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Historic Climate in Heritage Building and Standard 15757: Proposal for a Common Nomenclature

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Abstract: Research on the relationship between microclimate and heritage buildings or historic buildings has increased dramatically in the last few decades. Research has focused on indoor climate or indoor microclimate or the environment or micro-environment, and the field of these studies regards several variables, physical—air temperature, air speed, relative humidity—or chemical, dust, CO_2, pollution, etc., all of which can have an effect or damage buildings or artifacts inside buildings. Moreover, all these variables should be monitored in a monitoring campaign following the standard EN 15757; in spite of this, scientific literature contains mistakes with regard to the words and objects of study. In this short contribution, the author proposes a common nomenclature in the research field of climate and microclimate in heritage buildings and heritage artifacts. A new nomenclature should be useful for the community of heritage scientists working on preventive measures to distinguish between climate and environment, or the object of study, e.g., the room (wall, wood structure, fresco, etc.) where the artifacts are or the air around them (painting, canvas, statue, piece of furniture, documents, books, etc.).

Keywords: heritage building; historic indoor microclimate; indoor monitoring; monitoring campaign

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1. Introduction: A Short Overview of Scientific Literature

This paper aims to contribute to a specific research area concerning the study of indoor microclimate in heritage or historic buildings (e.g., museums, libraries, etc.) that adopt indoor environmental monitoring following the EN 15757 standard.

During the last few years part of the research on heritage buildings focused on "energy efficiency" and "indoor microclimate" as reported in literature reviews [1,2], specific research such as the 3encult project [3–5], and Horizon 2020 research on climate change effects on heritage buildings (https://www.heritageresearch-hub.eu/homepage/joint-programming-initiative-on-cultural-heritage-homepage (accessed on 5 December 2021)). Table 1 summarises the literature on research about microclimate in heritage buildings.

Scientific literature about heritage and indoor microclimate reports several case studies that follow the EN 15757 standard [6] and their concept of "historic climate" but makes mistakes in the use of these terms. This happens because of a misunderstanding or bias during research and data interpretation, e.g. historic climate is adopted in an article by Camuffo et al. [7] in Santa Maria Maddalena, in the Rocca Pietore Church in Italy, where it has been used the standard EN 15757 or in Bertolin et al. [8] where the EN 15757 is adopted to evaluate indoor relative humidity fluctuation in the case study of the old choir in S. Giustina in Cremona (Italy), or in Bertolin [9] in a laboratory test.

This research field needs to explain and to adopt a specific nomenclature to make clear if the aim of the research concerns the "historic climate" or the "historical indoor microclimate", the room space or the space around the artifacts, and the display cabinets with artifacts.

1.1. Observations about the Monitoring Period: Several Kinds of Approach

This section reports a short selection of research on monitoring campaigns of the indoor microclimate (temperature, humidity or pollutants) on heritage buildings, where they adopt several monitoring campaign periods never longer than a year. This confirms how hard it is to define, in literature, research using the same terms and methodology. Table 1 report a list of scientific literature about microclimate in heritage building.

Table 1. Literature on indoor microclimate in heritage buildings.

Authors	Reference	Museum	Visitors (i)	Artworks (ii)	Monitoring (iii)	Energy (iv)	Building Simulatio	IAQ (v)
Andretta et al., 2016	[10]	•		•	◊			
Bencs et al., 2007	[11]				◊	•		•
Bernardi et al., 1985	[12]	•			•			
Bucur et al., 2015	[13]			•				•
Camuffo D et al., 1999	[14]	•		•	◊			•
Becherini F, et al., 2016	[15]	•		•	◊			
Camuffo et al., 2001	[16]	•						
Cardinale and Ruggiero 2002	[17]	•		•	•			
Cardinale N et al., 2010	[18]				◊	•		
Caucheteux A et al., 2013	[19]				◊		•	
Corgnati, Fabi and Filippi 2009	[20]	• *			◊			
Fabbri and Pretelli 2014	[20]	•		•	x			
Ferdyn-Grygierek J. 2014	[21]	•			○	•		
G Litti and Audenaert 2018	[22]	•		•	○			
Garci et al., 2015	[23]	•			◊	•		
García-Diego et al. 2016	[24]	• *		•	• (x)			
Gigliarelli et al., 2016	[25]	•				•	•	
Silva HE and Henriques FMS 2015	[26]	• **			◊			
Klein et al., 2017	[27]	•			• (x)		•	
Kupczak et al., 2018	[28]	•		•		•	•	
Litti G et al., 2015	[29]	•			◊			
Martinez-Molina et al., 2018	[30]	•	•		○			
Maurerová et al., 2017	[31]	•				•	•	
Mesas-Carrascosa et al., 2016	[32]	•			• (x)			
Napp M et al., 2015	[33]				○		•	
Neri et al., 2009	[34]			•	•			•
Pasquarella et al., 2015	[35]	•			◊		•	•
Pereira, Gaspar, and Costa 2017	[36]	•		•	•			•
Pisello et al., 2015	[37]	• *		•		•	•	
Pisello et al., 2018	[38]	•	•	•	•			
Roberti F et al., 2015	[39]	•			◊		•	•
Said et al., 1999	[40]				◊			•
Saraga D et al., 2011	[41]	•			◊			•
Scatigno et al., 2016	[42]	•			◊			•
Silva and Henriques 2014	[43]	•			•			
Silva and Henriques 2016	[44]	• *			○			
Zivkovic V et al., 2013	[45]	•			○			

