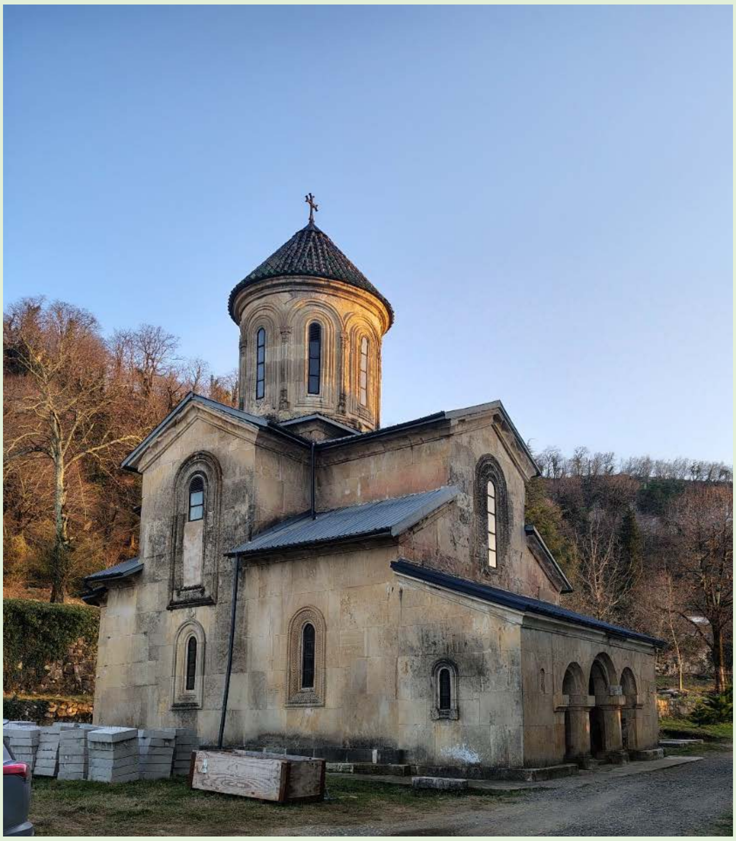
ANNEX 7.3.3

SIX-MONTH REPORT ON

CLIMATE, MICROCLIMATE AND ENVIRONMENTAL DIAGNOSTICS

ST. GEORGE CHURCH - GELATI MONASTERY - GEORGIA



REPORTING PERIOD: JANUARY – JUNE 2026

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Client: Gelati Rehabilitation Provisional Committee

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1. SCOPE

Based on the mandate established by Contracts No. 25 (Prof. Dario Camuffo), 26 (Dr. Antonio Della Valle) and 27 (CMR Lab srl), of 21th November 2025, this report presents the interpretation of the microclimate monitoring performed during the first 6 months of 2026 (from January to June) with the advanced monitoring system installed in the St. George Church, Gelati Monastery.

Details of the advanced monitoring system are provided in our report Annex 7.3.6, dated 30 January 2026.

2. SENSOR LOCATION

The figure below shows the locations of the monitoring sensors within the church, as represented in the east and south sections. The indoor air-temperature and relative-humidity sensors are positioned beneath the dome (sensor 2), in the upper part of the church (sensor 3), in the lower part of the church (sensor 4), and in a separate lateral room near the entrance (sensor 8). The corresponding surface-temperature probes monitor the dome (sensor 1a), the vault (sensor 1b), the entrance masonry (sensor 5a), and the floor (sensor 5b). Four additional surface-temperature sensors are installed on the external walls, one on each orientation: west (sensor 6a), south (sensor 6b), east (sensor 7a), and north (sensor 7b). The outdoor sensor provides the external reference conditions used for comparison.

3. PHYSICAL MEANING OF ATMOSPHERIC VARIABLES

RELATIVE HUMIDITY

Relative Humidity (RH) is a parameter that represents the degree of saturation of water vapour (not the saturation of air!), i.e. if the vapour is close to, or far from saturation.

When saturation is exceeded some H_2O molecules are removed from the system by condensation.

RH is the ratio between the actual partial pressure *e* of the water vapour and its saturation vapour pressure $e_{sat}(t)$ at the same temperature *t* (°C) and pressure (hPa), expressed in percent (%) of the saturation value.

$$\mathrm{RH} = 100\,\frac{e}{e_{sat}(t)}$$

RH changes when the moisture content, the temperature, the volume of the air parcel, or the ambient pressure change.

As the denominator $e_{sat}(t)$ is an exponential, it is not mathematically correct to perform arithmetic calculations, like daily or monthly averages. A representation in terms of frequency or percentiles is preferable and recommended.

MIXING RATIO

The mixing ratio of moist air is the ratio of the mass of water vapour m_{H2O} to the mass of dry air m_{N2+O2} in which H_2O molecules are dispersed.

This ratio represents the ponderal mixture of these two gaseous substances, i.e, H_2O and (N_2 + O_2) as well as the ratio between their number of molecules, i.e. n_{H2O} and n_{N2+O2}

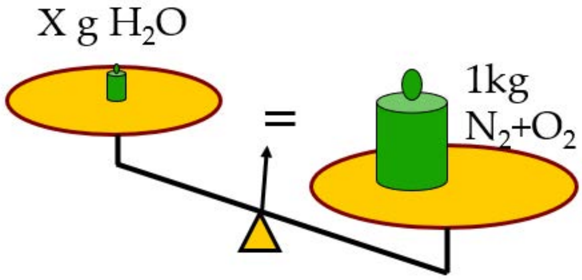
$$MR = \frac{m_{H2O}}{m_a} = 0\ 0.622\,\frac{n_{H2O}}{n_{N2+O2}}$$

The Mixing Ratio (MR) can be calculated from Temperature (t) and Relative Humidity (RH) values, provided the barometric pressure p (hPa) is known, using the following formula:

$$MR = 38.015 \times \frac{10^{\frac{7.65t}{243.12+t}} \times RH}{p - \left(0.06112 \times 10^{\frac{7.65t}{243.12+t}} \times RH\right)}\ (\mathrm{gkg}^{-1})$$

MR is a fingerprint of any air parcel because it is invariant to changes in air temperature, pressure and volume. It may change only if water molecules are added (evaporation, perspiration) or subtracted (sorption, condensation), or mixing occurs with drier or moister air.

This makes possible to recognize exchanges, sources and sinks of moisture.



From the above definitions, Mixing Ratio can be interpreted as a parameter that gives the number N of H_2O molecules mixed with 1000 molecules of dry air, i.e. MR = k N/1000 (where k is a proportionality coefficient)

Let us consider a building, and compare the MR values inside and outside, i.e. $MR_{in} = k\ N_{in}/1000$ and $MR_{out} = k\ N_{out}/1000$.

Three cases are possible:

1. $\mathbf{MR_{in} = MR_{out}}$, i.e. $\mathbf{N_{in} = N_{out}}$. When N is the same inside and outside the building, neither condensation nor evaporation occurs.
2. $\mathbf{MR_{in} < MR_{out}}$, i.e. $\mathbf{N_{in} = N_{out} – C}$. When inside the building the MR is lower than outside, this means that a number C of H_2O molecules has been removed from the external air by **sorption or condensation** on internal walls, or the floor.
3. $\mathbf{MR_{in} > MR_{out}}$, i.e. $\mathbf{N_{in} = N_{out} + E}$. When inside the building the MR is higher than outside, this means that a number E of H_2O molecules has been added to the external air **by evaporation from walls** or **perspiration from people**.

Dew Point (°C): The temperature of condensation

The dew point temperature, DP, is the temperature to which a parcel of moist air **reaches saturation** (at constant temperature and pressure).

Simply speaking, DP is a characteristic temperature of any air parcel: **the temperature threshold for condensation**. Let us consider a surface with temperature T_S

When $\mathbf{T_S > DP}$ **no condensation is possible;**

When $\mathbf{T_S = DP}$ **equilibrium threshold, in which evaporation = condensation**

When $\mathbf{T_S < DP}$ **condensation occurs on the surface**

On a surface, condensation may occur **only when its temperature $\mathbf{T_S}$ drops below DP.**

NOTE. It should be noted that wall efflorescence or contamination by soluble salts can cause **water sorption by deliquescence** at some critical RH levels. This is another mechanisms of physical chemistry, that should not be confused with condensation.

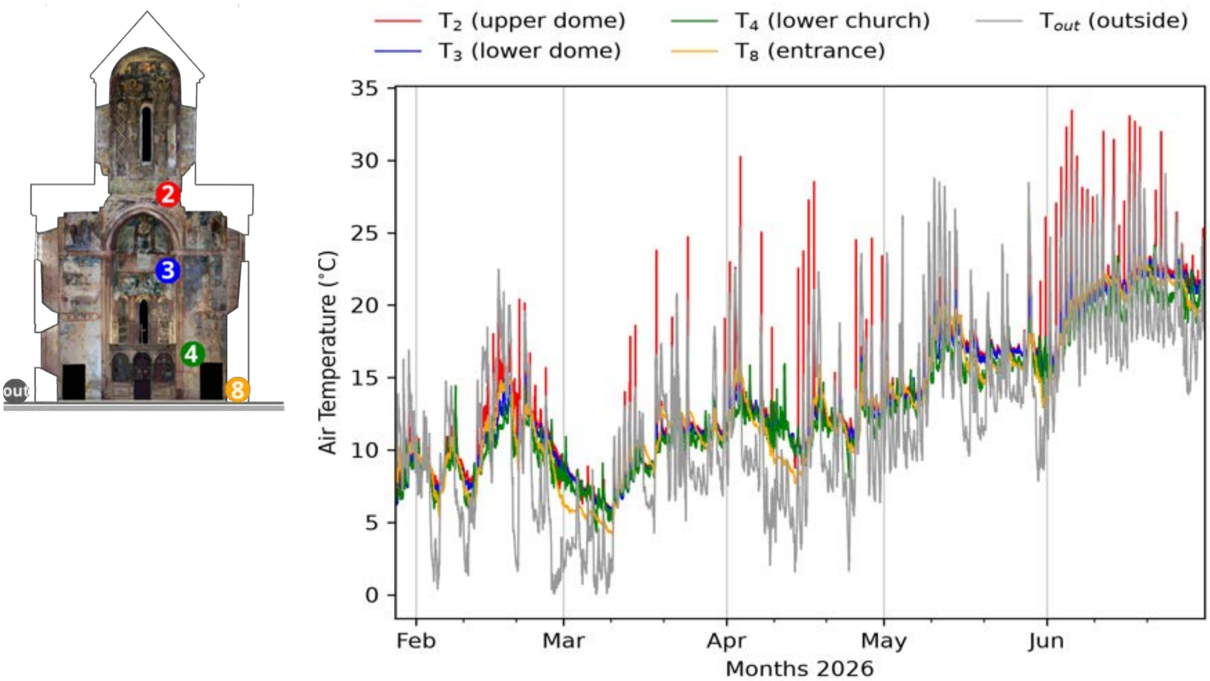
Dew Point Temperature (DP) can be calculated from Temperature (t) and Relative Humidity (RH) values, using the following formula:

$$DP = \frac{243.12 \times \ln\left(10^{\frac{7.65t}{243.12+t}} \times \frac{RH}{100}\right)}{17.62 - \ln\left(10^{\frac{7.65t}{243.12+t}} \times \frac{RH}{100}\right)} \ (^{\circ}\mathrm{C})$$

