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MICROCLIMATE MONITORING OF HISTORICAL BUILDINGS: THE CASE STUDY OF SAN ROMERIO CHURCH (ITALY)

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Abstract

At present, few studies have been published on the microclimate monitoring for the conservation of the Cultural Heritage (CH) in the Retic Alps. The present paper deals with the analysis performed on Saint Romerio church, located on the border between Switzerland and Italy. The analysis was carried out using three non-destructive methods: infrared thermography (IRT), psychrometric and microclimate monitoring. The monitoring objectives are evaluating the thermo-hygrometric imbalances naturally occurring inside the building, and establishing the threshold values of Temperature and Relative Humidity that allow the optimal conservation of the building.

The microclimate data processing resulted in obtaining the annual curve of the daily average of air T°C and RH% inside the building, in comparison with the outside climatic data.

The analysis of the curve deals with the shape (minimum, max values of T°C, date and lasting of the top plateau, the trend of the seasonal increasing/decreasing) in one year, its repeatability in comparison with some other series (although incomplete) recorded in other years.

Keywords: Microclimate, Cultural Heritage, Alpine Region, Humidity, Temperature, IR Thermography, Monitoring, Building Conservation.

1 INTRODUCTION

Microclimate monitoring is mandatory for assessing the environmental and usage-related risks in considering the preservation of Cultural Heritage. Several studies have been carried out on historical buildings in the last decades [1-3]. However, only a few of these pertain to the settlements situated at 1500 m asl in the Retic Alps.

On the contrary, the authors suggest that phenomena such as the increase in Temperature and decrease of the amount of rainfall for the Alps region [4] is to keep under a long-term monitoring [5]. For that, a primary focus on non-destructive techniques is necessary to accomplish these objectives, with the aim to avoid analysis on the historical materials that could require sampling.

This study aims to present the results of monitoring the microclimate of the San Romerio church at 1800 m asl, one of the most representative historical building in the Alps region between Italy and Switzerland. The Romanesque church dating back from 1000 AC and it is an important landmark [6] located on the edge of a precipice along the historical medieval route at mid-valley, that runs in Valtellina and Val Poschiavo.

The analysis deals with the data of three non-destructive methods for investigation: infrared thermography (IRT), psychrometric, and microclimate monitoring by probes. The monitoring objectives are evaluating the thermo-hygrometric imbalances naturally occurring inside the building, and establishing the threshold values of T°C and RH% that allow the optimal conservation of the building.

These methods help to identify and evaluate the minimum and maximum values, daily variations and to calculate the daily averages and imbalance in T°C and RH%, as well as to locate the presence of moisture in the walls. The obtained analysis is of particular importance for informing guidelines on the conservation of similar building typologies in the Alps, in the context of the climate variation.

Study case

San Romerio Church is located on a sheer mountain above the Poschiavo lake with a particular position and legal status. The building is owned by Tirano municipality, but it is located in Swiss territory. This particular national belonging of the church dates back to the middle age, as shown in the historical documentation[1] [7].

Due to the church location on a cliff and at an elevation that exposes the building to thermo-hygrometric conditions possibly critical, it is posed to serious conservation issues (Figure 1).

The church was restored in the 17th century and later in 1951-53, after that a lightning hit the tower. The entrance is through a small open porch from the eastern side of the building. The building has a unique nave, a crypt at the underground level, few openings: a small window is on the southern side of the apse, another one on the western side of the nave. At present, the two windows are kept open, for ensuring the ventilation inside the church.

An additional room is on the southern side, which originally could have been the ossuary. This space has not opening apart from the small door that is in the entrance from the nave of the church

The interior walls are plastered (some remains of a fresco are on the northern side), as well as mainly the exterior. The bell tower is located along the northern side of the nave, at a higher level. Outside, the bottom of this side of the church is underground because of the slope of the earth surrounding the building.

A dugout is along the nothern side. Large, thin stones constitute the roofing system, typical of the region. The double pitch roof has the drainage system inside, the roof is on sight.

Figure 1: Photo of San Romerio Church.

[1] A bishop's document from March 1237 reports of a union of San Romerio and Santa Perpetua churches, both belonging to Tirano jurisdiction. The union was confirmed by the Pope Innocenzo IV later on in 1252. After almost three centuries later, in 1517 the two churches were united under the sanctuary of Saint Mary church of Tirano and consequently, recognizing the property rights to the Municipality of Tirano.

