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Monitoring of indoor microclimatic conditions of an eighteenth-century church, with wireless sensors

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ABSTRACT

The correct storage and protection of works of sacred art, requires the guarantee of the optimal conditions of some parameters affecting the indoor microclimate of the place in which they are located. The temperature and humidity, are two of the most important parameters of the indoor microclimate. To avoid critical issues of the preservation process, these parameters must be kept constant during the day at each point of the place. In the conservation of works of religious art, there are two conflicting requirements: the use of the works themselves, and the need to protect the objects exposed to the deterioration, due at environmental factors. This can be achieved, by creating suitable conditions for their conservation. The arts work, usually are constituted by old materials that require for proper storage conditions depending on the type of material that constitutes them. In many cases, the ideal environmental conditions for the objects are not compatible with those most appropriate for the public. In this complex scenario the ecclesiastical monitoring, and its temperature and humidity control, exists a protocol unique accepted internationally, that establishing reference limits for the various parameters, and the only recommendations are contained in the (Italian Standardization body) UNI 10829/99. The most suitable approach, widely recognized is the "preventive conservation." This can be achieved through a mixture of measures and strategies, adapted to the case, aimed at minimizing the impact of environmental factors on the exhibited artifacts, to slow down the degradation. In this paper we present the results of a study focused on the use of wireless sensors for environmental monitoring. In this scenario with the use of the thermo-hygrometric sensors, you can realize systematic and adequate conditions.

1. INTRODUCTION

An artifact of historical, artistic or cultural interest cannot be considered isolated from the surrounding environment but it constitutes a unique physical system that interacts and evolves over time.

For the thermo-hygrometric comfort conditions of the materials and/or historic and artistic artifacts -as for the people- are established ranges of temperature and relative humidity values, inside of which is ensured a correct preservation. In past centuries, many works of art were damaged by inadequate internal microclimate conditions, among the most famous cases of art works damaged is Leonardo's Last Supper in Milan.

In many other cases, the painting techniques used, very sensitive to moisture, are been the subject for centuries at large and frequent changes in temperature and relative humidity [1].

High relative humidity caused the deterioration of paintings on the walls of the Chapel of the Scrovegni [2-3] and wooden objects in Rosslyn Chapel [4-5].

For all types of works of art, the rules suggest suitable intervals of microclimate [6-8]; in some cases, however, if the artifact was acclimatized at particular historical climate of the environment, it is preferable to maintain these conditions, instead of the values standard intervals, to prevent in the works at the climate shock [9-10].

The technical standard UNI 10829 lists acceptable values for illuminance and optimal and acceptable ranges for temperature and relative humidity (in some cases, cannot be achieved at the same time, comfort for visitor and proper conditions for conservation of the works art [11].

2. THE ROLE OF THERMO-HYGROMETRIC PARAMETERS IN THE CONSERVATION OF SACRED ART

Technical standards rules [6] discusses the complexity of the degradation problem, depending on the mutual interaction between art and the whole set microclimate.

The standard helps technicians, suggesting two temperature and humidity ranges relative to keep: a strict range and more tolerability.

If the microclimate is strictly in the range, the degradation of the works of art does not occur. If the microclimate is in the tolerable range, the degradation does not occur, if the relative changes of temperature and humidity are not too large or frequent.

In any case, the appropriate set of microclimatic parameters, for maintained the conditions, should be indicated by experts on the basis of the current state of conservation, to minimize the risks of conservation.

The sudden changes or short-term, fluctuations of days, if not hours, can often cause irreversible real changes; whereas the greatest risk to the conservation derives, from the spatial and temporal gradients of these parameters, it understands how impossible it is contextualizing these works [12].

It is a good idea to take into account experience of the restorers that suggest some basic principles that correlate the degradation with the temperature and humidity parameters:

- Low air temperatures are not harmful, in themselves, to museum objects, while high ones they can be favorable for chemical degenerative processes.
- fluctuation in Temperature of the air film in contact with the object, induces a thermal stress in that, causing expansion; increases damage if the object is made of different materials.
- The Relative humidity affects the changes in size and shape of objects and the chemical and biological processes. In particular, all the organic materials capable of absorbing water - such as wood, ivory, leather, paper increasing when relative humidity increases and shrink when it decreases, with consequent variations in weight, deformations, breaks fiber, cracks and fissures.
- Values of relative humidity greater than 45%, can favor different reactions, including metal’s corrosion, dyes' discoloration on cottons, linens, wools, silks and the weakening of organic fibers (textiles and paper), in the presence of light especially.
- Values of relative humidity above 65%, with temperature values higher than 20 °C, favor the development of molds and accelerate the half-life of many harmful insects [13].