4. DATA ANALYSIS

Air temperature

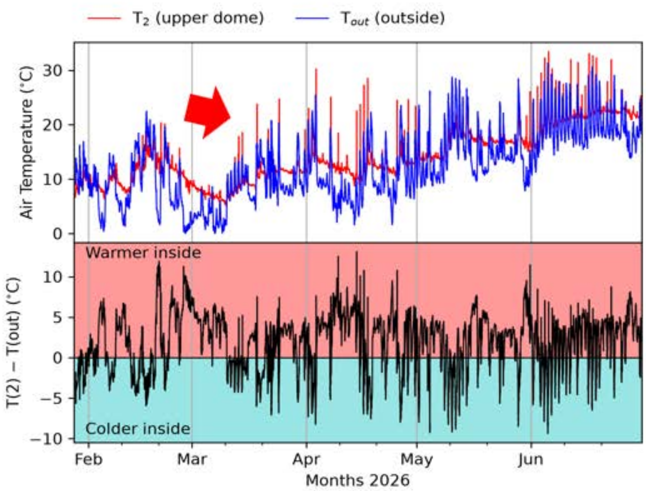
Air Temperature (°C) – All sensors

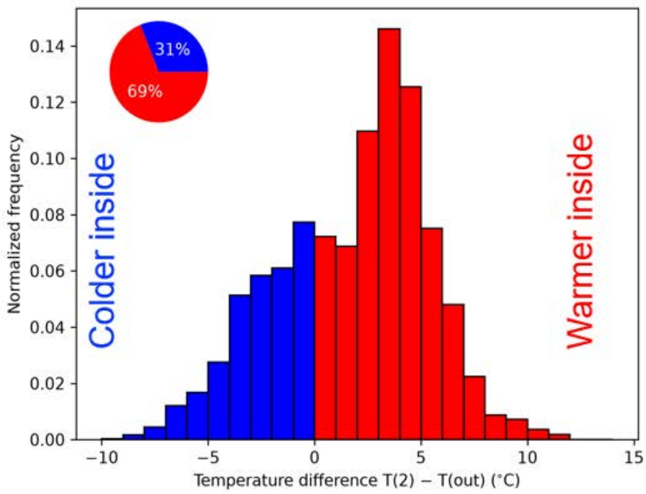


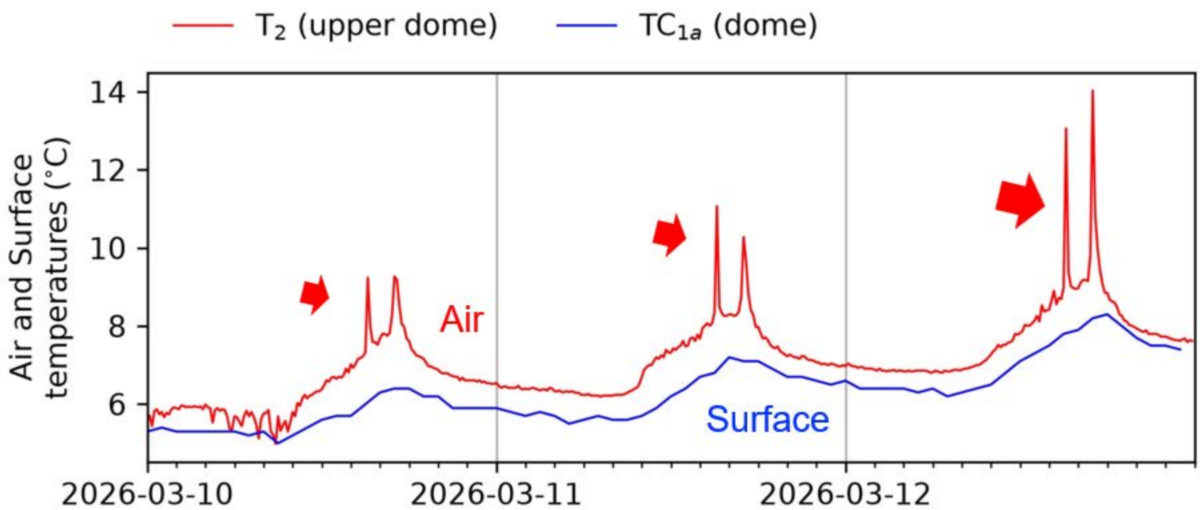
In average, the air temperature is a bit higher inside for the contribution of the solar radiation on walls.

In the following individual plots, the upper panel compares each indoor temperature with the outdoor series, whereas the lower panel and the histogram quantify the temperature difference and its frequency.

Air Temperature at Upper Dome (sensor 2)

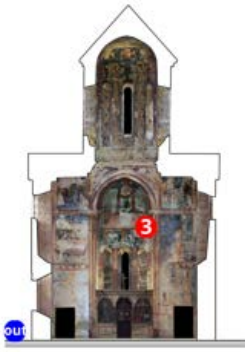


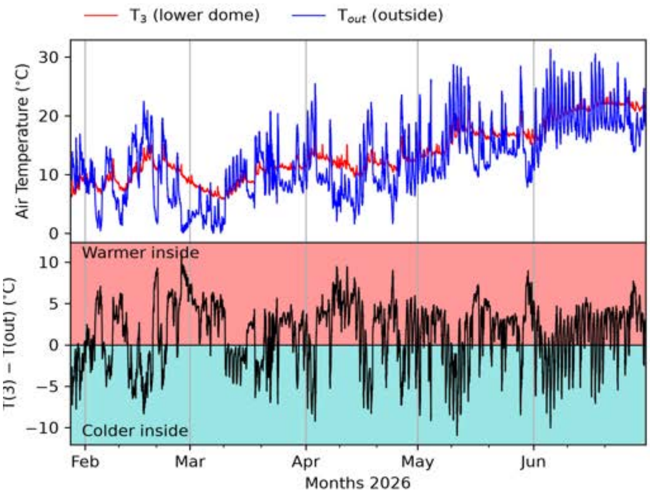


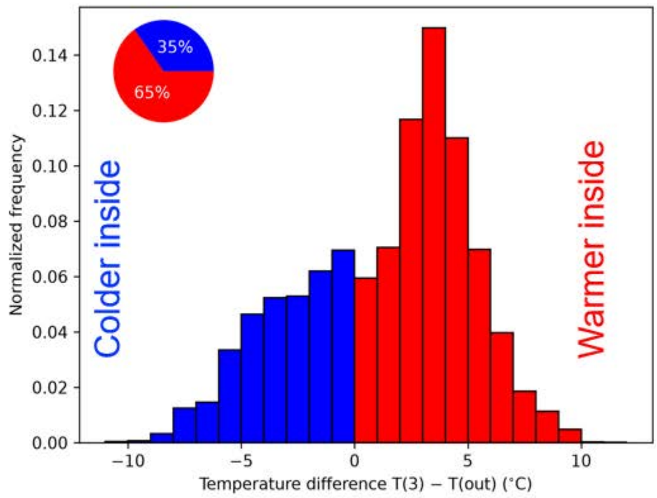


In March and April, some peaks of temperature, about 10°C, are visible in the upper dome (T2), higher than the external temperature. They are especially intense in March and April. An expanded view of the air and surface temperature inside the upper dome shows that the air temperature peaks (T2) are regularly repeated, with particular intensity in March. We should exclude the solar radiation through the windows, because the air is transparent to solar radiation and, as opposed, the wall should overheat. As opposed, the surface temperature is unaffected, while only the air temperature shows peaks. This suggests: (i) that the peaks are related to some human activity inside: (ii) some solar radiation is reflected and hits the sensor. The latter is likely.

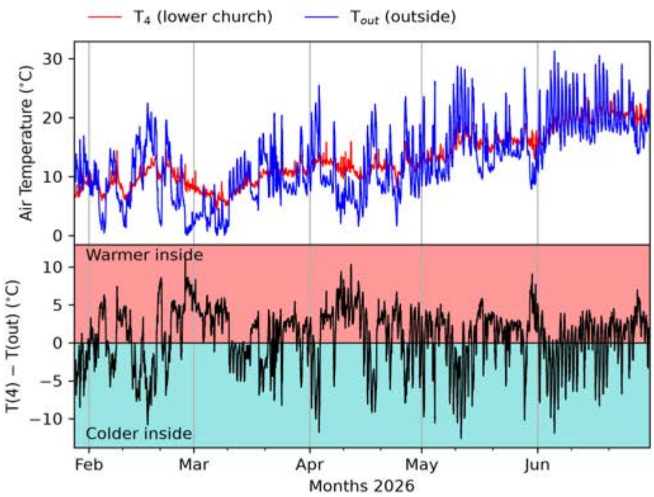
Air Temperature at Lower Dome (sensor 3)

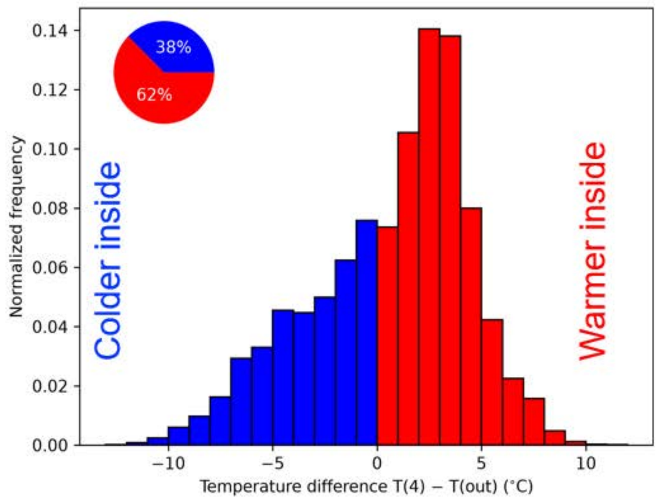




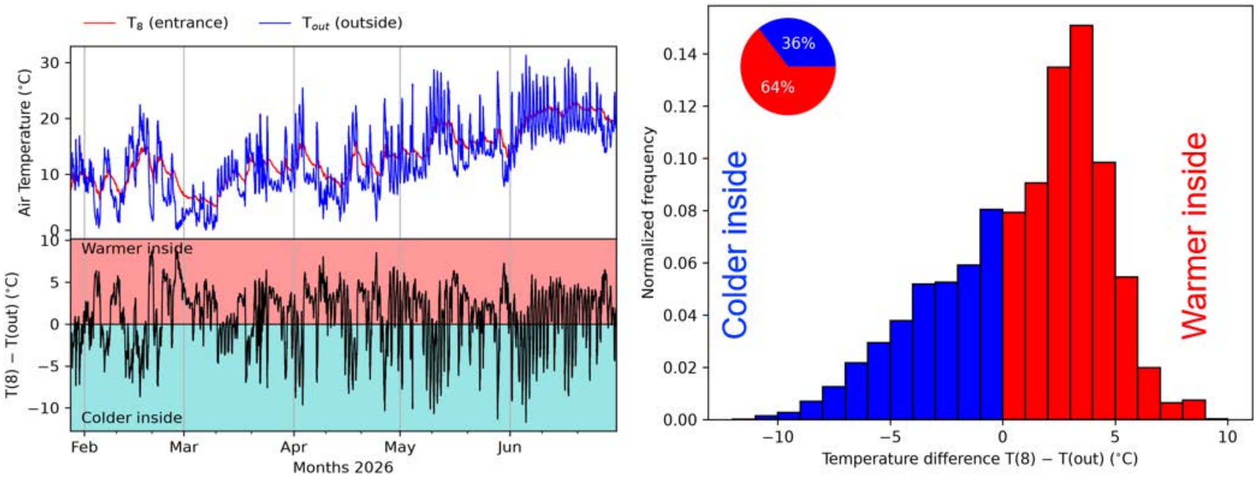


Air Temperature at Lower church (sensor 4)

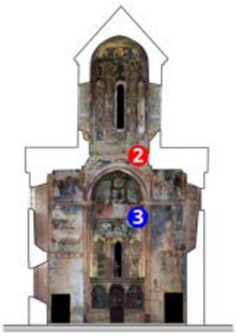


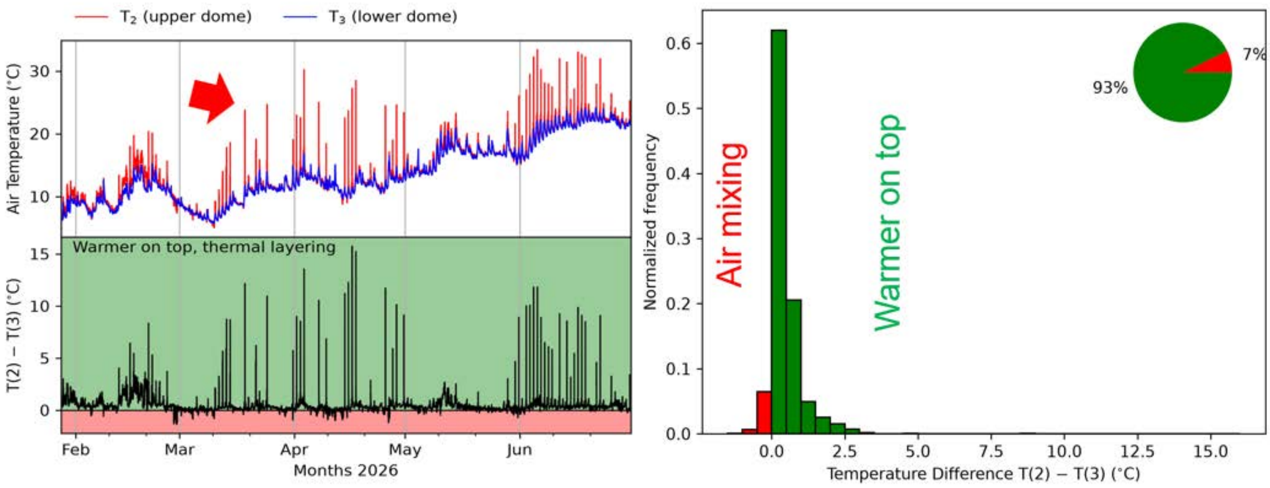


Air Temperature at Lower church (sensor 8)



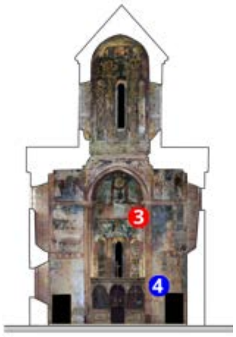
Thermal layering dome: upper (2) vs lower (3)

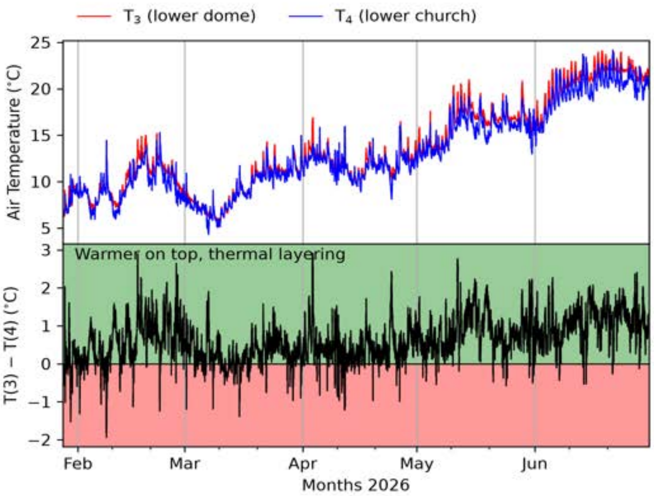


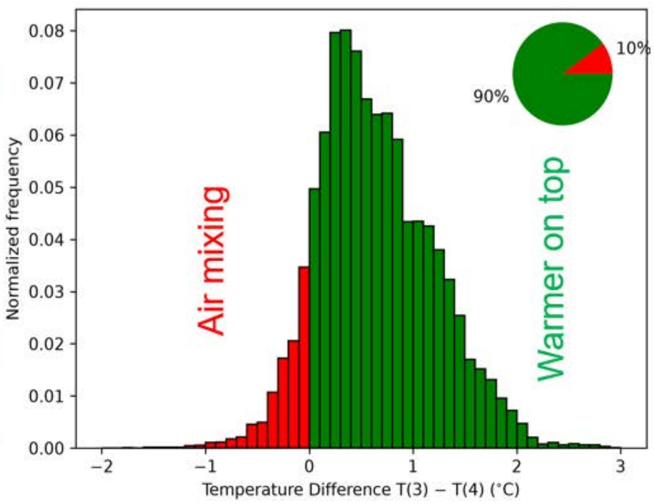


As consequence of the peaks in T2, some peaks of 10-15 °C are generated in the thermal layering T2-T3 that becomes very strong in such conditions. Internal instability and vertical air mixing are very rare and very weak.

