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Published Version:
Boeri, A., Longo, D., Fabbri, K., Pretelli, M., Bonora, A., Boulanger, S. (2022). Library Indoor microclimate monitoring with and without heating system. A Bologna University Library case study. JOURNAL OF CULTURAL HERITAGE, 53, 143-153 [10.1016/j.culher.2021.11.012].

Availability:
This version is available at: https://hdl.handle.net/11585/860103 since: 2022-02-17

Published:
DOI: http://doi.org/10.1016/j.culher.2021.11.012

(Article begins on next page)

Library Indoor microclimate monitoring with and without heating system. A Bologna University Library case study.

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Abstract
This paper aims to illustrate and give an interpretation of the results emerged from a pilot activity developed within the ROCK project, by the Department of Architecture of the University of Bologna, Alma Mater Studiorum. Through this activity, we studied the indoor microclimate of the University Library of Bologna (BUB), in the Archive and in the Lecture Hall, with the aim to detect how these spaces are affected by the influence of factors such as the outdoor climate and the cooling and heating systems. Moreover, the paper presents the customisation of the probes' alert system and of the probes itself, used for a *one-year* monitoring campaign started on the 20th of December 2018. In addition, we calculated the Heritage Microclimate Risk index, to verify the level of risk to which the heritage in the Library is exposed due to the indoor microclimate, and the Predicted Risk of Damage index, that evaluate the more specific risks of damage to which precise objects hosted in there are exposed. Therefore, this paper enriches the research field of Historic Indoor Microclimate, started in 2013, which concerns issues as preventive conservation and restoration in historic buildings. The new insights about the Bologna University Library facilitate the possibility to draw up a specific 'Indoor Microclimate Management Protocol (IMMP)' aimed at the preventive conservation of manuscripts and books in historical libraries.

Keywords
Library; heritage building; microclimate risk; monitoring; book; historic indoor microclimate; heritage microclimate risk; prediction risk damage

1 Introduction

Libraries have a double purpose: 1. to guarantee books' conservation and 2. to be accessible to the broader public. Both these aims have relevant connections with the indoor microclimatic conditions which characterize the same libraries. Indeed, microclimatic parameters, such as temperature (T) and relative humidity (RH), can affect: the conservation of the building itself and of the artifacts guarded inside it, and the thermal comfort of visitors.

Nowadays, the control of libraries' indoor microclimate parameters is typically guaranteed by the installation of HVAC systems, with the exclusion of few rare cases, as the Malatestiana library [1][2] and the historical library of the University of Salamanca [3], where the indoor microclimate just depends on construction materials, on the exposure of the building, on its dimensioning and design, etc.

When we are talking about historical libraries with HVAC systems, these plants have been clearly installed in a much later times in relation with the construction of the building itself, and their introduction can produce strong variations on the indoor microclimate. Those variations could be risky for the conservation of the Cultural Heritage (both of the building itself and of its contents) and for precautionary heritage preservation [4], has defined especially in a Camuffo research milestone [5].

With the aim of the preventive conservation of Cultural Heritage, this research treasures the results achieved thus far from the research field of "Historical Indoor Microclimate" (HIM), started in 2013 with the study of another library: the Malatestiana library, in Cesena, Italy. As defined by Prof. Marco Pretelli and arch. Kristian

Fabbri [6] [7] the HIM approach allows to understand how and which factors (including managerial, architectonical, and historical ones) determine variations on the indoor microclimate during the life cycle of a building, and the correlation between these factors and the Cultural Heritage conservation.
The scientific literature presents many researches about the study of the indoor microclimate as preventive conservation, with several specificities. We report a repertoire of articles about heritage building, preferability UNESCO heritage and/or museum, with indoor air monitoring given that building or artifact are so specific that we prefer to report several case studies. The majority of these studies are about museum buildings (e.g. [8][9] [10] [11][12] [13] [14][15]) with the aim to evaluate how the conservation state of collections are influenced by the indoor environmental parameters. Further researches evaluate the conservation requirements of heritage materials in heritage buildings and its risk of damage related to the indoor microclimatic conditions (e.g. [16] [17] [18] [19] [20] [21] [22] [23]). Moreover, other researches investigate the role of HVAC systems on the indoor microclimate in historic buildings about impact of "on" or "off" HVAC in conservation (e.g. [24]).
The common goal of all these studies is to create a knowledge baseline in order to identify correct strategies to guarantee the conservation of Cultural Heritage: each case-study contributes to the research field of microclimate and preventive conservation. However, most of the researches are about museums, while the indoor microclimatic conditions in libraries are rarely investigated (e.g. [25] [26] [27]) and that underlines a research gap. In addition, it is not clear if the majority of risk indexes present in literature (e.g. [28] [29][30][31][32]) can be applied to a specific indoor areas (e.g. a room) or also to specific materials hosted there. In this paper, rather, we applied the Heritage Microclimate Risk (HMR) and the Predicted Risk of Damage (PRD) indexes [33] to the main materials guarded in the Historical Library of the University of Bologna (BUL) and to the specific rooms of the library, too (archive and lecture hall).

In addition to the above researches (as part of a wider literature) we must consider standards related to indoor microclimate, physical parameter, monitoring campaign, etc.
In relation with heritage environmental and physics parameter range of artifact conservation, specific in Italy, we have two kinds of standard UNI 10829 [34] and MIBAC Guideline (MIBAC: Ministry of Culture) [35]. European standard about conservation of cultural property is EN 15758 [36], EN 15757 [37], and EN 15759 [38]. Other Italian standard concern cultural heritage field measurement of temperature [39] and relative humidity [40].

In our research we adopt the above standards in order to apply new heritage indoor microclimate risk indexes to a ROCK project case study. Our work introduced some innovations in the heritage research field, as a continuum indoor microclimate monitoring alert system based on historic microclimate, new alert indexes based on damage risk and a useful information graphics to explain indoor monitoring management, versus technician and not technician people, in order to understand environmental indoor microclimate physics data.
This research is a part of ROCK "Regeneration and Optimisation of Cultural heritage in creative and Knowledge cities"[41] as an Horizon 2020 project, granted with the G.A. 730280.

2 Aims of research

A part of ROCK project concerns the study of the indoor microclimate of the Bologna University Library (BUL), in the city centre of Bologna, Italy. The research question which guided that study was: how could we avoid that the indoor microclimatic conditions of an historical library jeopardize the conservation of books and of other valuable artefacts guarded inside it? Is it possible to avoid that and in a cheap and non-manual mode too? More specifically, to answers these questions the following activities are proposed into this paper:

- to customise an indoor monitoring system for the monitoring campaign of the BUL;
- to study the variation of the indoor microclimate of BUL in relation with several factors, such as seasons; the role of users; etc., with the goal to set solutions to evaluate (and if it would be necessary to improve) the indoor microclimatic parameters and
- to evaluate the differences -in terms of indoor parameters- between two areas of BUL Lecture Hall, where heating/cooling systems are operational and the Archive, without any heating /cooling systems.