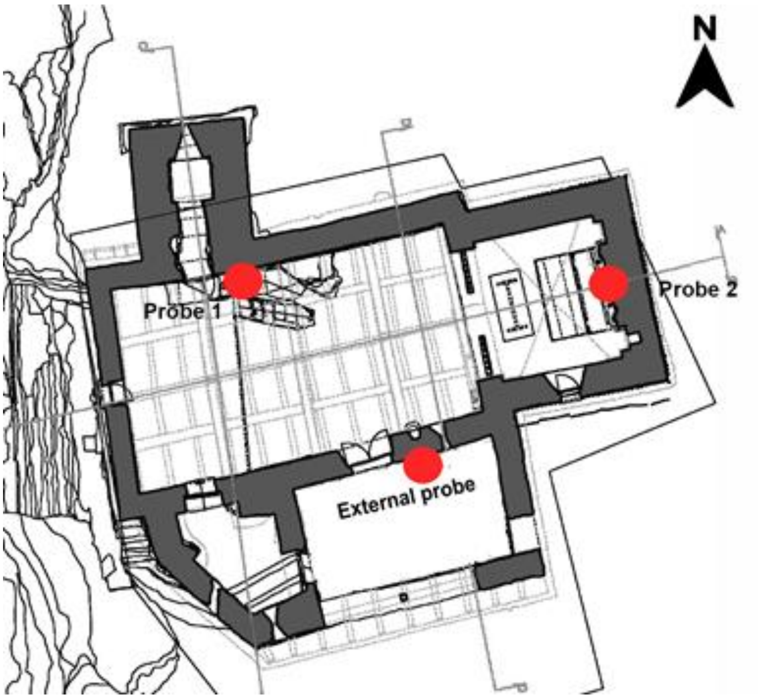


Figure 2: The plan of the probe location.

The church is reachable by the main road and walkable track only from June to October. During the winter the church remains isolated, because of the snow accumulation along the path and the risk of avalanche making the walk very challenging. That isolation, the elevation and the peculiar jurisdiction between Italy and Switzerland affected the possibility to regularly maintain, manage, use the building. For improving its conservation and valorization, the church was included in the EU project "La Conservazione Programmata nello spazio comune Retico" 2013-15, with the aim also of promoting the effective collaboration Switzerland-Italy in the interdisciplinary research for the conservation of the national heritage of the area.

The collaboration produced the most urgent analysis and emergent intervention, as the strengthening of the rampant arch at the base of the church along the cliff (western side), which was under the risk of collapse.

METHODOLOGY

The strategy of the investigation aimed to obtain a scan of the thermal anomalies on the building surfaces (interior and exterior) during the summer, when the higher thermal imbalance occurs every day due to the high solar irradiation and the cool Temperature at night.

The IRT was applied by passive approach inside, and during the heating phase outside (the eastern and southern sides were under solar irradiation; in addition, all the walls were under natural convective heating due to the natural rate of the daily Temperatures). The IR Thermography has been done on May 26, 2021[2].

The microclimate monitoring, by psychrometry and data logger, aimed to obtain the trend of the air T°C and RH% inside and outside the church. The psychrometric measurements were repeated seasonally, to ascertain the differences in T°C and RH% inside/outside the building.

The data monitoring started on July 2020 and it is yet ongoing. Four data loggers are located inside and outside (Figure 3-5). The rate of data acquiring is hourly.

[2] Enviromental data of the IRT session (26 may, h 11:00): T°C indoor: 23,5°C, T°C outdoor: 22,6°C; RH% indoor: 59-67%, RH% outdoor: 48,9%

Figure 3: Location of the external probe (south-western wall. outside).

Figure 4: Location of the internal probe, behind the altar (south-western wall inside).

Figure 5: Location of the internal probe, placed on the truss.

The data loggers have been installed on October 2020. Monitoring will last 18 months. These modalities are commonly accepted, as the standard confirms [8-10].

2 RESULTS

This paragraph shows the thermographic images and the trend of the microclimatic monitoring in the first year of measuring (up to 30 June 2021).

Generally speaking, the IR Thermography shows thermal anomalies outside, due to the solar irradiation and inside, especially at the bottom of the western side and in a spot at about 2 m from the floor.