Thermal layering: dome (3) vs church (4)

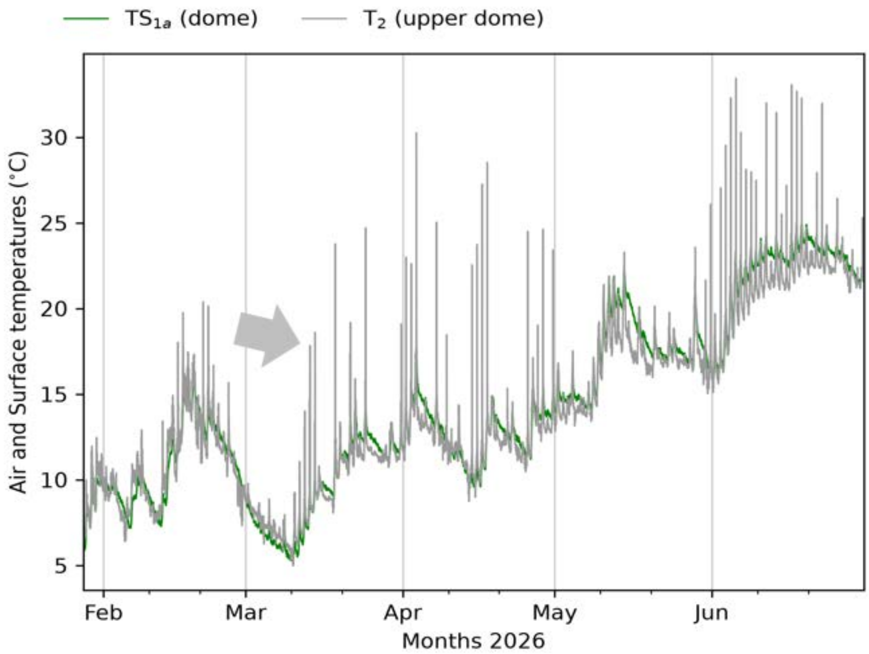






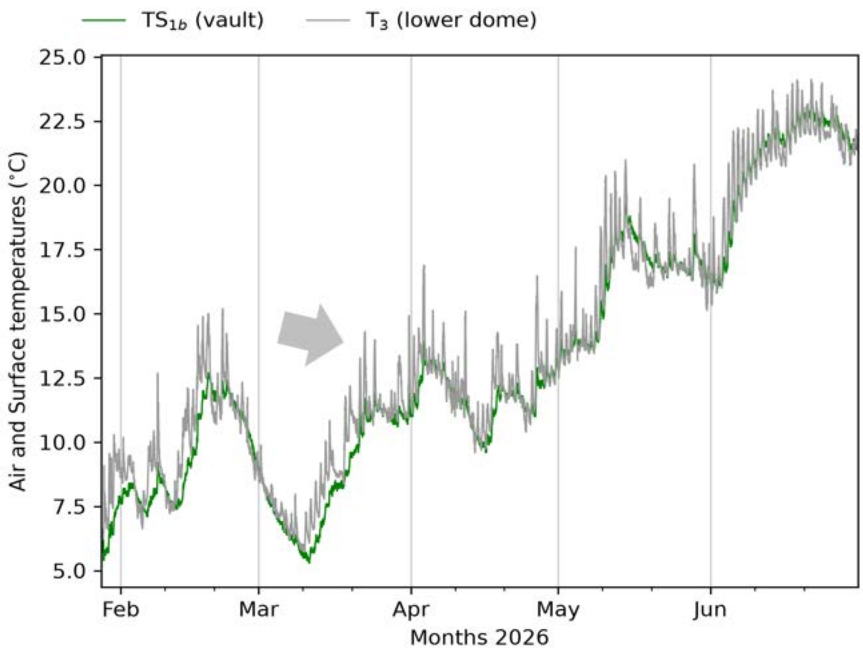
Surface and air temperatures

Dome surface temperature



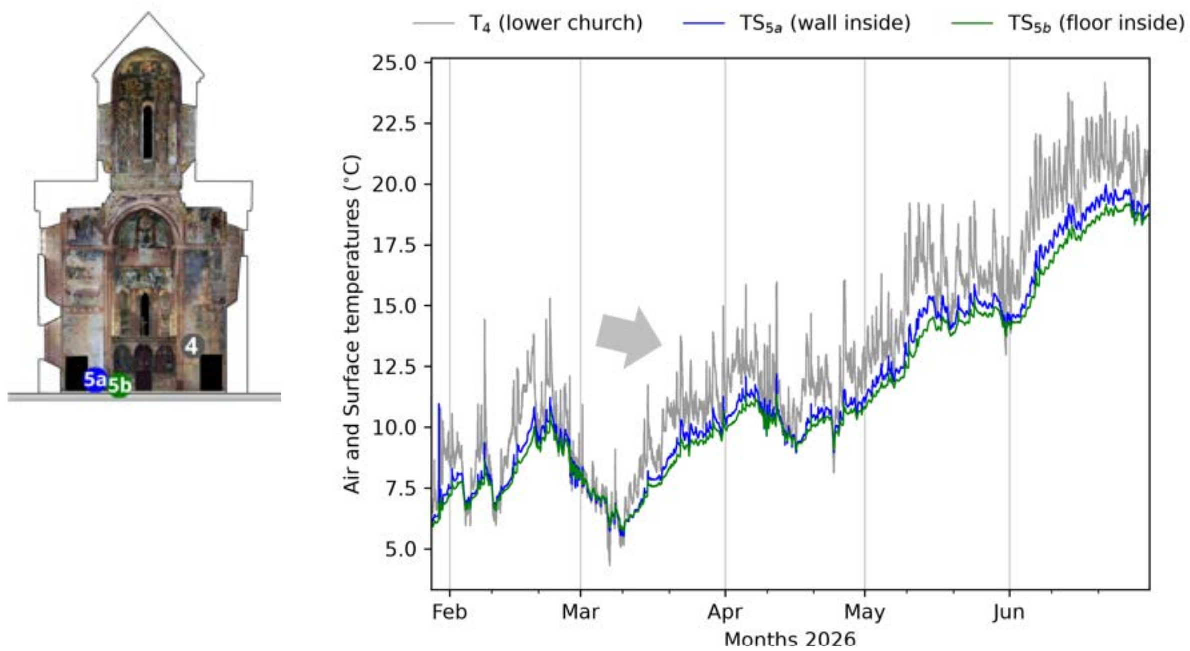
The slide of the Dome surface temperature shows that in general the vault temperature is close to the air temperature, but the above-mentioned sharp peaks in the air temperature T2 (10-15 °C) are limited to the air, without affecting the dome temperature.

Vault Surface temperature



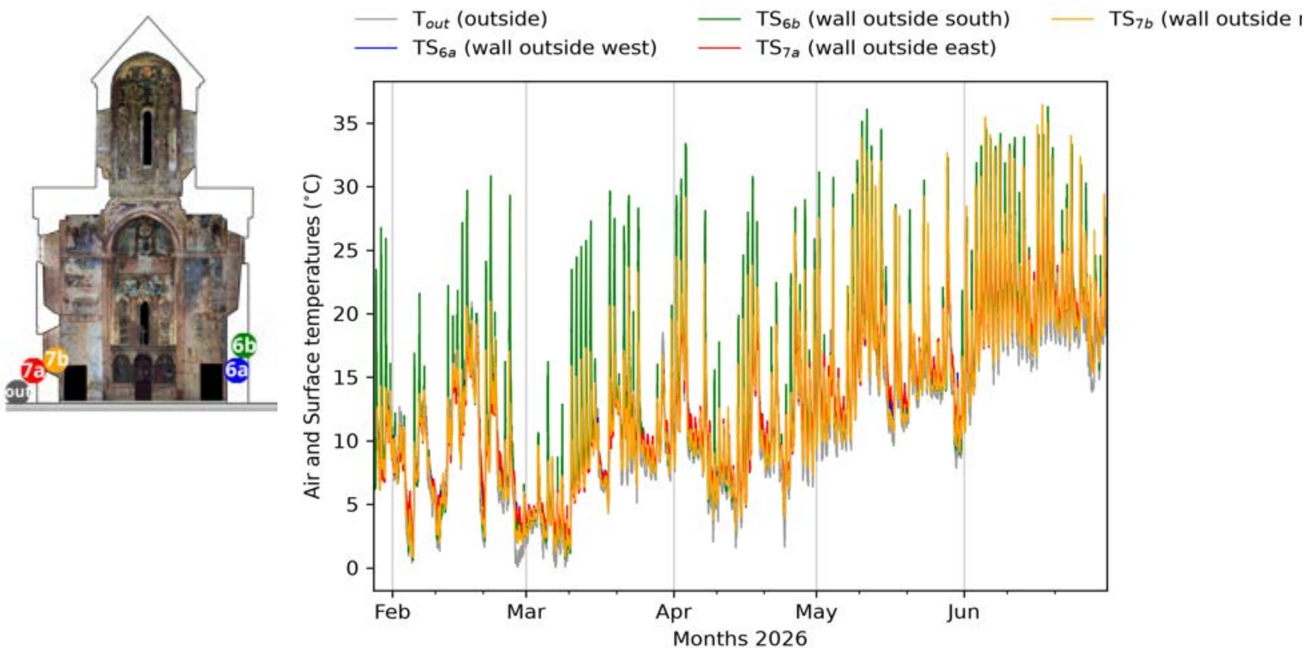
Also the sensor T3 shows some peaks, but these are smaller, regular, wider and seem related to external meteorological factors.

Entrance and ground floor surface temperature



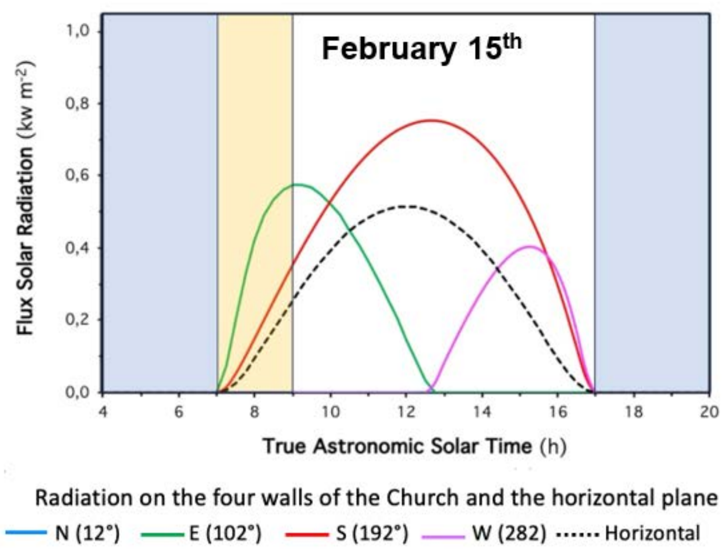
The sensor T4 located in the lower church shows a large variability, likely linked to infiltration of external air.