Table 1. Sensitivity of some materials at humidity and air temperature

PARAMETER	MATERIALS/OBJECTS	SENSITIVITY LEVEL
RELATIVE HUMIDITY	Inlaid furniture, gilded or painted, wooden musical instruments, paintings on panels or wooden sculptures, enlightened manuscripts (paper and parchment), oriental lacquer, chalks, Japanese screens	Extreme sensitivity to changes in relative humidity
	Costumes and textiles, oil paintings on canvas, works of art and documents of paper and parchment, paper mache, materials of plant origin (bark, grass, papyrus), polychrome wooden objects, wooden furniture, leather skin objects and clothing, armor, weapons, bones, ivory, miniatures, Chinese lacquered objects.	Require moderately stable relative humidity conditions
	Stone, marble, ceramic, glass stable, alloys of silver and gold	Relatively sensitive to changes in relative humidity
AIR TEMPERATURE	Fur, animal skins, animal exhibits (birds and mammals).	Require low values of air temperature

Table 1 shows some categories of materials and/or objects grouped according to classes of sensitivity to thermo hygrometric parameters.

It appears that the most important factor for degradation is relative humidity itself [14].

3. DETERIORATION MECHANISMS

The works of sacred art are subject to various types of deterioration, that may result from any of the following causes:

- physical type mechanisms;
- chemical type mechanisms;
- biological type mechanisms;
- anthropic type mechanisms

The physical mechanisms are correlated to the structural and thermo-physical characteristics of the building envelope; usually they favor phenomena such as transfer of thermal energy and/or water vapor.

The thermal gradients are able to give rise to tensions, changes in the volume of objects and micro cracks, with consequent reductions in the strength of the material, and penetration of water and soluble salts.

The greatest damage is manifested in objects made of materials with different coefficient of thermal expansion, which can show fractures, on the area interfaces bonding.

Values inappropriate of humidity, its fluctuations can produce stress in the materials, causing structural weakening with irreversible damage.

Particularly in hygroscopic materials, where these values do not fit, and may give rise to an exchange of water vapor between the environment and the work of art; such exchange implies mechanical stress, cracking, tearing, due to changes in volume and mass of the object.

The moisture values suitable for a correct preservation are in general quite limited:

- Values lower of 20-25%, in the materials of organic origin (such as wood and ivory), cause embrittlement, making them more susceptible to mechanical stress, inducing contractions, loss of flexibility and the appearance of the lesion.
- Values above 50%, besides determining an increase of the probability of degradation and mechanisms of initiation, can progressively make the materials more plastic and flexible up to the achievement of irreversible plastic deformation.

As a paradox it might not be unusual that, the materials of art works placed in Churches you can be adapted, over time, at conditions not well-being micro-climatic.

In these cases, in order to avoid risk of serious degradation, it may be more appropriate maintaining such environment conditions, rather than creating environmental parameters theoretically optimum, for that particular object and/or material.

The chemical mechanisms of degradation are triggered by various elements which can be divided into natural (oxygen, nitrogen, water, carbon dioxide, etc.) or artificial (pollutants such as sulfur dioxide, nitrogen oxides, acid rain, volatile substances, etc.).

They cause damage through redox reactions, depolymerization, hydrolysis or other.

Thermo-hygrometric variations strongly concur to cause chemical damage.

For example, water which carries various substances -such as salts from the interior of the walls, from the ground or atmosphere- can transfer and place them on the works, evaporating under specific physical conditions, so starting degrading processes.

The salts responsible of the most diverse mechanisms of deterioration are substantially the carbonates, sulfates, chlorides and nitrates.

The biological mechanisms are due by the action of animals or plants, in poorly polluted environments marked by high relative humidity, high temperature, poor ventilation, strong presence of light sources.

To prevent degradation due to biological agents, the temperature and relative humidity values control is not enough.

It should also be paid attention, to other parameters such, the air spare and its purity, the presence of flows and air currents.

The main difficulty in the maintenance of temperature and humidity conditions for the optimum chemical conditions of the materials, do not always coincide with those recommended for the prevention of microbiological attacks.

The restorer, or better yet the conservative, must make the best choices from time to time; under certain conditions, he will have to use particular devices or reliquaries in order to provide different conditions of storage (M.BB. DC., 2001) in the same environment.

Table 2 shows the recommended values specified in the Decree of the Minister of Heritage and Culture of l0 May 200l (M.BB. CC., 2001).

Table 2. Variables parameters thermo hygrometric, optimal for the prevention

ORGANIC ARTIFACT	**RH [%]**	**ΔRH_{max} [%]**	**T [°C]**	**ΔT_{max} [°C]**
Paintings on canvas	40-55	±6	19-24	±1,5
Paintings on wood	50-60	±2	19-24	±1,5
Wood	50-60	±2	19-24	±1,5
Archaeological wood	50-60	±2	19-24	±1,5
Wet wood			<4	
Paper	40-55	±6	18-22	±1,5
Pastels, watercolors	<65		<10	
Books and manuscripts	45-55	±5	<21	±3
Graphic material	45-55	±5	<21	±3
Leather, leather and parchment	40-55	±5	4-10	±1,5
Woven fabrics of cellulosic	30-50	±6	19-24	±1,5
Woven fabrics of proteic nature	>50-55		19-24	±1,5
Ethnographic collections	20-35	±5	15-23	±2
Stable materials	35-65		<30	

As for the attacks of the wood, due to insects, the interventions on microclimatic parameters are wholly inadequate, unless they reach temperature and relative humidity values quite incompatible with the well being, of both the most of the materials and humans.

