The moisture issue affecting the historical buildings in the Po valley: A case study approach

Elisabetta Rosina*, Megi Zala, Antonio Ammendola

Department of Architecture, Built Environment and Construction Engineering, Polytechnic University of Milan, Italy

ABSTRACT

This paper deals with the climate related risks associated with the conservation of historical buildings in Po Valley. The aim of this paper is to evaluate the influence of the seasonal/daily variations in the outdoor climate on the indoor microclimate of historical buildings. Seven case studies were identified to monitor and analyse the thermo-hydrometrical variation of air T °C and RH%, followed by a thorough assessment of the buildings with regards to their state of conservation, materials and building techniques, presence of rising damp and intervention for its reduction. The analysis is composed of visual inspections, microclimate monitoring using psychrometry and monitoring probes, Infra-Red (IR) Thermography and weighing tests. The result of the study evaluates the factors affecting the distribution of Water Content (WC) and explores the correlation with factors pertaining to building materials and construction techniques. Curves describing the daily mean values of T °C and RH% for a period of one year have been defined by the authors for each of the historical buildings. The temperature profiles showed similarities with regards to spells of annual peak and plateau across all the case studies. However, the RH% profiles resulted less similar; it has been able to identify some microclimatic characteristics of the Po valley region, which can lead to further research.

Introduction

The aim of this paper is to evaluate the influence of the seasonal/daily variations in the outdoor climate on the indoor microclimate of historical buildings, for assessing the possible risk for their conservation at the climatic conditions of Po valley (Pianura Padana), Italy.

In fact, the variation in T °C and RH% is a potential risk for the conservation of porous materials used in historical buildings. Among the risk factors, the frequent and sharp variations are responsible for damage due to crystallization of salts in the porous materials caused by low RH values, their solubilization and diffusion due to high values of RH, and other phenomena linked to moisture diffusion [1–8].

In addition, the scientific literature does not report a large amount of publication regarding this topic, which is crucial for the maintenance and the conservation plan of the cultural Heritage in that geographical area.

Taking advantage of the availability of annual time series of data collected by the authors, the microclimates of seven historic buildings located in the Po Valley were analysed. The methods and techniques used for data collection and processing follow the normative standard UNI10829 [14]. The innovation presented in the paper is the attempt to analyse the data for getting the common references and factors that could be attributed to the microclimatic characteristics. Moreover, the authors describe the characteristics of the indoor microclimate of the study cases and the relation between outdoor and indoor variations for possibly highlighting which, among the building characteristics, could affect the dependence of indoor climate with the outdoor climate.

Climate characteristics of the study cases

Generally speaking, the case study locations are characterised by similar climate: cold winter (reaching a few degrees below zero), seasonal rain (spring and fall), hot summer (up to 40 °C), limited daily temperature variations in winter and summer (about 5–10 °C), wider daily variation in the other seasons. In the last decades, the amount of annual rain has been around 80 cm, with a monthly amount of rainfall ranging between 30 and 90 mm [9].

At the elevation of the Po Valley, condensation phenomena are frequent only for a limited time of the year. Despite condensation being an important cause of damage, most of the decay is triggered due to the cycles of drying and re-hydration of the surface materials and salt transportation/crystallization. This research observes

* Corresponding author.
E-mail address: elisabetta.rosina@polimi.it (E. Rosina).

and analyses the interior microclimate of the study cases, in comparison with the exterior climate.

Criteria of the building choice

The selection of the case studies was based on their similar properties such as: building size and volume, typology, limited openings, surface materials, building age, elevation and vegetation level.

To analyse the effect of the moisture issue on the historical vernacular buildings, the authors display the microclimate and moisture monitoring in seven study cases in the surroundings and in the city of Milan.

Four of the case studies have similar characteristics, located in the surroundings of Milan area. Three additional study cases are comparable in most of their characteristics (volume, material and techniques of building, openings, building age), nevertheless they are located in the historical centre of Milan and have a heating system working occasionally. The comparison among the seven cases can provide useful insight on the characterisation of the indoor climate of historical buildings for this region.

Description of the case studies

All the study cases have simple volumes: the choice of such a regular shape has reason to avoid any influence due to the articulated volumes/irregular geometry of volumes that can delay the air exchange and affect the distribution of RH.

San Rocco Church

San Rocco Church is in Cornaredo, a commune in the western area of Milan. It was built in the 15th century and it is characterised by solid brick masonry, a main entrance (door) and two small openings. The facade faces the main road of the suburb and the structure is isolated from the urban fabric/settlements [10].