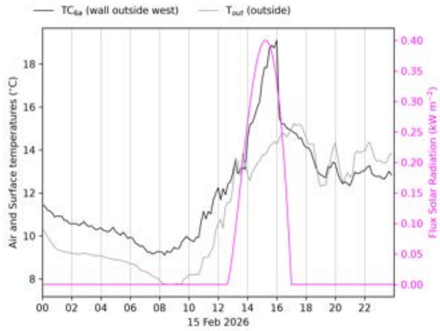
External wall surface temperature

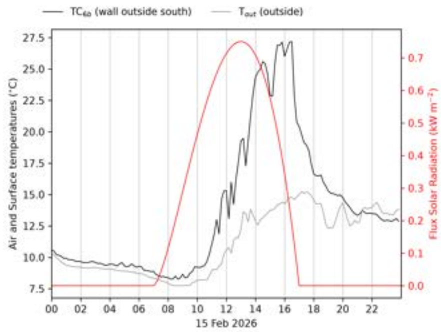


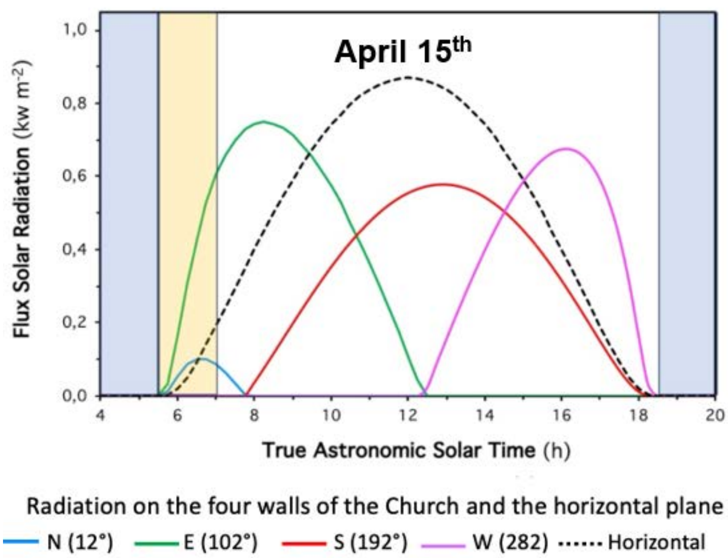
Solar Radiation and Wall surface temperature

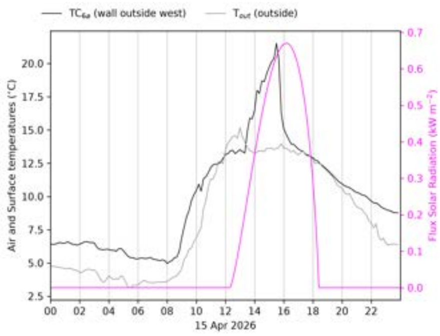
As an example, an expanded view is shown of the wall temperature and the calculated solar radiation on the southern and western walls on clear days near to February 15th, April 15th and June 15th. The northern and eastern walls have been omitted because of the too scarce radiation (the eastern side is in the shade of the eastern slope). The effect is visible. Please note that the solar graph and the wall temperature are referred the first to the apparent solar time, the latter to the clock time, and there is a difference between the two of some 30 minutes, continually changing during the calendar year, following the Equation-of-Time. This explains why the wall heating sometimes is contemporary to the radiation, sometimes a bit earlier or later.

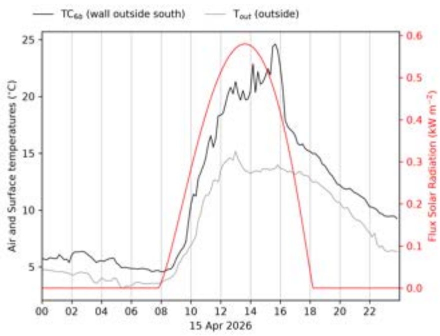


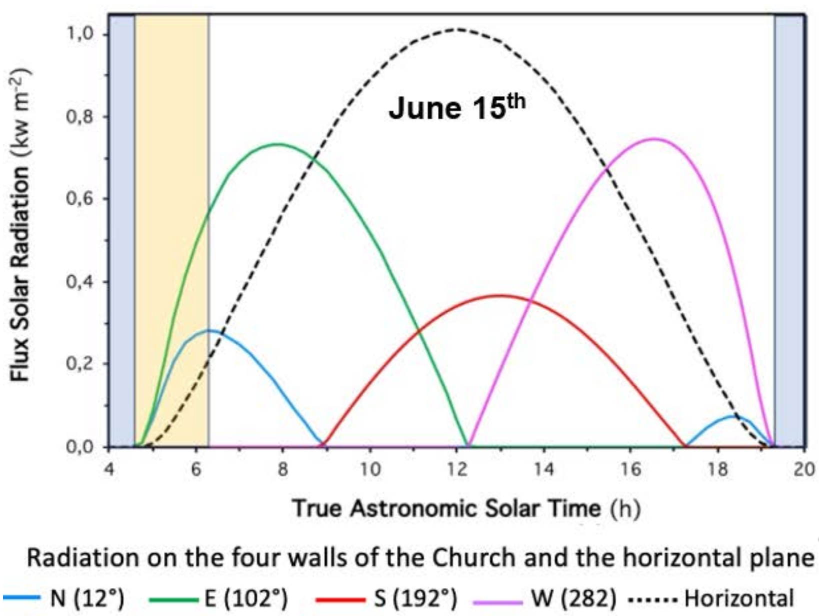


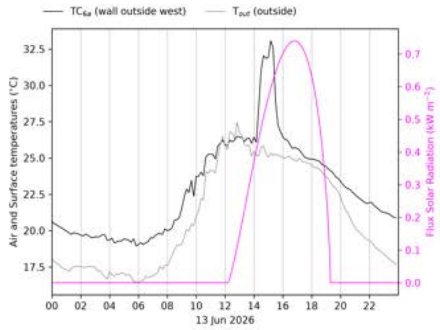


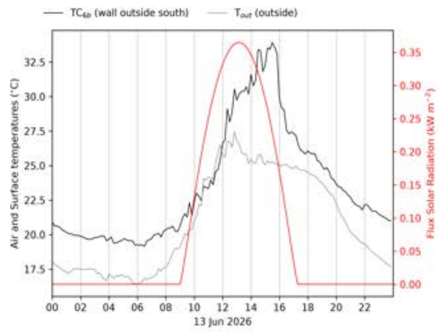






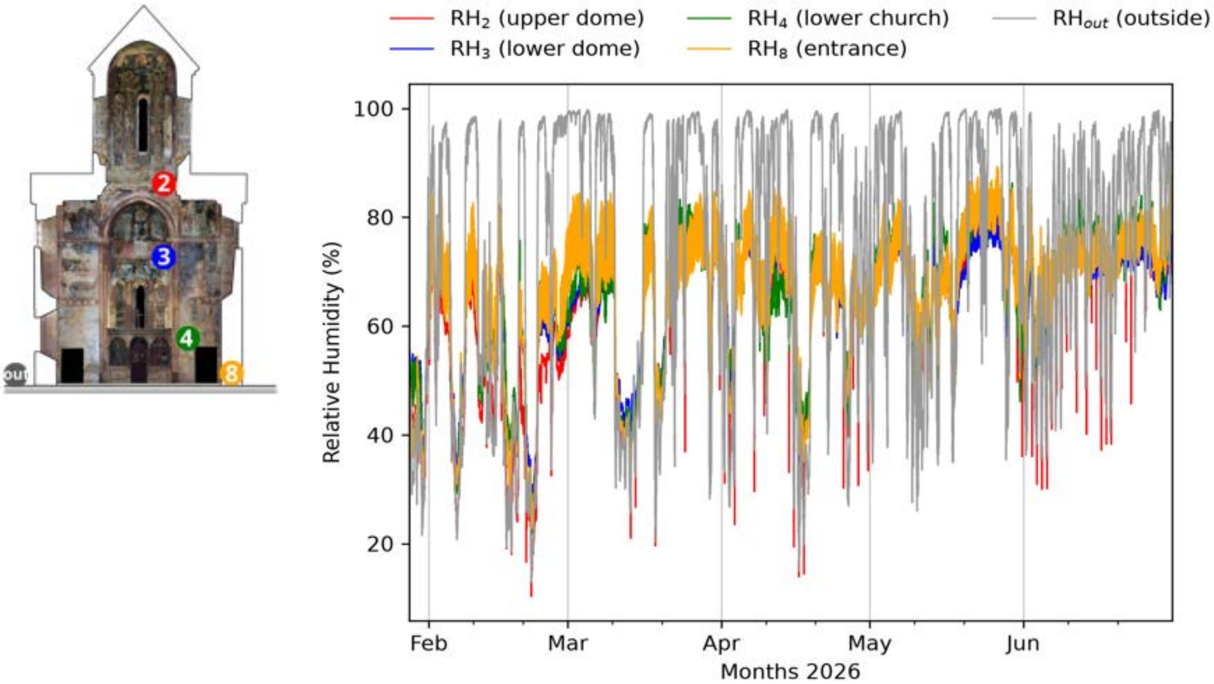

June 15th
Flux Solar Radiation (kw m^{-2})
True Astronomic Solar Time (h)
Radiation on the four walls of the Church and the horizontal plane
N (12°)
E (102°)
S (192°)
W (282)
Horizontal


(wall outside west)
(outside)
Air and Surface temperatures (°C)
Flux Solar Radiation (kW m^{-2})
13 Jun 2026


(wall outside south)
(outside)
Air and Surface temperatures (°C)
Flux Solar Radiation (kW m^{-2})
13 Jun 2026

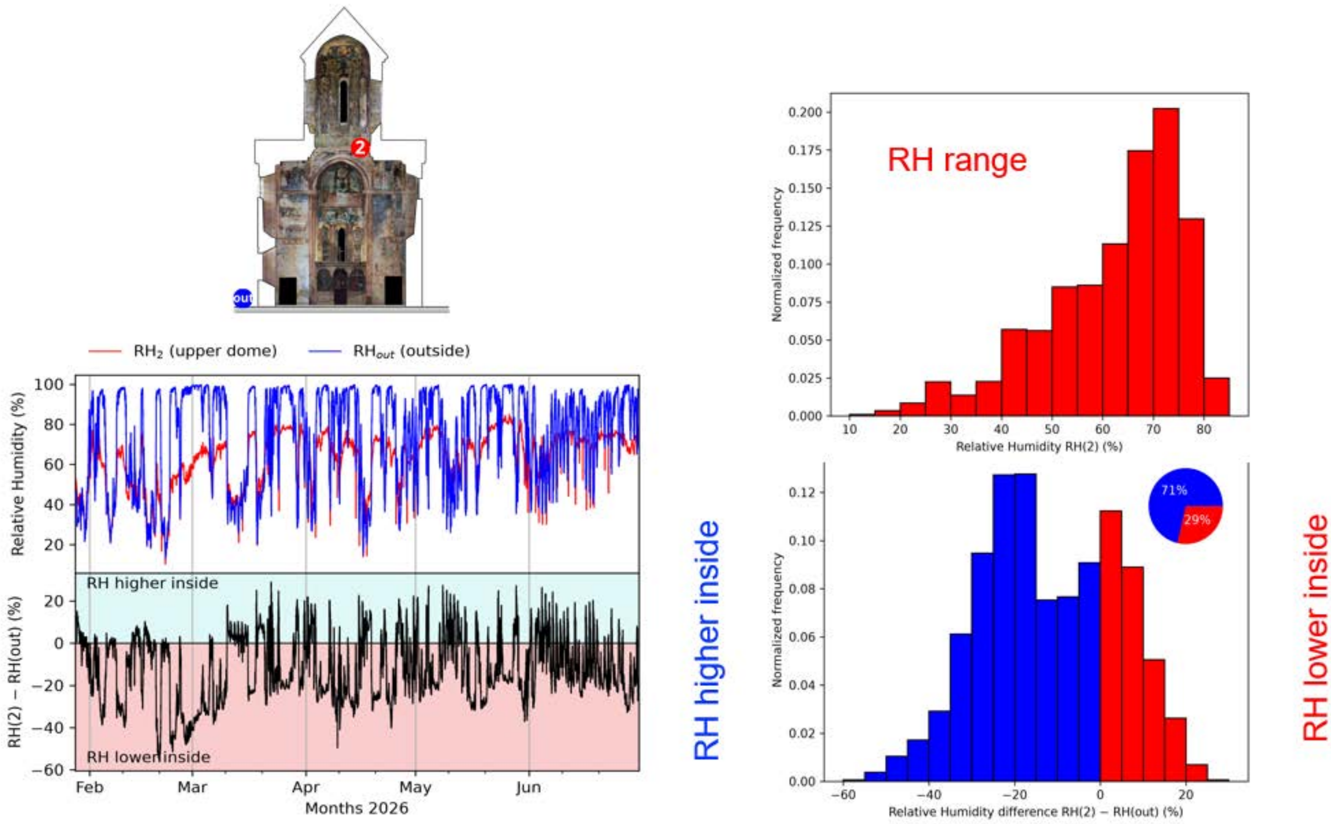
Relative Humidity

Relative Humidity – all sensors

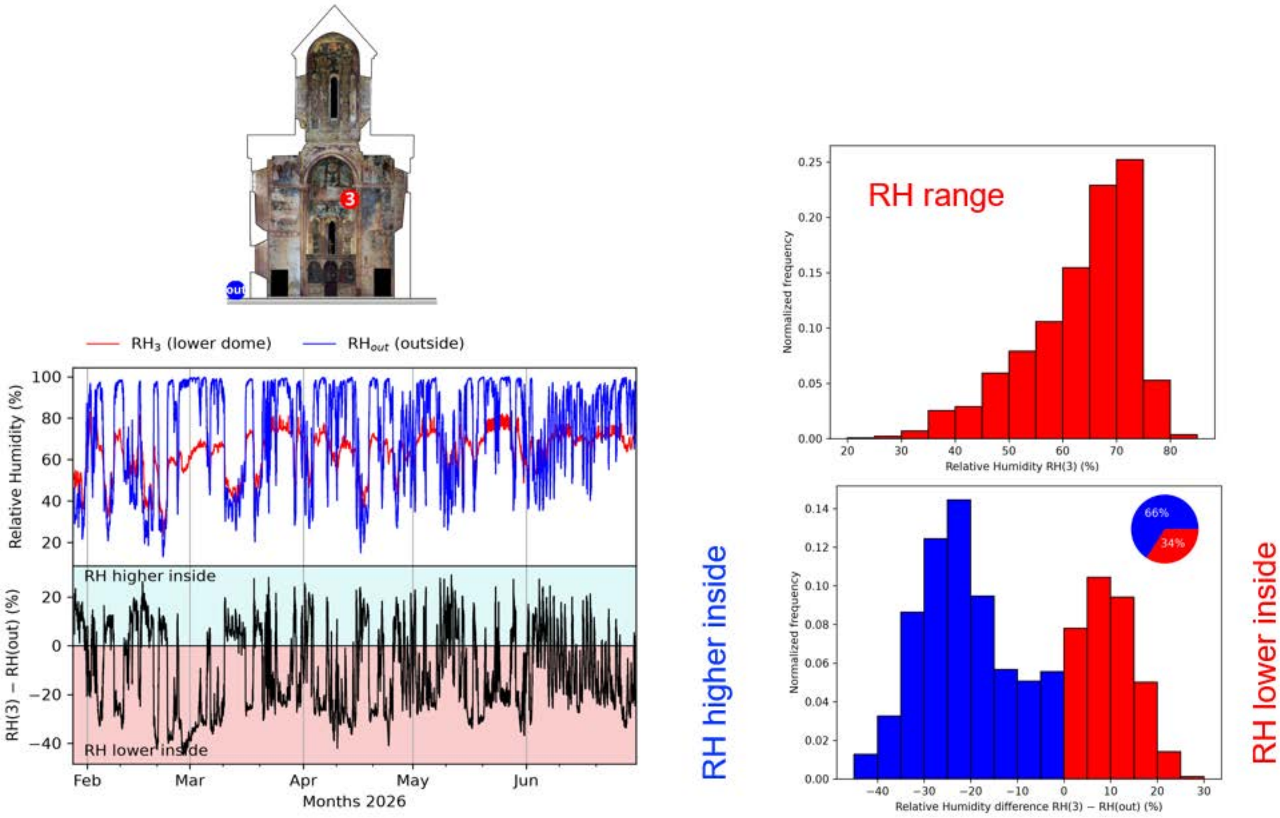


Despite the slightly higher internal temperature, the inside RH is mostly higher than outside, which is explained with the slightly larger moisture content (the humidity mixing ratio) inside.