Pathogenic bacteria are capable of producing toxins causing functional changes in living organisms and different features of the various disease processes.

The infecting charge takes place only for a certain pathogen concentration particular in the air, then is important a proper ventilation.

The temperatures favorable to the bacteria proliferation in general are included in a range from 25°C- 42 °C; optimal temperatures are between 35°C and 37°C.

The bacterium can remain dormant at temperatures lower than 20 °C; dies at more of 55 °C.

The anthropic mechanisms of degradation can be caused by: acts of vandalism (graffiti, murals, etc..), improper placement of technological elements (electricity, telephone, etc..), improper use of the object of art for devotional purposes and no maintenance.

4. THE CASE STUDY MONITORING

The microhabitat chosen for the parameters "indoor": temperature and air humidity, covers the monitoring of the seventeenth century church of SS. Crucifix in Milazzo (ME) and the microclimate of the niche placed on the altar of the nave [Figure 1].

Figure 1. The Niche and the Crucifix of SS. Crucifix Church of Milazzo (ME)

The shrines visible around the crucifix are made up of wooden frames decorated in gold leaf, protected by glass, some almost completely broken, others made opaque by time. Many of them show loss of adhesion with fragile support frames.

The shrines are intended to contain bone relics attributed to various saints, ancient scrolls, vestments, and votive offerings of precious metal.

The continuity solutions due to the low glass resistance therefore allow outside air to bring all manner of airborne pollutants within the shrines.

This amplifies the outdoor thermo-hygrometric variations creating harmful effects of inner surface condensation in the semi-enclosed areas of shrines themselves.

The shrines, as shown, are set into in a large wooden painted panel placed as a background of the SS. Crucifix sculpture.

5. DIAGNOSIS OF THE SENSORS FOR MICROCLIMATIC MONITORING

The thermo-hygrometric sensors are data loggers able to track in continuous, the informations of temperature and humidity, in order to check if they remain within specified ranges.

Figure 2. The Button-Thermochron, section of the internal components

Generally the Thermochron-loggers, make easy and economical monitoring all that is temperature sensitive and recording the results of a process that must be monitored, step by step to ensure compliance to a specific temperature profile.

For monitoring of the values of temperature and air humidity, were employed Button (see Fig.2), they are sensors, of computer encased in stainless steel capsules of 16 mm of diameter, small to be installed in environments and on surfaces, for measured the climatic parameters.

After recording, the data is downloaded to a PC via a special interface.

6. THE MONITORING AND THE ANALYSIS OF RESULTS

The first programming of monitoring step, is been the choice of the points where installing the Thermo-hygrometric sensors [15].

In particular, it was considered interesting to supply comparative data of few points within the Church, which they are considered very critical for fluctuations in temperature and humidity (f. e. the transept area and the choir placed above the entrance).

Such informations have been connected with the ones, revealing internal conditions in one of the set shrines of the panel background of the niche.

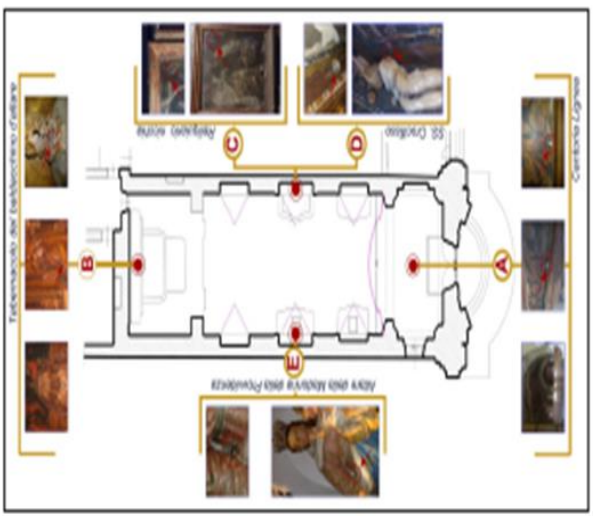

Figure 3. Positioning of the I-Button ® Thermochron

It is believed that relations, between incidence and variability of temperature and humidity quantities observed within the shrine are strongly connected and influenced by the macro-environment of the Church in which it is located [16].

Even more, considering the lack of perfect adherence of the reliquaries', the glass closure and the respective wooden frames support.

Temperature and relative humidity parameters' oscillations have been monitored in the five selected station points whose location is indicated in Fig. 3.

For convenience of detection it has been attributed to sensors some alphabet letters, the code, allows the correct recognition during the acquisition phase of the monitored data. Below, the positioning areas of each sensor is provided:

- "A" Button: located at the top of the seventeenth-century wooden choir, about 9 m height from the nave's floor, set in a position very close to the vault's frescoes and the windowed lunettes. he frescoes, in particular, are suffering from diseases of apparent separation, discoloration and florescence from the substrate.

- "B" Button: placed inside the wooden tabernacle behind the altar, at about 2.50 m height from the floor. The thermo-hygrometric trend detected by the sensor in object can be considered representative of the entire transept area, being light surrounding perturbation causes.