San Giovanni Battista Chapel

San Giovanni Battista Chapel is in Settimo Milanese and dates back to the 13–16th century. The building faces a small square and has the southern side along the main road of the small city. A narrow courtyard that separates the church from the surrounding buildings is along the eastern and northern sides [11].

Santa Maria Assunta Church

Santa Maria Assunta Church is located in Ruginello, a commune in the north-eastern countryside of Milan. It has a set-back distance of about 20 m from the nearest buildings of the settlement. The building dates to the 13–15th century.

Linterno Farmhouse chapel

Linterno Farmhouse, a solid brick masonry building, was built in the 13th century and is an instance of agrestic architecture of the surroundings of Milan. The monitoring is focused on the chapel of the farmhouse, characterized by two entrances and a window. The chapel is incorporated in the court of the farmhouse and it is considered to be the most ancient part of it. The facade faces the main road of the suburb area.

Sala delle Asse, Sforzesco Castle

Sala delle Asse is located in Sforzesco Castle, a medieval fortification and it is considered as one of the most important room in the castle (room VIII in the Museum of Ancient Art). The room is located on the ground floor of the Falconiera Tower (North-east) and it was decorated by Leonardo da Vinci. The castle dates back to the 15th century, it is located in the heart of Milan and is made of solid brick masonry. The complex includes three internal courtyards, it is surrounded by Sempione Park in the north and it faces a main square in the south. Sala delle Asse is oriented North East.

Borromeo Palace

Borromeo Palace is located in the historical city centre of Milan and dates back to the 14th century. The palace has undergone several major modifications through the century and it is characterised by a Gothic style, brick solid masonry, lime mortar and plaster (frescoes) and modern plaster (cement mortar) in some zones. The complex stands in a dense urban fabric in front of a small square and includes two internal courtyards

Grechetto Anteroom, Sormani Palace

Grechetto Anteroom is positioned at the first floor of Palazzo Sormani, at the end of the stairway called “Scala d’Onore”. It was built in the 16th century and it is characterized by solid brick masonry. Its name is due to the Hall next to it (Grechetto Hall), in which was exposed the cycle of paintings that represent the so called “Mito di Orfeo” of the Genuese painter Giovanni Benedetto Castiglione, better known as “Il Grechetto”. The entrance to the Grechetto Anteroom is isolated from the main entrance that faces a small garden and it is west oriented.

An illustration of the case studies and their proximity to the city of Milan is shown in Fig. 1.

The small churches (San Rocco Church, San Giovanni Chapel, Santa Maria Assunta and Linterno Farmhouse Chapel) show stained and damaged plaster, detachments, missing sections, and presence of cement mortar (rich in soluble salts) due to previous interventions at the bottom of the masonry. The buildings are functional and are used occasionally, typically a few days in a year for special events.

From the initial data and background information, the authors assumed that Santa Maria Church is the only church that has not been subject to any intervention against rising damp.

In fact, in the past decades, in San Giovanni Chapel, a dugout was added and the existing plaster on the foundation was removed and replaced with new water resistant plaster material. Moreover, a ventilated crawl space was added underneath the floor, and waterproof resin was injected in the southern side at about 0,5 m from the base.[1]

In San Rocco Church, the interventions consisted of replastering the exterior and interior walls (at the bottom, below the frescoes), restoring the frescoes, adding a new pavement around the building, and providing a rain collecting system.

Materials and methods

The scenario of changing climate and its consequences on the built heritage constitutes a challenge for the current standard methods for humidity measurements [13], both in the masonry and in the air. Most recurrent methods of measurement exploit the cross-referencing of data from different non-destructive (ND) techniques, with the aim to adopt an extensive qualitative approach for the preliminary tests and to ensure the least destructive application of the quantitative tests on sampling areas/spots such that it results in more significant collection of data and less disfiguring/destroying of the historical materials [14–18].

[1] Technical report of Settimo Milanese municipality office, 2017.

Fig. 1. Location of the case studies [12] and their proximity to Milan city centre.

Table 1
The techniques used for the case studies and the monitoring time.

