The moisture issue affecting the historical buildings in the Alps region

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Abstract

This paper deals with the climate-related risks associated with the conservation of historical buildings in the Alps region. The aim of the paper is to build the microclimatic curve of the T°C (temperature) and RH% (Relative Humidity) daily average in different locations (at a similar altitude in the same valleys), compare them against each other and also to the microclimatic curves obtained in the Po valley [3]. The case studies in Valtellina and Val Poschiavo Valley were identified to monitor and analyse the thermo-hydrometrical variation of air T°C and RH%, followed by a thorough assessment and documentation of the buildings (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. The result of the study explores the correlation with factors pertaining to building materials and construction techniques, the climatic and microclimatic characteristics. 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.

Keywords: cultural heritage, building conservation, microclimate monitoring, non-destructive techniques, historical building, preservation risk, ancient masonry.

Introduction of the case studies

The study presents four case studies located in the Alps region focus on evaluating and comparing the microclimatic conditions, including T°C and RH%. Additionally, this research explores the comforting aspects related to the location, building type, structure, elements, orientation, use, and altitude of each site. By investigating the microclimatic data, we aim to gain a deeper understanding of the indoor environmental behavior provided by these structures and identify the influence of various factors on the microclimate. The comparative analysis of temperature and relative humidity profiles across the sites allows for a comprehensive assessment of their thermal performance and humidity control strategies. By combining empirical data with the analysis, this study contributes to the understanding of how these can achieve the best comfort and preservation conditions [1, 2; 4-13]. As additional reference, we quote the standards in use for the measures: UNI 10829/99, UNI EN 16714-1/16.

San Romerio church, Brusio

San Romerio Church is located atop a mountainous ridge above the Poschiavo lake at 1.800 msl. The church features a compact, small and simple building structure, it has a unique nave, a crypt at the underground level, few small windows, and the belltower in its northern side. The church was restored in the 17th century and later in 1951-53. It is primarily constructed using local stone materials, plastered walls and some fresco remains in the northern interior wall. The church is oriented to face the south and its strategical locations expose the building to thermohydrometric conditions possibly critical, posing it to serious conservation issues.

Visconti-Venosta Palace, Tirano

The palace is in the historical heart of Tirano at an altitude of 440 m, in a dense low/ medium-rise urban form. From the analysis of stylistic features, the building dates to the 15th century and it went through different construction stages in the 18th century. The building is constructed with continuous masonry (stone), consisting of three full floors with vaulted ceilings on the ground floor, basement, and attic. The building has not been in used since 1985, showing noticeable absence of significant restoration processes.

Semadeni Palace, Poschiavo

Semadeni palace is part of a historical complex in

Site/building characteristics	**San Romerio Church**	**Visconti-Venosta Palace**	**Semadeni Palace**	**Besta Palace**
Building Materials	continuous masonry (stone)	continuous masonry (stone)	continuous masonry (stone)	continuous masonry (stone)
Construction date	17th century	15-18th century	19th century	15th century
Building use	Occasionally used during summer-autumn	Not in use	Not in use	In use by visitors
Elevation level	1800 m	440 m	1014 m	900 m

Tab. 1 Summary of the characteristics of the case studies.

Fig. 1 Image of the case studies: San Romerio church, Tirano (Brusio, Switzerland); Visconti Venosta palace, Tirano, Italy; Semadeni palace, Poschiavo, Switzerland; Besta palace, Teglio, Italy (left to right).

Poschiavo (at an altitude of 1014 m), built in the second half of the 19th century. It is included in the Inventory of Swiss Settlements to be Protected of National Importance (ISOS) and is on the List of Historic Gardens of Switzerland (ICOMOS). The building is constructed with continuous masonry (stone), consisting of a semi-basement, of three floors, and an attic. It is an almost metropolitan urbanization complex in its basic concept, with an orientation that maximizes natural light and heat gain, taking advantage of the sun path along its façade.

Besta Palace, Teglio

The palace is a significant historical site that was constructed during the 15th century and later transformed into the most important Renaissance court in Valtellina. It is in Teglio (So), at an elevation of 900 m. The building is constructed with continuous masonry (stone), consisting of three floors, with a central cloistered courtyard. The courtyard elevations and the upper floors are frescoed. Since1927 the palace opened to the public as a museum, and it has been subject to several restoration processes.

Methodology

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 [13].

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 main analysis focusses on the four case studies (San Romerio church, Visconti-Venosta Palace, Semadeni Palace and

Besta Palace) analysed in the same year (2022). The annual daily average graph of T°C and RH% of these case studies has been compared with all the other cases. Despite of the differences in location, size of the buildings, orientation there are many similar characters, 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. Statistical analysis was used for comprehending the T°C and RH dynamics in historical buildings: it enabled the identification of trends, variables, and correlations, shedding light on the factors influencing indoor microclimates. Probability density function (PDF) analysis was used to analyse the indoor climate data due to its ability to provide valuable insights into the statistical distribution of variables parameters such as T°C, RH%. By calculating the PDF, it was able understand the frequency and likelihood of different values occurring within a given range. This information is crucial for assessing the variability and stability of indoor microclimates, as well as identifying potential risks and hazards. PDF analysis allows to determine the most probable values and the spread of data around those values. It helps in understanding the central tendencies, such as mean, median, and mode, which are important for establishing reference values and setting appropriate environmental conditions and therefore quantitatively comparing the case studies. Furthermore, statistical analysis facilitates the identification of correlations between T°C and RH%. The correlation coefficient for T°C and RH was calculated to assess the similarities between buildings/indoor microclimate case studies. The correlation coefficient measures the strength and direction of the linear relationship between two variables. It quantifies the degree to which changes in one variable correspond to changes in another.