-"C" Button: placed inside the shrine, set on the right side of the background wooden panel of the niche of the SS. Crucifix, at 2.00 m height from the floor, approximately. The sensor was suspended inside the shrine, respecting as much as possible the presence of bare bones and votive in cloth and metal lying there.

-"D" Button: installed on the surface of the cross, inside the niche, external to the shrines.

-"E" Button: placed inside in the wooden statue of Our Lady of Providence, at about 3.50 m height from the nave's floor on the left altar, on the diametrically opposite side to the niche of the SS. Crucifix.

The two sensors (Crucifix "D") and (reliquary "C"), are placed in neighboring areas, because undergo at different micro environmental conditions, you want to compare the thermo-hygrometric parameters.

6.1 Expression of results

The monitoring interval chosen for the temperature and relative humidity parameters analysis is represented of the two central months of the summer period. This in order toacquire data, that show interesting excursions. The temperature and relative humidity values obtained by the sensors during the two months of monitoring are graphically expressed by the following figures. As can be seen in Fig.4, the trends of the temperature profile, at less than obvious differences of the peak values, are more or less overlapped.

This trend may be strongly affect by a continues thermal flow coming from high and wide windows in the choir, open during the entire day.

The effect of potential thermal wave damping - created by perimeter inertia of walls of the Church. As shown by the following graphs, all obtained values are well above the range considered optimal, as suggested by the UNI10829/99 concerning the conservation of the sculptures in painted wood. Different trend is logged in relation to the relative humidity rate [Fig.5].

The most pronounced peak hygrometric and thermal values belong to the sensor (magenta color) placed on the statue of

Our Lady of Providence on the left altar.

Both performance hygrometric and thermal excursions, are expressed in the graphs by Fig. 6.

It is clear that almost all of the hygrometric excursions, derived from monitoring data, fall well beyond the maximum recommended by the Standard UNI10829/99: H_{max}=4.

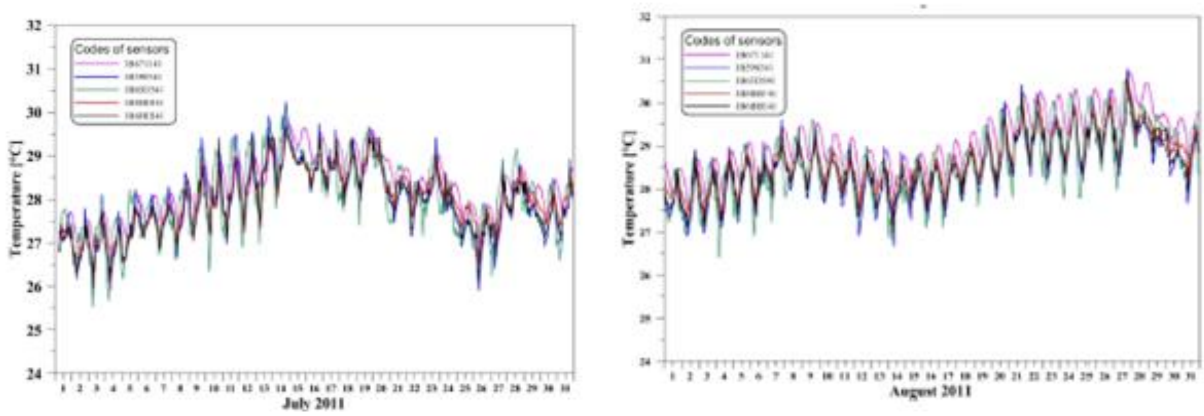

Figure 4. Evolution of the temperature profile acquired by the 5 sensors - July and Aug. 2011

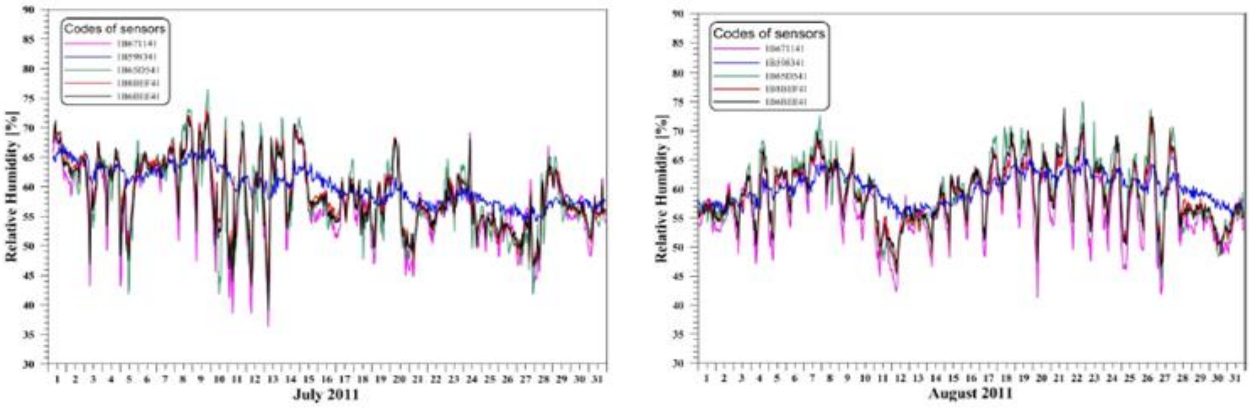

Figure 5. Evolution of the relative humidity profile acquired by the 5 sensors –July and Aug. 2011