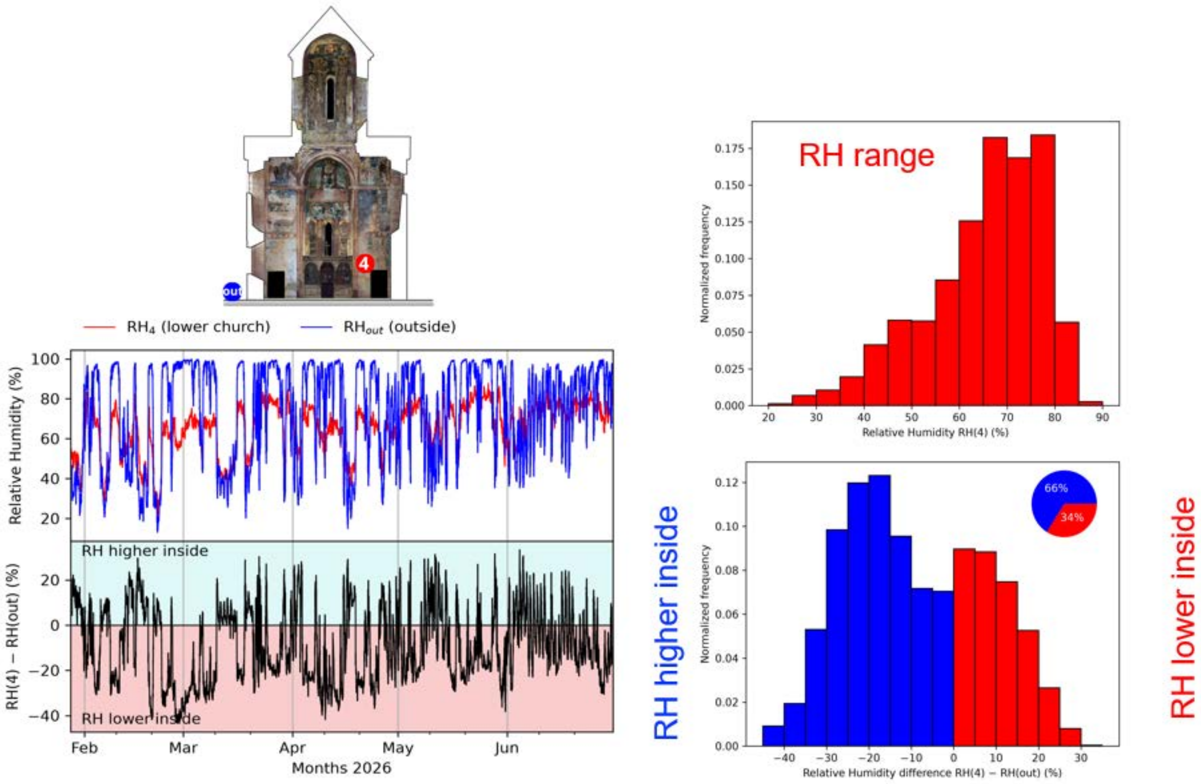
Relative Humidity at Upper Dome (sensor 2)



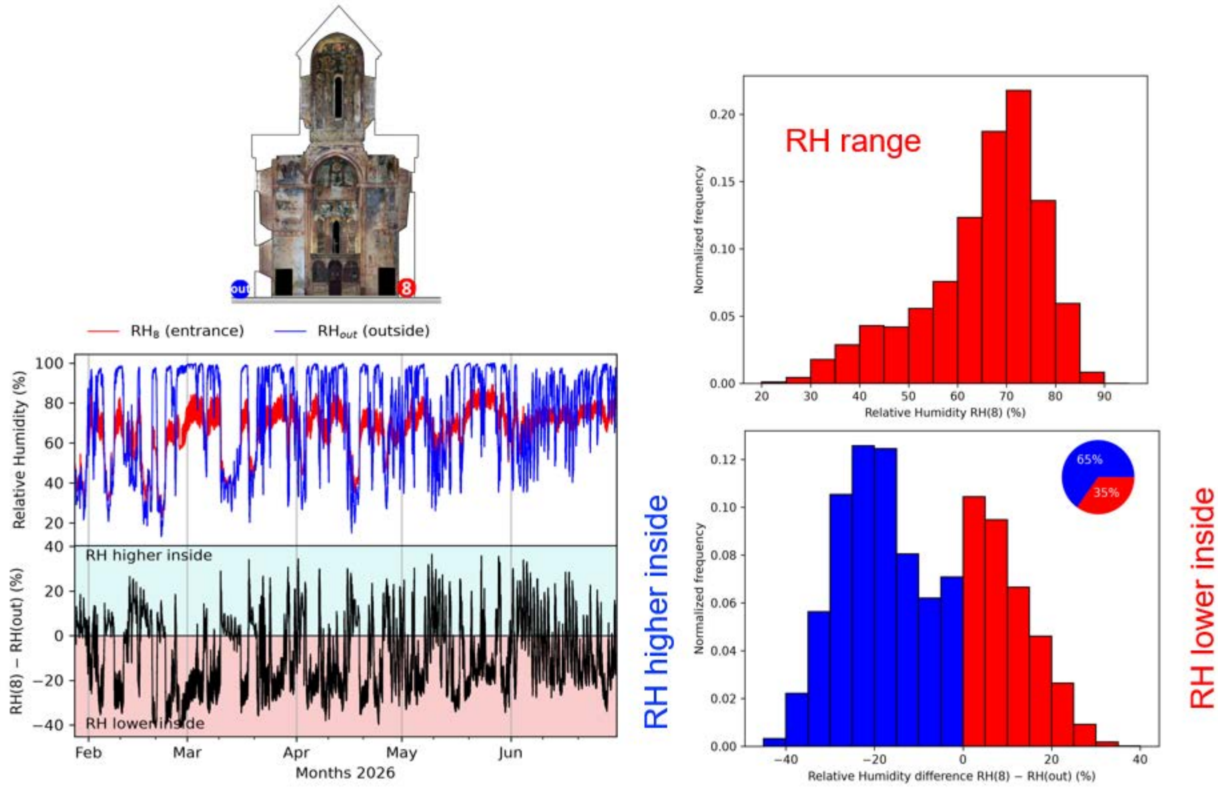
Relative Humidity at Lower Dome (sensor 3)



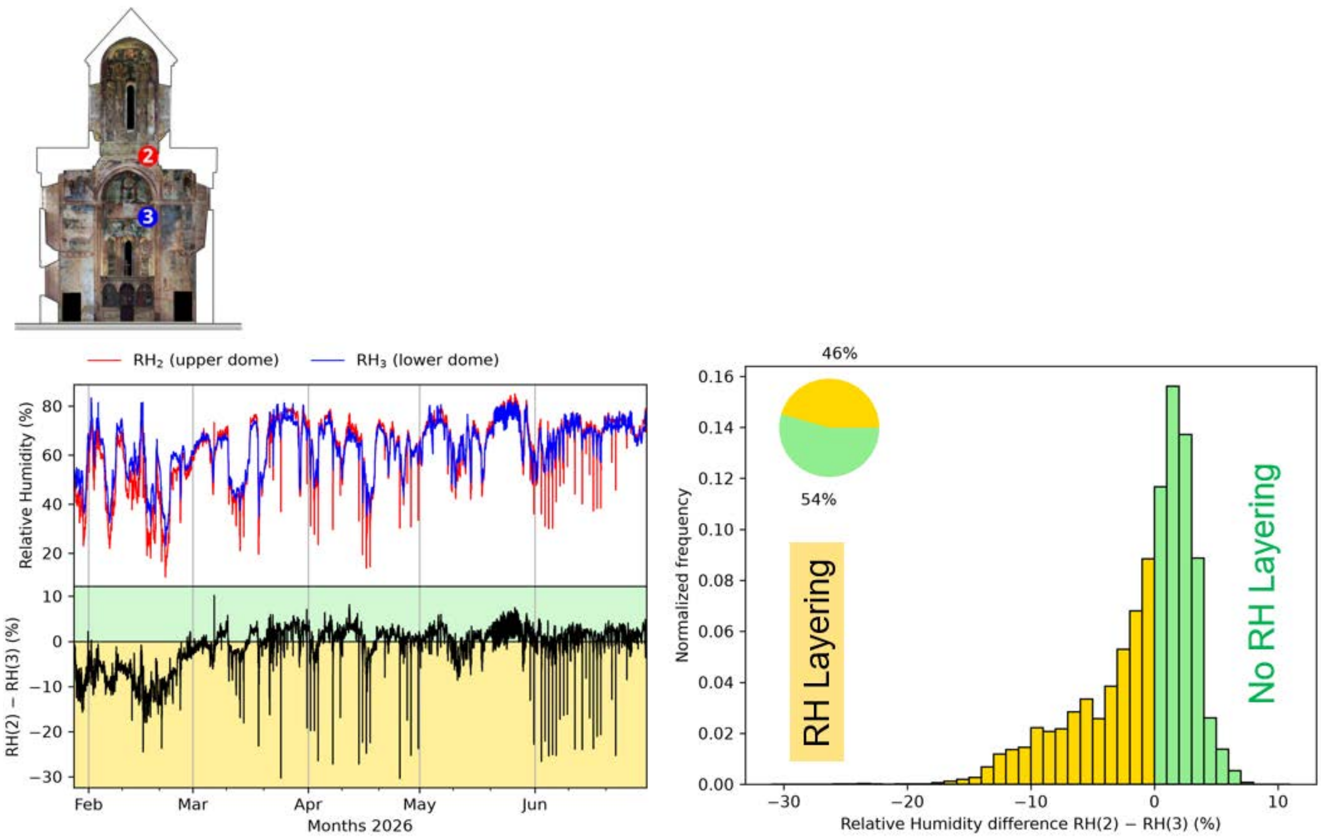
Relative Humidity at Lower church (sensor 4)



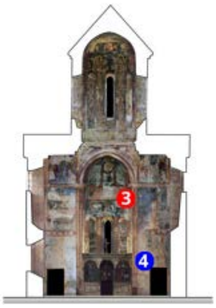
Relative Humidity at Lower church (sensor 8)

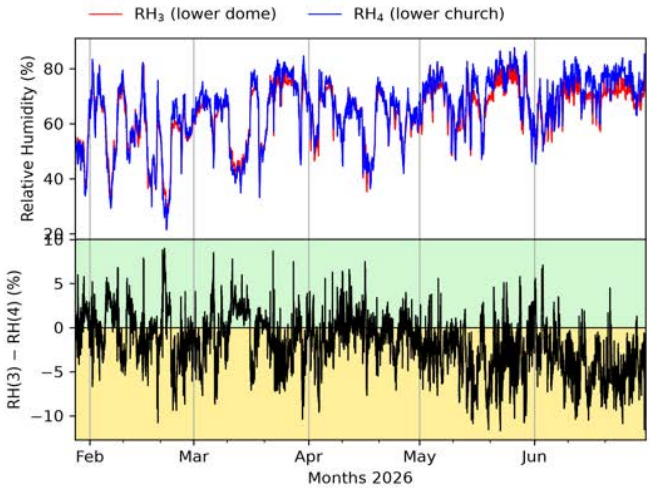


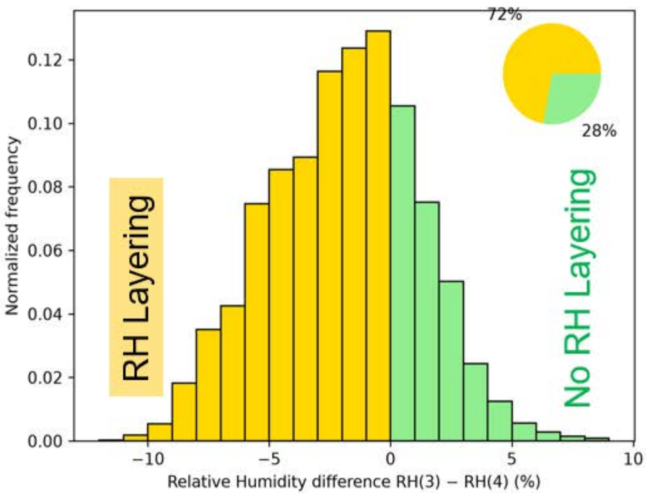
RH layering dome: upper (2) vs lower (3)



