Merello Giménez, P.; Fernández Navajas, Á.; Jorge Curiel-Esparza; Zarzo Castelló, M.; García Diego, FJ. (2014). Characterisation of thermo-hygrometric conditions of an archaeological site affected by unlike boundary weather conditions. Building and Environment. 76:125-133. doi:10.1016/j.buildenv.2014.03.009.

http://dx.doi.org/10.1016/j.buildenv.2014.03.009

Characterization of thermo-hygrometric conditions of an archaeological site affected by unlike boundary weather conditions

Paloma Merello [1,2,†], Ángel Fernández-Navajas [2,†], Jorge Curiel-Esparza [3,†], Manuel Zarzo [4,†] and Fernando-Juan García-Diego [2,3,†,*]

[1] CulturArts Generalitat (Instituto Valenciano de Conservación y Restauración de Bienes Culturales). Complejo Socio-Educativo de Penyeta Roja s/n. 12080 Castellón, Spain.

[2] Departamento de Física Aplicada (U.D. Industriales), Universitat Politècnica de València, Camino de Vera s/n, Valencia 46022, Spain.

[3] Centro de Tecnologías Físicas, Universitat Politècnica de València, Camino de Vera s/n, Valencia 46022, Spain.

[4] Departamento de Estadística, Investigación Operativa Aplicadas y Calidad, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain.

[†] All authors contributed equally to this work.

E-Mails: palomamerello@outlook.com (P.M.); afna100@gmail.com (A. F-N); jcuriel@fis.upv.es (J.C.); mazarcas@eio.upv.es (M.Z.).

* Author to whom correspondence should be addressed; E-Mail: fjgarcid@upvnet.upv.es; Tel.: +34-61-063-3671.

Abstract: This paper applies statistical techniques to analyse microclimatic data (temperature and relative humidity) recorded at the archaeological site of Plaza de l'Almoina (Valencia, Spain). This study has allowed us to quantify the effect of certain measures that were adopted for preventive conservation. The first monitoring campaign took place in 2010 at this archaeological site, showing harmful effects on the conservation state of the remains due to the presence of a skylight that partly covers the remains and causes a greenhouse effect. This skylight was covered with a water layer to prevent overheating of this archaeological site. However, this layer was removed in 2013 due to water leaks, and the indoor conditions changed. Over the summer, a temporary canvas was installed over the skylight to avoid heating of the archaeological site below by preventing the incidence of direct sunlight. The main importance of this work was to characterize the effect of unlike boundary weather conditions of different years in the indoor microclimate of the archaeological site, and to study the effect of the new boundary situation. This paper shows that the removal of water from the skylight caused a temperature increase inside the museum; meanwhile, the subsequent installation of the canvas cover allows appropriate daily cycles of temperature and relative humidity, especially in areas under the skylight. This work also shows that the replacement of a water ditch near the archaeological site by a PVC pipe was also detected by the sensors due to the difference in water vapour pressure.

Keywords: microclimate monitoring; archaeological preservation; temperature and relative humidity sensors.

1. Introduction

Preventive conservation of artworks has been improved in recent decades through scientific research that has provided a better understanding of the deterioration processes. The main causes of deterioration are environmental: temperature, humidity, light and atmospheric gases. Additional causes include mechanical damage due to inappropriate maintenance and assembly, chemical damage from contact with reactive materials and damage caused by biological organisms, plants, insects and animals.

All these factors can be controlled in most cases, although the effect of some of them such as air pollutants can rarely be eliminated. By controlling these factors, it is possible to significantly slow the deterioration processes, but not to stop it completely. The methodology of preventive conservation is therefore indirect: deterioration is reduced by controlling its causes [1].

Currently, there is growing interest in monitoring the climatic parameters in cultural heritage [2-13]. In the case of archaeological sites, temperature differences between various minerals in block surfaces and differences in surface and substrate temperature are sources of thermal stress. Experience shows that thermal and humidity stresses are important causes of micro-fractures between the mineral grains of blocks [14]. Moreover, thermal variations affecting mechanisms, such as salt crystallisation, may indirectly induce damage. Thermal cycles are more important for surfaces exposed to direct solar radiation [14]. The study of microclimatic conditions surrounding archaeological sites is essential to prevent deterioration and identify eventual consequences of corrective measures [15-18].

Some authors have studied the materials composing the roofs [19] and walls [20] of buildings and how they affect the thermal comfort inside, but always focused on the welfare of people, rarely in terms of preventive conservation of archaeological heritage. In our case, we must take into account both the people who visit the museum and the archaeological remains. Nor should we forget the importance of the microclimate on the energy demand in public buildings in the context of climate change [21].

The city of Valentia (Valencia, Spain) was founded by the Romans in 138 BC, and the exact founding point where the city started is located in Plaza de l'Almoina. Evidence of Roman settlement can still be seen in the excavated remains of the Roman forum and baths [22]. The archaeological subsurface gathers a group of monumental buildings that form a complete compendium of history and urban development of Valencia, from its origins until today.

L'Almoina is an archaeological museum located in a building about 3 metres below the current city sidewalk level. The archaeological remains are covered by a concrete structure, which forms an elevated plaza above the sidewalk. This cover connects with sidewalks through steps with different heights along its perimeter due to the slope of the sidewalk. There is no vertical retaining wall inside the museum to isolate the remains from water diffusion through capillarity from the surrounding areas. The archaeological remains cover an area of 2500 m^2 and retain vestiges ranging from the second century BC (Roman) until the fourteenth century (medieval). In 2007, an external concrete structure adapted to the archaeological site was built, and a skylight (25 × 25 m) covered with a water layer was installed, allowing passers-by a glimpse of the archaeological remains below.

Preventive conservation of the archaeological site at Plaza de l’Almoina includes maintaining stable and adequate temperature and relative humidity levels and managing light exposure, among others. An initial campaign of thermo-hygrometric monitoring in Plaza de l’Almoina [23] showed a relevant effect of the skylight on the variations in temperature and relative humidity, causing sharp rises and falls during daylight hours. Possible solutions to this problem were proposed [23], based on the experience of a previous monitoring study in the ruins of Ariadne’s house in Pompeii [11].

In early summer 2013, water leaks from the skylight occurred, dripping onto the archaeological site. As an initial solution, Valencia City Council, which manages the archaeological site, eliminated the water from the skylight to prevent further leaks. Later, in August, the City Council placed a waterproof canvas over the skylight, preventing rainfall leakage and the direct impact of sunlight. Moreover, in the year 2011 a water ditch built with porous bricks passing near the archaeological site [23] was substituted by a 110 mm PVC pipe. In general, microclimatic characterisation of an archaeological site must be repeated whenever environmental or boundary conditions change [23, 24]. So, a second monitoring campaign in Plaza the l’Almoina was carried out in 2013.