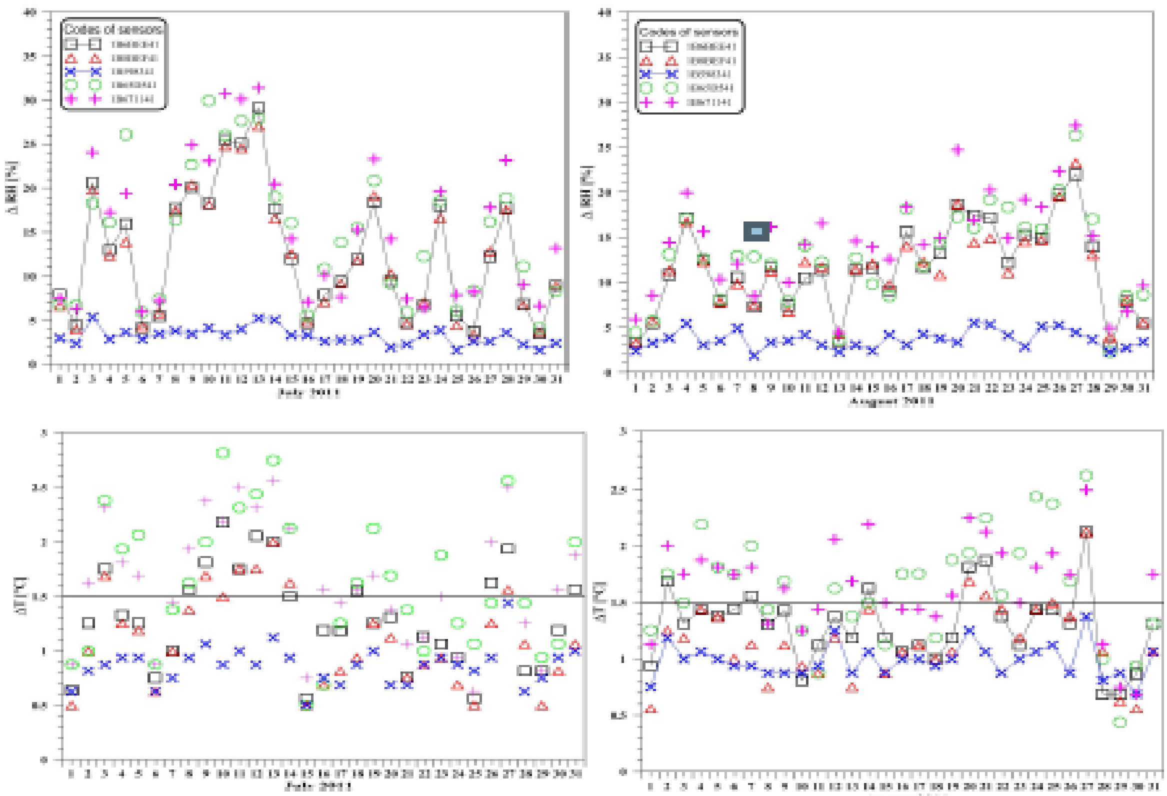

Figure 6. Evolution of hygrometric thermal excursions derived from the 5 sensors–Ju-Aug 2011