In addition, some images show the presence of warmer areas (Figure 6, blue squares) that indicate the possible delamination of plaster. In paragraph 2.1.1, more details are explained.

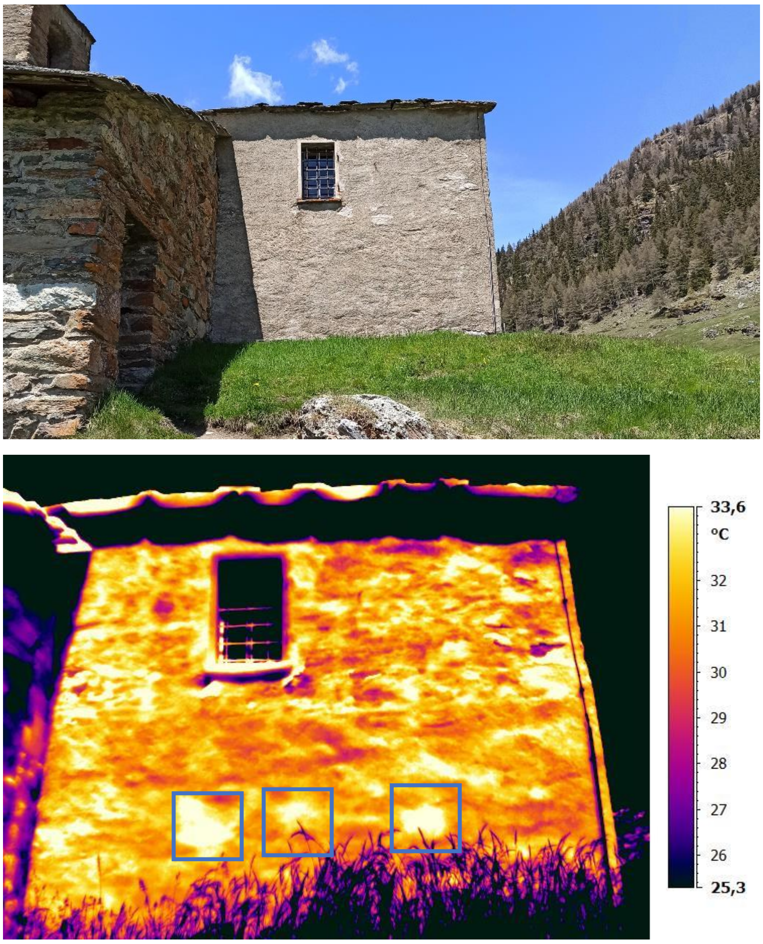


Figure 6: Photo and IR Thermogram composite of the south-eastern side, the apse

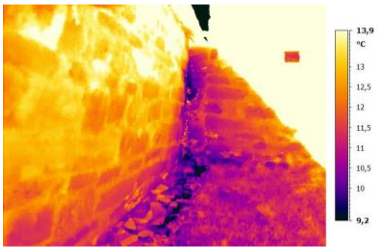
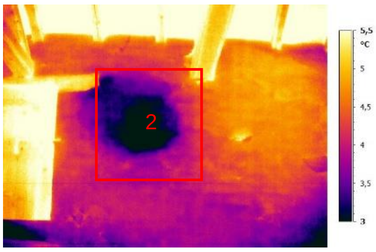
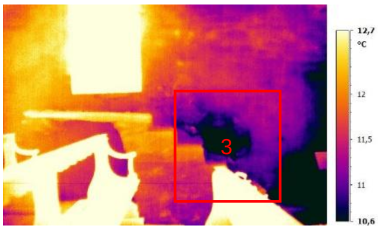
The result of the microclimate monitoring is a similar trend of the gathered data from the three probes inside, although located in different parts of the church. The measured values of RH% range between 45 and 82%, which are considered higher than the optimal ones for the conservation of the historical surfaces of the materials in the site. The few variations are synchronous with the larger external ones, in case their duration is of one day or more.

In the following, the paragraph 2.1.2 shows the observed differences, and the final discussion introduces the possible causes and correlation with the assessment of the risk factors for the conservation of the historical materials.

2.1.1 IRT results in detail

The following Figures resume the results of the IRT session made on 26 May.