In [25], the same problem of comparing the effect on thermo-hygrometric conditions of implemented measures is described, aimed at attributing the different levels of temperature and RH to these corrective actions. In this paper, the same data selection is performed and the selected data periods have similar outdoor environmental conditions (mainly in temperature). Now, the same procedure is applied in a buried archaeological site.

The main aim of this work is to assess the effect of different corrective measures and changes implemented in the archaeological site of Plaza de l'Almoina using statistical methods sparsely used in cultural heritage and with proven effectiveness [11, 15, 23], as well as to quantify the improvements achieved by the proposed solution which could be taken as an example for other similar archaeological sites in the future.

2. Materials and Methods

2.1. Data loggers and installation

The same data-loggers were installed as in the first monitoring campaign [23], in the same place (in this paper, sensor positions are shown in Figures 3 and 7) and with the same calibration methodology.

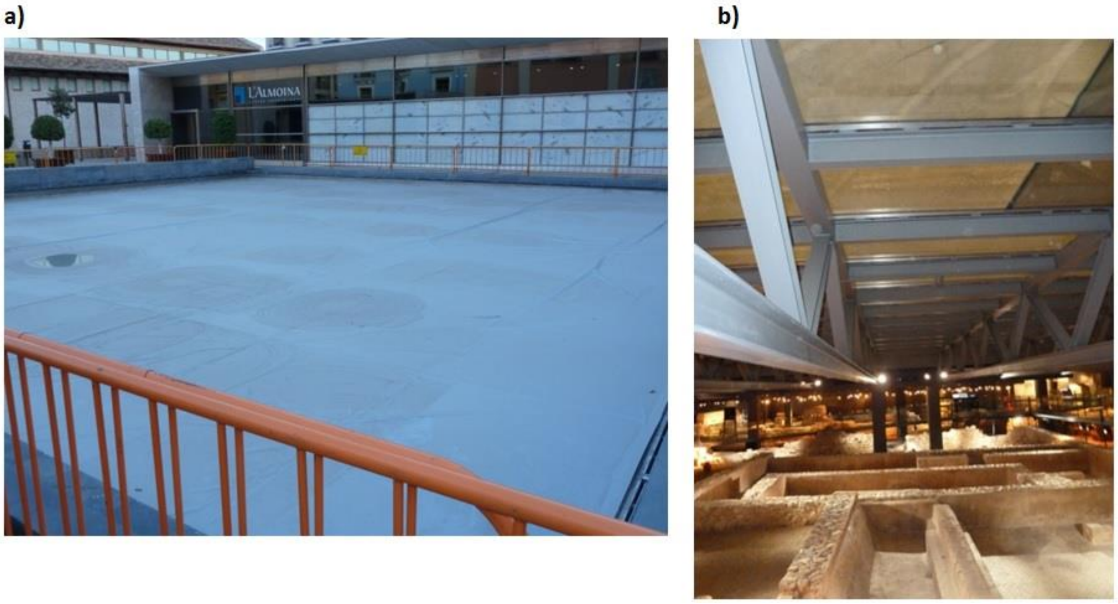
The second monitoring study began on 22 July 2013 and ended on 11 September 2013, resulting in a total period of 51 days. All data loggers were programmed to register one measurement every 30 min, which entails a total of 2,448 recorded values (i.e., 51 days × 24 h/day × 2 data/h).

Sensor coded as number 8 (#8) was stolen; therefore no data are available for this location. Sensors #3 and #4 were manipulated by third parties causing data loss for one week, from 09/05/2013 (at 18:00) to 09/11/2013 (at 23:59).

2.2. *Corrective action implemented*

As aforementioned, on 20 August 2013 the City Council of Valencia installed a canvas cover directly on the skylight. The canvas was white and 625 m^2 in area. It was installed directly onto the glass without a fixing system (Fig. 1).

Figure 1. **Canvas cover**, **a)** viewed from above, **b)** viewed from below.



2.3. *Statistical Analyses*

2.3.1 Data selection

In order to compare data obtained in the first monitoring campaign (2010, before removing the skylight water and installing the canvas) with data from the second campaign (2013), a data selection was performed because the two periods monitored are very different: the entire year was monitored in 2010, while only summer was monitored in 2013.

As was done in [25], to compare the effect on thermo-hygrometric conditions of implemented measures and in order to attribute the different levels of temperature and

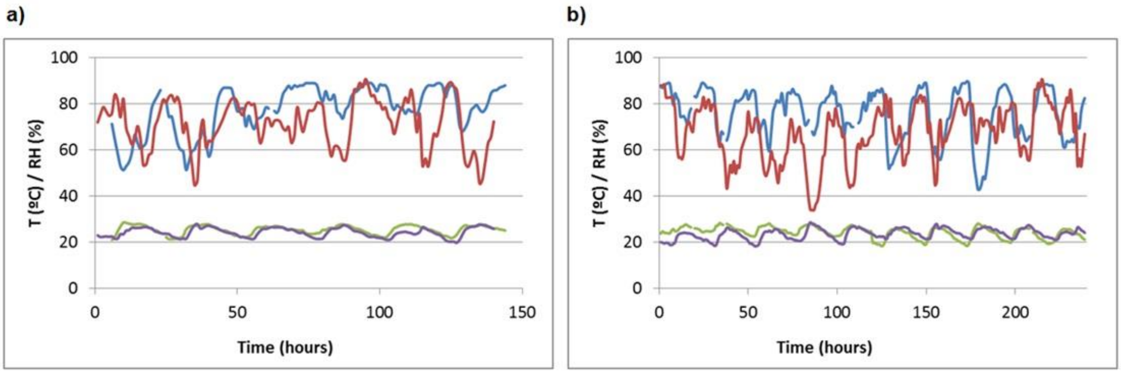
RH to these corrective actions, the time periods compared must have similar outdoor environmental conditions (mainly of temperature). This is necessary to avoid the confusion of effects such as attributing differences, for example, to a warmer period.

In this paper, we work with two different data matrices that correspond to similar thermo-hygrometric outdoor conditions (Fig. 2): one matrix to compare data recorded in 2010 with data registered in 2013 before installing the canvas, and another matrix to compare data recorded in 2010 with data obtained in 2013 after installation of the canvas cover (Table 1).

Table 1. Selected dates with similar outdoor conditions, to be used in the data analyses.

Period	Description	Data	selected dates 2010	selected dates 2013
A	Data 2010 vs. data 2013 before canvas installation	288 (6 days)	06/30/2010 – 07/05/2010	07/31/2013 – 08/05/2013
B	Data 2010 vs. data 2013 after canvas installation	480 (10 days)	06/25/2010 – 07/04/2010	08/20/2013 – 08/24/2013 and 08/31/2013 – 09/04/2013

Figure 2. **Similarity of periods selected from the first (2010) and second (2013) campaign. a)** Data for 2010 and 2013 before installing the canvas. Value 0 on the horizontal axis coincides with 06/30/2010 (0:00 h) and 07/31/2013 (0:00 h, period A). **b)** Data for 2010 and 2013 after installing the canvas. Value 0 on the horizontal axis coincides with 06/25/2010 (0:00 h) and 08/20/2013 (0:00 h, period B). Legend: blue line corresponds to RH data in 2013, red to RH data in 2010, green to temperature data in 2013 and violet to temperature data in 2010.



