehumidification capacity of 41 litres/24h and a tank capacity of 7 litres. The dehumidifiers do not operate at night when the electrical board is switched off for security reasons.

2.2. Monitoring

Two types of data loggers were used – thermo-hygrometers and paper hygrometers – to monitor the hygrothermal conditions in the indoor environment and inside collections and evaluate the dehumidifiers' effectiveness. The paper hygrometer was directly placed inside a dummy book, which was in the middle of collections.

The monitoring campaign was carried out between September 2023 and March 2024. Given the gradual installation of paper hygrometers within the library, the monitored periods of these loggers were insufficient to obtain a continuous analysis of hygrothermal conditions inside books. Therefore, the analysis period for this type of logger is split into two periods: before (Sep - Nov 2023) and after (Feb - Mar 2024) the installation of the dehumidifiers. All data loggers are placed along the north side of the ground floor, varying only in their longitudinal placement between Space 1 ("S1", closest to the main door), Space 2 ("S2", in the middle space) and Space 3 ("S3", furthest from the main door). Table 1 presents the specifications of the equipment employed during the monitoring campaign, along with the respective recording periods.

Table 1 – Monitoring equipment description.

Type	Data loggers	Accuracy	Timestep
Thermo-hygrometers	HOBO MX1102	**T:** ± 0.2 ºC **RH:** ±2% (within 20% - 80%)	Records every 10 min
Paper hygrometer	Schaller RH5	**T:** ± 0.3 ºC **RH$_{@25\,°C}$:** ± 1.5 %	

3. RESULTS AND DISCUSSION

Fig. 1 shows the hygrothermal conditions within the three spaces of the Noble Floor, before and after the installation of the dehumidifiers. Upon analysing this figure, it is possible to observe the insignificant effect of dehumidifiers in controlling the indoor relative humidity levels, as: (i) only around 14.2 % of the monitored time, the indoor relative humidity values were within the established RH set-point of 60 % for all spaces of the Noble Floor; (ii) the average RH indoors remained significantly high in both periods (above 65%) and higher RH fluctuations were observed in the period after (more than 5%). Also, relatively high T and RH fluctuations within a short period (24h) had never before been observed indoors as registered after the dehumidifiers' installation (in the middle of December); an RH maximum value of 81.5 % was reached in this period.

By observing the same figure, it can also be stated that the indoor hygrothermal conditions exhibit a dependence on the outdoor hygrothermal conditions, following its pattern in a relatively smooth way due to the high thermal inertia of the building. Following the thresholds of a previous study conducted with this case study [14] for acceptable values for short-term fluctuations (one to two weeks) – ±10 % and ±5 ºC – it can be contested that, particularly after the dehumidifiers' installation, variations of RH above 20 % were registered in certain weeks. This might be an effect of the dehumidifiers as they did not operate during the night. Inclusively, in the middle of November, a variation of 30% in the RH values was registered within two weeks, which extends beyond the established thresholds. Alongside, high fluctuations in T exceeded 5 ºC within 24 hours.

Comparing the hygrothermal conditions indoors and within the books (Fig.2) in the same space (Space 1), it also becomes clear the insignificant effect of dehumidifiers in controlling RH within books, as: (*i*) the relative humidity levels within books remained relatively stable and high (around 63% average) in both periods; (*ii*) the average relative humidity within books in the second period was slightly higher along with the corresponding fluctuations (from 62.9 ± 0.9 % to 63.5 ± 1.6 %).

During the second period, the average temperature indoors was lower (colder period), as well as its fluctuations (from 22.2 ± 1.4 °C to 16.0 ± 1.2 °C). As the temperature within books closely followed the temperature indoors (with a slight delay), the average temperature within books was also lower during the second period along with its fluctuations (from 22.1 ± 1.1 °C to 15.9 ± 0.9 °C).