RH layering: dome (3) vs church (4)



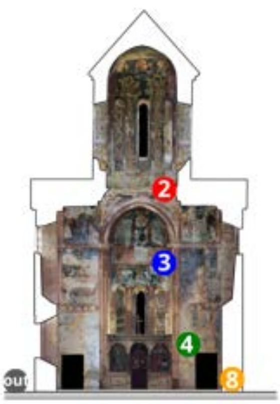


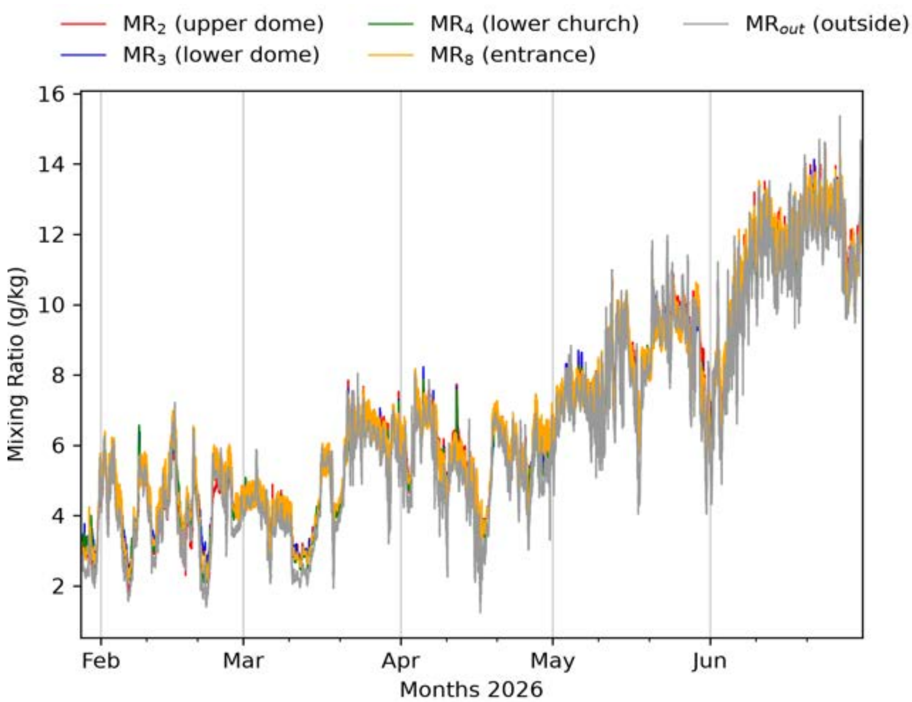


The internal temperature layering in association with an even MR distribution over the vertical generates an internal RH layering.

Mixing ratio

Mixing ratio – all sensors

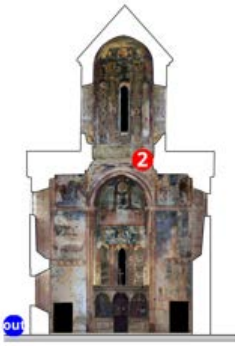


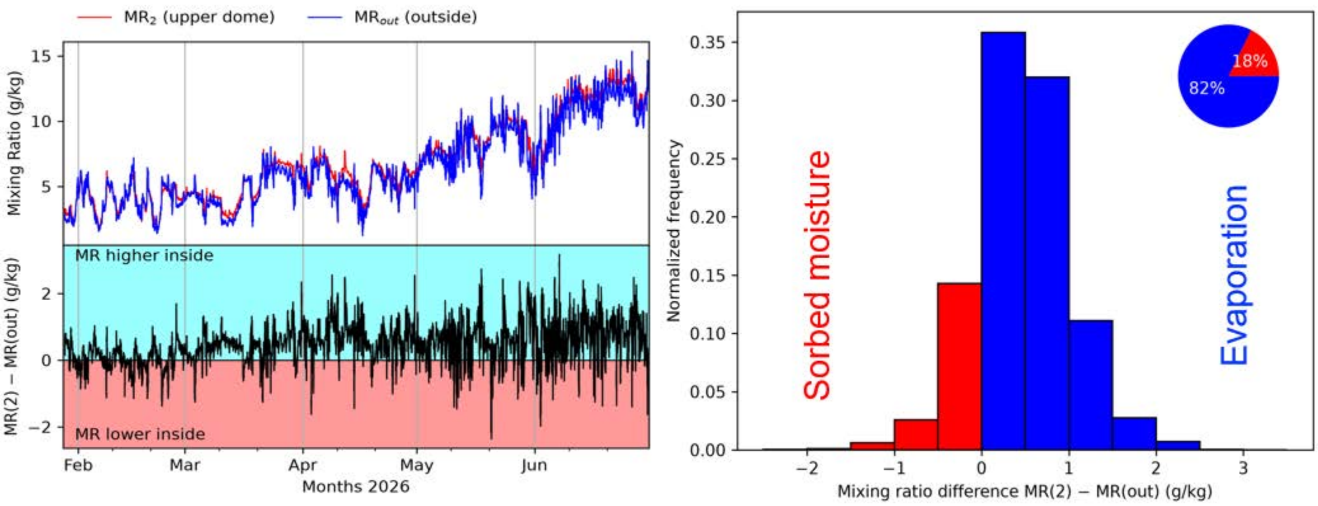


The indoor MR measurements shows values close to the outdoor sensor (MRout), but with some small differences, mostly within ±1g/kg, and rarely exceeding this value. The positive departures are dominant (some 80% of the time) over the negative departures (20% of the time).

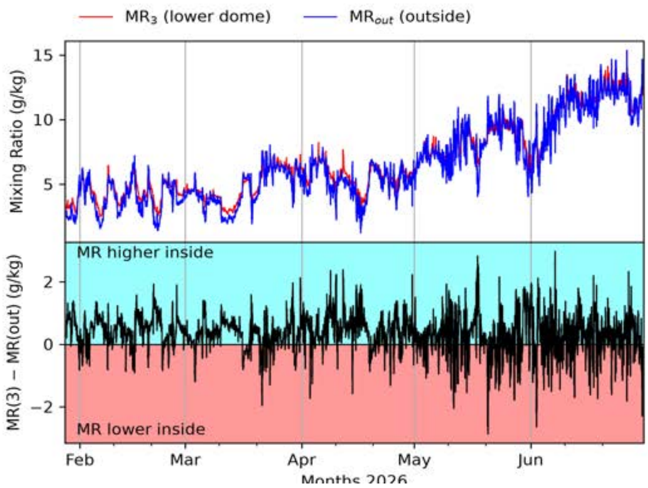
The above difference means that evaporation is dominant over moisture sorption. This fact suggests that there is (or there has been) some infiltration of water that supplies an excess of water that feeds the indoor evaporation.

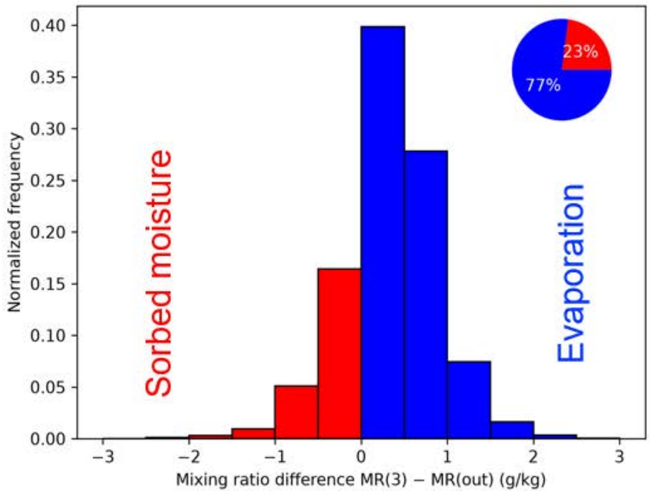
Mixing Ratio at Upper Dome (sensor 2)



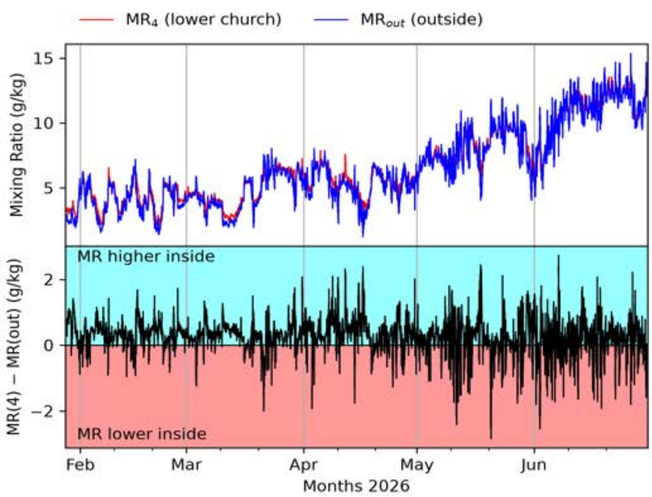


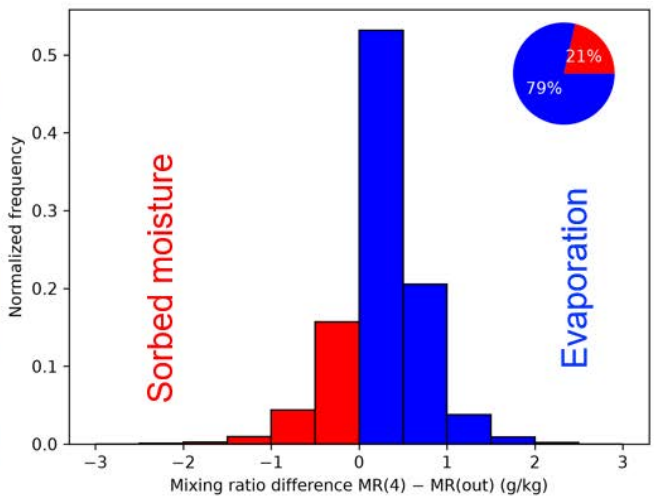
Mixing Ratio at Lower Dome (sensor 3)



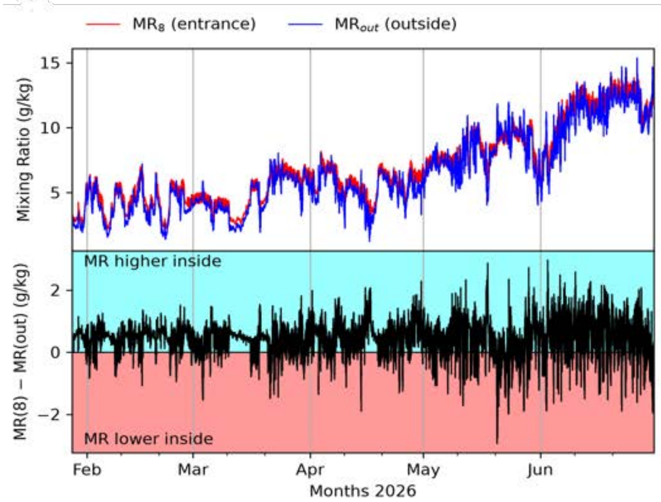


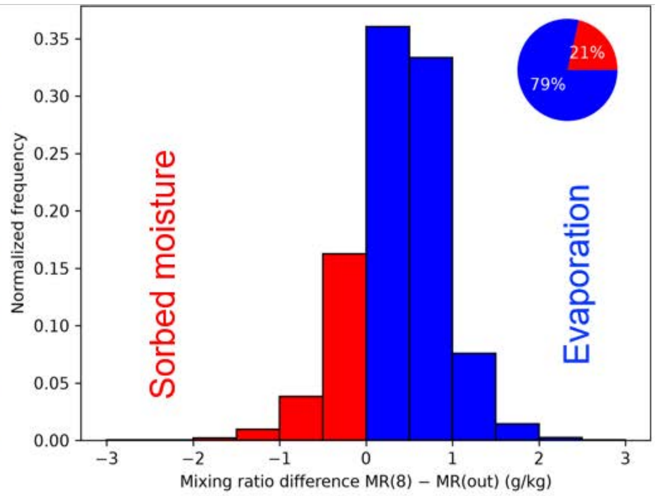
Mixing Ratio at Lower church (sensor 4)