Figure 7-8 from the top left, clockwise: (column a) The photo of the exterior (north-western side) and related thermograms, (column b) the photo of the interior and thermograms. Environmental condition: T°C indoor: 23,5°C, T°C outdoor: 22,6°C; RH% indoor: 59-67%, RH% outdoor: 48,9%

 *(7)*	 *(9)*
 *(8)*	 *(10)*
(Column a)	 (11) *(Column b)*

In the Column a, Figures 7 and 8 show the thermography of the junction between the north-western wall and the bell tower. A colder zone is detectable between the wall and the bell tower (in the red squares). At the registered environmental condition, the thermogram shows colder areas where moisture is present on the surface. Moreover, the thermogram shows a colder zone also in the dugout at wall foot that can indicate the presence of water stagnant in it (Column a, Figure 8).

Inside, the thermographic analysis of the north-western wall shows several colder areas, especially near the door of the bell tower (Column b, Figures 10 and 11, red squares). The colder area is due to a water infiltration in the junction of the roof and the bell tower (Column a, Figure 7). The thermography has been done after some days of rain (the day before the recapture, rain level reached 25 mm), therefore the difference of the surface Temperature could be caused by the water spreading in the structure in that spot, as well as its evaporation on the surface under recapture.

The figure 12 shows the graph of the amount of rain in May: numerous and intensive precipitations occurred between 11 and 13 May (40 mm of rain).

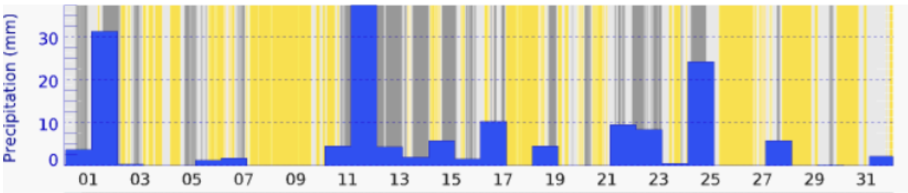


Figure 12: Precipitation data for May 2021 [11-12].

2.1.2 Analysis of the psychrometric maps

The psychrometric data acquiring was carried out at different times of the same day (morning and afternoon) to verify the distribution of the air T°C and RH% inside the building (Figure 13 and 14).

As shown in Figure 13, the distribution of the air Temperature can be considered relatively homogeneous in the morning and afternoon; the maximum Temperature difference is 1°C in the morning and 1,5°C in the afternoon. From the morning to the afternoon occur a Temperature variation of 1°C. The lowest Temperature in the morning is registered near the bell tower.

The areas that are most affected by the T°C and RH% of the external environment are nearby the entrance, ossuary and bell tower, where the air exchange with outside is higher due to the presence of the openings.

In the morning, the location of the most humid air mass is close to the bell tower. During the afternoon, the distribution of the air T°C and RH% is more homogenous despite T°C increases in the western side of the church, due to the solar radiation hitting the western masonry.

However, it can be observed that the external conditions do not have a strong influence on the internal conditions within a short period. In fact, even if from the morning until afternoon the Temperature has had an increment of about 1°C (also the span is 1°C wider than the morning) the RH% remains almost the same and does not have a strong dependence on the external conditions. This indicates that this particular building facilitates the balance of the microclimate, that prevents the damage of porous material.

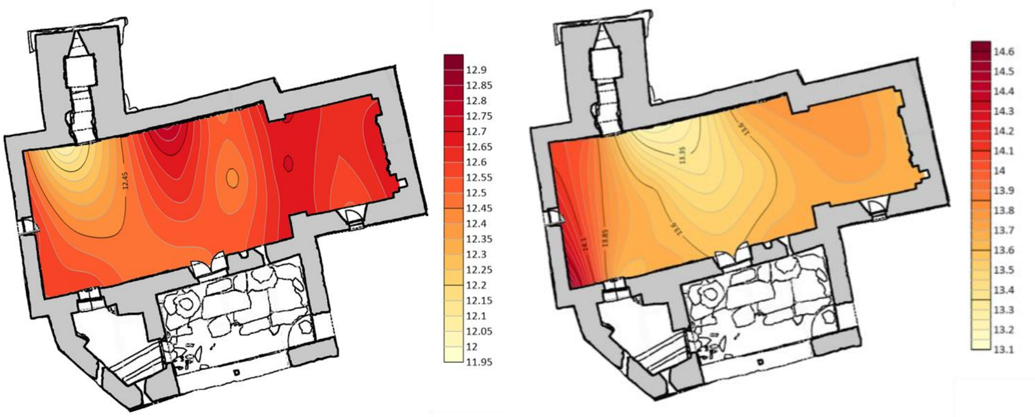


Figure 13: Psychrometric maps of T°C? in the morning (a) and afternoon (b).