Study case	IRT	Psychrometry	Weighting test	Years of microclimate monitoring	Number of installed probes
San Rocco Church (Cornaredo)	Seasonal	–	Spring, Autumn	4 years	2
Santa Maria Assunta Church (Ruginello)	Spring, Winter	Seasonal	Seasonal	1 year	3
San Giovanni Battista Chapel (Settimo Milanese)	Seasonal	–	Seasonal	7 years	4
Grechetto Anteroom, Sormani Palace (Milan)	Winter, Spring	Winter, Summer. Autumn	–	1 year	3
Sala delle Asse, Sforzesco Castle (Milan)	Spring	Seasonal	Spring	5 years	8
Linterno Farmhouse Chapel (Milan)	Spring, Summer	Winter, Spring, Summer	Spring, Summer	1 year	4
Borromeo Palace (Milan)	Autumn	Seasonal	Autumn	3 years	8

Owing to the advancement in microclimate monitoring techniques and procedures, fast scan working techniques have a considerable advantage over those techniques that give punctual data back while also requiring a long time for the processing phase. Gathering the documentation about the building, damage location, its evolution over time, the use across years to devise an effective diagnostic plan, remains mandatory, as it is for all other diagnostic techniques. The triage settings include the multispectral analysis (IR,[2] visual photos) on the surfaces of the buildings, weighting test for assessing the water content[3] (WC) for a few selected spots identified through the multispectral analysis, and microclimate monitoring by psychrometry and probes installed for a continuous /periodic recording of air T °C and RH% (using DATALOGGER EasyLog USB-2). These three methods have been used for this study.

Continuous /periodic recording of the surface T °C and RH% or WC facilitates significantly in enhancing testing methods and detecting the amount of dampness due to changes in the air conditions (T °C and RH%). In the presented cases the monitoring of the surface temperature was not applied, due to the lack of surveillance of the sites and security issues pertaining to the same.

The techniques applied to the study cases are resumed in Table 1.

The main analysis focusses on the two case studies (San Rocco and Santa Maria Assunta Church) analysed in the same year (2012). The annual daily average graph of T and RT of these two case studies has been compared with all the other cases.

Despite of the differences in location, year analysed, size of the buildings and orientation, there are many similar characteristics, especially during the late spring- summer. On the other hand, the main differences are registered in late autumn, winter and early spring, as further presented in the next paragraphs.

As a conclusion of this paragraph, the additional study cases brought stronger evidence of the recurrent characteristic of the Milanese climate in terms of:

-identifying the period of the year with higher and lower T and RH.

-months with higher variability of humidity that has been observed as frequent occurrence of such peak in years 2012–2020.

Results and discussion

Since the diagnostics already applied during 2012–2020, rising damp was shown to be the main cause of damage at the bottom of the masonry. However, it was also the case that past instances of water seepage from the roof alongside the critical microclimatic condition caused additional damage to the interior plaster and frescoes.

IRT results

IR thermograms show the presence of a cooler zone at the bottom of the masonry in San Rocco Church. On closer inspection of the surface, it was found that the plaster of the facade was different from the bottom up to the horizontal band above the door. This implies that the differences in temperature were due to the materials instead of the presence of water.

In San Giovanni Chapel, lower temperatures are presented along the plinth level nearby the soil. The temperatures in this section of the masonry are significantly lower than in the rest of the elevation.

The thermography in Santa Maria Church. Borromeo Palace and Sala delle Asse show the texture of the masonry underneath the plaster and the plaster's differences, but no evidence of cooler zone and presence of water.

Linterno Farmhouse Chapel presents lower temperatures along the lower part of the eastern wall, than can indicate presence of rising dump. Grechetto Anteroom shows the presence of a cooler zone on the vault, due to thickness differences. In addition, the thermogram indicates the presence of a possible infiltration that occurs close to the west window.

Gravimetric and psychrometric analysis

The highest values of WC are measured in San Giovanni Chapel, in which the dampness spread reaches the highest elevation level in the masonry (13% up to 20 cm and 11% at 120 cm from the asphalt pavement of the road).

The results of the gravimetric test (Table 2) show that the lower level of water in Santa Maria Church, is possibly due to the structure materials i.e., pebbles. On the contrary, the brick masonry of San Giovanni Chapel, San Rocco Church and Linterno Farmhouse Chapel show higher degree of water content indicating a potential reason for the incremental rise in dampness.

The following Tables 2-4 present the results of the gravimetric and psychrometric tests. Higher values of RH in Santa Maria Church, and higher values of WC in San Giovanni Chapel have been observed.

Because of the highest values found in San Giovanni Chapel, it implies that all the interventions applied have not been effective.[4]

[2] Longwave Infrared Thermal Camera FLIR 640 LW, (LW = 8:14 μm), with spatial resolution of 1.4 mrad, emissivity is 0.92.