Notes: (i) research include visitor thermal comfort; (ii) research include study of single artifact conservation; (iii) research include monitoring campaign: ○ 1 year or more; ◊ less than 1 year; • without information about monitoring period; (x) focuses on probes and sensors; (iv) building energy performance, energy efficiency and/or HVAC; (v) indoor air quality; * Monitoring campaign following standard EN 15757; ** Monitoring campaign following standard PAS 198 (PAS 198 Specification for Environmental Conditions for Cultural Collections, British Standards Institution, London, UK, 2012).

A monitoring campaign of indoor microclimate should ideally last at least one year, to evaluate the effects of the four seasons.

Several papers present research that respects this indication, often applied to heritage buildings used as museums, as in Napp M et al. [33], where the research lasts from April 2012 to December 2013, and in Zivkovic V. et al. [45] where the monitoring covered the entire year 2010. Ferdyn-Grygierek J [21] covered 1 year as well, as the measurements started in October 2009 and were completed in September 2010, and the discussion of the results analyzed each month. The study of Silva and Heriques [26], relative to the Church of St. Christopher, a national monument of Portugal located on the slopes of the S. Jorge Castle Lisbon-Portugal, covered an even longer period of almost 2 years: from November 2011 to August 2013.

Despite 1 year being the ideal minimum length for monitoring, shorter periods can deliver more than adequate data to understand the indoor microclimate of buildings. Several published papers describe the results of monitoring over much shorter periods, in some cases even 1 month or less.

In the specific case of this research, it has been impossible to carry on the monitoring campaign for an entire year because of both the exigencies of the restoration works and of funding; despite this, we believe the results of this monitoring are useful and explanatory, not only because they cover several different seasons- basically referring to three out of the four seasons, but also because the very same results have been successfully used to address the restoration works themselves.

In our opinion, as long as the results refer to more than one season and are adequately interpreted, monitoring periods shorter than 1 year are admissible, as they help to characterize indoor microclimate of buildings. Several studies, listed here, were carried on for periods shorter than 1 year.

The article from Corgnati SP et al [46] clarifies that the monitoring period can be short, as long as a single week, repeated during the year, or a long-term sequence of spans, e.g., on a yearly basis, can give interesting results. In the specific case described, the monitoring time is shorter than 1 year and is relative to the time of a temporary exhibition, from 18/10/06 to 06/04/07, a period of about 7 months. In a paper from Camuffo D et al. [14] concerning the Correr Museum in Venice, the monitoring was undertaken in two different years, for a total length of 2 days each time.

The validity of the monitoring length can be expressed as a function of the number of data obtained and of their accuracy. Generally speaking, if the accuracy is low and the number of data points is small, the monitoring should be carried on for longer periods. On the contrary, if the accuracy of the monitoring is high as the number of data points, the length of the monitoring depends on the goal of the research. In the study by Roberti F et al. [39] on the Waaghaus weigh house, located in the historic center of Bolzano, the monitoring system includes internal air and surface temperature sensors for each floor and for the three facades, so that a monitoring campaign of about 4 weeks during two winter months from 8 to 25 January 2012 and from 1 May to 26 October 2012 was long enough to give relevant results. The paper by Caucheteux A et al. [19] describes monitoring that went on for 2 weeks in December, because the monitoring has been used to calibrate the model for the building simulation. In the research by Cardinale N et al. [18], monitoring was carried on in multiple sites, not continuously, for 12–15 days in each season. The study of Litti G et al. [29] describes the results of a monitoring campaign of an indoor microclimate of the Vleeshuis Music instruments museum of Antwerp, which was conducted on the S-W oriented masonry from 7 March 2014 to 7 May 2014, for a total period of 2 months. Camuffo D et al. [15] carried on monitoring to evaluate the effects of HVAC systems between 1 October 2002 al 30 March 2003 for about 5 months. Garci et al. [23] describe a monitoring campaign carried on following the UNI 10829, only in some of the rooms, for each of which the monitoring lasted about 1 week.