In line also with the ROCK project framework, the specific objectives of this paper are the following:

- to define specific Alert-range based on the Indoor Microclimate Monitoring (IMM) results;
- *to apply heritage risk indexes proposed in previous research by Fabbri and Bonora* [33] *that calculate Heritage Microclimate Risk and Predicted Risk of Damage indexes of risk, to which the artifacts of BUL are exposed.*

Those steps enrich the basis of knowledge about the indoor microclimate inside historical libraries, facilitating future drafting of management protocols to preserve manuscripts, books, or artifacts in that kind of buildings: Indeed, the knowledge of the indoor microclimate helps to prevent risks of artifacts and collection damage, and what we have done during the research allowed us to understand the indoor microclimate behavior of BUL, so to control the indoor microclimate risk of that library.

The *novelty* of research paper concerns several issues: first one, research setting up a customized monitoring system designed ad hoc for heritage buildings, which allows you to monitor and compare two (or more) environmental space (lecture hall and archive) by a remote control. This methodology is replicable in others research. Second one, during the monitoring campaign, we defined an alert system based on the indoor microclimate as "historic microclimate" (as define in EN 15747) or, in other words,) we defined an alert system embedding the real indoor microclimate of the historic buildings and not only standard values. This is a novelty compared to standards, and it is useful because (as recognized in EN 15757) for every material there are specific microclimate ranges that are more suitable for conservation than others. However, if the same type of material has been acclimatized for years to a specific historical microclimate, any change in its microclimatic conditions would only be exposing it to a risk of damage.
Finally, the originality of the research concerns the application of new heritage risk indexes HMR and PRD to a real case: the case study of the University Library was an opportunity to apply original research ideas developed over several years of study on the historical topic of indoor microclimate to a real case.

3 Methodology

The proposed methodology has provided:

a) a *one-years* monitoring campaign from the 20th of December 2018, with the installation of ASE (Advanced Slope Engineering) probes in order to detect air temperature and relative humidity inside the *Lecture Hall* and the *Archive of the Library*, where manuscripts, books, and artifacts are hosted, include the analysis of the emerged monitored data;
b) the definition of specific 'Alert-range' ad hoc for the library;
c) the calculation of Heritage Microclimate Risk (HMR) and Predicted Risk of Damage (PRD) indexes.

These steps are detailed in the following sub-paragraphs.

3.1 Installation of Advanced Slope Engineering (ASE) probes

The first step was the installation of ASE probes [42] inside the BUL located in Via Zamboni, in Bologna, Italy. For the indoor monitoring campaign, we used the Modular Underground Monitoring System (MUMS), that is designed to measure horizontal and vertical ground movements and deformations of civil structures and also in geotechnics. Each probe can be customized with many sensors, to record parameters as temperature (T measured in °C); relative humidity (RH measured in percentage); Air Pressure (measured in pascal), carbon dioxide (CO_2 measured in ppm) and illuminance (measured in lux).
Thanks to the wireless system, the recorded parameters are sent to the Bridge datalogger which makes them available online, on any devices (computer, smartphone, tablet).
The measuring and accuracy range for T and RH of these sensors are as follows:

- Temperature (°C): range -40 °C ÷ +65 °C; accuracy: Typ. ± 0.2°C
- Relative Humidity [%]: range 0 ÷ 100 %RH; accuracy: Typ. ± 1.5 %RH
- Air pressure [Pa]: range 300 – 1200 mbar; accuracy: Typ. ± 0.01 mbar
- Carbon dioxide [ppm]: range 0 – 5000 ppm: accuracy: Typ. ± 5 %
- Illuminance [lux]: range 0-60'000 lux; accuracy: Typ. ± 3 %

3.2 *Define indoor microclimate alert-range*

Thanks to the one year of indoor microclimate monitored data inside the BUL, we identified two specific ranges to be considered as two "comfort zones" for conservation of books, manuscripts and artifacts hosted here: one range is for the heritage stored in the Lecture Hall, the second one is for the Archive.
These zones have been defined as "comfort zones" for the conservation of books, manuscripts and artifacts hosted into the BUL, because of the indoor microclimate that characterize the Lecture Hall and the Archive: the mean microclimatic data of T and RH recorded during the monitored year represent the mean conditions in which these books, manuscripts and artifacts have been acclimatized during decades. Indeed, in line with the above-mentioned UNI 15757, those data constitute the historical microclimate of the Lecture Hall and of the Archive.
We specify that we chose to distinguish the "*alert-range*" because these two rooms of the same library are characterized by different conditions (the Lecture Hall has operating cooling and heating systems; the Archive does not) and different goods. Indeed, the ones hosted inside the Lecture Hall are less valuable than the others preserved in the Archive, (not only books but also maps, original manuscripts and the oldest Torah of Europe).
The Alert-range is based on a psychometric chart that shows the point cloud generated from all data recorded by the probes located in the investigated room. The area where the point cloud is more concentrated represents the "comfort zone" (see following figure 8); instead, all the spot values out of this range are considered as anomalous conditions which trigger an alert feedback by e-mail. The decision to customise the Alert-range in this way was driven by the definition of historical climate in EN 15757: climatic conditions in a microenvironment where a cultural heritage object has always been kept or has been kept for a long period of time and to which it has become acclimatized [37].

3.3 *Calculation of heritage risk indexes: heritage microclimate risk and predicted risk of damage.*

We calculated the Heritage Microclimate Risk (HMR) and the Predicted Risk of Damage (PRD) indexes for both rooms of the Library: Lecture Hall and Archive. The equations to calculate these indexes have been published in [43]. HMR allows to assess the risk to which the cultural heritage is exposed inside a room, caused by the indoor microclimate. PRD assesses the possibility (expressed as a percentage) of damage for a specific material preserved in a room. HMR depends on the indoor microclimate and PRD depends on HMR and the material type: each material has different weakness (e.g. some materials are more sensitive to the T parameter; while others are to RH).
The reference scale of risk level for HMR is shown in table 1. Moreover, we specify that for PRD index the minimum percentage risk expressed is equivalent to 5%, because we cannot consider any indoor place completely free from the risk of damage for the conservation of any type of material.

Table 1. Range of Heritage Microclimate Risk

HMR	**- 1.00**	**- 0.80**	**- 0.60**	**- 0.40**	**- 0.20**	**0.00**	**+ 0.20**	**+ 0.40**	**+ 0.60**	**+ 0.80**	**+ 1.00**
Risk level	Maximum	High	Medium	Moderate	Low	Minimum	Low	Moderate	Medium	High	Maximum

4 ***Case-study***

The Bologna University Library is located in the high-density historical center of city of Bologna, Italy (figure 1), in the middle of Po Valley. According to the Köppen-Geiger classification [44], this area can be classified as Humid subtropical climates (Cfa) Mediterranean Climate, i.e. humid climate with short dry summer and heavy precipitation occurring during mild winters.
The Library was commissioned by the Pope Benedict XIV, and the construction of the new library for the Science Institute of Bologna was completed in 1744 by Carlo Francesco Dotti (1669-1759) and it opened to the public in 1756.
The Lecture Hall, 35 metres long and 11 metres wide, has a vault supported by four large columns decorated with Corinthian capitals and it is furnished with valuable shelving in solid walnut, with briarwood finishes. This room is composed by the Lecture Hall, with various reading stations, and an upper part, with mezzanine.