The results are discussed according to international standards [26, 27]. The recommended range of RH and temperature for stones and rocks is 40–60% and 19–24

°C, and a maximum daily variation of 6% in RH (no recommended daily variation is available for temperature).

2.3.2 Contour plots

Contour plots were analysed in this paper as done in [15, 23]. These plots were obtained with a CAD program. The graduation of the parameter was obtained by triangulation from the physical parameter value (its daily mean value) in a sensor and its closest neighbour. This was performed for all sensors. Next, equal graduation points were connected with splines, obtaining a contour plot for the physical parameter.

2.3.3 Mean daily trajectories

Plots of mean daily trajectories allow us to condense the information of large time periods and discern differences between sensors by visual inspection [11, 15, 23]. In this work, mean daily trajectories were calculated as the average of the data recorded from all sensors per fraction of time (in this case, every hour) for the entire period of interest.

2.3.4 Normal probability plot

The normal probability plot is a graphical technique for normality testing, assessing whether or not a data set is approximately normally distributed. This plot has been previously used for detecting anomalous behaviour of thermo-hygrometric parameters in cultural heritage [23]. We are interested in detecting those sensors whose differences from the average are abnormal. For this purpose, we worked with the average of inner sensors (calculated considering sensors from #1 to #11) since the main interest was to characterise differences inside the archaeological site.

2.3.5 Analysis of Variance (ANOVA)

To study the effect of the waterproof canvas installed, different ANOVA models were tested for data recorded in 2013, considering the following factors: *day*, *sensor* (from #1 to #11) and *canvas* (0=no installed vs. 1=installed, depending on the state of the skylight during this period). ANOVAs were performed using the software Statgraphics 5.1 [24].

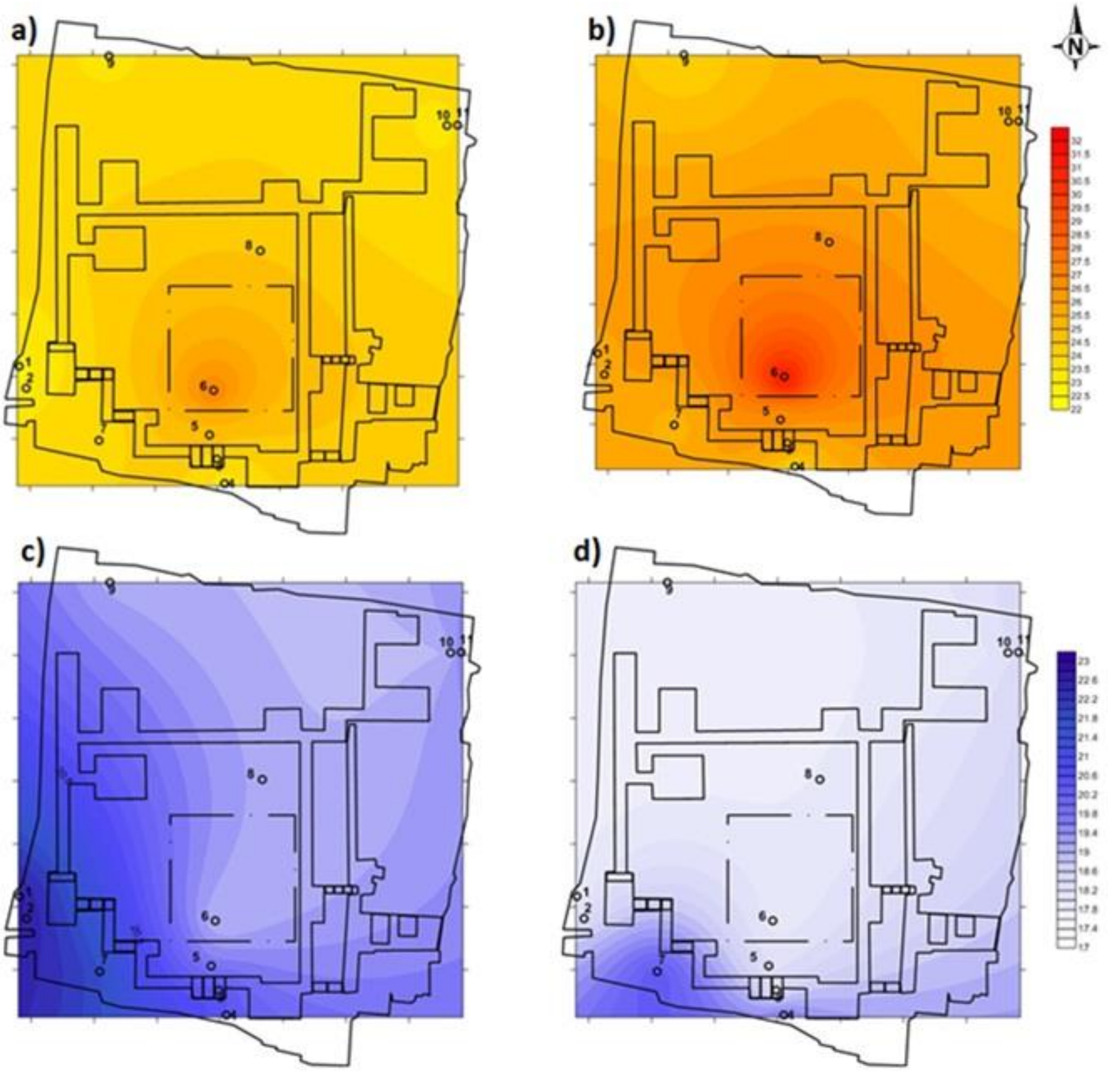
ANOVA analyses were carried out for all data recorded in 2013 without selecting any time interval, since the entire monitoring period corresponds to summer and differences between periods can be studied with the factor *day*.

3. Results and Discussion

3.1. Microclimate characterisation after removing the skylight water layer (period A)

This section studies the effects on the microclimate inside the archaeological site in 2013 as a result of removing the water on the skylight. For this purpose, data recorded in 2013 were compared with data registered in 2010 (period A), when conditions for conservation of the archaeological site were unfavourable [23].

