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Conservation of Stained Glass Windows: An Innovative User-Friendly Portable Device Coming from the EU-VIDRIO Project

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Abstract: An innovative, cost-effective, user-friendly and portable device (dew sensor) to directly detect condensation on glass surfaces was developed within the EC-VIDRIO project (contract No. EVK4-CT-2001-00045), aimed at finding sustainable solutions to preserve ancient stained glass windows. The results of the research showed that the direct survey of condensation with the new sensor is more accurate and reliable than the traditional indirect microclimatic measurements. Since the construction of the first prototype, the dew sensor was developed further, continuously improved, validated in the laboratory and applied successfully on different surfaces at sites of interest in the field of Cultural Heritage; on the stained glass windows in the Saint Urbain Basilica of Troyes (France), Sainte Chapelle of Paris (France) and Cologne Cathedral (Germany); on stone walls in Petrarca's Tomb (Padua, Italy) and the Hagar Qim Temple (Malta). Now the sensor is being used in the Lascaux Caves (France). The newly built device was patented (PTC/EP2005/050665) and gave such interesting results that the Italian Ministry of University and Research financially supported a spin-off project that has lead to the creation of a new company (R.E.D. s.r.l.) in order to develop the prototype further and to produce the sensor at industrial scale.

Key words: Surface condensation, dew sensor, microclimate, stained glass windows, cultural heritage conservation.

1. Introduction

The research undertaken within the European VIDRIO project (contract No. EVK4-CT-2001-00045) [1] was aimed at getting a more profound understanding of the impact of the environment on glass and grisaille, at evaluating the effect of different protective glazing systems, in order to identify the best practice to preserve ancient stained glass windows close to their original condition, also taking into account their exposure to mass tourism [2-10].

The study carried out during the project was focused on three buildings where important medieval stained glass windows are preserved: Saint Urbain Basilica of Troyes (France), Sainte Chapelle of Paris (France) and Cologne Cathedral (Germany), the last two being included in the UNESCO's World list of Cultural Heritage. In each site, two windows—one with and one without protective glazing were monitored and studied, at three different heights—high, middle and low [11].

As condensation is one of the main causes of glass weathering, an accurate methodology to detect this phenomenon on glass surfaces had to be developed within the project. Laboratory tests showed that the traditional indirect measurement of condensation (i.e. calculation of the condensation conditions starting from the measured values of the thermo-hygrometric parameters of the air and the surface) was not as accurate and reliable as expected, because it was affected by several errors related to on one hand the

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instruments traditionally used to perform the microclimatic measurements, on the other hand the environmental conditions [12]. In particular, the chemical and physical state of the surface (e.g. the presence of pollutants that can act as condensation nuclei), the influence of solar radiation and of ventilation are key factors having a strong influence on the formation of superficial condensation. All these factors aren't taken into account in the indirect calculation of the condensation conditions.

Hence, the CNR-ISAC, coordinator of the VIDRIO project and in charge of the microclimatic analysis, in collaboration with an Italian company, TECNO PENTA sas, developed an innovative, user-friendly and low cost device (dew sensor) to directly detect condensation on the glass surface. This device could be employed in the control and maintenance plans of the stained glass windows [8, 12].

2. Experiment

The working principle of the new sensor is based on a known effect, i.e. the diffusion phenomenon of a light beam in the infrared band on the surface with condensed water. When condensation takes place on the glass surface, the beam emitted is diffused, so a weaker beam is collected by the receiver.

The main technical information on the new dew sensor is summarized hereunder:

- Glass was used directly as reflecting surface;
- Phototransistors were chosen as receivers because they are more sensitive to reveal the phenomenon;
- The best emitter wavelength was identified in the near infrared band (800-950 nm);
- The angles of incidence/reflection and the distances emitter-glass and glass-receiver corresponding to the maximum efficiency were determined;

An innovative technical solution (Fig. 1) to minimize the interferences to the signal was developed: the sensor was equipped with two different sets of emitter-receiver, one closed within an anhydrous environment, the other in open air. The difference between the two signals changed only in case of attenuation of the signal due to the condensation detected by the pair in open air;

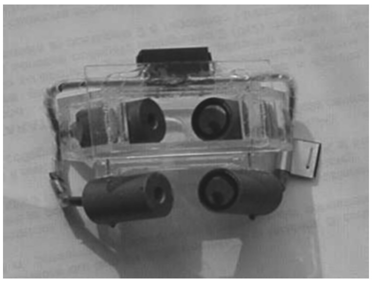

Fig. 1 Prototype of the new dew sensor (60 mm × 60 mm × 35 mm).