The upper part is crowned by clay busts representing famous men of the ancient culture. These were made by some eighteenth-century Bolognese plastic workers.
The library of the Institute of Sciences became the University Library when the University of Bologna itself moved from the seat of the Archiginnasio to Palazzo Poggi in 1803.
Actually, the Lecture Hall of the Library is rarely used for conferences and it is not possible to study here, because it is still not sure that the presence of a consistent amount of people is safe for the conservation of books. The access to the Archive of this Library, in which several rare and ancient books collections are stored and protected, is even more limited: it is just allowed to the employees.

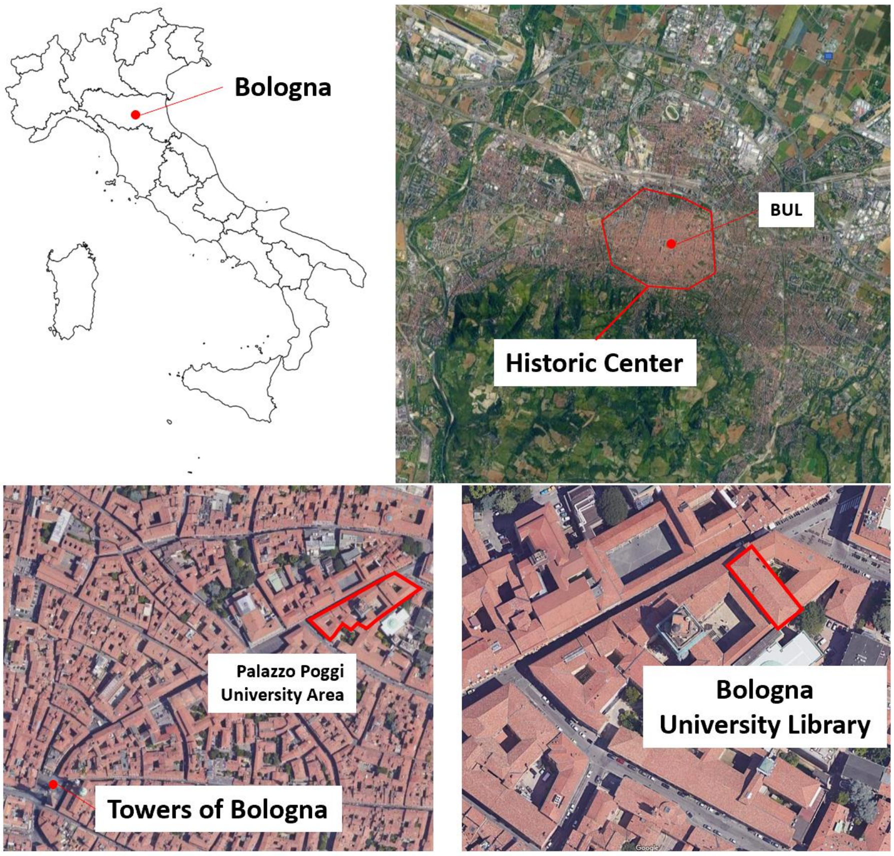

Figure 1. Bologna localization and BUL into city historic center

5 Monitoring campaign

The tool has been installed inside the library and it worked one year from the 20th of December 2018. It allowed us to collect indoor microclimate data for four seasons. However, the monitoring campaign had some gaps during the data recording, due to some setbacks (e.g. probes detached from tables, sensors bugs etc.). This happened especially during the first months of the campaign.

5.1 Monitoring tools

Together with the engineers of ASE, we defined electronic and physics variables; variable ranges; sensor outputs, etc. In this phase, the main difficulty was the installation of the Bridge datalogger and of the monitoring system inside the BUL, selected as pilot case study. The problem was that Bridge datalogger needs a continuous electrical connection; probes need to send wi-fi signals to dataloggers, without any obstacle such as thick walls, security door, etc. Indeed, data transmission from BUL to online platform uses GPRS. Therefore, to calibrate our monitoring system, we did several inspections before choosing the datalogger and the probes location.
During these on-site visits, we met the Library Director (Dott. Giacomo Nerozzi) and his assistant to establish a collaborative approach and to define together the better solutions to respect the library: in the Lecture Hall

(Lecture Hall) we positioned 4 probes under the tables and other 2 in the mezzanine library shelves, among books; in the Archive we placed 2 probes on the table (figure 2 and 3).

From the entire monitoring campaign, the sensors detected the air temperature, the relative humidity, carbon dioxide (CO2) and illuminance (lux). However, we didn't consider carbon dioxide and illuminance data because we observed that data were not relevant. The reasons are the following: CO_2 depends on people, and in our case the number of visitors was very few to have an effect on microclimate, and illuminance could not be measured because probes are under table in order to avoid the risk that some visitor can touch or steal them. In addition, we organised on-site inspections with the sensor provider ASE, especially for what concerned the testing of the existing electric and electronic networks: to install our monitoring system, we had to update the library electric system, and this required some additional weeks of work.

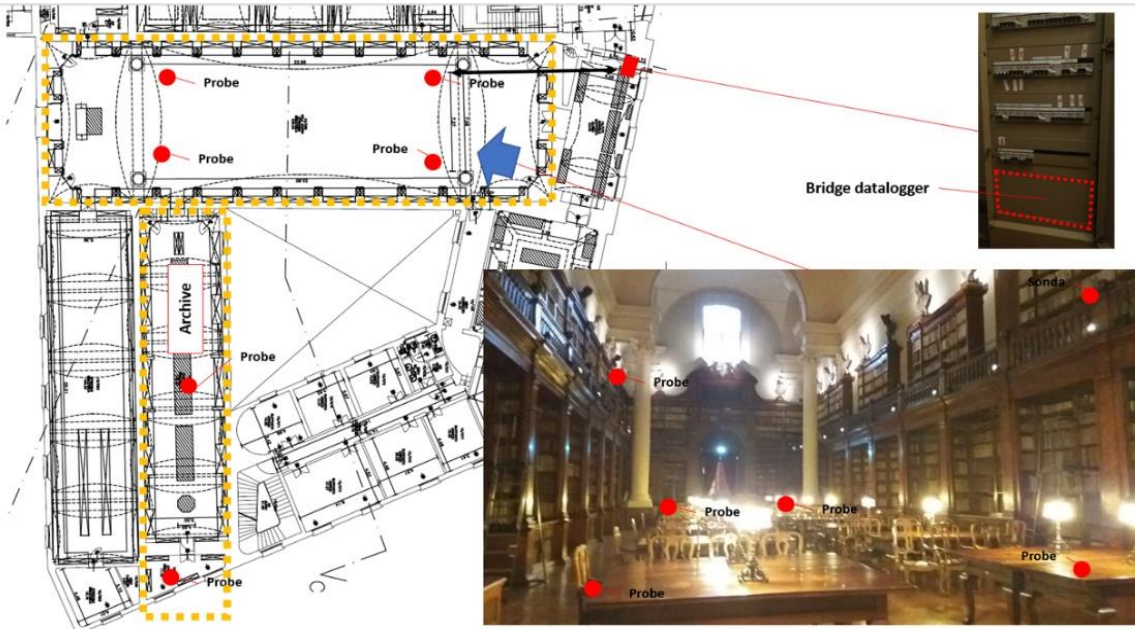

Figure 2. Bologna University Library, Bridge datalogger and probes location inside library