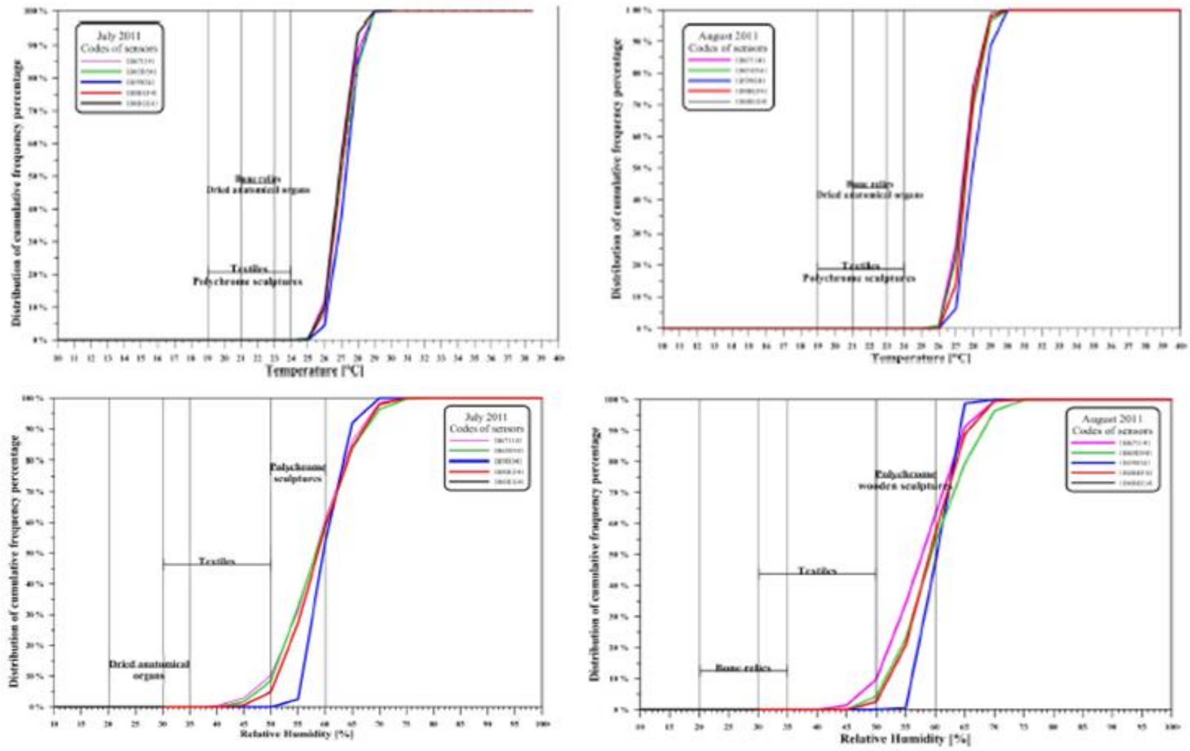

Figure 7. Percentage distribution of cumulative frequency -Temp and Hum. July-August 2011

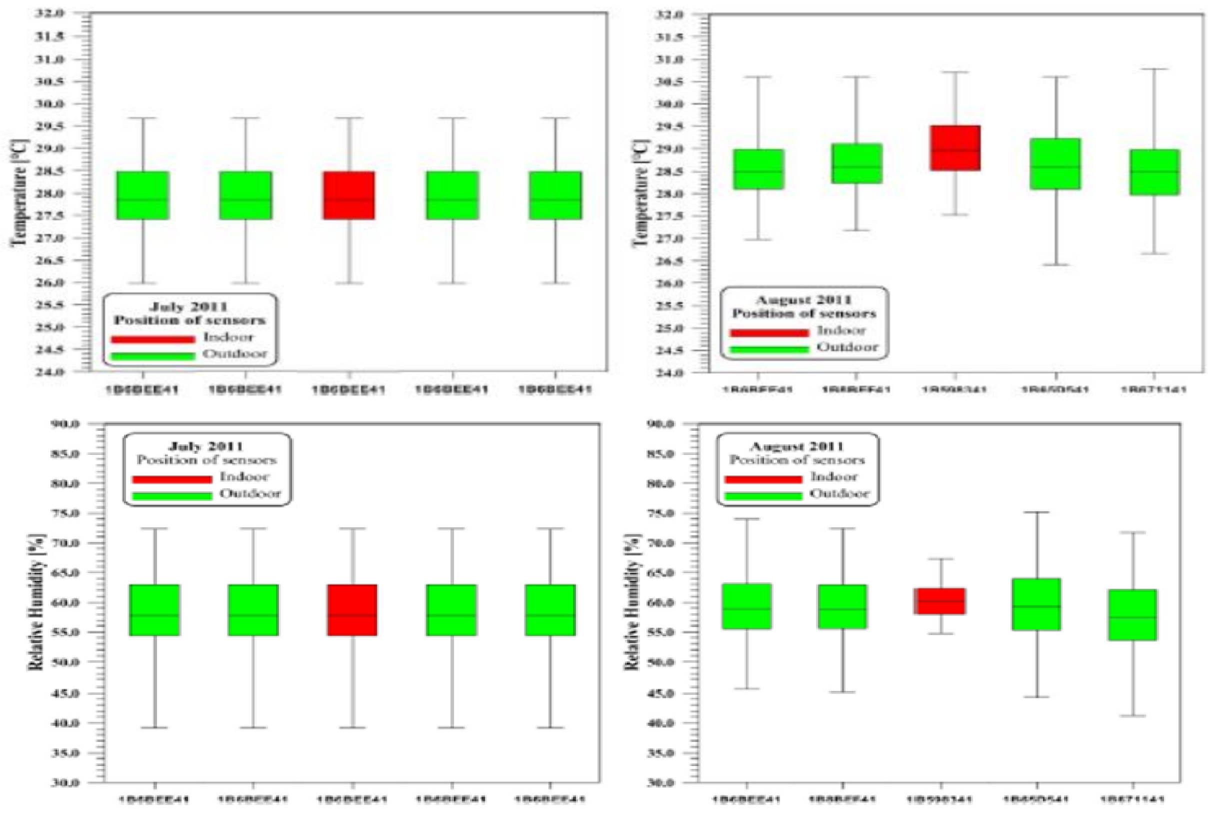

Figure 8. Deviations indicators of thermal and hygrometric data July and August 201**1**

A further analysis of monitoring results is provided by graphs of cumulative frequency distribution [Fig. 7] and by the associated indicators of deviation [Fig. 8]. Both during the monitoring in the month of July, than in August [Fig. 7], you can see how thermal values recorded are located well beyond the range of values considered optimal by the reference standard.