Other research has conducted even shorter monitoring campaigns, lasting several weeks, in particular when the building has several rooms or when the measures concern chemical pollutants, such as volatile organic compounds (VOC) and/or particulate matter. In their paper, Saraga D et al. [41] show the results of the indoor monitoring of three diverse types of building, for each of which the monitoring was a week long.

Finally, Said et al. [40] analyzed a heritage house, the “Laurier House” located in Ottawa, as a case study, where the monitoring campaign was carried out in two phases: a preliminary indoor monitoring in February–March 1993, and a second long-term campaign from March 1995 to August 1996. This double campaign is preferable, if the findings are sufficient, as such a campaign gives a more detailed analysis, comparable, if not equal, to continuous monitoring.

1.2. The Standard EN 15757

In the research field of heritage buildings and heritage artifacts, the words “historic” and “climate”, sometimes define the same things. The standard EN 15757 adopted “uncritically”, with monitoring of different case studies divided by destination (e.g., churches, museums, etc.) or volume of the building and instrumental equipment. The common element of these few case studies is the duration of the monitoring and the use of the historic climate concept as the object of study of the monitoring itself.

In research on “La Specola” museum of Florence [47] the object of monitoring was the indoor air of the museum but artifacts were inside display cabinets. Other research was on artifact collections such as that of di Huijbregts [48] that monitored the indoor climate condition of a wooden cabinet and damage depending on room microclimate; this research used the concept of historic climate of standard EN 15757. Other case studies as Bichlmair et. al. [49], Caratelli et al. [50], De Backer et al. [51], Muñoz-González, et al. [52], Silva and Henriques [26] adopted the standard EN 15757 for their indoor monitoring campaign (1 year of campaign) but did not report if they had measured the room air or the air around the artifact. Litti and Audenaert [22] monitored the Vleeshuis Museum, in Antwerp. The literature review by Lucchi [2] refers to preventive conservation in museum buildings and quote EN 15757 as standard to allow “determined the target ranges and variability of microclimate condition temperature and relative humidity developing the idea of historical climate announced by Camuffo’s theory”.

In the research field on historic and/or indoor microclimates in heritage buildings, also during paper submission sometimes there is a misunderstanding about some definitions following standard EN 15757. In other words, sometimes, the same word has different meanings depending on the reviewer. Moreover, standard EN 15757 published in 2010 and several research done during last 10 years.

This contribution aims to propose an upgrade of EN 15757 nomenclature for a related audience such as conservators, researchers on heritage conservation (also architecture, art, art crafts, and other manufactured conservation) also the collection/museum/building manager in order to help to define a monitoring campaign.

A new nomenclature should be useful for the community of heritage scientists working on preventive measures to distinguish between climate and environment, or the object of study, e.g., the room (wall, wood structure, fresco, etc.) where the object is or the air around the object (painting, canvas, statue, piece of furniture, documents, books, etc.).

The aims are to stimulate a debate about actual nomenclature and (maybe) a revised/upgrade standard EN 15757 following the definition below.

2. A Nomenclature Proposal for Historic Climate and Microclimate in Heritage Buildings

In scientific literature words like “climate”, “historic”, “monitoring” are normally adopted in a generic way, not specifying whether they refer to an artifact or a building, or to the present activity or to studies relating to past behaviour or future projections. The following is a proposal for a terminology that allows defining the terms for various research areas and purposes.

The nomenclature proposal, following theoretical evaluation, research and experimental observation on-site, and debate with management of museums and heritage buildings, aims to support this research field and to contribute to the review of the standard EN 15757.

The words that are the objects of nomenclature are the following:

- a distinction between ‘climate’ and ‘environment’; where ‘climate’ includes all thermo-geometric phenomena that depend on a spatial contest (e.g., room, building, courtyard, etc.) and with ‘environment’ all the phenomena that have an effect on the object of study (e.g., artifact, object. etc.) and their damage also including indoor air pollutants or thermal comfort;
- a distinction between ‘historic’ (last 1 year) and ‘historical’ where historical refers to past events (10 or more years);
- the word “-micro”, as prefix or suffix, must refer to a portion of space to a human scale;
- “proximity”, or “nearness in place, time or relation” of artifact.

With regard to the first items, we must distinguish between ‘climate’ and ‘microclimate’:

- ‘climate’ is a word with several declinations, generally we intend it as “the weather conditions prevailing in an area in general or over a long period” (online Oxford Dictionary); another is ‘climate change’, also in heritage buildings [53] defined as, “A change in global or regional climate patterns, in particular a change apparent from

the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels." (online Oxford Dictionary). In the case of buildings with or without heating systems, 'climate' should be intended as 'indoor microclimate'. In our research field the word 'climate' includes all energy or mass exchange of air that should be explained with psychrometric, fluid dynamics or comfort studies;
- 'microclimate' is defined as: "climate on a small spatial scale", by EN 15757 at point 3.8, and air volume inside a room.