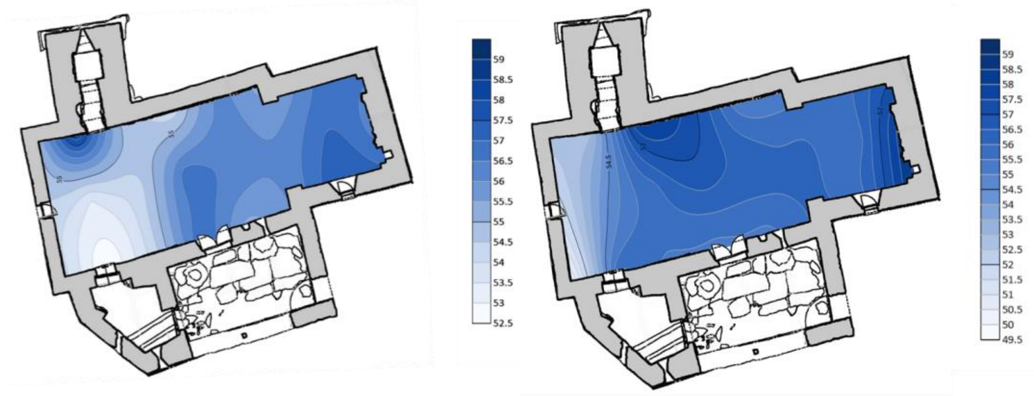


Figure 14: Psychrometric map of RH% in the morning (a) and afternoon (b).

- *Table 1: Summary of the psychometrical results*

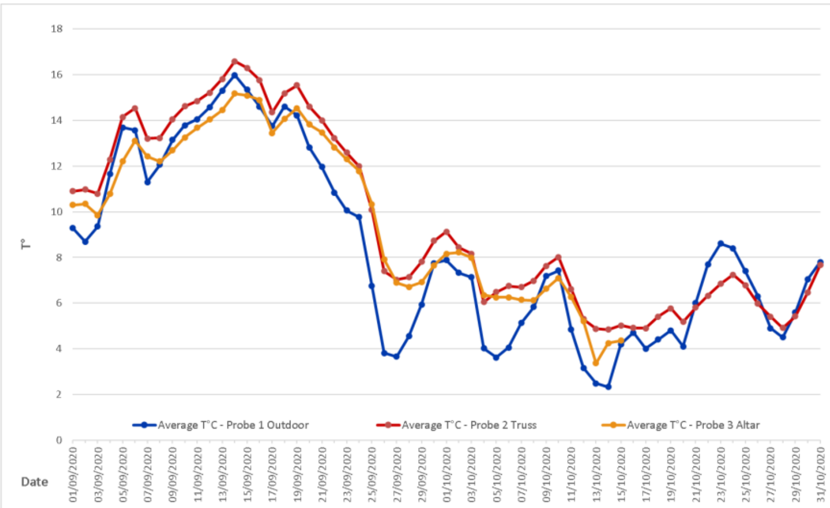
	T°C	RH%
Morning	12 - 13	50 - 59
Afternoon	13 - 14	53 - 59

External conditions:

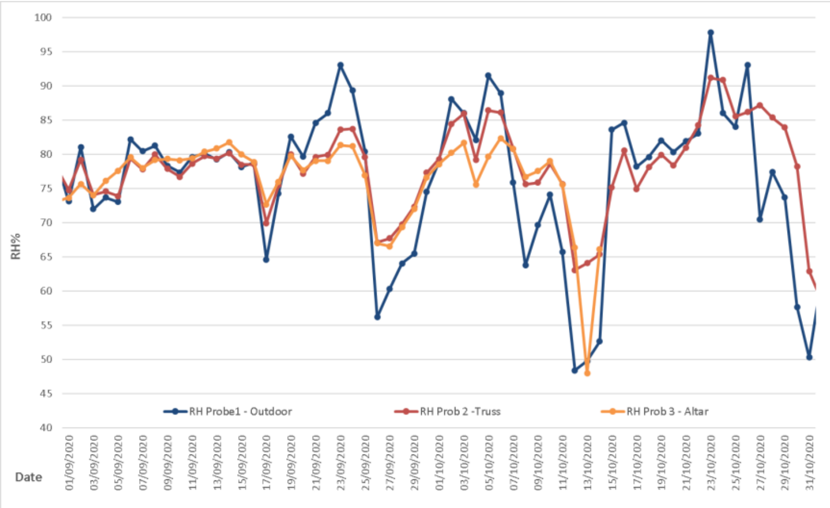
- Morning (at 10:00): T°C = 12,4°C, RH% = 59%
- Afternoon (at 15:30): T°C = 15°C, RH% = 45%