[3] Sartorius MA35 thermobalance was used for gravimetric investigations with an accuracy of 0.001 g.

[4] The dugout work was done between June and August 2017 and consisted in: accurate maintenance and cleaning; the construction of the containing walls, insu-

Table 2
Summary of the gravimetric test (values of WC%).

Height of drilling points (cm)	San Rocco Church (Cornaredo) WC%	Santa Maria Assunta Church (Ruginello) WC%	San Giovanni Battista Chapel (Settimo Milanese) WC%	Sala delle Asse, Sforzesco Castle (Milan) WC%	Linterno Farmhouse Chapel (Milan) WC%	Borromeo Palace (Milan) WC%
10 - 20cm	0,7 – 8,6	7,1 – 11,7	0,8 – 13,3	0.5 – 0.6	6.8 – 13.9	1.7 – 2.7
50 - 60 cm	0,5 – 3,3	2,5- 7,1	–			
80 cm	–	1,5–1,8	–	0.4	1.6 – 3.1	
100–110 cm	0,8 – 1,3	0,9 – 1,3	0,3- 11,1			
156–186	4–6	–	–			

Table 3
Summary of temperature T(°C) observations obtained from the seasonal psychrometric measurements.

Seasonal Measurements	Santa Maria Assunta Church (Ruginello) T (°C)	San Giovanni Battista Chapel (Settimo Milanese) T (°C)	Grechetto Anteroom (Milan) T °C	Sala delle Asse, Sforzesco Castle (Milan) T °C	Linterno Farmhouse Chapel (Milan) T °C	Borromeo Palace (Milan) T °C
Winter	7,2 – 11,6	3,3 – 4,5	–	14 – 15.5	10 - 13	19.2 – 21.3
Spring	10,8 – 14,2	12,7 – 15	15 - 21	20.7 - 21	13.8 – 18.6	18.6 – 23.4
Summer	22,7 – 27,7	25,6 – 30,5	25.5 - 28	24.3 – 24.8	22.8 – 26.5	25.5 – 26
Autumn	17,5 – 21,5	18,4 – 20,6	19 – 20.5	26 - 29		24.5 – 25.4

Table 4
Summary of RH% observations obtained from the seasonal psychrometric measurements.

Seasonal Measurements	Santa Maria Assunta Church (Ruginello) RH%	San Giovanni Battista Chapel (Settimo Milanese) RH%	Grechetto Anteroom (Milan) T °C	Sala delle Asse, Sforzesco Castle (Milan) T °C	Linterno Farmhouse Chapel (Milan) T °C	Borromeo Palace (Milan) T °C
Winter	53 – 90	68 – 82		35.5 – 43.5	62 - 77	34 - 39
Spring	61 – 88	66 – 77	39 - 59	61.8 – 63.6	50 - 59	39 - 44
Summer	75 – 87	46 – 60	48.5 – 56.5	32.5 – 34.8	52 - 57	56 – 58.5
Autumn	77 – 82	64 – 72	59 - 63	38.5 – 46.5		60 - 69

This conclusion is to be further verified by carefully inspecting the existing dugout, in the future phases of the research.

On the other hand, Sala delle Asse and Borromeo Palace have registered the lowest WC values among the case studies, within an acceptable range value (Table 3).

Microclimate analysis

The microclimate was monitored using data loggers. Figs. 2-3 represent the annual daily average of T °C and RH%.

On a yearly basis, the indoor median temperatures were higher than the outdoor ones. The outdoor temperatures differed depending on the site with a variability (from −7 °C to 32 °C).

The indoor temperatures for all the case studies showed comparable levels and trends from June to September, except for some sporadic T drops. In cold seasons, Sala delle Asse, Borromeo Palace and Grechetto Anteroom behaved similarly due to the switching on of the heating system that works occasionally, whereas the other buildings experienced lower T. This can also be used to explain the trends during the summer season, in which these buildings registered the lower temperatures.

The lowest temperatures throughout the year are registered in Santa Maria Church (−2 °C), where the highest temperatures result in Linterno Farmhouse Chapel, San Rocco and San Giovanni Chapel reaching 32 °C.

lation of the pvc pipes (20 cm with) for running rainwater into the sewage system addition of the waterproof floor and outlet for the extra flow in the sides, removal of the existing damaged cement-based plaster and re-plastering the foundation with hydraulic lime, to improve the evaporation of moisture in the structure, improvement of the southern eave downspouts,adding the pavement of the pedestrian area around the church and along the bike path. The new stone pavement had a waterproof membrane and a sand and cement bed.