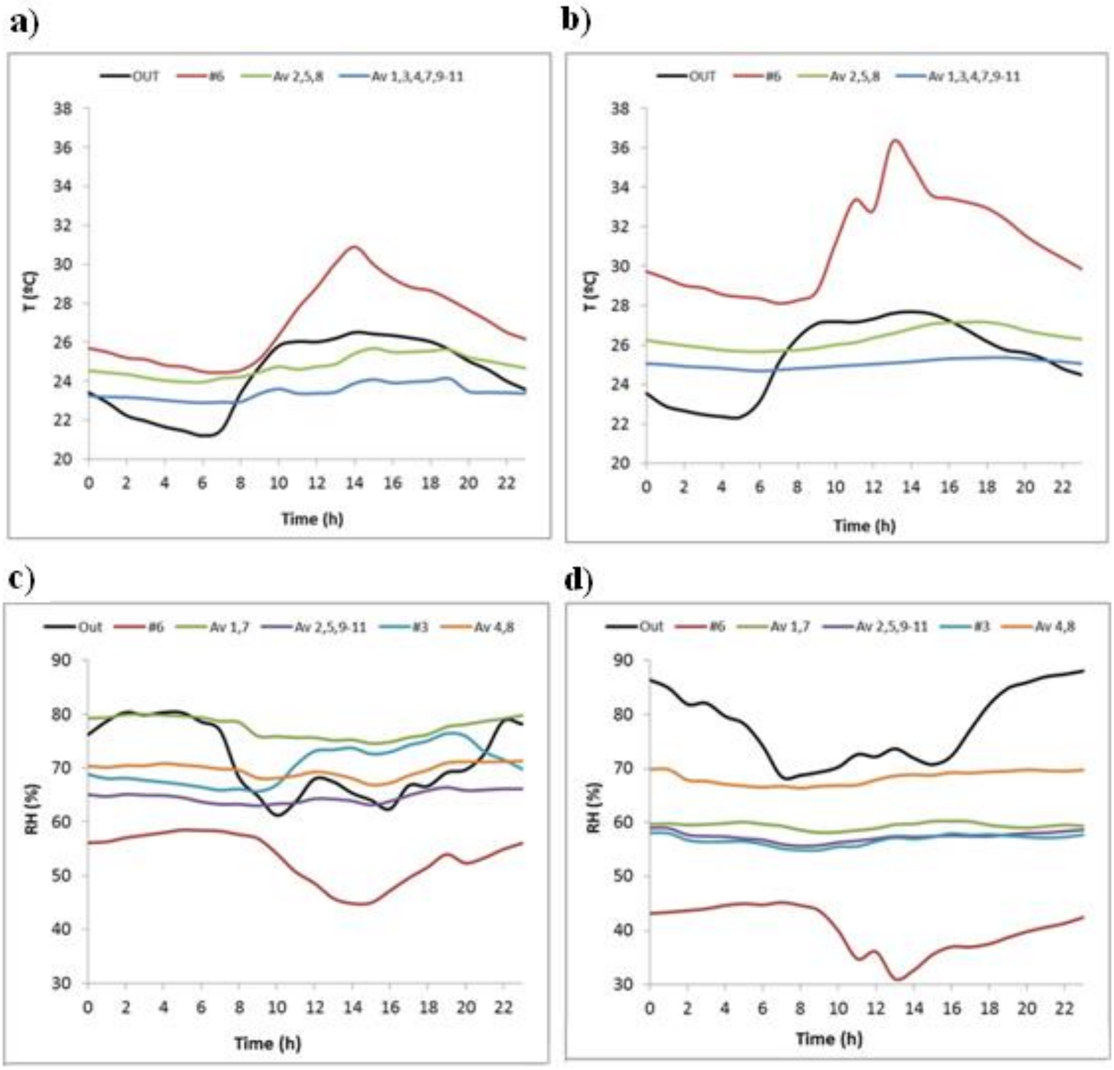
Figure 3. **Contour plots (period A), a) of temperature (ºC) in 2010**, **b)** of temperature (ºC) in 2013, **c)** of water vapour pressure (mbar) in 2010, **d)** of water vapour pressure (mbar) in 2013.



The main change in the mean temperature of the archaeological site as a result of emptying the skylight (Fig. 3a and b) is a generalised increase of this parameter, especially in those sensors located below the skylight (#6), as a consequence of the direct impact of sunlight on the glass and the non-existent energy filter effect of the water.

Regarding the water vapour pressure (Fig. 3c and d), the substitution of the water ditch with a PVC pipe has substantially modified the gradient; whereas in 2010 it ran from west to east, in 2014 it is less pronounced and runs from north to south.

Figure 4. **Mean daily trajectories of temperature (a, b) and RH (c, d) of sensors contained in clusters defined in [20]. a, c)** Data recorded in 2010 (period A), **b, d)** data recorded in 2013 (period A).

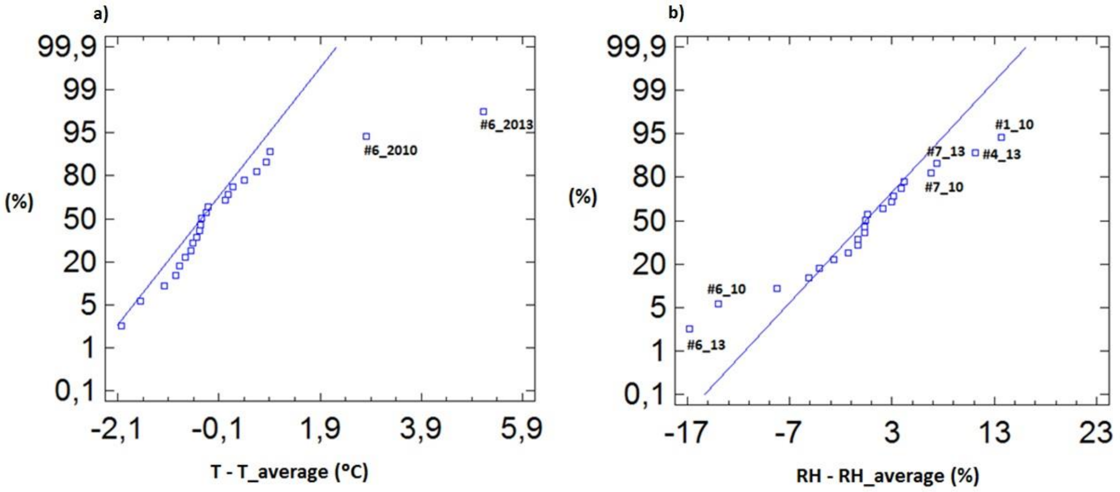


As shown in Fig. 4a,b the mean daily temperature trajectory of the outdoor sensor is almost coincident in both years, which implies that both periods are comparable and the differences observed in sensor #6 are a consequence of having removed the water layer from the skylight. Thus, sensor #6 has increased its mean daily temperature. Its mean daily maximum reaches 37 ºC, a value that is detrimental to conservation of the archaeological site, as it exceeds 24ºC, which is the temperature recommended by the standards [26, 27]. The remaining sensors inside the archaeological site have also increased their temperature by 2 °C on average. Note that in 2013 the average trajectory of inner sensors at the archaeological site was above 24ºC during the monitored period, which is the recommended temperature value for preservation of the remains [26, 27].