- To reduce the luminous interference and the difference in the conditions of illumination on the two pairs, every receiver was equipped with a narrowband filter;
- To reduce thermal influence the box containing the sensors was made of plexiglas (pmma) and its dimensions were minimized, making the instrument more suitable for the application on ancient stained glass windows (especially when installed in the interspace between the original window and the protective glazing);
- The switching on of the sensor was not continuous but limited to the time necessary for the measurement, this to avoid thermal drift due to the electrical power feed, to minimize the influence of the measuring system on the microclimatic conditions and to keep the sensor signal more stable over time;
- A new software was developed to drive the sensor in choosing the measuring configuration, in changing the off set and sensibility, and consequently in reducing or avoiding some problems related to changes in the calibration due to variations of the state of the surface (pollution deposition, weathering processes), to interferences due to different illumination conditions, drift in the signal, etc.;
- The sensor can be connected to an alarm system which is activated when the dew sensor output reaches a certain value corresponding to the start of the condensation phenomenon.

Because of its working principle, the dew sensor is able to reveal the condensation phenomenon in its first phases, i.e. just at the formation of the first molecular layer on the surface of the material, physically named monolayer, when one cannot speak of the formation of liquid water yet and when the chemical bonds between the molecules, consequently the energies involved, are still strong. The signal is semi-quantitative, that means that the height of the peaks that indicate the presence of condensation is proportional to the intensity of the event itself.

Many problems related to its functioning and use, in particular those linked to the interference of light, were carefully evaluated and studied in laboratory, in order to find the best and easiest solutions to get a useful, reliable, cost-effective, user-friendly and portable instrument. The possibility to give also quantitative results is being studied.

Since the construction of the first prototype, the dew sensor was further developed, improved, validated in the laboratory, optimised and applied successfully on different (from glass to stone) surfaces in sites of interest in the field of Cultural Heritage: besides the three ones mentioned above, Petrarca's tomb in Italy, Hagar Qim Temple in Malta and Lascaux Caves in France are shortly presented in the following section.

A European patent has been filed (PTC/EP2005/050665) and other funding has been obtained by means of a spin-off project aimed at developing new meteorological and microclimatic instruments to measure the main physical parameters in extreme environments. Within this project the improvement of the prototype was also foreseen; at the present stage the device is being miniaturized in order to introduce it into the market. The spin-off project, supported by the Italian Ministry of University and Research, leads to the creation of a new company: R.E.D. s.r.l. (Research and Environmental Devices [13]) where TECNO PENTA sas and CNR are partners. In Fig. 2, the first miniaturized version of the sensor is shown, characterized by many technological improvements with respect to the prototype, in particular concerning the optical components and the geometry of the housing.

3. Results and Discussion

In Fig. 3, an example of the direct investigation of condensation carried out in the Sainte Chapelle (Paris) is reported. The graph shows the signals of the first version (following the prototype) of three dew point sensors installed on two ancient windows—one protected and one unprotected—and on the glazing; important condensation was detected on the protective glazing, less on the unprotected window, the least on the protected one at the internal side [2, 11, 12].

Though the direct survey of condensation with the dew sensor is in general accordance with the traditional microclimatic measurements, the former is more accurate and reliable than the latter. Fig. 4 shows a comparison between direct (second version of dew sensor) and indirect measurements of condensation performed on protective glazing, at the low level of the window, in the Cologne Cathedral [2]. When the dew sensor signal already clearly indicated condensation, it happened that the difference between glass temperature and air dew point didn't reach zero value, i.e. in theory no condensation took place according to the traditional measurement. This behaviour can be explained by taking into account the fact that traditional sensors have technical limits, especially under extreme hygrometric conditions, and that the errors related to the measure of a single parameter propagate through the calculations [12].

Besides the three churches already mentioned, the two versions of the dew sensor developed within the

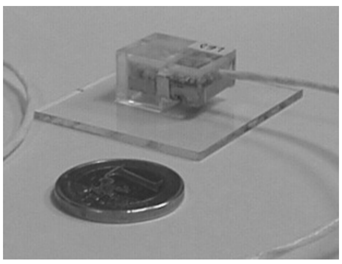

Fig. 2 First miniaturized version of the dew sensor (20 mm × 15 mm × 11 mm).