2.1.3 *Analysis of the monitoring by probes*

Figure 15 and Figure 16 present the daily variation of T°C and RH% in Autumn 2020 (September-October) and Spring 2021 (April-May). For the outdoor conditions, the values of RH% range 57-97% during the Autumn and 36-96% during the Spring. Moreover, inside the church, the values of RH% range 64-92% during the Autumn, and 46-86% during the Spring. Overall, the graphs show higher daily average values of T°C and RH% during the Autumn than in Spring.

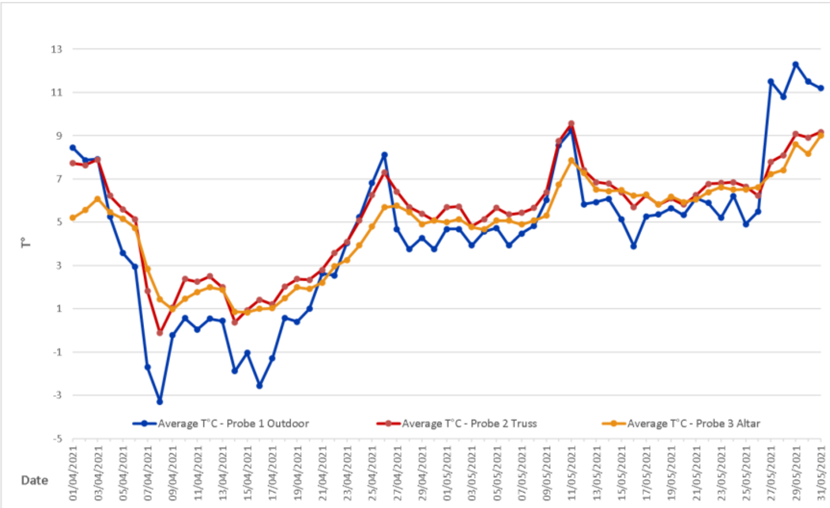


(a)

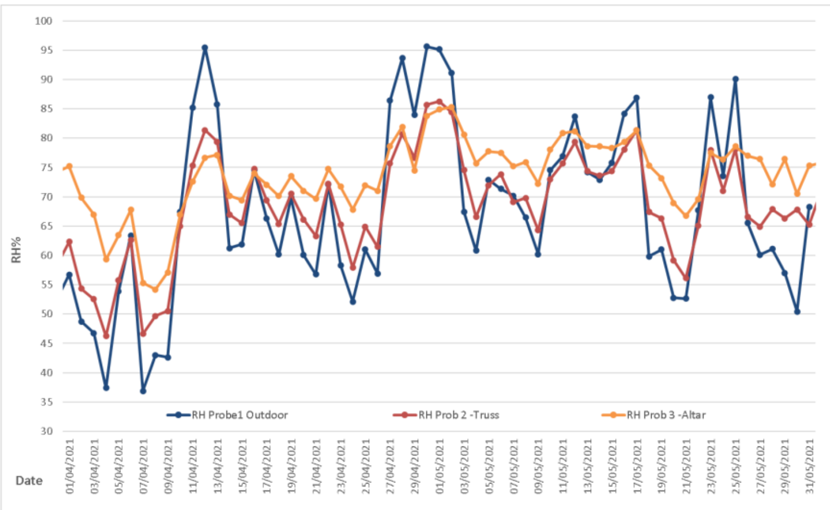


(b)

Figure 15: Bimestral graphs of the daily average T°C (a) and RH% (b) in Autumn 2020.