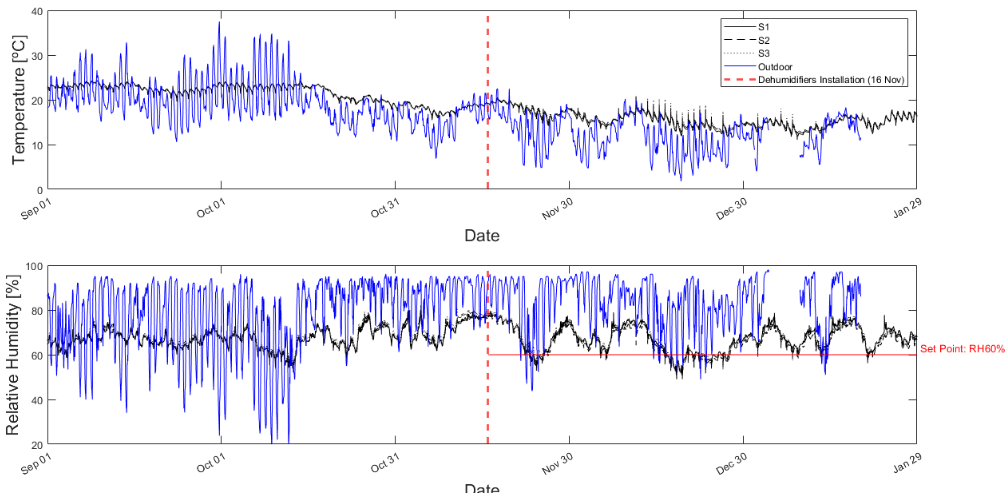

Figure 1 – Time evolution of the indoor hygrothermal conditions in the three spaces of the Noble Floor, from September 2023 to February 2024.

Conversely, while significant relative humidity fluctuations were experienced indoors, the relative humidity within books remained highly stable. This behaviour can be attributed to books exhibiting higher hygroscopic than thermal inertia.
Following ASHRAE's methodology [15] of focusing on the running averages, which are depicted in Fig.2, additional observations emerge. The 30-day running average of relative humidity values, as stated in the guidelines, aligns with the paper collections response to the indoor RH fluctuations, in this case study. However, the 7-day running average for T values, following the same guidelines, fails to match the books' response to indoor T fluctuations. In this way, the parametric approach using R^2 was applied to determine the best fitting period for the running average of indoor temperature values to predict the book's response to T fluctuations. A running period (RP) of 7 hours reached the best R^2 values (0.99). A similar RP of 24 hours was determined in Verticchio et al. [3] using a different formula found in Martens and Schallen [16]. The RP of 30 days for indoor RH values reached a satisfactory R^2 value and it is similar to the one determined in the case study conducted by Bülow [2]. Bülow, based on monitored data within dummy books, revealed that books required 5 weeks to adjust to the surrounding RH environment.
Additional compelling observations emerge from the present analysis. The daily maximum temperature within books is usually reached during night-time, as the daily maximum temperature indoors is normally reached at the end of each day. In this way, the average time that books take to respond to the daily indoor temperature peaks was about 5 hours, in the first period, and about 4 hours, in the second period.

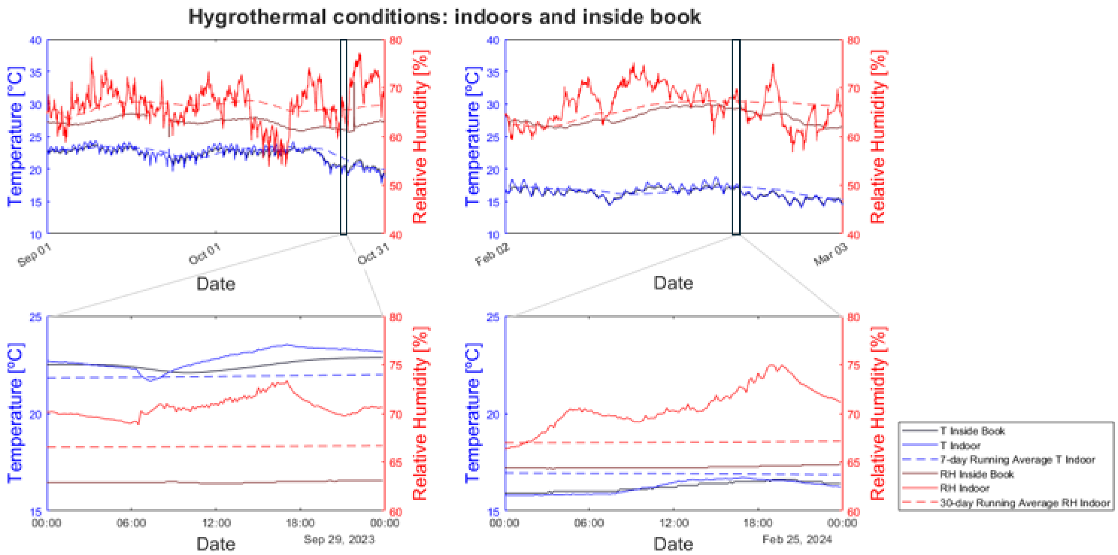

Figure 2 – Hygrothermal conditions indoors and within books over the monitoring periods, along with daily fluctuations.

4. CONCLUSIONS

Through the monitoring campaign carried out between September 2023 and March 2024, the effectiveness of dehumidification in a case study, the Joanina Library, was unveiled along with the analysis of hygrothermal conditions indoors and within books.