Furthermore:

- 'environment' is defined as an "Area within a building where cultural heritage objects are preserved", by EN 15757 point 3.7, and refers to all physical and chemical phenomena included in indoor air quality, chemical reactions, dust etc.
- 'microenvironment' is defined as: the volume in proximity of an artifact (of less than 1 m) inside or outside of a building.

The microclimate should also distinguish between:

- 'Indoor microclimate', if referring to a room or a space inside a building.
- 'Outdoor microclimate', if referring to an outdoor space, e.g., garden, park, square, etc.

Figures 1 and 2 report a scheme of above nomenclature and hierarchy in order to clarify.

Secondly, we must distinguish between research on 'heritage buildings' and research on 'heritage artifacts' also inside heritage buildings.

The research on 'heritage buildings' regards geometry, thermophysics, technical systems, energy performance, visitors and human behaviour, etc. and of all building parameters that should have an effect on indoor microclimate, and/or building conservation or damage such as mud, humidity, condensation, etc. In this way we should distinguish the research about:

- 'heritage buildings', as buildings for several cultural activities e.g., churches, offices, schools, etc.
- museums, as the design of new museums must respect all indoor microclimate reference values [54];
- heritage buildings used as museums, a heritage building as a museum in itself, or a heritage building used as a museum.

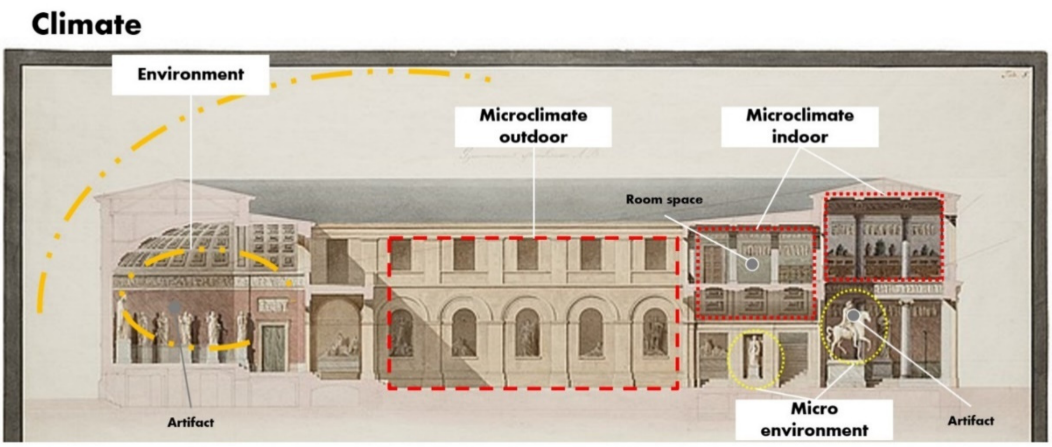

Figure 1. Graphical scheme of nomenclature.