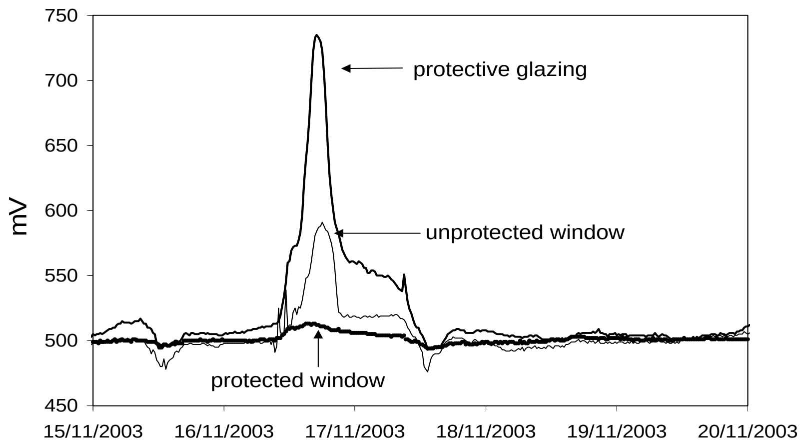

Fig. 3 Sainte Chapelle, Paris—direct investigation of condensation on glass surface by mean of the new dew sensor.

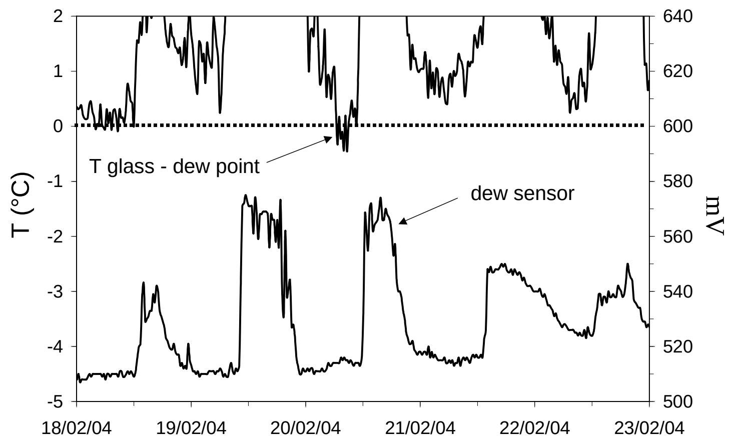

Fig. 4 Cologne Cathedral—comparison between direct and indirect measurements of condensation on a protective glazing.

VIDRIO project were also tested on a surface different from glass in two other important Cultural Heritage sites. As in both cases the device was installed on limestone, a reflecting surface was needed to detect the phenomenon, otherwise the stone would have absorbed all the condensed water eventually formed. Hence, the dew sensor investigated the superficial condensation on a thin sheet of plexiglas stuck on the stone and in thermal balance with it, because of its low thermal capacity.

It is well known that, among the phenomena related to water phase transitions, porous materials like limestone are strongly sensitive to internal condensation/evaporation. Nevertheless, in the case-studies mentioned it was worthwhile to investigate also the phenomenon of superficial condensation in order to analyse the different behaviour of differently oriented surfaces.

On the occasion of the seventh century of Petrarca's birth (1304-2004), the tomb was opened and a multidisciplinary study was carried out (from December 2003 to July 2004) aimed at investigating the state of conservation of the Poet's remains. As the wooden box housing the Poet's remains showed critical conditions, differentiated for two sides (north and south), the microclimate inside the tomb was monitored in order to understand this difference, to evaluate if the environmental conditions were suitable for the future conservation of the Poet's remains and eventually to find solutions to improve these conditions, before putting the remains back in the tomb. Fig. 5 shows the dew sensor (first version) installed on the

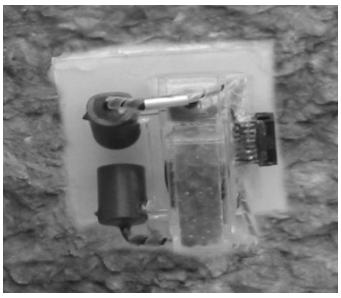

Fig. 5 Petrarca's tomb, Arquà Petrarca (Padua-Italy)—the dew sensor installed in the internal stone walls.

internal walls of the Petrarca's tomb, in Arquà Petrarca, Padua. The monitoring performed gave evidence of more (in term of number) and greater (in term of amplitude) events of condensation on the north wall of the tomb than on the south one, as we can clearly see in Fig. 6 [14].