The indoor relative humidity observations were found to be significantly lower than the outdoor ones (Fig. 4b), especially during the Autumn and Winter season. However, in some of the case studies (Linterno Farmhouse Chapel, San Giovanni Chapel and Santa Maria Assunta) the range of RH is registered between 60 and 80% that can be considered higher than the acceptable range.

To demonstrate the dependence of the microclimate on the structure, consider the trend of the graph of the Grechetto and Sala delle Asse with respect to the other case studies:

The variation of RH of the indoor environment of these two case studies are always contained within an acceptable range value (30–65%) despite reaching 80% outdoors (Fig. 4b). However, the RH drop can be associated with T rises caused by the heating system only during the cold season.

On the other hand, the two case studies t (San Rocco and Santa Maria Assunta Church) analysed in the same year (2012) have a RH range difference of 15–20%. San Rocco Church has registered the highest values of the external RH among the case studies; however, the internal conditions present a range difference that goes up to 25% between the outdoor and the indoor environment.

As a conclusion of the discussion, Table 5 summarises the risk factors individuated through the direct experience of the authors and from an extended literature review of the last 20 years [19–23]. Due to rare presence of visitors, the correlated risk has not been a priority in the list.

Conclusions

The proposed method for the study of the microclimate made it possible to confirm the permanence of some microclimatic characteristics in the Po Valley.

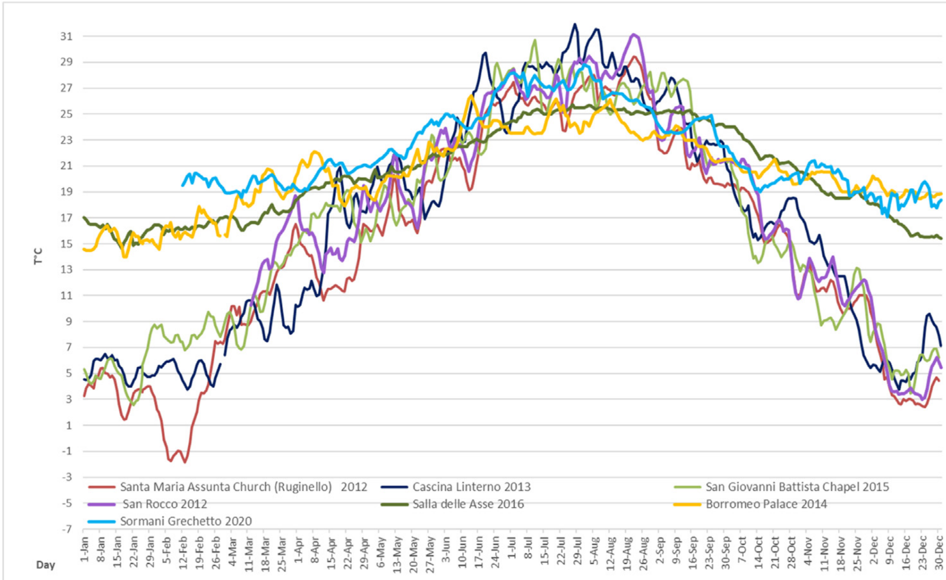

Fig. 2. The annual graph representing the daily air temperature on the indoor environment for the case studies.