Fig. 4c,d shows that removing the water from the skylight has caused an increase in temperature (Fig. 4b) as well as a drop in RH in the areas immediately under the glass, primarily reflected by the trajectory of sensor #6, which shows a mean daily variability in both years of roughly 14% of RH, which is higher than the standard recommended value (6%). On the other hand, the adjacent water ditch [16] caused higher levels of RH in sensors #1 and #7 in 2010 (Fig. 4.c), as a result of substitution of the water ditch by a PVC pipe in 2013. There is no such contribution by capillary action and the trajectories in sensors #1 and #7 resemble the trajectories of sensors #2, #5, #9-11 (Fig. 4d).

Notice the shift recorded by sensor #3, which in 2010 captured the effects of the climate control system and presented an inverted trend compared to the rest of sensors. In 2013, this sensor underwent a very similar pattern to sensors #2, #5, #9-11. The reason could be that the climate control strategy was changed; the air conditioning system was working intermittently in 2010 depending on the needs of the archaeological site, whereas in 2013 it was working continuously throughout the day.

Figure 5. **Normal probability plot comparing data recorded in 2010 with data recorded in 2013 (period A),** for **a)** temperature difference of each sensor with respect to the inner average this year, **b)** RH difference of each sensor with respect to the inner average this year.



The normal probability plot in Fig. 5 helps us identify those sensors whose differences compared to the inner average depart from normality.

In the case of temperature (Fig. 5.a), sensor #6, which is located directly below the skylight, appears further away from the normal trend followed by all sensors of the archaeological site and this difference has increased as a result of emptying the skylight.

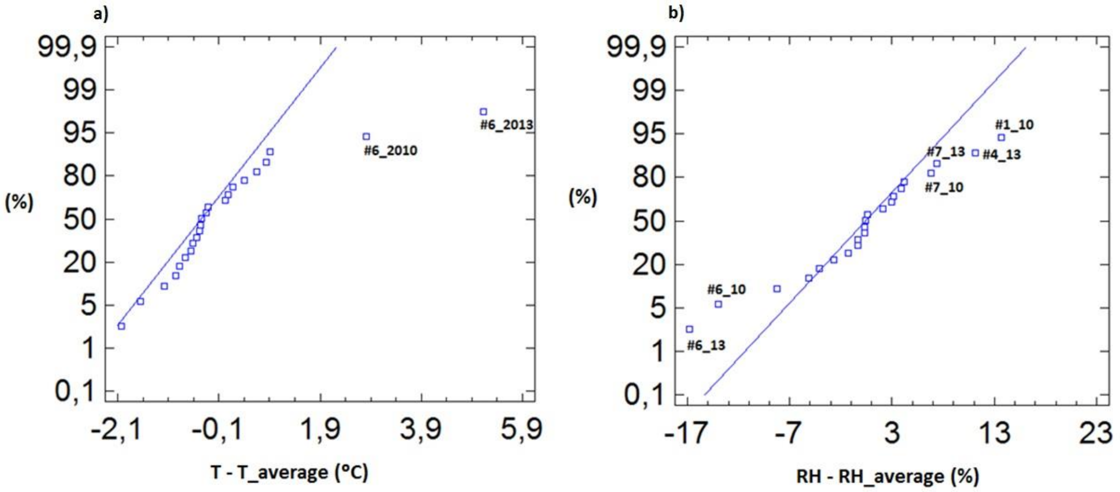
For RH (Fig. 5.b), the abnormality of sensor #6 is more noticeable in 2013 than in 2010, mainly due to the decrease in the daily minimums (Fig. 4c, d). On the other hand, sensor #1, which recorded abnormally high RH values in 2010 as a result of water infiltration by capillarity from the nearby water ditch, presents normal behaviour in 2013 after substituting it by a PVC pipe. Finally, note that sensor #4 appears as anomalous in RH in 2013 (Fig. 5.b) because its mean daily trajectory of RH is very similar in both years (2010 and 2013, Fig. 4.c, d), while the other sensors have substantially changed in 2013, thus changing the inner average of RH, and now #4 appears as one of the wettest sensors, in accordance with the results shown by the contour plot of water vapour pressure (Fig. 3 c and d).

3.2. Microclimate characterisation after installing the canvas (period B)

In this section we assess whether installation of the canvas cover has improved the microclimatic conditions affecting the ruins in 2010 [23].

Thus, as was done for data recorded before installing the canvas cover (period A), a normal probability plot was represented (Fig. 6) for the differences compared to the inner average, in order to identify which sensors have a different behaviour compared to the general trend followed inside the archaeological site in that particular time period (2010 and 2013, period B).

Figure 6. **Normal probability plot comparing data recorded in 2010 with data recorded in 2013 (period A),** for **a)** temperature difference of each sensor with respect to the inner average this year, **b)** RH difference of each sensor with respect to the inner average this year.



Sensor #6 is the most anomalous in temperature, especially in 2010 when no cover was installed, exceeding the inner mean temperature by 3.54 °C. In 2013, when the canvas was installed (period B), sensor #6 exceeds the inner mean temperature by approximately 1.8 °C.

As in section 3.1, after substituting the water ditch with a PVC pipe, sensor #1 reflects RH values similar to the average. However, sensor #7 continues recording RH values above the average in 2013, which may indicate that the contribution of moisture received by this sensor is not related to the water pipe but with the waterproofing of the town square located immediately above this area of the archaeological site.

On the other hand, the temperature increase caused by the skylight during daylight hours resulted in remarkable differences to the average RH in 2010 (#6_2010, RH values 16.09% lower than average), and after installing the canvas cover (_C) these differences were smoothed (#6_C, RH values 8.27% below average).

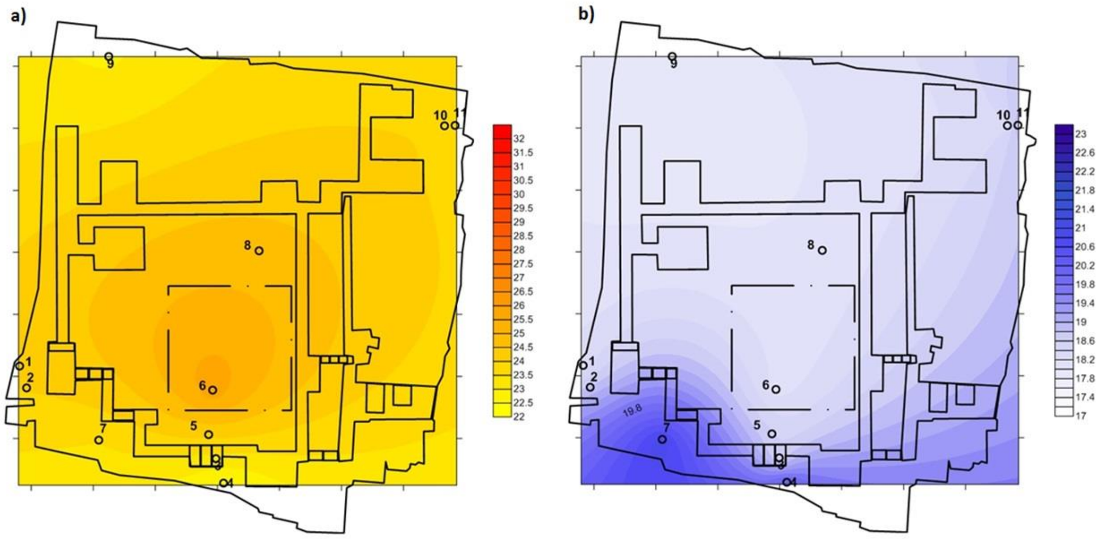
Note that Normal probability plots have also been performed for *amplitudes* (daily maximum minus minimum), *maximums*, *minimums*, and for the differences of these parameters compared to the inner average. As the results were similar, only the plots for the mean value are presented here to simplify the discussion.