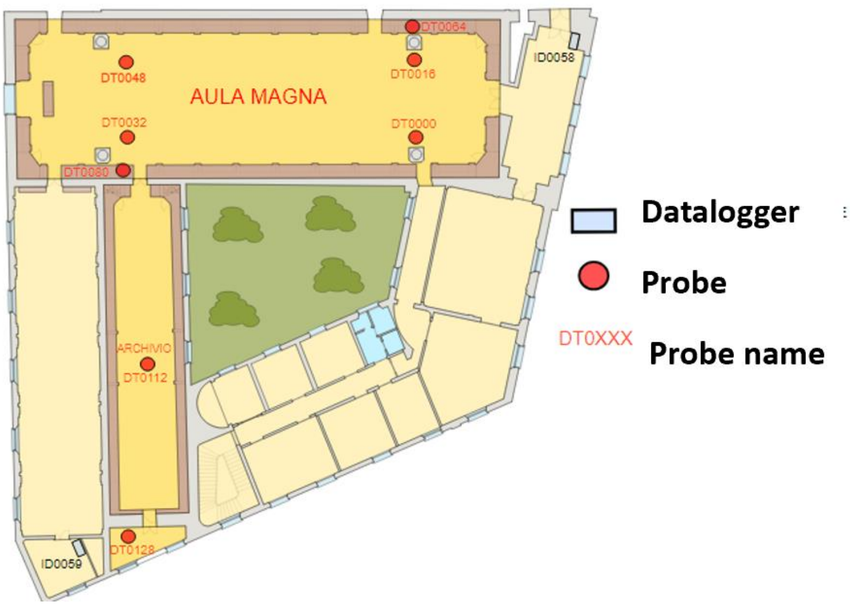

Figure 3. Probes' location and denomination. Aula Magna = Lecture Hall; Archivio = Archive

6 Results

After one-year of monitoring, we reported the results to the BUL Director in order to define the effectiveness of the monitoring campaign and the indoor microclimate characteristic, problems, gap etc. We organized results following two ways: single probe results and all probes results. That's allow us to explain results to technicians, in order to understand indoor microclimate parameter trends, air temperature and relative humidity, and to not-technicians (e.g. BUL director and librarian). This modality has been useful to engage a collaborative and fruitful discussion about results and measures to be taken, with not-technicians.
The following paragraph reports probes data results.

6.1 Probes' data

In this paper, we show a summary of the monitoring campaign results, and figure 4 describes the results for sensor DT0000, located in the Lecture hall in particular it shows:

- the indoor air temperature trend and the relative humidity trend (the dashed line in the figure represents the standard UNI 10829 range);
- the frequency of registered data about air temperature and relative humidity;
- (in grey) the outdoor air temperature and relative humidity.

The air temperature trend shows that recorded values were around 20°C during springer, following outside temperature trends, then during summer air temperature increased over 28°C – 30°C because cooling system was out-of-order until the month of July. When cooling system were fixed indoor temperature decreased under 26°C.
The frequency analysis shows that the air temperature range has been between 17°C – 19°C and the relative humidity between two ranges: 28 % - 38 % and 52% - 57%. This shows that the relative humidity is more variable than the indoor air temperature. That could depend on the manual activation of cooling / heating systems.

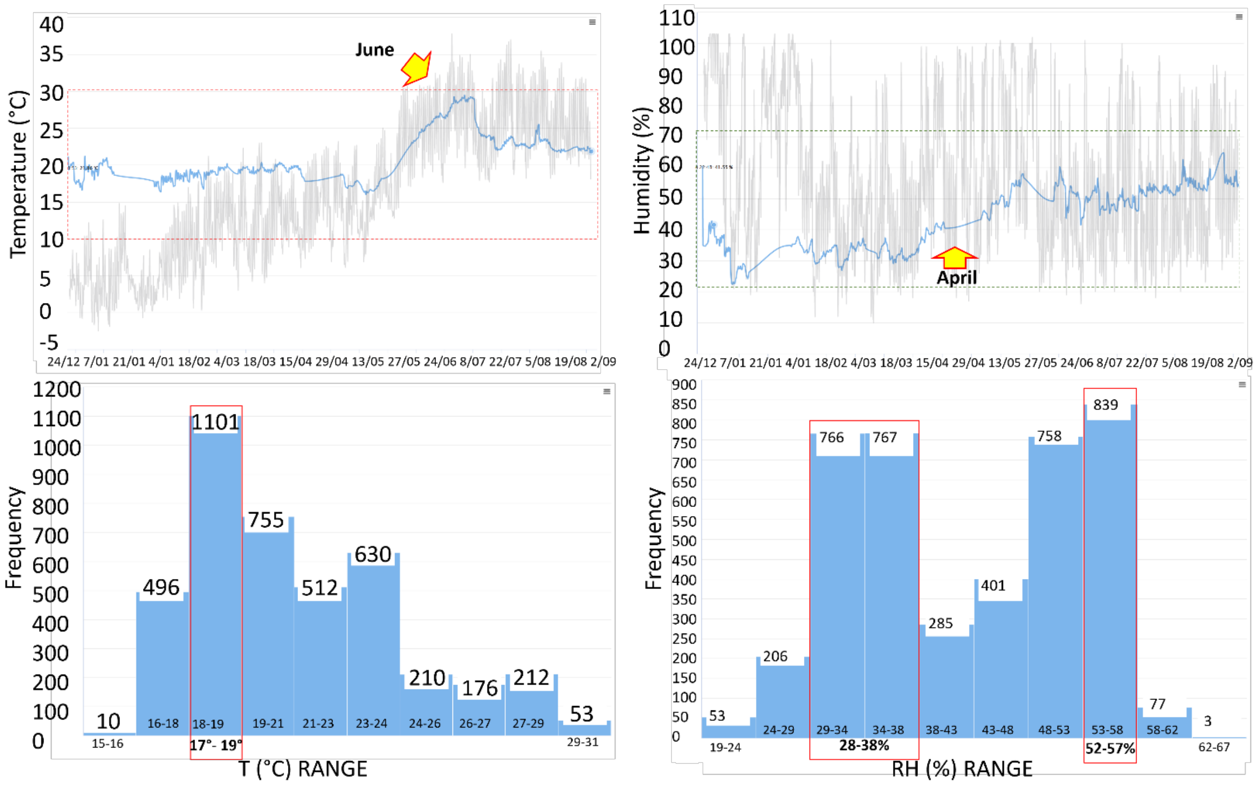

Figure 4 – Results of sensor n. DT000 – Lecture Hall

Figure 5 shows data related to the Archive. In this latter case, we don't see any fluctuation, indeed the cooling /heating system is absent, as well as visitors and lighting systems. In fact, only the librarian staff is admitted in the archive. Archive data results show that indoor air temperature follow outdoor air temperature and relative humidity values are, ever, between 50% - 55%.