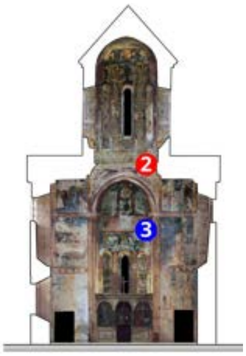


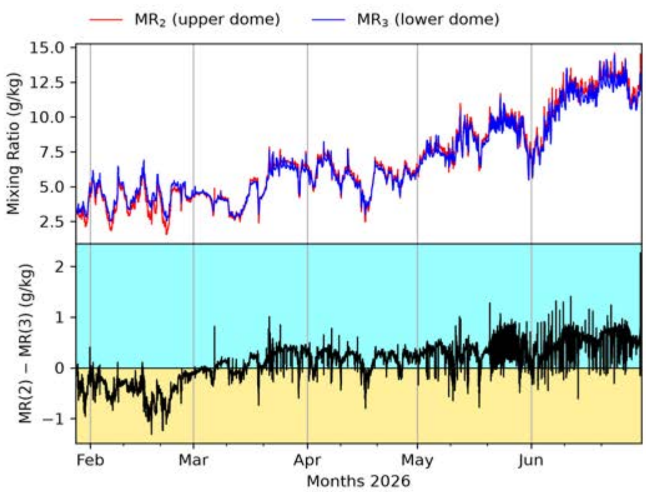
Mixing Ratio at Lower church (sensor 8)

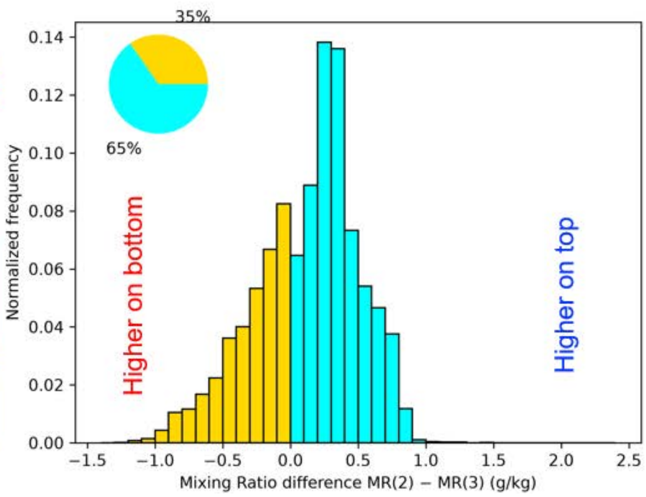




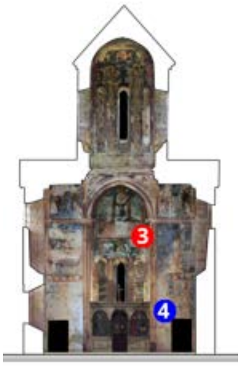
MR layering – dome (3) vs lower church (6)

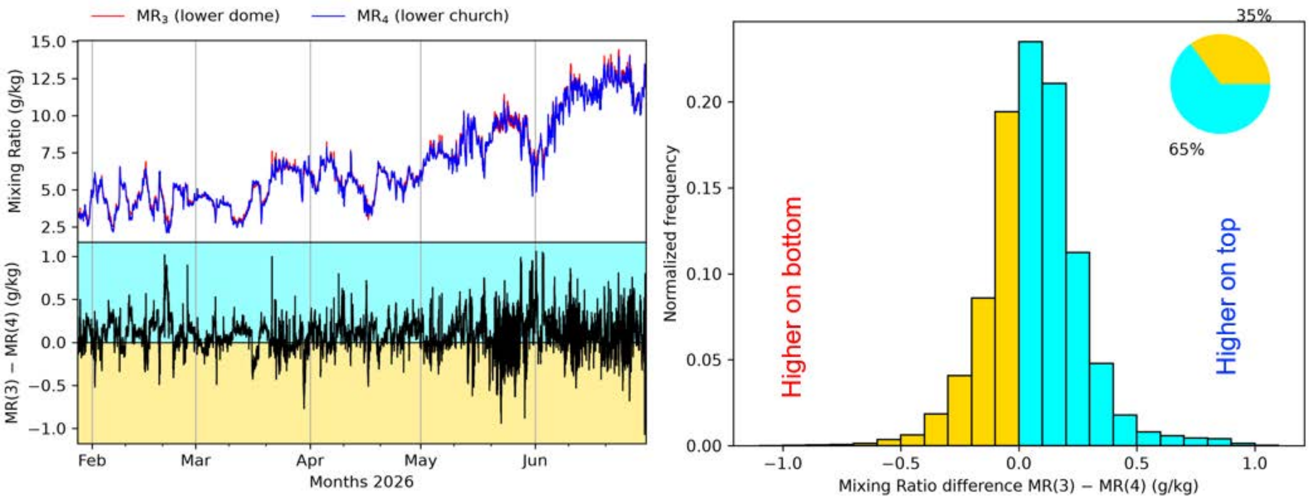






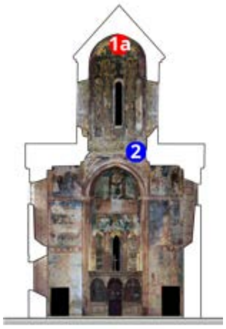
MR layering: dome (3) vs church (4)

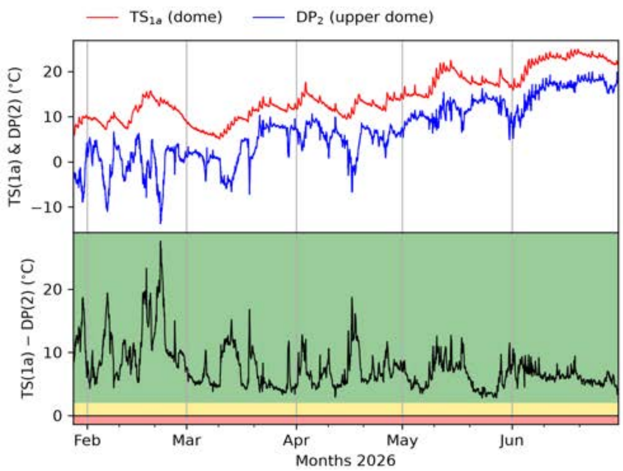


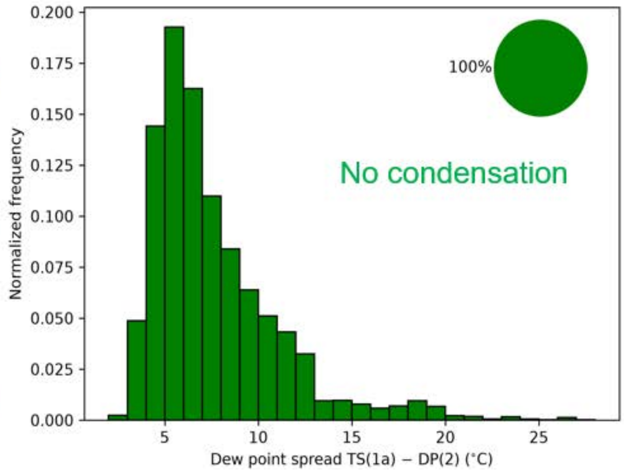


Dew point and condensation

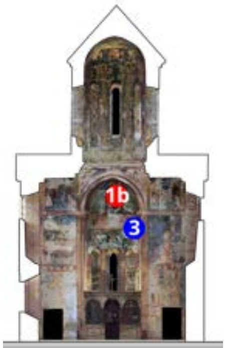
Dome – Is it affected by condensation?

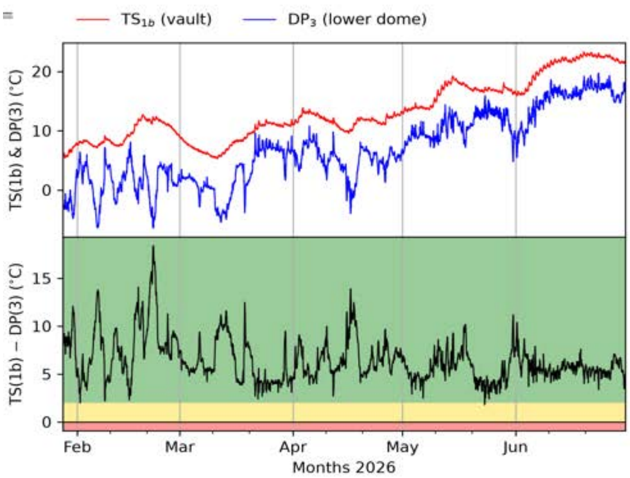


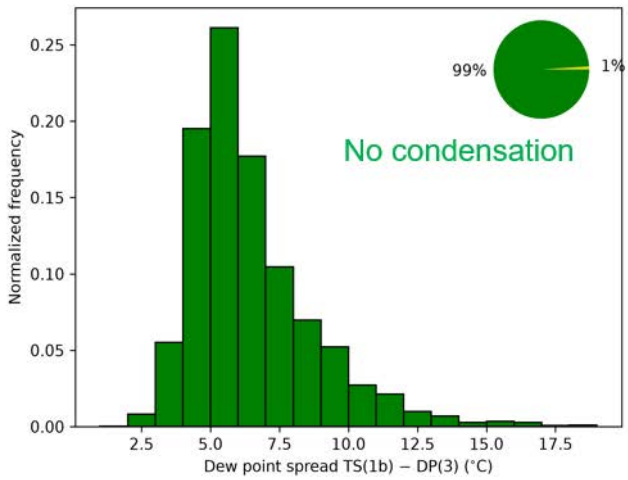




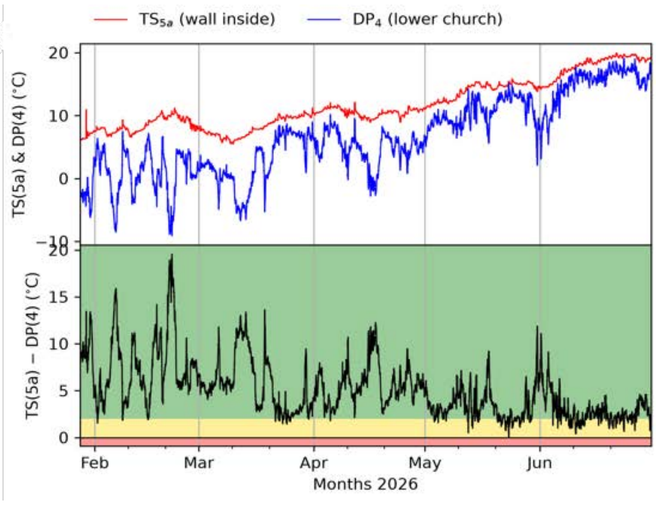
Vault – Is it affected by condensation?

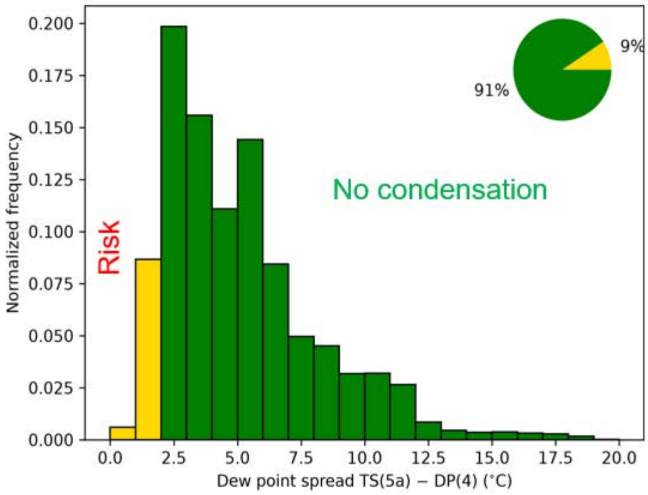




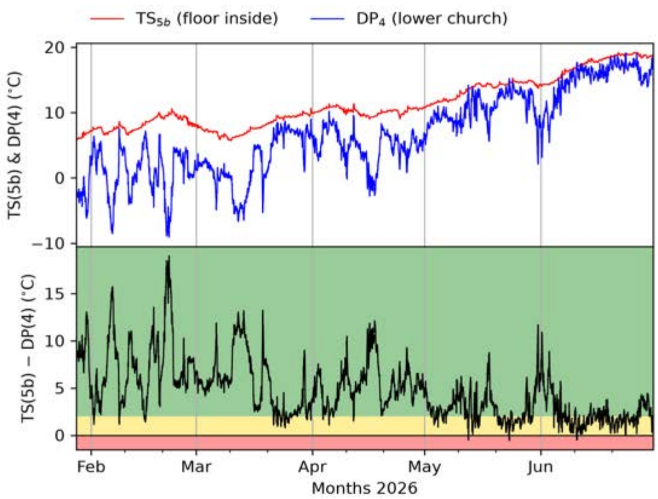


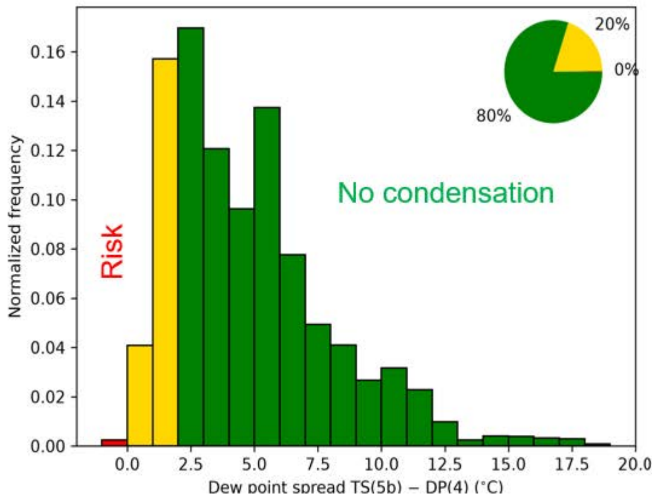
Internal wall (lower side) – Is it affected by condensation?





Floor - Is it affected by condensation?