3.3. Comparison of data recorded in 2013, before and after installing the canvas cover

The temperature gradient after installing the canvas cover (Fig. 7a) remains centred on the skylight, as the major source of heat inside the archaeological site. However, thanks to the installed cover, the place has a more uniform temperature at the different areas and the average temperature in the areas near the skylight has decreased.

In 2013, the substitution of the water ditch with a PVC pipe was reflected in the water vapour pressure gradient (Fig. 3.d, Fig. 7.b). Higher levels of water vapour pressure at sensor #7 reflect the lower waterproofing of the urban square bounding at the south-west with the archaeological site.

Figure 7. **Contour plots in 2013 (period B)**, **a)** of temperature (ºC), **b)** and water vapour pressure (mbar).



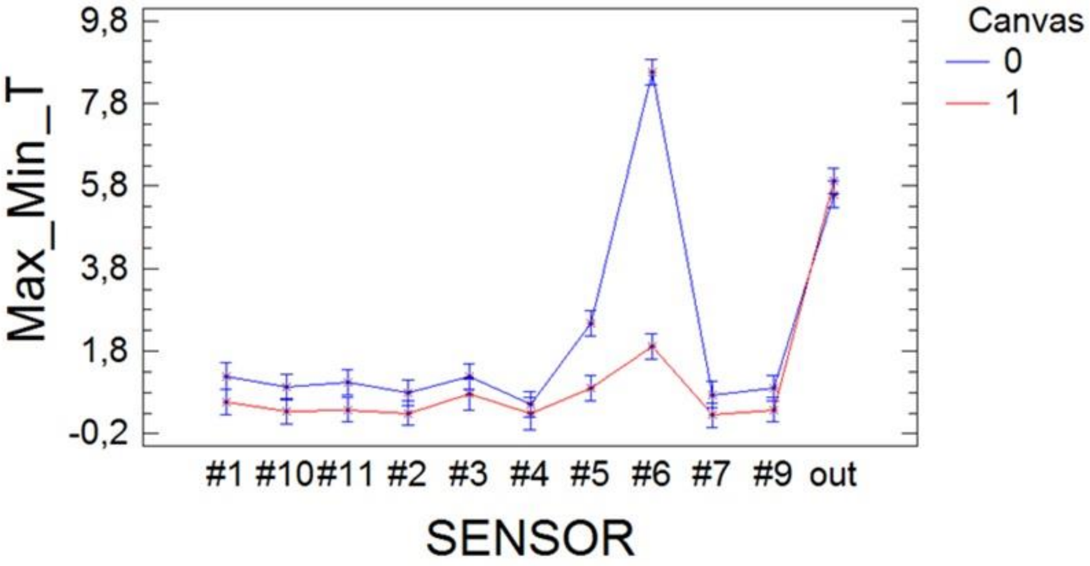
The effect of the canvas cover on the thermo-hygrometric parameters, considering the emptying of the skylight (data 2013), was also studied by statistical techniques.

As explained in the Materials and Methods section, in order to quantify and empirically demonstrate the effect of the canvas cover on the thermo-hygrometric parameters at the archaeological site, analysis of variance (ANOVA) was applied for data recorded in 2013, considering the amplitude (max - min) of temperature (and RH) as independent variables and two factors (*sensor* and *canvas*).

The two factors and their interaction were statistically significant (p-value <0.00001) and relevant in practice. Especially noteworthy is the effect of the canvas installation on sensor #6 (immediately below the skylight) and #5 (in surrounding areas), which have reduced their daily amplitude by 6.7 ºC and 1.6 ºC, respectively (Fig. 8).

It should be kept in mind that the differences reflected by ANOVA for the factor "*canvas*" are not attributable to a relevant difference in the outdoor temperature values in the compared periods, because the least significant difference (LSD) intervals of outdoors sensor overlap, and thus their differences are no statistically significant.

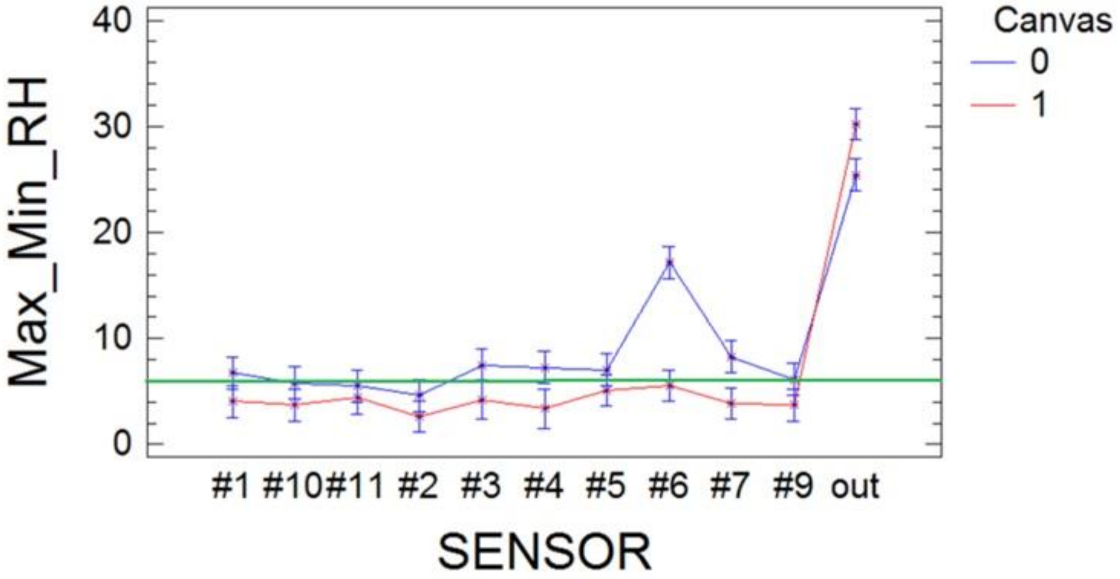
Figure 8. **ANOVA Interaction plot**, with the daily amplitude of temperature as dependent variable and "sensor" and "canvas" (takes the value 1 when the canvas was installed and 0 otherwise) as factors. ANOVA analyses will be performed for the data recorded in 2013 without selecting dates.