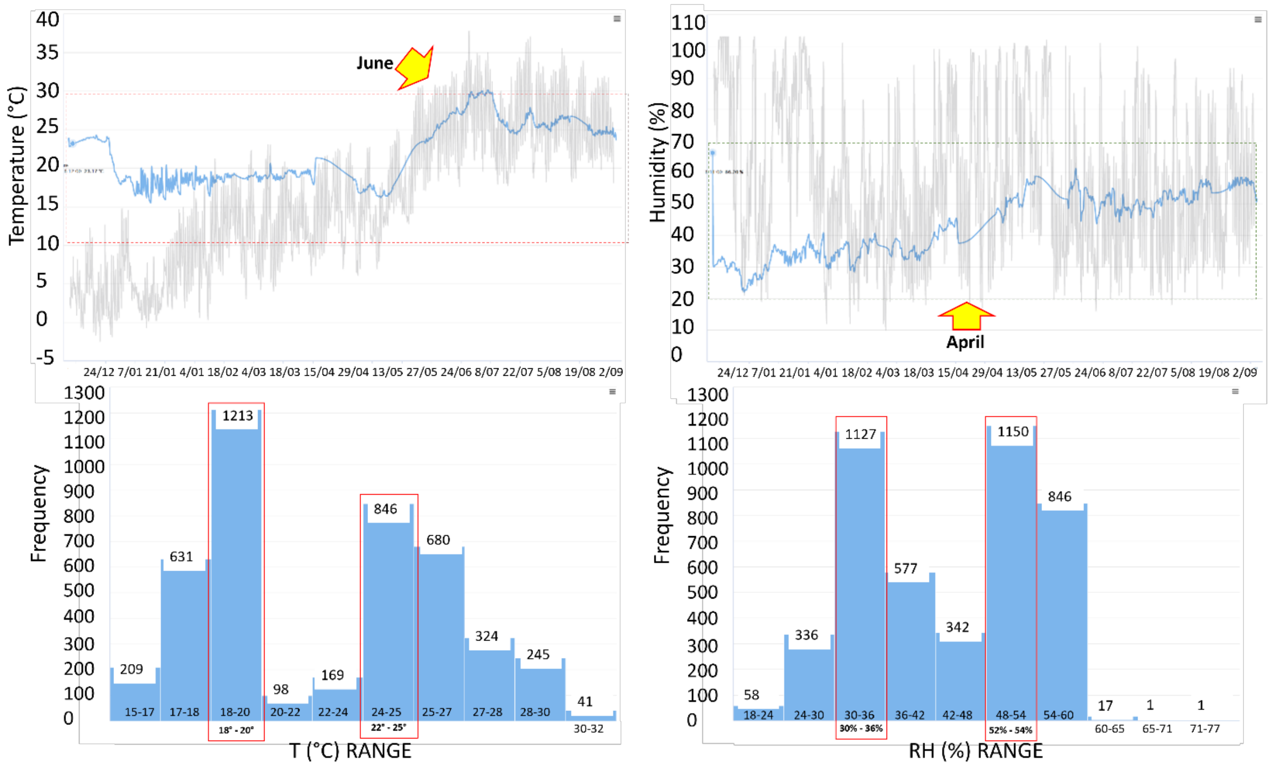

Figure 5 – Results of sensor n. DT0080 – mezzanine

We noticed that all measured data are inside the UNI 10829 ranges [34] which is the Italian standard for the preservation of historical and artistic artifacts. We registered very few exceptions with out-of-range data that can be considered as marginal. So, we can affirm that the University Library of Bologna is already guaranteeing the correct indoor microclimate to preserve books, manuscripts, papers, etc.

6.2 The role of cooling and heating systems

Figure 6 shows the air temperature trends recorded in the Lecture Hall, in the mezzanine and in the Archive. The air temperature measured in the mezzanine is more than +2°C higher than in the Lecture Hall. That depends on the natural air stratification inside the building. Specifically, here air stratification is probably also due to the presence of cooling and heating systems, but its entity it doesn't seem to be a problem for the conservation of the artifacts. Instead, the monitoring campaign shows that the heating system should be the cause of indoor microclimate risky situations because it is not possible to activate or deactivate it independently from the other rooms of the library. In this year we saw two kind of problems: first one, a centralized heating system for the entire university building (called Palazzo Poggi) is not adequate for the specific requirements needed by the BUL indoor microclimate.
Moreover, it is possible to note that the air temperature trends in the archive followed the outdoor temperature and they shifted during summer season when the indoor air temperature in the archive is higher than the air temperature in the Lecture Hall, which includes both the mezzanine and the Lecture Hall.

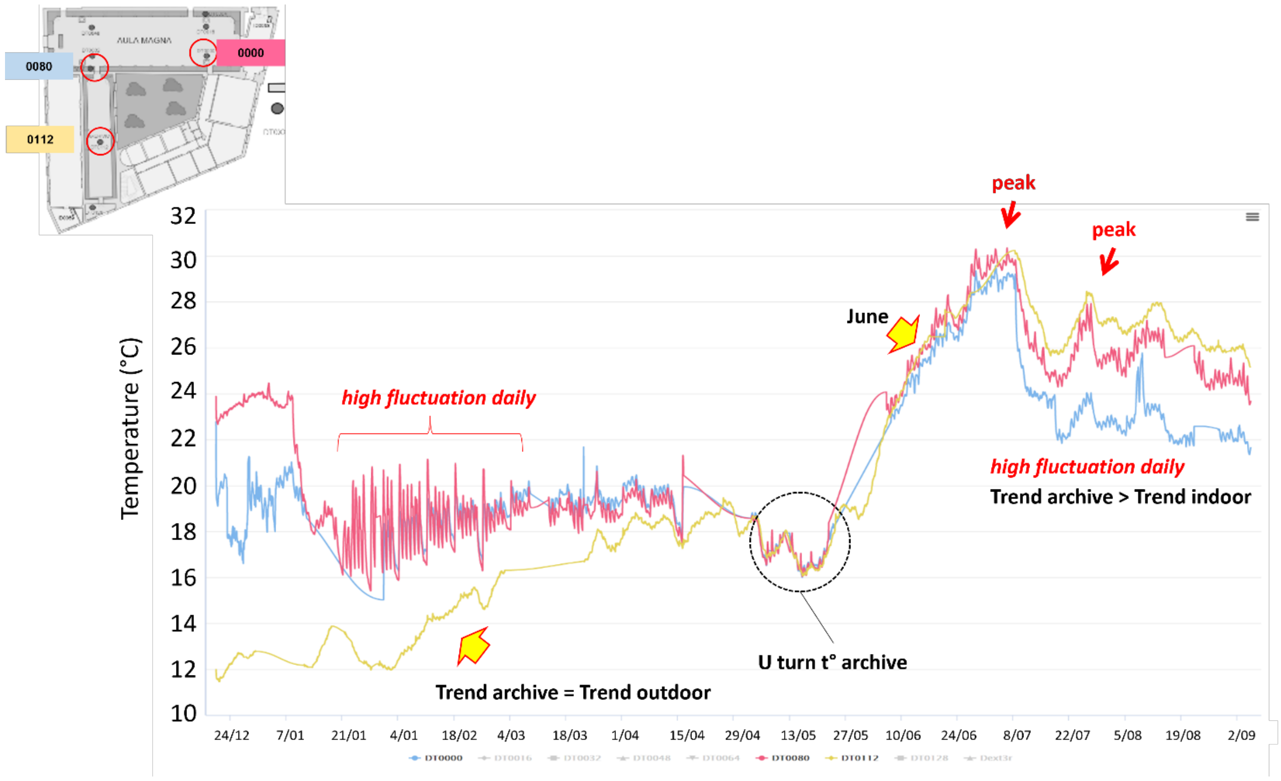

Figure 6 – Air Temperature Trends: Lecture Hall, Mezzanine and Archive. Period: from 24th December 2018 to 2nd September 2019.