(a)



(b)

Figure 16: Bimestrial graphs of the daily average T°C (a) and RH% (b) in Spring 2021.

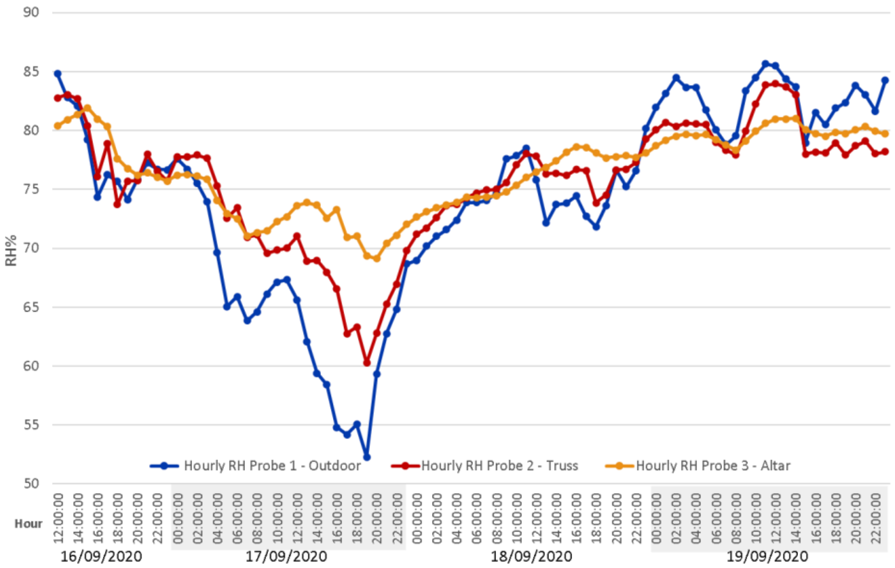
Table 1: Summary of T°C and RH% minimum and maximum for Autumn and Spring seasons

	Autumn	Spring
T°C	3,8 – 16,7	0 - 9
RH%	48 - 91	46 - 75

In Autumn (Figure 15) several T°C peaks do not correspond to a decrease of RH%, for example, from 28 September to 3 October the T°C increases of 3°C and RH% increases of 30% (from 55 to 87%). The same observation can be done from 21 to 27 October, in which an increase of 2°C corresponds to an increase of RH% of about 12% (from 85 to 97%)[3]. These kinds of variations, occurring in a long period (about a week), are not dangerous for the plasters as the quick variations are. The reason is that the increase/decrease of RH% in a long period is a suitable condition for the formation of soluble salts but the frequency of the occurrence is lower than the one of the fast variation, which are the main cause of damage for historical porous materials [13-14].

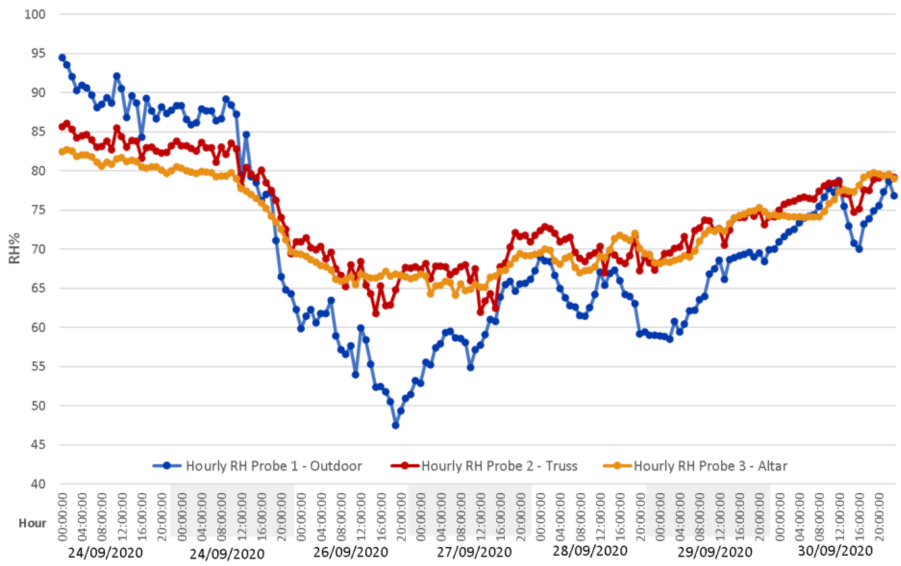
In the spring season, several peaks of T°C correspond to a decrease of RH%, for instance from 23 to 25 April, with an increase of 4°C in three days (from 4 to 8°C). In the same days, RH% decreased 20% (from 75 to 55%). Another period that can be considered is from 9 to 11 of May, in which T°C increases 4°C (from 6 to 9°C), which causes a rapid decrease of RH% in three days. The fast alternances of dry/wet conditions will increase the diffusion of soluble salts on the surfaces and the consequent damages [4].