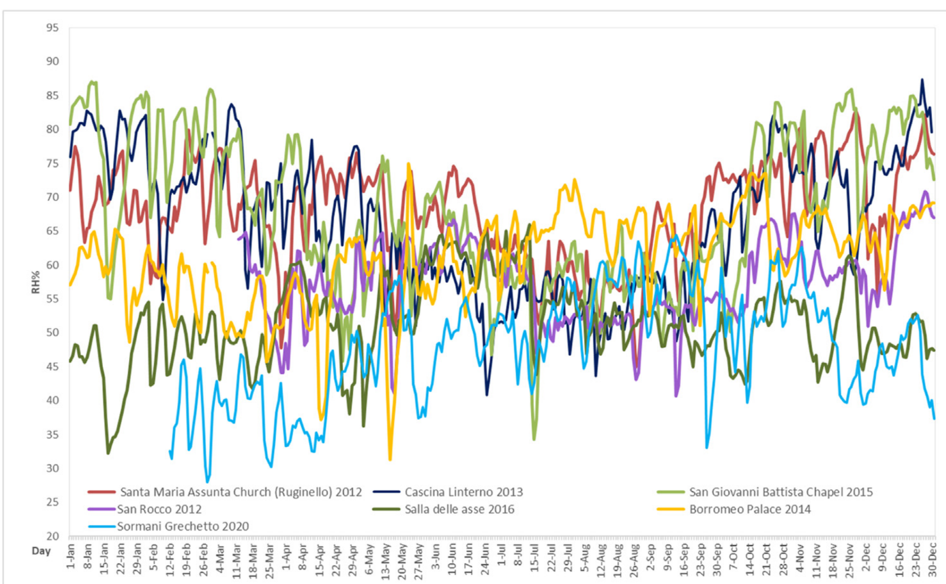

Fig. 3. The annual graph representing the daily relative humidity on the indoor environment for the case studies.

Table 5
Summary of the risk factors.

Risk factors	**San Rocco Church (Cornaredo)**	**Santa Maria Assunta's Church (Ruginello)**	**San Giovanni Battista Chapel (Settimo Milanese)**	**Grechetto Anteroom (Milan)**	**Sala delle Asse, Sforzesco Castle (Milan)**	**Linterno Farmhouse Chapel (Milan)**	**Borromeo Palace (Milan)**
Rising Damp (cm)	156 - 186	52	100	–	–	80	10
Annual Precipitation (mm)	907mm	794mm	907mm	773mm	931mm		1314mm
Solar Radiation	6,89 kW-hr/m²/day	6,89 kW-hr/m²/day	6,89 kW-hr/m²/day	6,89 kW-hr/m²/day	6,89 kW-hr/m²/day	6,89 kW-hr/m²/day	6,89 kW-hr/m²/day
Wind Speed (annual average)	1,3 m/s	2,6 m/s	4,1 m/s	1,2 m/s	1,2 m/s	1,.3 m/s	1,3 m/s
Shading	Not present	Not present	The northern side in winter	The eastern side	The northern side in winter	Not present	The northern side
Sides of the room that are part of the building envelope	6	6	6	2	2	4	3

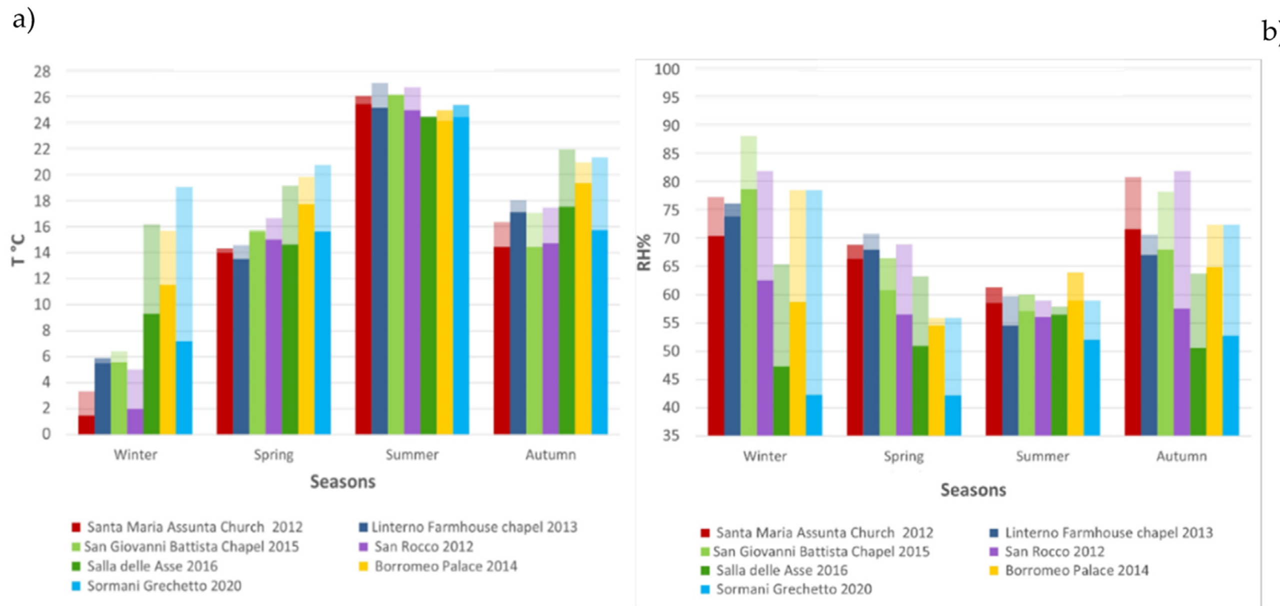

Fig. 4. The average seasonal temperature (a) (outdoor data highlighted in bold colour) and RH (b) (indoor data highlighted in bold colour) of the indoor and outdoor environment for the case studies.