This study revealed a meaningless effect of dehumidification on controlling the RH levels in the indoor environment and inside books, in this case study. Moreover, it highlighted the significant impact of the outdoor climate on indoor hygrothermal conditions. The running periods recommended by guidelines (30 days for RH and 7 days for T) for indoor values to predict the books' response to RH and T fluctuations were contested, using the R^2 parametric approach. The 30-day running period aligned with the books' response to indoor RH fluctuations, while a running period of 7 hours was found to better predict the books' response to indoor T fluctuations. These results were compared with those in the existing literature.

High relative humidity levels were observed both indoors (above 65 % on average) and within the collections (around 63 % on average). High indoor RH fluctuations were also observed. Thus, it is crucial to study, implement and evaluate other humidity control strategies in this case study to ensure the ongoing preservation of collections.

5. REFERENCES

[1] V. Živković and V. Džikić, "Return to basics—Environmental management for museum collections and historic houses," *Energy Build*, vol. 95, pp. 116–123, May 2015, doi: 10.1016/J.ENBUILD.2014.11.023.

[2] A. Bülow, "Preventive Conservation for Paper-based Collections within Historic Buildings," 2002.

[3] E. Verticchio, F. Frasca, C. Bertolin, and A. M. Siani, "Climate-induced risk for the preservation of paper collections: Comparative study among three historic libraries in Italy," *Build Environ*, vol. 206, Dec. 2021, doi: 10.1016/J.BUILDENV.2021.108394.

[4] J. Ferdyn-Grygierek, J. Kaczmarczyk, M. Blaszczok, P. Lubina, P. Koper, and A. Bulinska, "Hygrothermal Risk in Museum Buildings Located in Moderate Climate," *Energies 2020, Vol. 13, Page 344*, vol. 13, no. 2, p. 344, Jan. 2020, doi: 10.3390/EN13020344.

[5] L. Bellia, A. Capozzoli, P. Mazzei, and F. Minichiello, "A comparison of HVAC systems for artwork conservation," *International Journal of Refrigeration*, vol. 30, no. 8, pp. 1439–1451, Dec. 2007, doi: 10.1016/J.IJREFRIG.2007.03.005.

[6] E. Verticchio, F. Frasca, P. Cavalieri, L. Teodonio, D. Fugaro, and A. M. Siani, "Conservation risks for paper collections induced by the microclimate in the repository of the Alessandrina Library in Rome (Italy)," *Herit Sci*, vol. 10, no. 1, pp. 1–15, Dec. 2022, doi: 10.1186/S40494-022-00714-5/FIGURES/13.

[7] J. Leissner *et al.*, "Climate for culture: Assessing the impact of climate change on the future indoor climate in historic buildings using simulations," *Herit Sci*, vol. 3, no. 1, pp. 1–15, Dec. 2015, doi: 10.1186/S40494-015-0067-9/FIGURES/17.

[8] M. Wessberg, "Design and analysis of energy efficient indoor climate control methods for historic buildings," Czech Technical University in Prague, 2018.

[9] M. Napp and T. Kalamees, "Energy use and indoor climate of conservation heating, dehumidification and adaptive ventilation for the climate control of a mediaeval church in a cold climate," *Energy Build*, vol. 108, pp. 61–71, Dec. 2015, doi: 10.1016/J.ENBUILD.2015.08.013.

[10] R. Thomson, "Heating or Dehumidification? Maintaining Appropriate Relative Humidity Levels in Historic Buildings Containing Museum Collections," *Studies in Conservation*, vol. 65, no. S1, pp. 321–326, Aug. 2020, doi: 10.1080/00393630.2020.1779523.

[11] P. Larsen and T. Broström, "Climate Control in Historic Buildings in Denmark," 2011.

[12] N. B. Saraiva, L. D. Pereira, A. R. Gaspar, and J. J. Costa, "Measurement of particulate matter in a heritage building using optical counters: Long-term and spatial analyses," *Science of The Total Environment*, vol. 862, p. 160747, Mar. 2023, doi: 10.1016/J.SCITOTENV.2022.160747.

[13] E. Schito, L. Dias Pereira, D. Testi, and M. Gameiro da Silva, "A procedure for identifying chemical and biological risks for books in historic libraries based on microclimate analysis," *J Cult Herit*, 2018, doi: 10.1016/j.culher.2018.10.005.

[14] L. D. Pereira, A. R. Gaspar, and J. J. Costa, "Assessment of the indoor environmental conditions of a baroque library in Portugal," *Energy Procedia*, vol. 133, pp. 257–267, Oct. 2017, doi: 10.1016/J.EGYPRO.2017.09.385.

[15] ASHRAE, *ASHRAE Handbook - HVAC Applications: Chapter 24 Museums, Galleries, Archives and Libraries*. 2019.

[16] J. Ashley-Smith, A. Burmester, and M. Eibl, Eds., "Climate for Collections: Standards and Uncertainties," 2013.