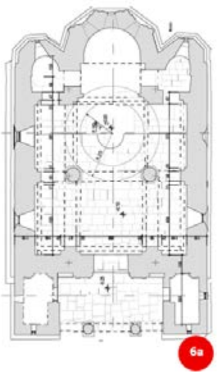


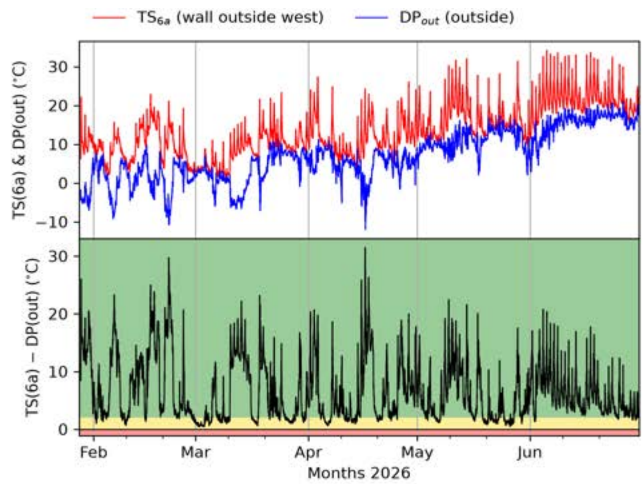
The comparison between surface temperatures and the corresponding dew-point temperatures indicates that no effective surface-condensation events occurred on the dome, vault and the upper walls during the monitored period. At the dome and vault levels, the surface temperature remained consistently above the dew point, with a generally wide positive dew-point spread. These areas therefore showed a substantial safety margin against condensation.

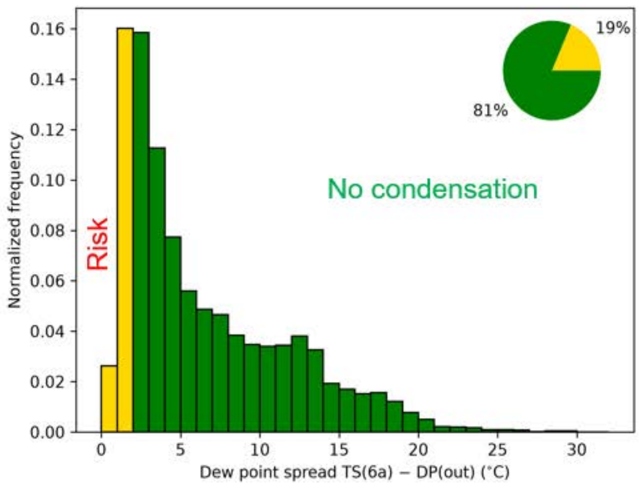
The lowest margins were observed at ground level, particularly on the foot of the lower wall and on the floor. The internal wall approached potentially critical conditions for approximately 9% of the monitoring period, whereas the floor was close to the dew point for approximately 20% of the time. Nevertheless, the surface temperatures did not significantly fall below the dew point, and the recorded conditions should therefore be interpreted as a risk or near-condensation condition rather than evidence of persistent condensation.

As already commented for the Nativity Church, it may be useful to specify that, on the floor stone, once condensation has collected some liquid water, this will likely remain visible for a relatively long time, as evaporation is difficult for the high humidity level inside. It should be kept in mind that the condensation time is not necessarily coincident with the time in which floor dampness is visible.

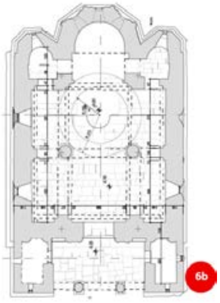
External wall, West - Is it affected by condensation?

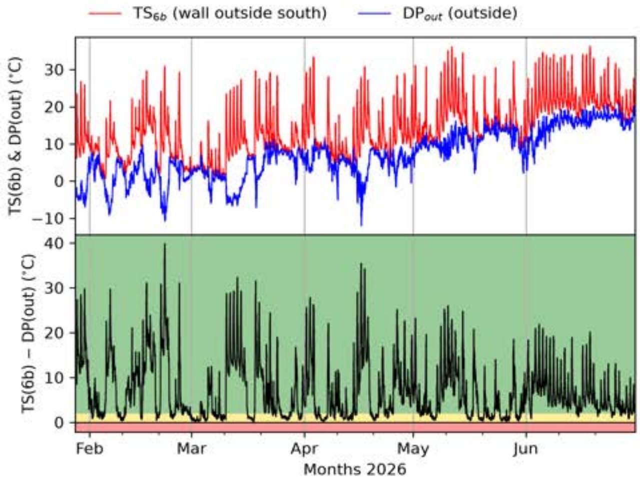


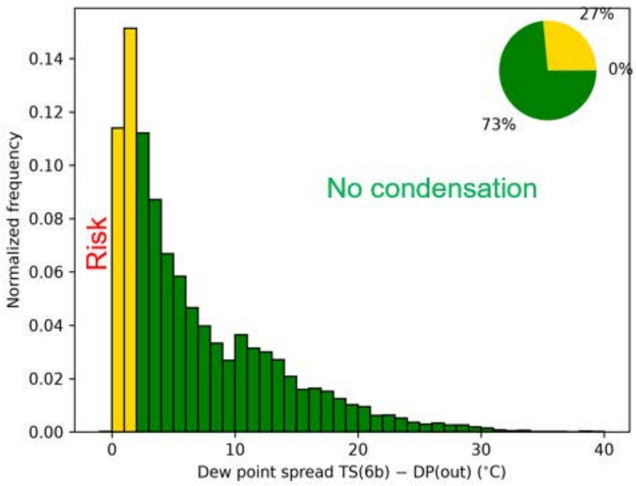




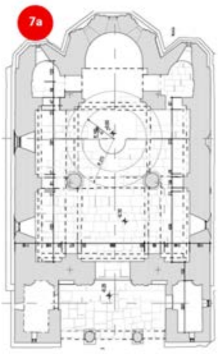
External wall, South – Is it affected by condensation?

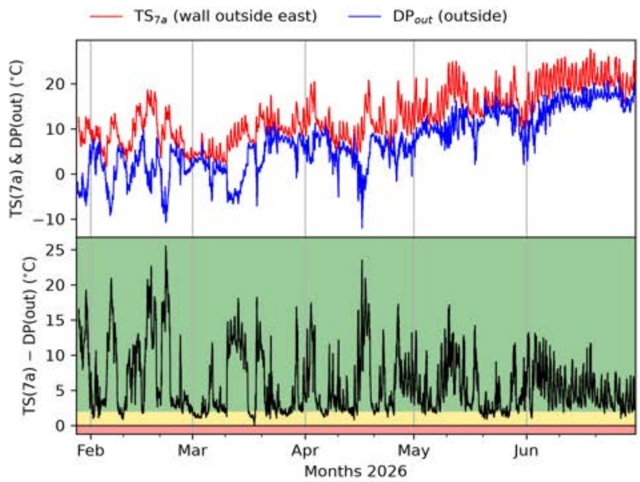


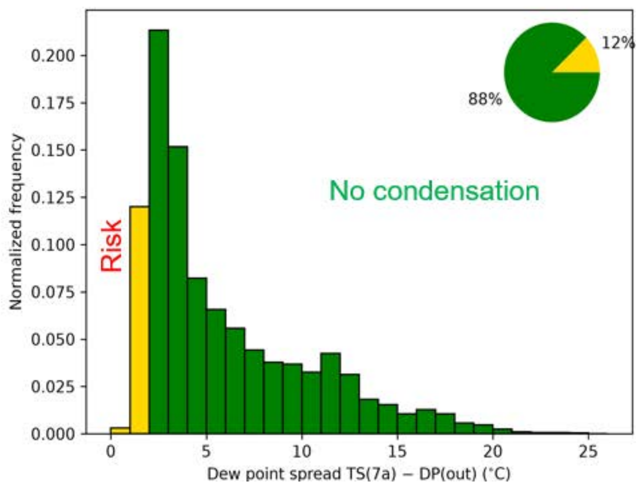




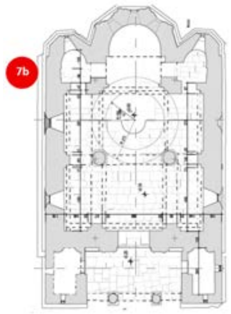
External wall, East – Is it affected by condensation?

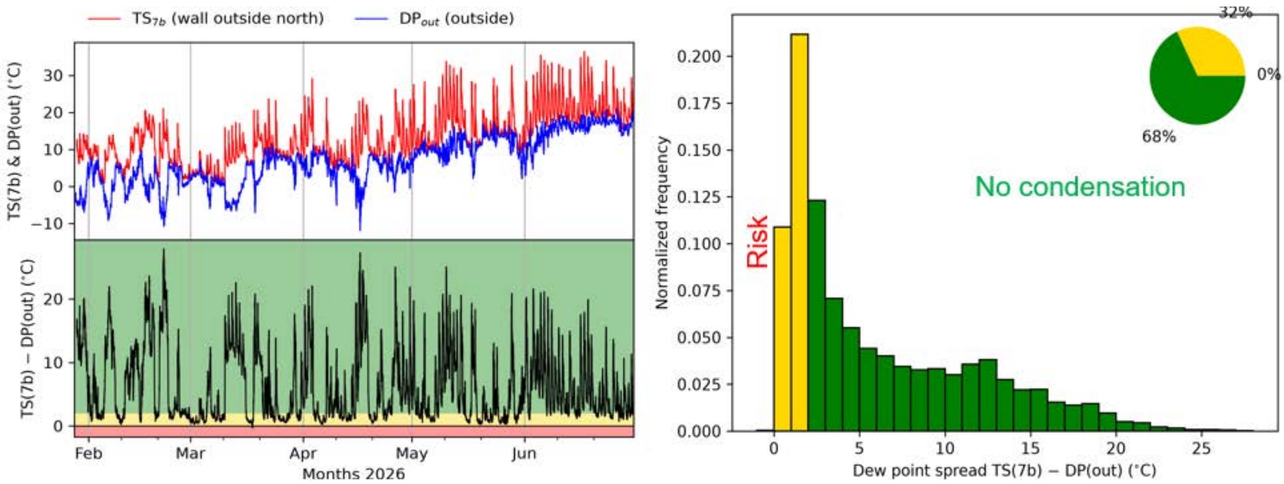






External wall, North – Is it affected by condensation?





The external walls also remained predominantly above the dew point of external air, but not always. The frequency of near-critical conditions varied according to orientation, being approximately 19% on the west wall, 27% on the south wall, 12% on the east wall and 32% on the north wall. The north-facing wall consequently showed the smallest thermal margin, consistently with its reduced exposure to direct solar radiation. Overall, the results exclude significant condensation during the investigated six-month monitoring period, while identifying the floor, the lower internal masonry and the north-facing external wall as the most vulnerable surfaces under cold and humid conditions.

5. Conclusions about the first 2026 six-month monitoring

The monitoring performed between January and June 2026 shows that the indoor microclimate of St. George Church is strongly controlled by the thermal inertia of the building envelope and by exchanges with the outdoor environment. Indoor air temperatures generally followed the seasonal external trend but were moderately buffered by the massive masonry. The air in the upper dome was periodically affected by short and pronounced temperature peaks. It should be attributed either to: (i) some solar radiation reflected inside, which reached the sensor; (ii) temporary human activity which raised the air temperature.

A stable vertical thermal stratification was frequently observed, with warmer air in the upper portions of the church and limited vertical mixing. The relative-humidity distribution was correspondingly influenced by the temperature gradient, while the mixing-ratio values remained broadly uniform throughout the internal volume. Indoor and outdoor mixing ratios were generally close, with differences mostly within approximately ±1 g/kg. The moderate prevalence of positive indoor–outdoor differences suggests that evaporation from the building fabric remained present, although not at a particularly high intensity. This may indicate residual moisture within the masonry or limited water leakage from the roof or the windows, and will be verified with the future monitoring.

From a conservation perspective, no significant surface condensation was detected on the dome, vault, internal walls during the monitoring period. The most vulnerable areas were located at ground level, where the floor and lower masonry periodically approached the dew point, particularly toward the end of the spring. The external north-facing wall also showed some near-critical conditions because of its reduced solar exposure.

As commented for the Nativity, the internal climate can be improved adopting some conservation heating, i.e. some gentle floor heating operated from May to August. The European Standard that deals with church heating for comfort, or for conservation purposes is EN 15759-1: 2011 “*Conservation of cultural property—indoor climate—part 1: guidelines for heating churches, chapels and other places of worship*”, Section 7.2.2 “Conservation heating”. This is not a necessary measure, but it may be considered in the case the Gelati Rehabilitation Committee would require a better and safer internal climate over the whole calendar year.

6. Relevant European Standards

EN 15757: 2010. Conservation of cultural heritage — Specifications for temperature and relative humidity to limit climate-induced mechanical damage in organic hygroscopic materials.
EN 15758: 2010. Conservation of cultural heritage — Procedures and instruments for measuring temperatures of the air and the surface of objects.
EN 16242: 2012. Conservation of cultural heritage — Procedures and instruments for measuring humidity in the air and moisture exchanges between air and cultural property.
EN 16682: 2017. Conservation of cultural heritage — Methods of measurement of moisture content, or water content, in materials constituting immovable cultural heritage
EN 15759-1: 2011. Conservation of cultural heritage — Indoor climate - Part 1: Guidelines for heating churches, chapels and other places of worship.
EN 15759-2. Conservation of cultural heritage — Indoor climate - Part 2: Ventilation management for the protection of cultural heritage buildings and collections.

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