Figure 17 presents the hourly variation of internal RH% of few events, due to a sudden decrease/increase of external RH%. For instance, on 17 September 2020 (Figure 17, a) the interior RH decreases of 22% reaching a minimum peak of 60% and following the outdoor trend. Similar observation can be seen on 24 September (Figure 17, b) and during the Spring months (Figure 17, c).



(a)

[3] measurements at so high rate of RH% is beyond the accuracy that the instruments warrant



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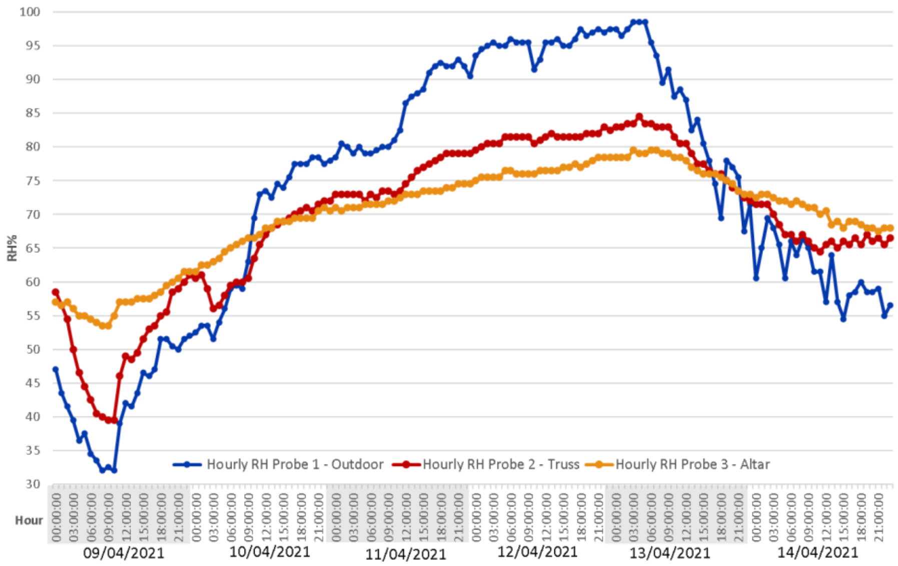

(c)

Figure 17: Hourly values of RH% from 16–19 September (a), from 24-30 September. (b), from 9-14 April (c).

3 DISCUSSION

Based on the obtained results, the indoor condition is considered stable and not strongly correlated to the outdoor condition. The data of the outdoor probe have almost the same trend as the ones inside, which is due to the location outside in a protected part of the building (Figure 1, b).

For improving the maintenance of the buildings, some comments of the presented data are in the following of this paragraph.

The first reccomandation is to keep closed the doors of the entrance to the church and the bell tower, trying to isolate them with appropriate devices (for instance close the empty spaces between the doors and the walls with an infilling material, compatible with the conservation of the historical materials) for avoiding the risk of imbalances that can occur in the opening's proximity, as it can be observed from the psychrometric analysis, and to improve the conservation conditions. Moreover, it can be made a plan about the restriction of the number of visitors, to decrease the microclimate imbalances that they can create. Obviously, this restriction has to be applied mainly in the case of public event that have a large public, but it is not to underestimate also the recurrent opening and visit of the alpinists passing by during the summer vacation time.

Furthermore, a thorough inspection of the roof is recommended to prevent dangerous infiltration of water inside the structure walls, especially in the junction between the bell tower and the western wall.

Also, the drainage system of the dugout outside the building is not totally effective after the Spring rain, and it is recommended an improvement for reducing the permanence of the water.

However, despite the few localized, critical points listed above, San Romerio church has a good microclimate balance, which is suitable for the conservation as it has been in the past.

4 ACKNOWLEDGNEMENTS

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