6.2 Considerations trend parameters thermo-hygrometric (Sensors "C" AND "D")

You could compare the monitoring results related to two sensors, in particular: the -Button- "D", installed on the crucifix surface, inside the niche but external to the display cases, and the -Button- "C", placed inside the reliquary, set in the wooden panel of the same niche bottom. The following Fig. 9, show the parameters of thermal and hygrometric performance. The interpretation of results can ot ignore the present preservation state, it requires action of monitoring. The shrine is not provided with laminated glass firmly fixed to the wooden support, nor it is equipped with the traditional technical devices suited to ensure the "seal" to the outside air penetration.

As is shown by both temperature trends and humidity, with rather muted oscillations of both parameters. The shrine pays an evident state of degradation: the frames display a great solution of continuity with the eighteenth-century glass, which is extremely thin, corroded, cracked and badly placed to the back support.

The glass sheet high transmittance, makes the thermal trends recorded by the two neighboring sensors fairly overlapping; this to underline how the shielding offered by the shrine to the thermal fluctuations on the environment outside can be low and deficient [see Fig. 9].

On the contrary, the shrine has a higher resistance to fluctuations in relative humidity, only due to the glass protection, at penetration of the steam rate inside the air/steam mixture.

This condition makes the “sensor Humidity”, with a profile almost homogeneous marked by damped oscillations daily. Similar considerations can be applied to the temperature daily and at humidity trend about the reference standard indications, Fig. 9 and Tab. 3.

As you can appreciate, the daily thermal excursions [see Fig. 10]- represent the temperature values logged by the sensor inside the shrine, remain below maximum value indicated by the standard (ΔT_{max}=1.5), in both months. The outside sensor, shows that the 37% of values have exceeded, for the month of July and 20% in August.

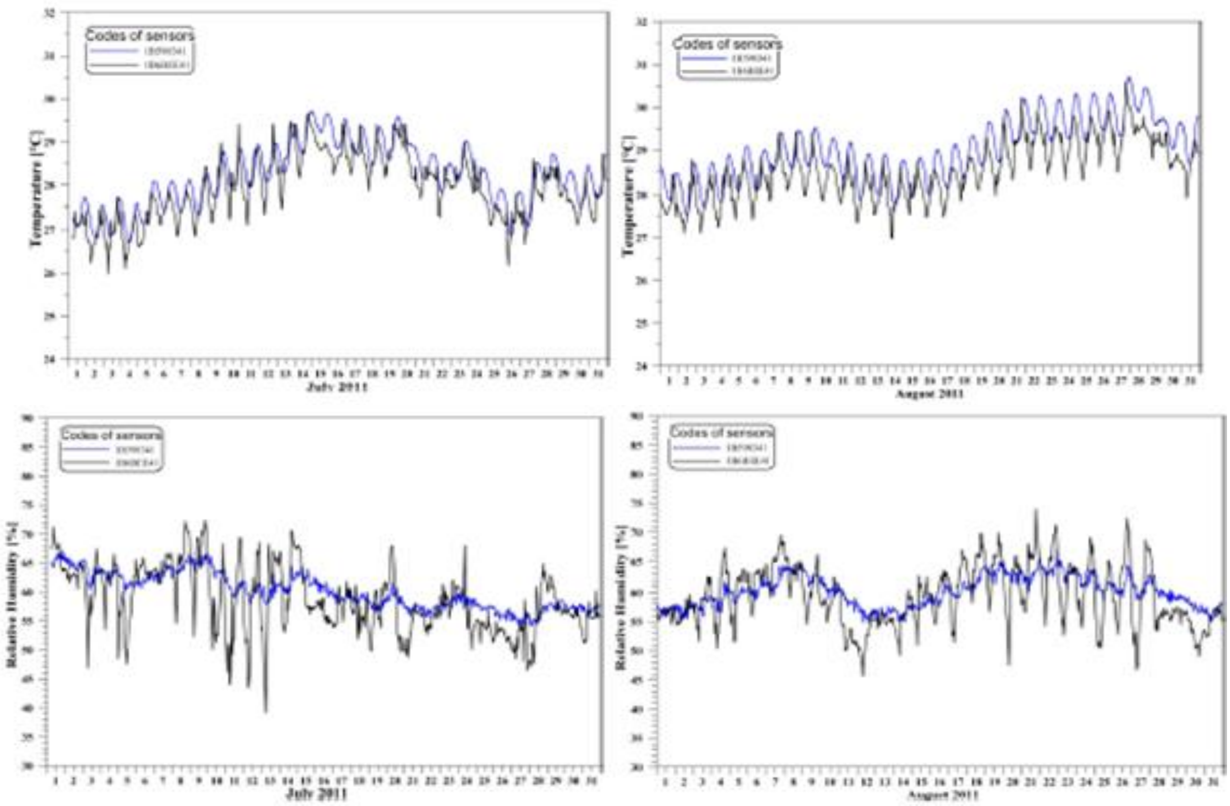

Figure 9. Evolution of temperatures and humidity profile obtained July-August 2011