To assess whether the differences are also relevant in practice for the canvas factor in those sensors displaying little reduction in variability, an ANOVA analysis was performed eliminating data from sensors #6 and #5. In such case, both factors (canvas and sensor) are significant (p-value <0.00001), but the interaction between them is not statistically significant (p-value = 0.46). This result indicates that the effect on the daily variability caused by installing the canvas is relevant, but approximately the same for all sensors.

In the case of RH, both factors and their interaction were significant (p-value <0.00001). The installation of the canvas cover reduced the daily amplitude by 11.8% RH and 1.7% for sensors #6 and #5, respectively, their mean daily amplitudes now being below the 6% recommended by the standards (Fig. 9).

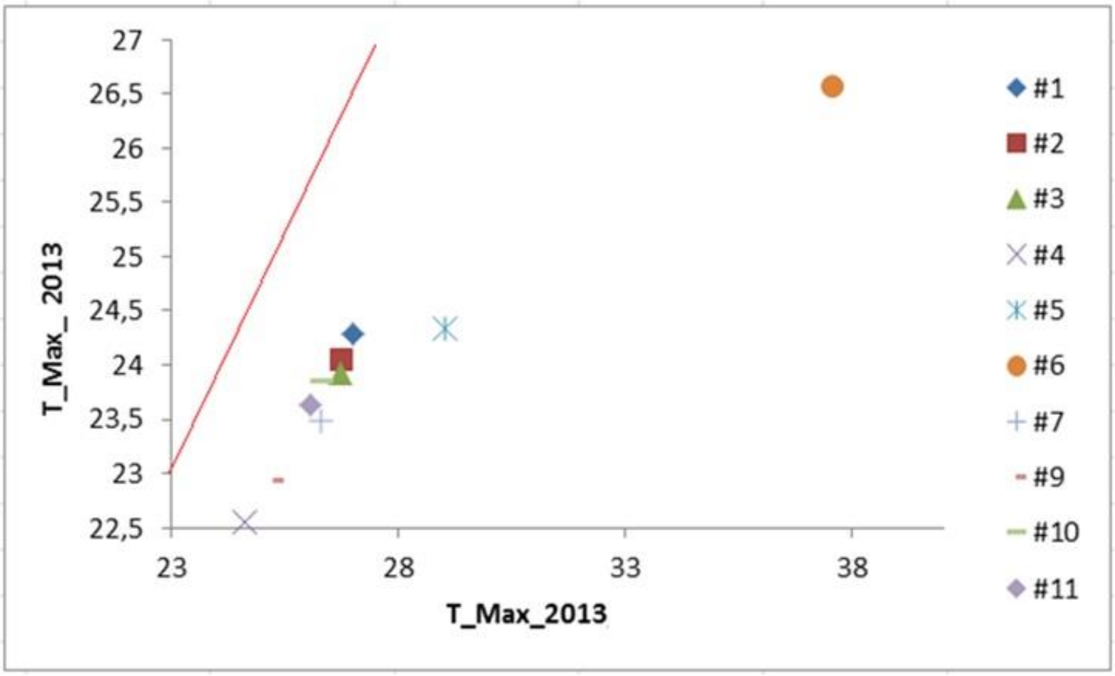
Figure 9. **ANOVA Interaction plot**, with the daily amplitude of RH as dependent variable and "sensor" and "canvas" (takes the value 1 when the canvas was installed and 0 otherwise) as factors. ANOVA analyses will be performed for the data recorded in 2013 without selecting dates. Green horizontal line indicates the variability of RH recommended by the standards (6%) [23, 24].



As for temperature, ANOVA of RH was performed removing data corresponding to sensors #6 and #5, both factors being significant (p-value <0.00001), but not their interaction (p-value = 0.11). Again, it can be deduced that the effect on the daily variability caused by installing the canvas is relevant and the same for all sensors.

The interpretation of the interaction can similarly be deduced in the bivariate plot shown below.

Figure 10. **Bivariate plot of the mean daily maximum temperature, before (horizontal axis) and after (vertical axis) installing the canvas cover (2013)**. The red line represents the scenario in which the mean maximum temperature reached without cover is identical to that achieved after installing the canvas.



The vertical distance to the red line measures the change undergone after installing the canvas cover. Thus, #6 is the sensor that has most decreased its mean maximum of temperature (Fig. 10), distantly followed by sensor #5. The other sensors have dropped their mean maximum by an average of 2.24 °C, which coincides with the non-significant interaction of the *canvas* and *sensor* factors in the ANOVA analysis when data from sensors #5 and #6 are removed. Results are similar for the mean minimum of RH, as the maximums of temperature are significantly correlated with the minimums of RH (p-value <0.001) with a correlation coefficient of -0.8.

4. Conclusions

Recorded thermo-hygrometric data have allowed us to quantify the increase of the daily temperature maximums (and the consequent decrease in the RH minimums) in 2013 as a result of removing the water layer on the skylight (prior to installation of the canvas cover), especially in those areas immediately below it.

On the other hand, installation of the canvas has improved temperature and humidity conditions for conservation of the archaeological remains, because the covering has created a microclimate more stable and less harmful for conservation purposes according to the recommended values of temperature and relative humidity provided by the international standards.

The canvas cover has been a provisional solution, whose effectiveness has been proven in view of the results presented here, and a definitive solution more in keeping with the aesthetics of the public square that houses the archaeological site could be designed.

The substitution of the water ditch by a PVC pipe has decreased the RH levels of sensor #1. However, sensor #7 maintains similar RH levels; this suggests that the supply of moisture in this area comes from a different waterproofing of the area under which it is located.

The proposed methodology resulted in a useful procedure to compare results from unlike boundary weather conditions, based on comparing data from different campaigns in order to determine the effect of a corrective measure using statistical techniques. This methodology allowed us to evaluate the three changes implemented in 2013 at Plaza de l'Almoina and their surroundings, as well as the effects that these changes have had on the thermo-hygrometric conditions of the site, always taking into account that they have a direct impact on the conservation based on the international standards. The satisfactory results of this study can be taken as an example by similar archaeological sites to study and quantify the adequacy of corrective actions.

Acknowledgments

This work was partially supported by the Spanish Government (Ministerio de Ciencia e Innovación) under projects HAR2010-21944-C02-01 and HAR2010-21944-C02-02. The authors thank the collaboration of the archaeologist Albert Ribera and Carmen Perez from CulturArts Generalitat (IVC+R).

References

[1] Ward P. The Nature of Conservation: A Race Against Time. California: Oxford University Press; 1990.

[2] Stewart J, Julien S, Staniforth S. An integrated monitoring strategy at Chedworth Roman Villa (Gloucestershire). In: Taryn J, Nixon P, editors. Preserving Archaeological Remains in Situ? London: Museum of London Archaeology Service; 2004, p.179-87.