Results and discussions

The microclimate was monitored using data loggers. Fig. 2 (a,b) represent the annual daily average of T°C and RH%. The indoor temperature data represents the conditions within a controlled environment. The absence of heating systems or other climate control system in all the case studies reveals a significant dependency on the outdoor environment for indoor temperature regulation. As expected, San Romerio church exhibits consistently lower indoor temperatures throughout the year, ranging from -1°C to 21°C. This finding confirms the lapse rate phenomenon observed in the alpine region, wherein temperature decreases with increasing altitude. The indoor environment of San Romerio experiences temperatures between 4°C to 8°C lower compared to the other buildings, further validating the impact of altitude on temperature differentials within the alpine setting. Visconti-Venosta and Besta palaces exhibit similar temperature patterns throughout the year, with the highest values occurring during the summer season, ranging from 20°C to 29°C. This can be attributed to factors such as limited window openings in Visconti-Venosta palace or the influx of visitors in Besta palace. Additionally, the presence of urban form in these case studies may contribute to the observed temperature trends. In contrast, Semadeni palace demonstrates greater temperature stability during the cold seasons. This stability can be attributed to the construction of the building and its non-utilization, which effectively regulate the internal temperature by reducing heat exchange with the external environment. The annual indoor RH% graphs unveil discernible and distinct patterns. In the cases of San Romerio, Visconti-Venosta Palace, and Besta Palace, RH exhibits seasonal fluctuations that closely align with the outdoor humidity trends. San Romerio and Visconti-Venosta Palace consistently demonstrate elevated RH% values ranging from 40% to 90% during

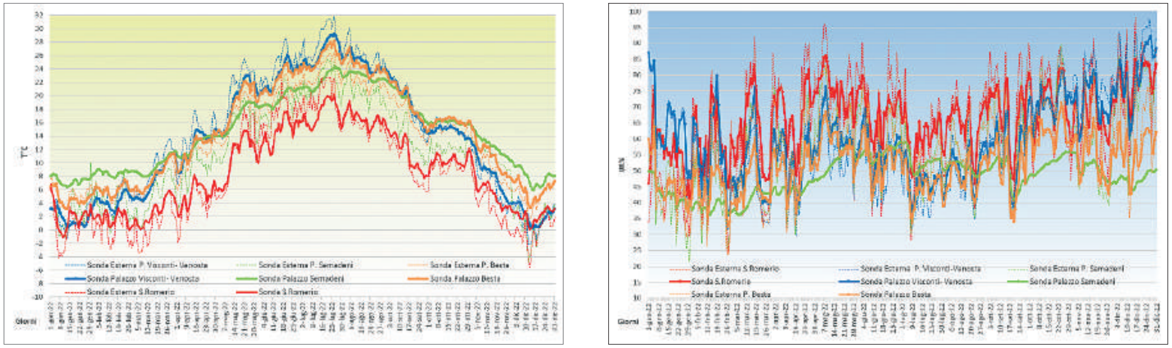

Fig. 2 a) The annual graph of the daily average tempratures for the case studies; b) The annual graph of the daily average RH% for the case studies.

the spring, autumn, and winter seasons. However, there exists a discrepancy of approximately 10% between the indoor and outdoor environments throughout the year, underscoring a notable exchange rate between these two domains. Notably, San Romerio Church records the highest RH% values during the summer season, ranging from 50% to 87%. Of particular significance is Semadeni Palace, as it stands out from the other locations due to its relatively stable RH% levels throughout the year. This stability is likely attributed to the non-utilization of the building, which effectively regulates the exchange of heat and humidity with the external environment. Besta Palace exhibits higher RH% levels during the cold seasons, primarily resulting from moisture infiltration, while lower RH% levels are observed during the warm seasons due to enhanced ventilation and the influx of visitors. These observed patterns shed light on the influence of outdoor climate, building materials, and ventilation on the dynamics of indoor RH% in the absence of central heating.

Conclusions

Looking at the annual graph of T°C, the strong correlation between temperature and altitude in the alpine region can be attributed to several factors. Firstly, the lapse rate phenomenon, which describes the decrease in temperature with increasing altitude, is prevalent in mountainous areas. Secondly, the alpine region often experiences similar weather systems and atmospheric conditions across different altitudes. This coherence in weather patterns, such as temperature inversions or temperature fluctuations due to regional wind patterns, valley orientation or exposure to solar radiation can help maintain the strong correlation between temperature and altitude.

These findings contribute to our understanding of the complex interplay between altitude and temperature in alpine environments and have implications for climate studies, ecological research, and regional planning in these unique and dynamic landscapes.

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