Table 3. UNI 10829/99 - Excursion maximum values on a daily basis

HISTORICAL AND ARTISTIC HERITAGE	Δô [°C]	Δô$_{max}$ [°C]	HR [%]	ΔHR$_{max}$ [%]
Fabrics, curtains, carpets, upholstery fabric, silks, tapestries, costumes, clothing, religious vestments, natural fibers’ materials, jute	From 19 to 24	**1.5**	From 30 to 50	**6**
animals, dried anatomical organs, mummies	From 21 to 23	**1.5**	From 20 to 35	**--**
polychrome sculptures of wood, painted wood, paintings on wood, icons, wooden clocks, wooden musical instruments	From 19 to 24	**1.5**	From 50 to 60	**4**

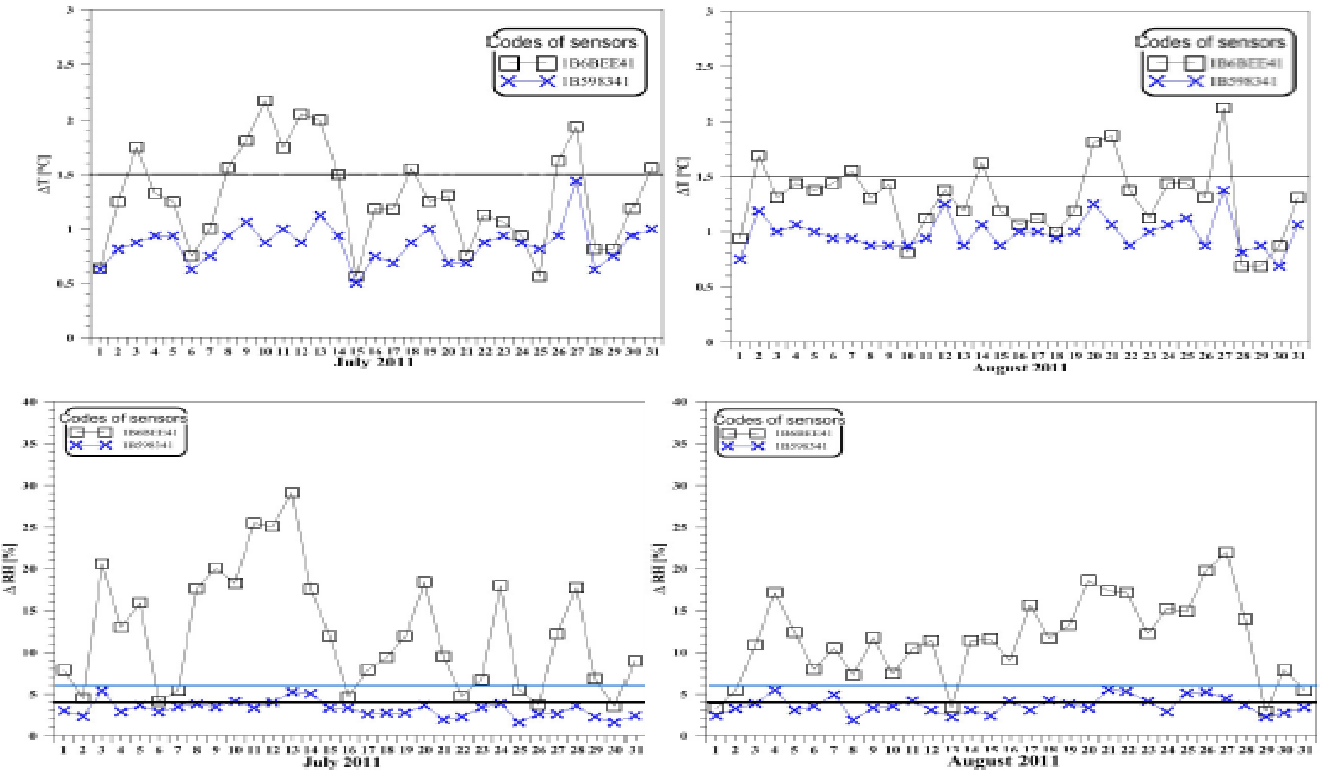

Figure 10. Air temperatures and humidity excursions for sensors (C and D)

As regards the excursions of the hygrometric performance [see Fig. 10], legislation gives the value of ΔH_{max}=6, for antique textiles and robes (blue line on the chart) and equal to ΔH_{max}=4 for the polychrome sculptures in painted wood (black line on the chart).

The rules standards don't give any indication about humidity excursions, concerning bone relics. It is noted that the sensor outside the shrine, reveals for almost all hygrometric excursions, values far superior to that reported as a maximum in the standard.

Instead the performance of inner sensor remains steadily below by standard parameters.

7. CONCLUSIONS

In conclusion, the glass screen of the shrine, is unable to keep an internal microclimate, with

respects the hygrometric values maintenance within internal regulatory range (19°C<T<24 °C with 30%<H<50% for religious vestments and 21°C<T<23°C with 20%<H<35% for organic relics) autonomously. This in relation to the chosen monitoring time (summer) values are monitored are greatly exceeding. However, they tend to damp the oscillations of the excursions of both parameters monitored, in mode that remain well below the maximum expected value.

Subsequent research purposes will be oriented to create devices able to control, so as discreetly as possible, heat and humidity the variations so harmful for works of art and keep them within the regulatory parameters of reference [17-20].

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