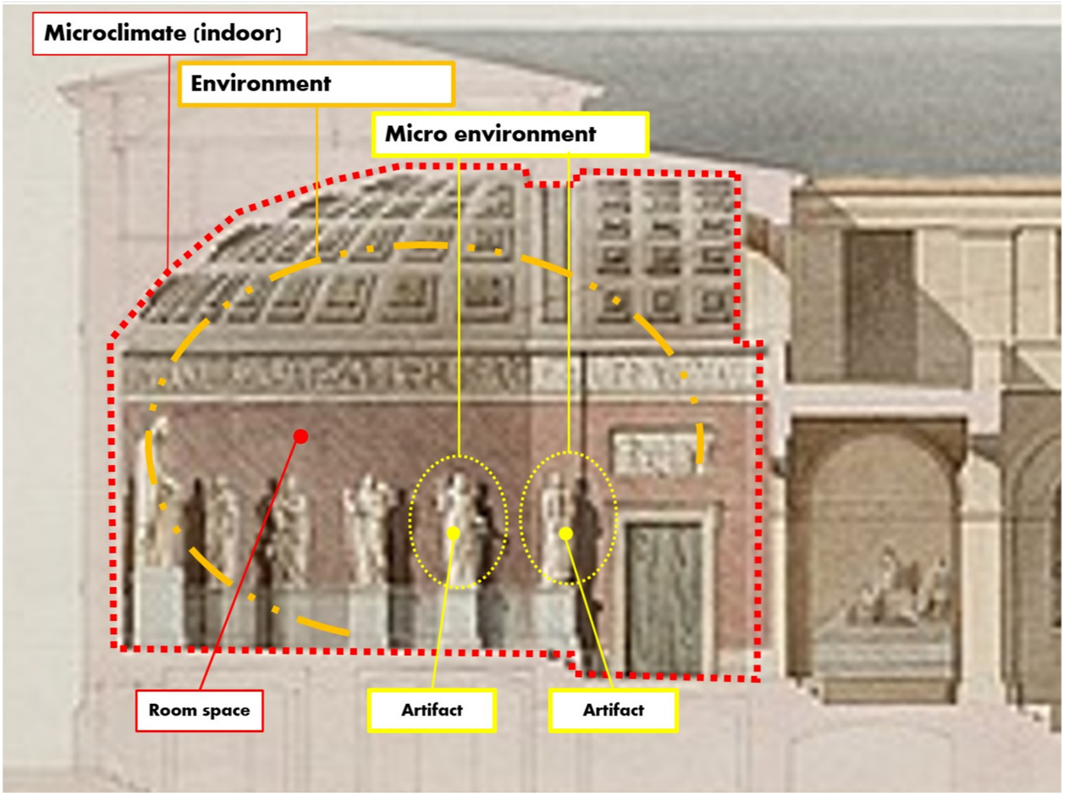

Figure 2. Hierarchy between microclimate, environment e micro-environment.

The research on 'heritage artifacts' (e.g., paintings, sculptures, books, furniture's, etc.) concerns the artifact's conservation against damage, related to used materials, age, originality, etc. and includes the damage risk if the artifact must be removed from one space to another with a different microclimate.

Finally, we must clarify the word 'historic' in the case of microclimate: which is the period we are referring to? The approach should be distinguished as:

- research on the artifact conservation, where the period coincides with a monitoring period;
- research on heritage buildings, including their history, restoration, etc. where the period depends on the history of the building and/or their future.

In the first case, we can talk about 'historical climate' defined as: "Climatic conditions in a microenvironment where a cultural heritage object has always been kept or has been kept for a long period of time at least one year and to which it has become acclimatized" EN 15757 point 3.5.

In the second case, we talk about "Historic Indoor Microclimate" (HIM) [55,56] defined as " ... the study of evolution in time of the characteristic micro-climate of an architecture, in relation to the variation in fruition conditions linked to food, clothing, and behavioural habits; to the changes involving the building in structural terms destruction, changes or construction of walls and ceilings, addition or removal of new parts, opening and closing of windows, etc.; and finally to the introduction of new or successive HVAC systems" [57]. In this case, the period should be the building lifespan from its construction (original indoor microclimate) to today (actual indoor microclimate).

In both cases, research should provide a monitoring campaign on site, and in these cases, we must define the right monitoring period, which should be at least 1 year if referring to 'historic climate'; or a shorter period if monitoring is used to calibrate building simulation.

3. Conclusions

Every word should have a different and specific meaning: it is not obvious that the same term has always the same meaning when used to express different concepts or fields of application. Following the study of the scientific literature in the heritage building and artifact and climate sectors, some concepts have been applied with different meanings. Since several articles have been published in this research area during recent years, as well as at congresses and conferences, and also funding has been provided for new/more research lines, this article has aimed to introduce a nomenclature capable of defining the different fields of study regarding the relationship between climate, time (history) and heritage buildings and artifacts.