6.3 Psychrometric chart (all probes' data)

Another typology of outputs about indoor microclimate monitoring concerns the representation of data on a Psychrometric Chart (ASHRAE Chart). This chart allows us to verify if data are inside the standards UNI 10829 ranges. Figure 7 show results on the psychrometric chart. We can observe that measured data in the Lecture Hall and the Archive (green, red, black, yellow points) have a "*dense cloud of points*" in spite of outdoor climate data (blue points). Evidently that's depend on building and technical systems, which guarantee a better condition than outside. Results show a cloud-of-points in form of a "*circle*" for the Lecture Hall and Mezzanine and of an "*elongated oval*" cloud-of-points for the Archive.

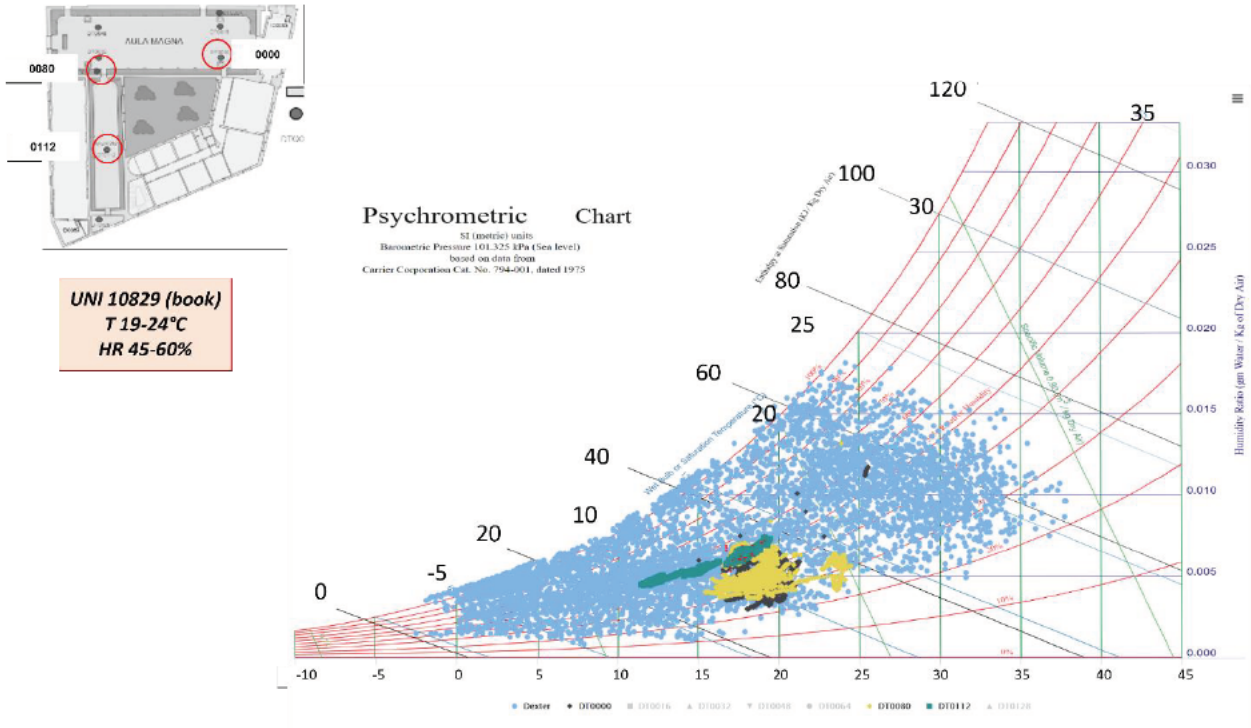

Figure 7 – Psychrometric Chart with indoor and outdoor (blue) values

6.4 Alert-range for Archive and Lecture Hall

A part of research concerned the definition of an alert range to advice and notify when the BUL indoor microclimate could cause any library and books damages, both in the Lecture Hall and in the Archive.

We decided to don't adopt standard values as a limit of range because they are not representative of the specific microclimate present in the building, and they should be cause of "false-alert" or "no-alert".

Thus, we defines a specific alert range area. Tables 1 and 2, and figure 8 show the psychometric charts with the two comfort zones for the preventive conservation of book, manuscripts and artifacts preserved in the Archive and in the Lecture Hall.

Thanks to these specific ranges, identified from the indoor microclimate monitoring analysis of the Library for almost one year, it is now possible to receive an automatic e-mail when the T and/or RH parameters result out of the defined ranges. That allows to detect immediately any situation of risk due to no matter factor which can influence the indoor microclimate of the Library: being it the presence of visitors; malfunctioning of the cooling or heating systems; a forgotten window open; etc.

Table 2. Archive's alert-range values

	T (°C)	UR (%)	x (kg_v/kg_a)	p_{ws} (Pa)	h (kJ/kg)
1	19	55	0.007515	2199,47	38.17
2	19	45	0.006136	2199.47	34.67
3	10	50	0.003414	1229.12	19.62
4	10	55	0.004178	1229.12	20.58

Table 3. Lecture Hall's alert-range values

	T (°C)	UR (%)	x (kg_v/kg_a)	p_{ws} (Pa)	h (kJ/kg)
1	20	60	0,008741	2340.57	42,30
2	22	22	0.003595	2646.76	31.27
3	18	22	0.002802	2065.88	25.21
4	15	60	0,006350	1706.83	31,14