Also the results of the indirect calculation of condensation indicated that the north wall was more affected by condensation phenomenon because of the surface temperature generally lower than the south wall. Nevertheless, there wasn't a complete accordance between the indirect and direct methods [14]. This confirms that, besides the environmental factors already mentioned (i.e. solar radiation ventilation, pollution), which are practically absent in a semi-confined environments like a tomb, the indirect measurement is affected by other errors related to the experimental limits of the traditional microclimatic sensors [12].

The monitoring and the evaluation of the environmental conditions at Hagar Qim Temple in Malta are fundamental prerequisites in order to determine an appropriate strategy for the protection and preservation of these monuments, that have suffered severe damage in the last century. The role and impact of the main physical, chemical and biological factors were studied in order to identify the main weathering processes affecting the temples [15]. The microclimatic analysis covered the study of the impact of the condensation phenomenon on differently oriented stone surfaces, both calculated and directly measured by mean of the second version of the dew sensor. The graph in Fig. 7 shows an example of the investigation carried out in Hagar Qim Temple: during the autumn and winter seasons the surfaces oriented towards north were more subjected to the phenomenon than the south ones [14].

At the same time of the experimental campaigns, the dew sensor was tested in laboratory in order to get rid of many problems related to its functioning and use. The financial support of the spin-off project provided the possibility to miniaturize the sensor: in this operation it was necessary to design again the device, to change the geometry and to choose different optoelectronic components. The miniaturized version of the dew sensor is now installed in the Lascaux Caves (Fig. 8), where the condensation phenomenon on the rock surface is being monitored (Fig. 9). In recent years, the appearance of black spots nearby the

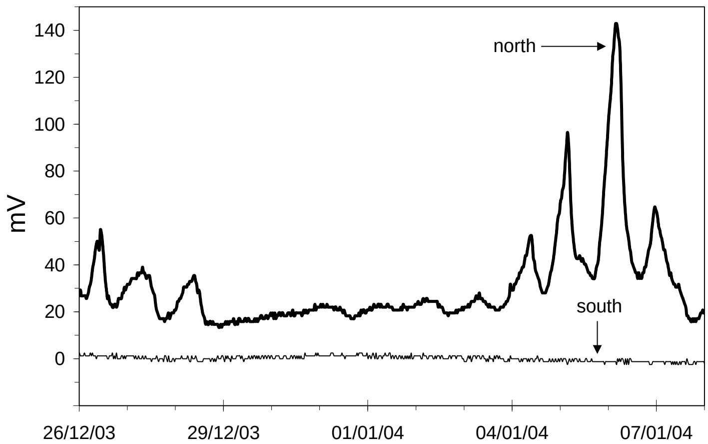

Fig. 6 Petrarca's tomb, Arquà Petrarca (Padua-Italy)—monitoring of condensation in the north and south walls of the tomb with the dew sensor.

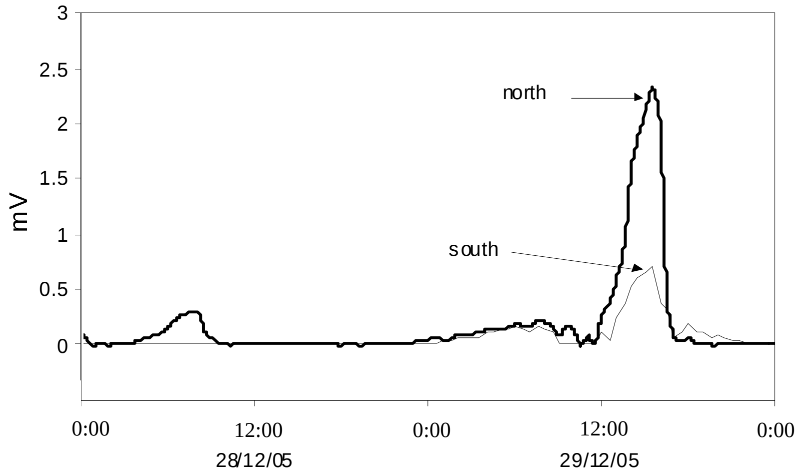

Fig. 7 Hagar Qim Temple, Malta—direct survey of condensation on the surface of two differently oriented stones.