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References

1. Martínez-Molina, A.; Tort-Ausina, I.; Cho, S.; Vivancos, J.L. Energy efficiency and thermal comfort in historic buildings: A review. *Renew. Sustain. Energy Rev.* **2016**, *61*, 70–85. [CrossRef]
2. Lucchi, E. Review of preventive conservation in museum buildings. *J. Cult. Herit.* **2018**, *29*, 180–193. [CrossRef]
3. Vieites, E.; Vassileva, I.; Arias, J.E. European Initiatives Towards Improving the Energy Efficiency in Existing and Historic Buildings. *Energy Procedia* **2015**, *75*, 1679–1685. [CrossRef]
4. Roberti, F.; Oberegger, U.F.; Lucchi, E.; Troi, A. Energy retrofit and conservation of a historic building using multi-objective optimization and an analytic hierarchy process. *Energy Build.* **2017**, *138*, 1–10. [CrossRef]
5. Berg, F.; Flyen, A.C.; Godbolt, Å.L.; Broström, T. User-driven energy efficiency in historic buildings: A review. *J. Cult. Herit.* **2017**, *28*, 188–195. [CrossRef]
6. EN 15757 Conservation of Cultural Property. *Specifications for Temperature and Relative Humidity to Limit Climate-Induced Mechanical Damage in Organic Hygroscopic Materials*; CEN European Committee for Standardization: Bruxelle, Belgium, 2013.
7. Camuffo, D.; Pagan, E.; Rissanen, S.; Bratasz, Ł.; Kozłowski, R.; Camuffo, M.; della Valle, A. An advanced church heating system favourable to artworks: A contribution to European standardisation. *J. Cult. Herit.* **2010**, *11*, 205–219. [CrossRef]
8. Bertolin, C.; Camuffo, D.; Bighignoli, I. Past reconstruction and future forecast of domains of indoor relative humidity fluctuations calculated according to EN 15757:2010. *Energy Build.* **2015**, *102*, 197–206. [CrossRef]
9. Bertolin, C.; Luciani, A.; Valisi, L.; Camuffo, D.; Landi, A.; Del Curto, D. Laboratory tests for the evaluation of the heat distribution efficiency of the Friendly-Heating heaters. *Energy Build.* **2015**, *107*, 319–328. [CrossRef]
10. Andretta, M.; Coppola, F.; Seccia, L. Investigation on the interaction between the outdoor environment and the indoor microclimate of a historical library. *J. Cult. Herit.* **2016**, *17*, 75–86. [CrossRef]
11. Bencs, L.; Spolnik, Z.; Limpens-Neilen, D.; Schellen, H.L.; Jütte, B.A.H.G.; Van Grieken, R. Comparison of hot-air and low-radiant pew heating systems on the distribution and transport of gaseous air pollutants in the mountain church of Rocca Pietore from artwork conservation points of view. *J. Cult. Herit.* **2007**, *8*, 264–271. [CrossRef]
12. Bernardi, A.; Camuffo, D.; Del Monte, M.; Sabbioni, C. Microclimate and weathering of a historical building: The Ducal Palace in Urbino. *Sci. Total Environ.* **1985**, *46*, 243–260. [CrossRef]
13. Bucur, E.; Vasile, A.; Diodiu, R.; Catrangiu, A.; Petrescu, M. Assessment of indoor air quality in a wooden church for preventive conservation. *J. Environ. Prot. Ecol.* **2015**, *16*, 7–17.
14. Camuffo, D.; Brimblecombe, P.; Van Grieken, R.; Busse, H.J.; Sturaro, G.; Valentino, A.; Bernardi, A.; Blades, N.; Shooter, D.; De Bock, L.; et al. Indoor air quality at the Correr Museum, Venice, Italy. *Sci. Total Environ.* **1999**, *236*, 135–152. [CrossRef]
15. Becherini, F.; Bernardi, A.; Di Tuccio, M.C.; Vivarelli, A.; Pockelè, L.; De Grandi, S.; Fortuna, S.; Quendolo, A. Microclimatic monitoring for the investigation of the different state of conservation of the stucco statues of the Longobard Temple in Cividale del Friuli (Udine, Italy). *J. Cult. Herit.* **2016**, *18*, 375–379. [CrossRef]
16. Camuffo, D.; Van Grieken, R.; Busse, H.-J.; Sturaro, G.; Valentino, A.; Bernardi, A.; Blades, N.; Shooter, D.; Gysels, K.; Deutsch, F.; et al. Environmental monitoring in four European museums. *Atmos. Environ.* **2001**, *35*, S127–S140. [CrossRef]
17. Cardinale, N.; Ruggiero, F. A case study on the environmental measures' techniques for the conservation in the vernacular settlements in Southern Italy. *Build. Environ.* **2002**, *37*, 405–414. [CrossRef]
18. Cardinale, N.; Rospi, G.; Stazi, A. Energy and microclimatic performance of restored hypogeous buildings in south Italy: The "Sassi" district of Matera. *Build. Environ.* **2010**, *45*, 94–106. [CrossRef]
19. Caucheteux, A.; Stephan, E.; Ouest, C. Transient simulation calibration of an old building using an experimental design: evaluating uncertainty results. In Proceedings of the 13th Conference of the International Building Performance Simulation Association, Chambery, France, 25–28 August 2013; pp. 677–684.
20. Fabbri, K.; Pretelli, M. Heritage buildings and historic microclimate without HVAC technology: Malatestiana Library in Cesena, Italy, UNESCO Memory of the World. *Energy Build.* **2014**, *76*, 15–31. [CrossRef]