Despite of the urban environment changes that might occur (increasing of urban sprawl, presence of brownfields, decreasing of agricultural areas, emerging of protected areas, urban or *peri* urban parks) are not linked to have a significant effect on the T and RH for the case studies.

The major defects of the historical buildings that the authors report refer to the last 10 years of monitoring and are helpful to pinpoint the main characters of climate.

These characters are substantially high RH (winter- spring- autumn) that is mainly linked to the prolonged rainfalls for several days; the variation of the outdoor T, cause scarcely decreases of the indoor T apart from the cases in which the buildings are subject of frequent openings, frequent use of minor activities.

Although the rising dump is present in many of the case studies, the high values of RH are mainly linked to the outdoor RH. In the cases of “encapsulated” rooms, the building surrounding the room has the ability to mitigate the variations and to improve and guarantee a more balanced microclimate inside the monitored rooms. More than the difference between RH_{ind}- RH_{out}, for the building is important to consider the time required for these differences to be reflected in the indoor environment.

It can be said that the presence of a heating system reduces the risk factors during the cold months. However, it can expose the building to greater microclimatic imbalances between the outdoor and the indoor environment when the system is switched on and off. The heating system can play a significant role in mitigating microclimate unbalances, but it cannot be considered as essential.

The assessment of the humidity levels inside a building with the aim of evaluating the effects for conservation, can be considered a recent scientific acquisition (of the last 30 years). And thus, despite being a defused practice it is still disregarded in several current practices.

For the ancient buildings, the morphology can be considered more important than the heating system. Therefore, to keep a balanced microclimate, it can be concluded that the parameters most affecting the microclimate variation are the articulation of the building itself and the main protection it provides for the indoor environment. By analysing different risk factors, it was observed that the embedded characteristics of the room certainly represents a mitigation factor since it acts as insulation.

Limitation of the study and recommendations for further studies

The study is based on the comparison of seven buildings. Despite that this comes as a limitation, it can be said that a limited number of studies have been found in literature for the Po Valley region, for a period of not more than 1 year.

From the diagnostic point of view, the paper presents innovative diagnostic methods accepted by national standards [14–18]. Further data was collected by diagnostic methods and can help developing the research further.

This article is a first step in identifying the microclimatic characteristics of the Po Valley. Additional research could lead to defining the characterization of the recurring climatic parameters with an assessment of the frequency of occurrence and its relationship with observed damages.

Author contributions

All authors have read and agreed to the published version of the manuscript.

CRediT authorship contribution statement

Elisabetta Rosina: Conceptualization, Methodology, Writing – review & editing, Writing – original draft. **Megi Zala:** Formal analysis, Investigation, Writing – review & editing. **Antonio Ammendola:** Formal analysis, Investigation, Writing – review & editing.

Acknowledgments

We thank Settimo Milanese Municipality and the technical office arch. Sara Trulli and eng. Marco Baldassare for their assistance in the data gathering 2014–2021.

References

[1] S. della Torre, Italian perspective on the planned preventive conservation of architectural heritage, Front. Archit. Res. 10 (2021) 108–116, doi:10.1016/J.FOAR.2020.07.008.
[2] S. Della Torre, E. Rosina, Rapid techniques for monitoring historic fabric in preservation plan, in: P. Tiano, Pardini (Eds.), in Situ Monitoring of Monumental Surface, ICVBC, 2008 ISBN 9788879703901.