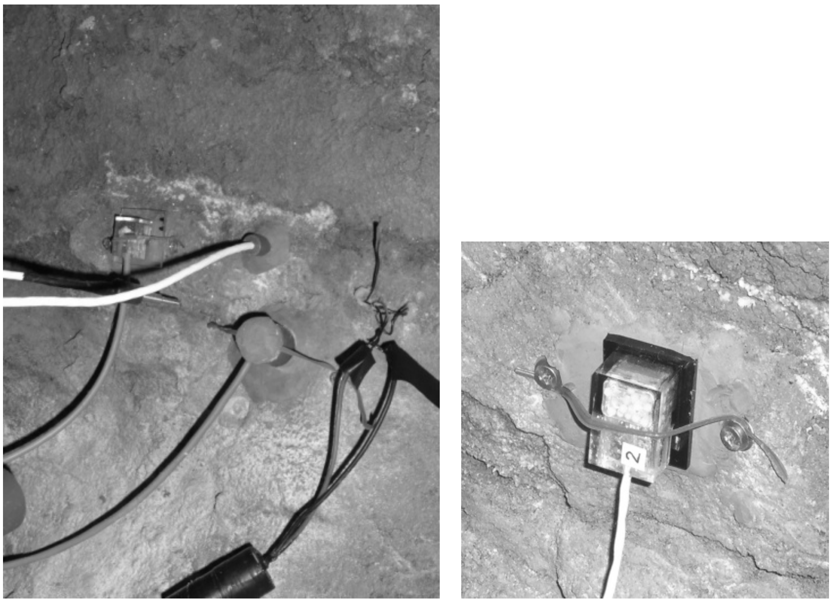

Fig. 8 Lascaux Caves, France—direct survey of condensation on the rock surface by means of the miniaturized dew sensor.

Fig. 9 Microclimatic instruments installed in the so-called Painted Gallery of the Lascaux Caves, France.

paintings led the Ministry of Culture to promote a research project aimed at correlating the microclimatic conditions inside the Caves with the risk of micro-biological impact. In fact, the microclimatic conditions together with the different kinds of substrate may be the main response to the differences in micro-biological growth. The analysis performed have highlighted several differences in the microclimate of the zones affected by micro-biological growth and the ones not affected; even if these differences are small in absolute value, they can be important for the fragile equilibrium of the caves.

4. Conclusions

The knowledge and technology transfer from research to industry is the current European trend in the field of Cultural Heritage Conservation. The innovative sensor (dew sensor) to detect the superficial condensation can be considered as an exemplary outcome of this tendency. In fact, it was designed within a European research (VIDRIO) project aimed at finding sustainable solutions for a better preservation of immovable works of art and it has been developed through a spin-off project, leading to the birth of a new company (R.E.D. srl). The results of the research performed within the VIDRIO project showed clearly that the direct survey of condensation with the new sensor is more accurate and reliable than the traditional indirect microclimatic measurements, and also than the other devices in commerce. Since the construction of the first prototype, the dew sensor was further developed and improved in order to find the best and easiest solutions to get a useful, reliable, cost-effective and user-friendly portable instrument. It was successfully applied on the limestone surfaces at sites of interest in the field of Cultural Heritage, such as Petrarca’s Tomb in Italy, Hagar Qim Temple in Malta, Lascaux Cave in France where the miniaturized version is being used. The advantage of the miniaturization is not even the low aesthetic impact of the device, which is certainly important in the field of Cultural Heritage, but mainly the reduction of possible structural errors due to the larger prototype dimensions, and also the perturbation of the condensation phenomenon during its detection.

The scientific and technological knowledge gained during VIDRIO project has been disseminated throughout Europe, giving useful information for the future management of the medieval stained glass windows in terms of local and European policies, legislation, standardisation and sustainability strategies.

The newly built device gave such interesting results that it should lead to a specialised industrial production and to enhance new applications and deployments.

Besides the dew sensor, the critical microclimatic conditions of the Lascaux Caves led the new company to design and built innovative instruments characterized by a greater accuracy than the devices commercially available. In fact, in the caves the physical parameters related to the air and the surfaces undergo only very small variations; as an example, the daily air temperature changes are few hundred of degrees.

The growth of the new company will have several implications, such as scientific and technical support in the Cultural Heritage management, increased public interest and awareness in this field, better exploitation, economic advantage in the reduction of restoration interventions, social relevance in enhancing new skills and employment.

In conclusion, the development of the innovative dew sensor is a very good example of synergism between a multidisciplinary team of scientists, companys and final users, which enhanced the contact and exchange of expertise amongst different work environments, both academic and industrial. Moreover, the foundation of a company concretizes the innovative results of the research and creates new job opportunities.

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