21. Ferdyn-Grygierek, J. Indoor environment quality in the museum building and its effect on heating and cooling demand. *Energy Build.* **2014**, *85*, 32–44. [CrossRef]
22. Litti, G.; Audenaert, A. An integrated approach for indoor microclimate diagnosis of heritage and museum buildings: The main exhibition hall of Vleeshuis museum in Antwerp. *Energy Build.* **2018**, *162*, 91–108. [CrossRef]
23. Astiaso Garcia, D.; Di Matteo, U.; Cumo, F. Selecting Eco-friendly Thermal Systems for the "Vittoriale Degli 8 Italiani" Historic Museum Building. *Sustainability* **2015**, *7*, 12615–12633. [CrossRef]
24. García-Diego, F.-J.; Verticchio, E.; Beltrán, P.; Siani, A. Assessment of the minimum sampling frequency to avoid measurement redundancy in microclimate field surveys in museum buildings. *Sensors* **2016**, *16*, 1291. [CrossRef]
25. Gigliarelli, E.; Calcerano, F.; Cessari, L. Implementation analysis and design for energy efficient intervention on heritage buildings. *Lect. Notes Comput. Sci.* **2016**, *10058 LNCS*, 91–103. Available online: https://link.springer.com/chapter/10.1007%2F978-3-319-48496-9_8. (accessed on 5 December 2021).
26. Silva, H.E.; Henriques, F.M.A. Preventive conservation of historic buildings in temperate climates. The importance of a risk-based analysis on the decision-making process. *Energy Build.* **2015**, *107*, 26–36. [CrossRef]
27. Klein, L.J.; Bermudez, S.A.; Schrott, A.G.; Tsukada, M.; Dionisi-Vici, P.; Kargere, L.; Marianno, F.; Hamann, H.F.; López, V.; Leona, M. Wireless sensor platform for cultural heritage monitoring and modeling system. *Sensors* **2017**, *17*, 1998. [CrossRef]
28. Kupczak, A.; Sadłowska-Sałęga, A.; Krzemień, L.; Sobczyk, J.; Radoń, J.; Kozłowski, R. Impact of paper and wooden collections on humidity stability and energy consumption in museums and libraries. *Energy Build.* **2018**, *158*, 77–85. [CrossRef]
29. Litti, G.; Khoshdel, S.; Audenaert, A.; Braet, J. Hygrothermal performance evaluation of traditional brick masonry in historic buildings. *Energy Build.* **2015**, *105*, 393–411. [CrossRef]
30. Martinez-Molina, A.; Boarin, P.; Tort-Ausina, I.; Vivancos, J.-L. Assessing visitors' thermal comfort in historic museum buildings: Results from a Post-Occupancy Evaluation on a case study. *Build. Environ.* **2018**, *132*, 291–302. [CrossRef]
31. Maurerová, L.; Selucká, A.; Jakubec, P.; Hirš, J. Use of simulation analysis to assess efficiency of heating by the "conservation heating" method in a historical building [Uplatnění simulační analýzy při o věření efektivity vytápění metodou "conser vation heating" v historické budově]. *Vytap. Vetr. Instal.* **2017**, *26*, 270–277, ISBN-978-80-87967-17-1. Available online: https://mck.technicalmuseum.cz/wp-content/uploads/2018/06/Buildings-for-Storing-Cultural-Heritage-Objects-%E2%80%93-Principles-and-Methods-for-Assessing-Indoor-Environments.-N%C3%A1rodn%C3%AD-pam%C3%A1tkov%C3%BD-%C3%BAstav-2017.-ISBN-978-80-87967-17-1.pdf (accessed on 5 December 2021).
32. Mesas-Carrascosa, F.J.; Verdú Santano, D.; de Larriva, J.E.M.; Ortíz Cordero, R.; Hidalgo Fernández, R.E.; García-Ferrer, A. Monitoring heritage buildings with open-source hardware sensors: A case study of the mosque-cathedral of Córdoba. *Sensors* **2016**, *16*, 1620. [CrossRef]
33. Napp, M.; Kalamees, T. 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.* **2015**, *108*, 61–71. [CrossRef]
34. Neri, A.; Corbellini, S.; Parvis, M.; Arcudi, L.; Grassini, S.; Piantanida, M.; Angelini, E. Environmental monitoring of heritage buildings. In Proceedings of the 2009 IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems, EESMS 2009—Proceedings, Crema, Italy, 25 September 2009; pp. 93–97.
35. Pasquarella, C.; Balocco, C.; Pasquariello, G.; Petrone, G.; Saccani, E.; Manotti, P.; Ugolotti, M.; Palla, F.; Maggi, O.; Albertini, R. A multidisciplinary approach to the study of cultural heritage environments: Experience at the Palatina Library in Parma. *Sci. Total Environ.* **2015**, *536*, 557–567. [CrossRef]
36. Pereira, L.D.; Gaspar, A.R.; Costa, J.J. Assessment of the indoor environmental conditions of a baroque library in Portugal. *Energy Procedia* **2017**, *133*, 257–267. [CrossRef]
37. Pisello, A.L.; Castaldo, V.L.; Pignatta, G.; Cotana, F. Integrated numerical and experimental methodology for thermal-energy analysis and optimization of heritage museum buildings. *Build. Serv. Eng. Res. Technol.* **2015**, *37*, 334–354. [CrossRef]
38. Pisello, A.L.; Castaldo, V.L.; Piselli, C.; Cotana, F. Coupling artworks preservation constraints with visitors' environmental satisfaction: Results from an indoor microclimate assessment procedure in a historical museum building in central Italy. *Indoor Built Environ.* **2018**, *27*, 846–869. [CrossRef]
39. Roberti, F.; Oberegger, U.F.; Gasparella, A. Calibrating historic building energy models to hourly indoor air and surface temperatures: Methodology and case study. *Energy Build.* **2015**, *108*, 236–243. [CrossRef]
40. Saïd, M.N.A.; Brown, W.C.; Shirtliffe, C.J.; Maurenbrecher, A.H.P. Monitoring of the building envelope of a heritage house: A case study. *Energy Build.* **1999**, *30*, 211–219. [CrossRef]
41. Saraga, D.; Pateraki, S.; Papadopoulos, A.; Vasilakos, C.; Maggos, T. Studying the indoor air quality in three non-residential environments of different use: A museum, a printery industry and an office. *Build. Environ.* **2011**, *46*, 2333–2341. [CrossRef]
42. Scatigno, C.; Gaudenzi, S.; Sammartino, M.P.; Visco, G. A microclimate study on hypogea environments of ancient roman building. *Sci. Total Environ.* **2016**, *566–567*. [CrossRef]
43. Silva, H.E.; Henriques, F.M.A. Microclimatic analysis of historic buildings: A new methodology for temperate climates. *Build. Environ.* **2014**, *82*, 381–387. [CrossRef]
44. Silva, H.E.; Henriques, F.M.A. Hygrothermal analysis of historic buildings: Statistical methodologies and their applicability in temperate climates. *Struct. Surv.* **2016**, *34*, 12–23. [CrossRef]
45. Živković, V.; Džikić, V. Return to basics—Environmental management for museum collections and historic houses. *Energy Build.* **2015**, *95*, 116–123. [CrossRef]