[3] M. Ricci, S. Laureti, H. Malekmohammadi, S. Sfarra, M. Melis, G.L. Agresti, C. Colantonio, G. Calabrò, C. Pelosi. Multi-spectral and thermography imaging techniques for the investigation of a 15th century wall painting. (2020). https://doi.org/10.21203/rs.3.rs-97372/v1.
[4] J.L. Nguyen, J. Schwartz, D.W. Dockery. The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity, (2013). https://doi.org/10.1111/ina.12052.
[5] D. Coley, T. Kershaw, Changes in internal temperatures within the built environment as a response to a changing climate, Build. Environ. 45 (2010) 89–93, doi:10.1016/J.BUILDENV.2009.05.009.
[6] J. Leissner, R. Kilian, L. Kotova, D. Jacob, U. Mikolajewicz, T. Broström, J. Ashley-Smith, H.L. Schellen, M. Martens, J. van Schijndel, F. Antretter, M. Winkler, C. Bertolin, D. Camuffo, G. Simeunovic, T. Vyhlídal, Climate for culture: assessing the impact of climate change on the future indoor climate in historic buildings using simulations, Herit. Sci. 3 (2015), doi:10.1186/s40494-015-0067-9.
[7] C. Sabbioni, P. Brimblecombe, C. Cassar, The Atlas of climate change impact on European Cultural Heritage, Scientific Analysis and Management Strategies, Anthem Press, London/New York, 2012.
[8] Climate change 2007: impacts, adaptation and vulnerability, in: M. Parry, O.C anziani, J. Palutikof, P. van der Linden, C. Hanson (Eds.)Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Published for the Intergovernmental Panel on Climate Change, Cambridge University Press, New York, NY, USA, 2007.
[9] Clima, Condizioni Meteo Per mese, Temperatura Media Milano (Milano, Italia), Weather Spark, 2021 https://it.weatherspark.com/y/62545/Condizioni-meteorologiche-medie-a-Milano-Italia-tutto-l%27anno Accessed September 2, 2021.
[10] Comune di Cornaredo. Ambito di Trasformazione AT 3 (ex AT 7) Fase Proposta di Piano Attuativo D.02.b Relazione Geologica /Idraulica. (2020) Available online: URL https://comune.cornaredo.mi.it/wp-content/uploads/2021/02/D.02.b_Rel-geologica.pdf (accessed on 06.09.2021).
[11] Oratorio Mantegazza (San Giovanni Battista) di Cascine Olona a Settimo Milanese , Milano nei Cantieri dell'Arte. Milanoneicantieridellarte.it. http://www.milanoneicantieridellarte.it/interventi/400-500/oratorio-mantegazza-san-giovanni-battista-di-cascine-olona-a-settimo-milanese. (2021). Accessed September 10, 2021.
[12] Google Earth Pro MapSite. Image Landsat Copernicus. Available online: https://earth.google.com/web/(accessed on 15 July 2021).
[13] E. Rosina, When and how reducing moisture content for the conservation of historic building. A problem-solving view or monitoring approach? J. Cult. Herit. 31 (Supplement) (2018) S82–S88, doi:10.1016/j.culher.2018.03.023/.
[14] UNI 10829Works of Art of Historical Importance - Ambient Conditions or the Conservation - Measurement and Analysis, Ente Nazionale Italiano di Unificazione (UNI), 1999.
[15] UNI EN 13187Thermal Performance of Buildings - qualitative detection of Thermal Irregularities in Building Envelopes - Infrared Method, Ente Nazionale Italiano di Unificazione (UNI), 2000.
[16] UNI 11085Cultural Heritage - Natural and Artificial Stones - Moisture content determination: Gravimetric method, Ente Nazionale Italiano di Unificazione (UNI), 2003.
[17] UNI EN 16714-1Non-destructive Testing - Thermographic Testing - Part 1: General Principles, Ente Nazionale Italiano di Unificazione (UNI), 2016.
[18] E. Rosina, A. Sansonetti, San Rocco Church: a typical ancient structure in Northern Italy. Technical focus: moisture evaluation techniques. The American Society for Nondestructive Testing, Mater. Eval. 69 (1) (2011) 33–40.
[19] P. Carroll, E. Aarrevaara, Review of potential risk factors of cultural heritage sites and initial modelling for adaptation to climate change, Geosciences 8 (9) (2018) 322, doi:10.3390/geosciences8090322.
[20] A. Kaslegard, Climate change and cultural heritage in the Nordic Countries, Tema Nord 2010:599 (2011) 9–18 ISBN 97-92-893-2195-2.
[21] H. Phillips, The capacity to adapt to climate change at heritage sites—the development of a conceptual framework, Environ. Sci. Policy 47 (2015) 118–125, doi:10.1016/J.ENVSCI.2014.11.003.
[22] G. Forino, J. MacKee, J. von Meding, A proposed assessment index for climate change-related risk for cultural heritage protection in Newcastle (Australia), Int. J. Disaster Risk Reduct. 19 (2016) 235–248, doi:10.1016/J.IJDRR.2016.09.003.
[23] D. Camuffo, Microclimate for Cultural Heritage Measurement, Risk Assessment, Conservation, Restoration, and Maintenance of Indoor and Outdoor Monuments, 3rd ed., Elsevier, 2019 ISBN 978-0-444-64106-9.