[3] Lopez-Arce P, Garcia-Guinea J. Weathering traces in ancient bricks from historic buildings. Build Environ 2005; 40 (7): 929-941. DOI: 10.1016/j.buildenv.2004.08.027

[4] Lourenço PB, Luso E, Almeida MG. Defects and moisture problems in buildings from historical city centres: A case study in Portugal. Build Environ 2006;41 (2):223-234. DOI: 10.1016/j.buildenv.2005.01.001

[5] Lillie M, Smith R, Reed J, Inglis R. Southwest Scottish Crannogs: using in situ studies to assess preservation in wetland archaeological contexts. J Archaeol Sci 2008;35(7):1886-1900. DOI: 10.1016/j.jas.2007.11.029

[6] Zítek P, Vyhlídal T. Model-based moisture sorption stabilization in historical buildings. Build Environ 2009;44 (6):1181-1187. DOI: 10.1016/j.buildenv.2008.08.014

[7] Angelini E, Grassini S, Corbellini S, Parvis M, Piantanida M. A multidisciplinary approach for the conservation of a building of the seventeenth century. Appl Phys A-Mater 2010;100 (3):763-769. DOI: 10.1007/s00339-010-5654-8

[8] García-Diego F-J, Zarzo M. Microclimate monitoring by multivariate statistical control: The renaissance frescoes of the Cathedral of Valencia (Spain). J Cult Herit 2010;11(3):339-344. DOI: 10.1016/j.culher.2009.06.002

[9] Nava S, Becherini F, Bernardi A, Bonazza A, Chiari M, García-Orellana I, Lucarelli F, Ludwig N, Migliori A, Sabbioni C, Udisti R, Valli G, Vecchi R. An integrated approach to assess air pollution threats to cultural heritage in a semi-confined environment: The case study of Michelozzo's Courtyard in Florence (Italy). Sci Total Environ 2010;408 (6):1403-1413.

[10] Zarzo M, Fernández-Navajas A, García-Diego F-J. Long-term monitoring of fresco paintings in the Cathedral of Valencia (Spain) through humidity and temperature sensors in various locations for preventive conservation. Sensors 2011;11(9):8685-8710. DOI: 10.3390/s110908685

[11] Merello P, García-Diego F-J, Zarzo M. Microclimate monitoring of Ariadne’s house (Pompeii, Italy) for preventive conservation of fresco paintings. Chem Central J 2012;6:145. DOI: 10.1186/1752-153X-6-145

[12] Huijbregts Z, Kramer R.P, Martens MHJ, van Schijndel AWM, Schellen HL. A proposed method to assess the damage risk of future climate change to museum objects in historic buildings. Build Environ 2012;55:43-56. DOI: 10.1016/j.buildenv.2012.01.008

[13] Pérez MC, García-Diego F-J, Merello P, D’Antoni P, Fernández-Navajas A, Ribera-Lacomba A, Ferrazza L, Pérez-Miralles J, Baró J-L, Merce P, D’Antoni H, Curiel-Esparza J. Ariadne’s house (Pompeii, Italy) wall paintings: A multidisciplinary study of its present state focused on a future restoration and preventive conservation. Mater Construcc 2013;63 (311):449-467. DOI: 10.3989/mc.2012.00812

[14] Ponziani D, Ferrero E, Appolonia L, Migliorinia S. Effects of temperature and humidity excursions and wind exposure on the arch of Augustus in Aosta. J Cult Herit 2012;13:462–468. DOI: 10.1016/j.culher.2012.01.005

[15] García-Diego FJ, Fernández-Navajas A, Beltrán P, Merello P. Study of the Effect of the Strategy of Heating on the Mudejar Church of Santa Maria in Ateca (Spain) for Preventive Conservation of the Altarpiece Surroundings. Sensors 2013;13:11407-11423. DOI: 10.3390/s130911407

[16] Staniforth S. Benefit versus costs in environmental control. In: Keene S, editor. Managing Conservation: Papers Given at a Conference Held Jointly by the United Kingdom Institute for Conservation and the Museum of London. London: The United Kingdom Institute for Conservation; 1990, p. 28-30.

[17] Staniforth S, Ballard WM, Caner-Saltik EN, Drewello R, Eck-mann I-L, Krumbein WE, Padfield T. Group report: what are appropriate strategies to evaluate change

and to sustain cultural heritage? In: Krumbein WE, Brimblecombe P, editors. Durability and Change: The Science, Responsibility, and Cost of Sustaining Cultural Heritage. New Jersey: John Wiley & Sons Inc.; 1992, p. 175.

[18] Staniforth S, Griffin I. Damp problems in the Chapel at Cliveden. In: The Conservation of Heritage Interiors, Proceedings of Conference Symposium 2000, Ottawa, Canada, May 17 to 20 2000; Canadian Conservation Institute: Ottawa, Canada, 2000; 177-84.

[19] Ouldboukhitine SE, Belarbi R, Djedjig R. Characterization of green roof components: Measurements of thermal and hydrological properties. Build Environ 2012, 56: 78-85. DOI 10.1016/j.buildenv.2012.02.024

[20] Kumar A, Suman BM. Experimental evaluation of insulation materials for walls and roofs and their impact on indoor thermal comfort under composite climate. Build Environ 2013, 59: 635-643. DOI 10.1016/j.buildenv.2012.09.023

[21] Ouedraogo B, Levermore GJ, Parkinson JB. Future energy demand for public buildings in the context of climate change for Burkina Faso. Build Environ 2012, 49: 270-282. DOI 10.1016/j.buildenv.2011.10.003

[22] Prythercha DL, Boira JV. City profile: Valencia. Cities 2009:26 (2):103–115.

[23] Fernandez-Navajas A, Merello P, Beltrán P, García-Diego F.-J. Multivariate Thermo-Hygrometric Characterisation of the Archaeological Site of Plaza de l'Almoina (Valencia, Spain) for Preventive Conservation. Sensors 2013;13 (8):9729-9746. DOI: 10.3390/s130809729

[24] Statgraphics Software. Available online: http://www.statgraphics.net (accessed on 6 November 2013).

[25] Merello P, García-Diego F-J, Zarzo M. Evaluation of corrective measures implemented for the preventive conservation of fresco paintings in Ariadne's house (Pompeii, Italy). Chem Central J 2013;7 (1):87. DOI: 10.1186/1752-153X-7-87

[26] Ministero per i Beni e le Attività Culturali. DM 10/2001. Atto di Indirizzo sui Criteri Tecnico-scientifici e Sugli Standard di Funzionamento e Sviluppo dei Musei. Rome: Gazzetta Ufficiale ; 2001, n. 244, 19 ottobre 2001, DL 112/1998 art. 150 comma 6.

[27] UNI 10829. Works of Art of Historical Importance; Ambient Conditions for the Conservation. Measurement and Analysis. Milano: UNI Ente Nazionale Italiano di Unificazione; 1999.