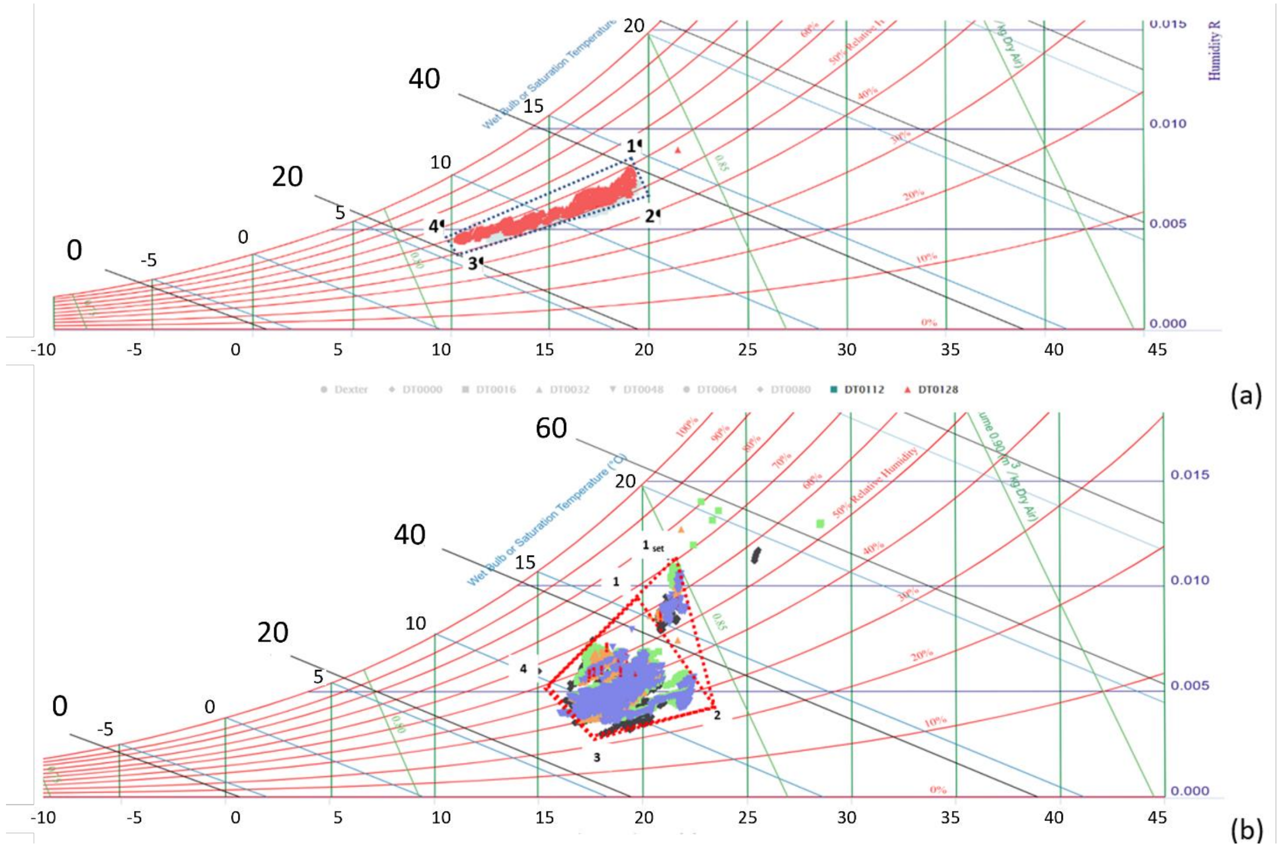

Figure 8. Range alert (a) Archive, (b) Lecture Hall

6.5 HMR and PRD indexes

Thanks to the parameters of T and RH recorded by the probes in the Archive, we calculated the $HMR_{standard}$ and the consequent PRD for the object hosted inside that room. The $HMR_{standard}$ calculated following formula (1) and (2) of Fabbri and Bonora [33] research (for detail about formulas please see the original research)

$$HMR = (HMR_{env} + HMR_{osc})/2 \quad (1)$$

$$HMR_{env} = 1 - \left[\left(\frac{HMR_{e.high} - HMR_{env,data}}{HMR_{e.high} - HMR_{e.low}}\right) \cdot 2\right] \quad (2)$$

Following we apply above formulas to Archive and Lecture Hall.

<u>$HMR_{standard}$ and PRD for the Archive</u>

The formula 1 results, for the Archive, is equivalent to +0.07. HMR_{env} standard and HMR_{osc} standard are respectively +0.06 and +0.09. That value of $HMR_{standard}$ corresponds to an environment with a minimum microclimate risk (table 1). The PRD value correspondent to the category of "books and archival assets" - which are the most important artifacts preserved in the Archive- results equivalent to 7.48% (figure 9).
This PRD result shows a reduced probability of damage for books and archival assets. Moreover, the PRD values emerged for the other categories of materials are equivalent to a minimum risk of damage, too; the Archive's indoor microclimate can guarantee the preventive conservation of the goods hosted there.

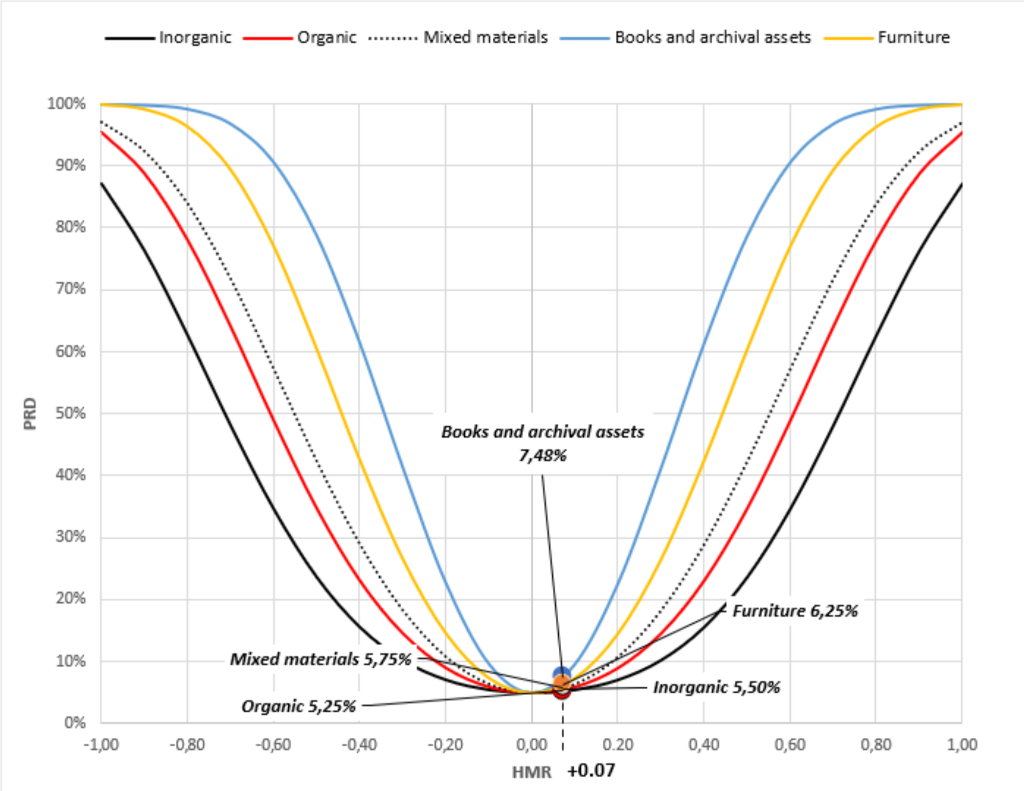

Figure 9. Results of the PRD Index for the Archive based on the value of HMR_{st} = + 0.07.

<u>$HMR_{standard}$ and PRD for the Lecture Hall</u>

We calculated $HMR_{standard}$ and PRD for the Lecture Hall too, considering the medium values from the monitored data of the 4 probes under the tables in the Lecture Hall and the 2 other probes in the mezzanine. The results show a value of HMR_{st} equivalent to -0.11 (Figure 10). Results of HMR_{env} standard and HMR_{osc} standard are respectively -0.09 and -0.12. The PRD for "books and archival assets" is equivalent to 10.65%: that value is slightly higher than the one emerged from the Archive's PRD, but it is still low. However, what comes out here is that books and archival assets seems to be more delicate than the other material's categories considered (inorganic, organic, mixed material, and furniture), for which the risk is absolutely minimum: between 5.60% and 7.89%.

As shown by both indexes HMR and PRD results, the fact that the risk in the Lecture Hall of BUB, results higher than in the Archive depends on the heating and cooling systems, which are only present in the Lecture Hall and it demonstrates that plants could be a risk for the BUL artifacts because of their malfunctioning and because they can't be managed directly.