46. Corgnati, S.P.; Fabi, V.; Filippi, M. A methodology for microclimatic quality evaluation in museums: Application to a temporary exhibit. *Build. Environ.* **2009**, *44*, 1253–1260. [CrossRef]
47. Sciurpi, F.; Carletti, C.; Cellai, G.; Pierangioli, L. Environmental monitoring and microclimatic control strategies in "la Specola" museum of Florence. *Energy Build.* **2015**, *95*, 190–201. [CrossRef]
48. Huijbregts, Z.; Schellen, H.; van Schijndel, J.; Ankersmit, B. Modelling of heat and moisture induced strain to assess the impact of present and historical indoor climate conditions on mechanical degradation of a wooden cabinet. *J. Cult. Herit.* **2015**, *16*, 419–427. [CrossRef]
49. Bichlmair, S.; Raffler, S.; Kilian, R. The Temperierung heating systems as a retrofitting tool for the preventive conservation of historic museums buildings and exhibits. *Energy Build.* **2015**, *95*, 80–85. [CrossRef]
50. Caratelli, A.; Siani, A.M.; Casale, G.R.; Paravicini, A.; Fiore, K.H.; Camuffo, D. Stucco panels of Room VI in the Galleria Borghese (Rome): Physical-chemical analysis and microclimate characterization. *Energy Build.* **2013**, *61*, 133–139. [CrossRef]
51. De Backer, L.; Janssens, A.; Steeman, M.; De Paepe, M. Evaluation of display conditions of the Ghent altarpiece at St. Bavo Cathedral. *J. Cult. Herit.* **2018**, *29*, 168–172. [CrossRef]
52. Muñoz-González, C.M.; León-Rodríguez, A.L.; Navarro-Casas, J. Air conditioning and passive environmental techniques in historic churches in Mediterranean climate. A proposed method to assess damage risk and thermal comfort pre-intervention, simulation based. *Energy Build.* **2016**, *130*, 567–577. [CrossRef]
53. Camuffo, D.; Bertolin, C.; Bonazzi, A.; Campana, F.; Merlo, C. Past, present and future effects of climate change on a wooden inlay bookcase cabinet: A new methodology inspired by the novel European Standard EN 15757:2010. *J. Cult. Herit.* **2014**, *15*, 26–35. [CrossRef]
54. Pavlogeorgatos, G. Environmental parameters in museums. *Build. Environ.* **2003**, *38*, 1457–1462. [CrossRef]
55. Fabbri, K. Energy incidence of historic building: Leaving no stone unturned. *J. Cult. Herit.* **2013**, *14*, 25–27. [CrossRef]
56. Pretelli, M.; Fabbri, K. Historic Indoor Microclimate. In *Historic Indoor Microclimate of the Heritage Buildings*; Springer: Cham, Switzerland, 2018; pp. 73–83. [CrossRef]
57. Fabbri, K. The Study of Historic Indoor Microclimate. In *Historic Indoor Microclimate of the Heritage Buildings*; Springer: Cham, Switzerland, 2018; pp. 85–117. [CrossRef]