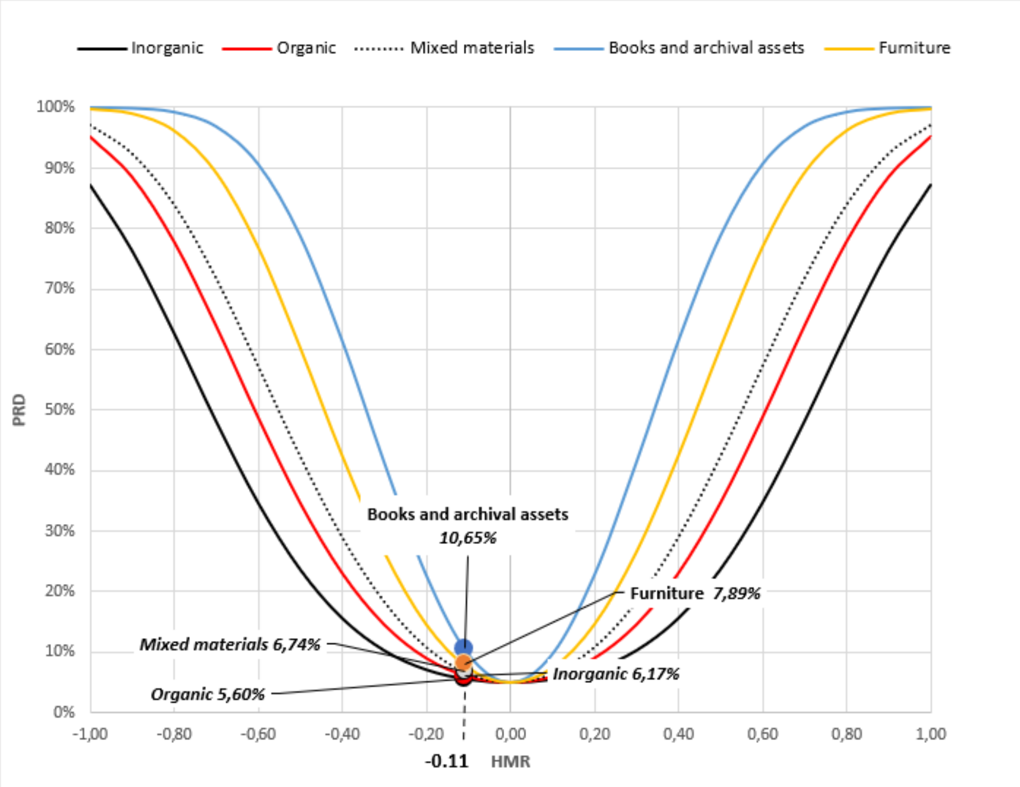

Figure 10. Results of the PRD Index for the Lecture Hall based on the value of HMR_{st} = -0.11.

7 Discussion

This research allowed to choose how to customise the indoor monitoring tools for the BUB's monitoring campaign.

Results show that Indoor Microclimate Monitoring (IMM) - referred to manuscripts, books, and artefacts in Bologna University Library - permits to define specific alert range, based on the IMM, which can be useful for the creation of indoor microclimate management protocols for the preservation of goods conserved inside libraries. Moreover, the study of the indoor microclimate of this library, has made it possible to evaluate which factors could expose the content of the Lecture Hall and the Archive to a risk of damage. It emerged that the valuable books and archival assets and the other artifacts stored in the Archive -without any HVAC system on working- are preserved in microclimatic conditions which can guarantee its preventive conservation. Instead, thanks to the excel analysis of monitored data and the calculation of HMR and PRD risk, it showed that books and archival assets hosted in the Lecture Hall are exposed to a higher risk of damage due to the indoor microclimate, than the ones in the Archive (even if we are talking about a reduced risk of damage: PRD equal to 10.65%). This higher risk is due to the role of the operational heating and cooling systems installed in that room: their malfunctioning and the impossibility to manage it directly constitute a risk for the conservation, by altering the indoor microclimate conditions, which, on the contrary, would be constant to guarantee the appropriate conditions for the preventive conservation of manuscripts, books, furniture, etc.

Finally, the methodology approach adopted for this research has been used since 2013 in the research field of the Historic Indoor Microclimate and it includes: (a) the study of the evolutions of a building, which can affect its indoor microclimate (it means changes in terms of use, interventions, etc.); (b) the indoor monitoring campaign of a specific room that stores valuable objects; (c) the analysis and interpretation of the monitored data to evaluate if the actual indoor microclimate of the studied room could guarantee the preventive conservation of its content.

The novelty in the case-study presented in this paper is:

1. the application of the risk indexes HMR and PRD at a specific case study. In literature it is hard to find specific indexes capable to correlate the indoor microclimate and the risk of damage on materials

and the case study of the University Library was an opportunity to apply original research ideas, developed over several years of study on the historical topic of indoor microclimate, to a real case. The added value of calculating HMR and PRD indicators on this case is, on the one hand the possibility to verify its efficacy and validity (confirmed given that the results are in line with the data analysis and according to what reported by UNI 15757); on the other hand, the possibility to determine both the level of aggression exerted by the indoor microclimate towards BUL artefacts (HMR) and the likelihood of risk of damage to which the specific materials that make up the objects conserved in BUL (PRD);
2. the definition of alert-range *ad hoc* based on the historical microclimate [37] of the investigated rooms.

8 Conclusion

The presented methodology showed to be effective, and it could be interesting to evaluate its replicability in other cases, with different functions . Nevertheless, the methodology proposed is already replicable in buildings hosting cultural heritage to be preserved. In particular, this analysis allowed to identify specific measures as well as good and bad practices for the daily management of these spaces. The results, in fact, have been discussed with the management of the library, leading to an increased understanding of the library microclimate behaviours and of the possible risks. Indeed, more research on this space are planned in order to check the possibility to open the two rooms to more people, for organizing events. This is actually something that is avoided, but with an in-depth analysis some new protocols can be identified.
We illustrated the results to the BUL Director and his staff, and we argued about it and about potential actions to preserve books, visitors' timing, and book loans. Indeed, about the future prospects, the Director of the BUL expressed his interest to verify the possibility to make more exhibitions in the Lecture Hall. Still today it was decided to avoid the presence of many people at the same time in the Library, because it wasn't known if that presence could expose the BUL's content to a risk of damage. Results show that Heritage microclimate risks HMR and PRD show that library indoor microclimate are not in risk area, despite heating and air-conditioning system failure. Today the purpose is to verify this possibility through a constant monitoring of the Library with the customised alert activated and a regular analysis of the indoor monitored data.

Acknowledge

The authors would like to thank to Edoardo Cavalca to ASE staff and ASE srl, for their useful support during monitoring campaign.
A special thanks goes to Guglielmo Pescatore (Dean of University Library System), Giacomo Nerozzi (BUL Director), Giorgio Floris and Sara Mantovan, his staff, for their kind support during all phases of research and monitoring, and for useful question&answer during our meeting.

Funding information

ROCK (Regeneration and Optimization of Cultural heritage in creative and Knowledge cities) funded under the Horizon 2020 project, by the European Commission, under the Grant Agreement n° 730280

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