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INFLUENCE OF ENVIRONMENTAL CONDITIONS IN THE STORAGE SYSTEMS FOR THE CONSERVATION OF MACROVERTEBRATE FOSSILS

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Abstract

The macrovertebrate fossil collections are one of the most important tools for studying past ecosystems. However, the conservation of the fossil material is sometimes conditioned by the environmental conditions surrounding the fossil specimen during its storage. The control of these factors can be a complex task.In the current study, we propose an analysis of the capabilities of damping the effects related to the environmental factors in the fossil specimen, and the protection offered by several different materials readily available in the storage of paleontological material. For this reason, we have analysed two series of tests made in four different types of material used in the making of the storage systems. Not all the materials have been specifically made for its use in storage and conservation of paleontological collections. The study and record over time of the different conditions on the different support materials have allowed developing a methodology adequately for the characteristics of each fossil specimen and also to stabilize the specimen and protect against vibrations. This protection permits that these supports can acts as protection, therefore isolating the specimen from extreme environmental factors that could risk its conservation.

***Keywords**: Environmental conditions; Storage supports; Palaeontology; Conservation*

Introduction

The paleontological collections are composed of irreplaceable fossil specimens that are, in most cases, representatives of the scientific and natural heritage of reference for knowing the history of life on planet Earth. Its conservation status is extremely variable, even among the specimens of the same collection, and its structural features and the composition of the fossil material determine this status, which ultimately causes these specimens to be sensitive to environmental conditions [1]. The storage space of the fossil specimen can be a determinant for its conservation because it can produce not only physical alterations but also be a catalyst for several chemical reactions capable of accelerating its deterioration [2]. A high percentage of damage happens during fossil storage [3], or it is related to the movement and transportation of the specimens, when the risk of harming the specimen increases [4]. The making of support for the specimens allows control over the element and isolates it from factors of the surrounding

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environment, an essential consideration in order to guarantee their safety. This consideration has always been present indirectly in conservation works, both in situ at the fossil site as well as in the laboratory and storage facilities.

Bearing in mind all the present considerations, this study tries to present a comprehensive analysis of the particular problems of conservation of this type of heritage based on the study of the main support mediums. The main characteristics analyzed in these supports are the isolating capabilities from external environmental conditions in paleontological collections, preventing their interaction with the fossil specimen to improve the conservation and future preservation of the fossil.

The main objective of the current work is the analysis of the behavior of the main material usually used for the conservation of fossil specimens and its capabilities for damping the effects of external environmental factors. Also, specifically, this study includes:

- The study of the environmental and climatic factors that specifically affect the conservation of the paleontological collection of vertebrate remains from Lo Hueco (Upper Cretaceous, Fuentes, Cuenca) This study includes the main external storage facilities of the Museum of Palaeontology of Castilla-La Mancha (MUPA) in Cuenca, as well as the preparation laboratory in the Fine Arts Faculty of the Complutense University of Madrid (UCM), where they are deposited temporarily for preparation and restoration.

- The analysis and interpretation of the dampening capabilities of four materials usually employed in the making of storage systems The analysis is made in non-controlled environmental conditions, in controlled environmental conditions with artificial aging of the sample, and with control of environmental temperature and humidity in both tests.

- The formal proposal of support systems following their dampening capabilities and environmental isolating capabilities could be more adequate for the preservation of the palaeontology collections in their museum storage.

Experimental part

The macrovertebrate fossil collections are composed of specimens that, given their physical characteristics, weight, and presence of anatomical or taphonomical structures, present a specific problem for their conservation during collection storage and specimen handling [1]. Moreover, the fossil composition and conservation status of the fossil material can be determinants for the conservation of these specimens [5], requiring a controlled environment that avoids excessive fluctuations that could produce a loss of structural stability in the specimens. In this study, data has been collected on environmental factors in the external storage facility of the Museum of Palaeontology of Castilla-La Mancha, as well as the conditions in a storage package made of polyethylene film in the Fine Arts Faculty of the UCM laboratory, where part of the Lo Hueco collection is in storage under conservation and restoration works. The analysis of weather data records shows numerous evidence of the influence of the environmental conditions in the storage place of the specimens, which can lead to significant damage to the fossils in some cases. For this reason, the making of individual storage units for each specimen that surround and guarantee the physicochemical stability of the specimen can be a valid strategy of conservation that maintains the fossil in stable weather conditions.

Materials

There is a wide variety of materials, and each institution develops its own storage system; however, synthetic materials (insulating foams and non-abrasive films) are the materials usually employed based on their physicochemical characteristics, which make them adequate for use in the making of storage systems [6–8]. Herein, we analyse four prototypes built with different polymeric materials that have been selected among the most commonly used nowadays in the conservation of paleontological material and fossil specimen storage:

- Prototype I: support made in Styrofoam™.
- Prototype II: support made in Styrofoam™ and Propore®.
- Prototype III: support made in Ethafoam®.
- Prototype IV: support made in Plastazote®.

All the prototypes follow the same common blueprint and are made by superposition of layers with total measurements of 21x15x15cm (Fig. 1). This disposition does not allow sealing between the joints of the layers. So, an adhesive sealant film has been placed in order to permit only the transmission of weather conditions along the material. The environmental conditions were measured from the interior of each prototype with a measuring device or data logger, which continuously records the humidity and temperature inside the fossil storage unit. In this case, the monitoring of both parameters was made following the policy UNE-EN 16893 [9, 10] of "Specifications for the emplacement, construction, and modifications on buildings or rooms destined for the storage or use of heritage collections", which recommends that the measurements be made periodically, at least every hour [11–16].

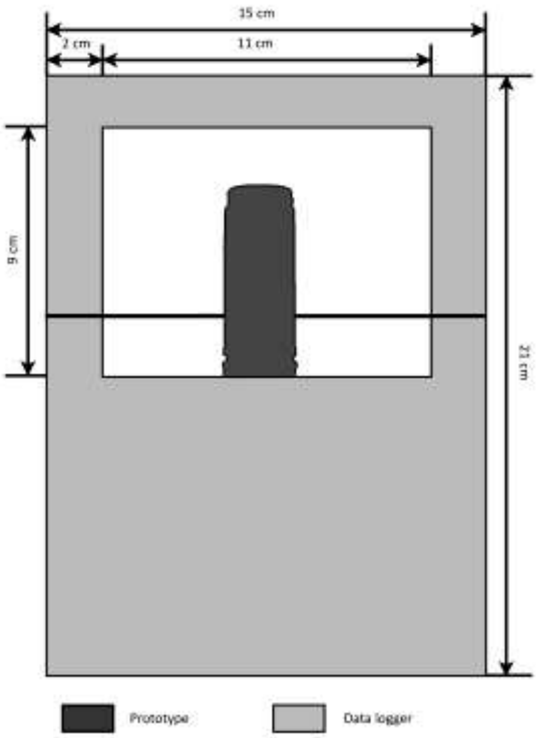

Fig. 1. General blueprint of the prototypes with the measurements showing the location of the measurement device or data logger in the interior.

Methods

For this study, two series of tests were applied, one in the interior of a climatic chamber and the other outdoors without environmental control.

The first study was realised in a climatic chamber with the simulation of a series of temperature and relative humidity-controlled conditions for assessing the dampening of the weather conditions in each of the prototypes under these programmed factors. There is no specific ruling for this type of study, so in this study we applied the policy ISO 9142 [10, 17] for "Adhesive: Guides for the Selection of Standardised Ageing Conditions in Laboratory for Testing Glued Joints,", as most of the specimens have been under a process of conservation-restoration with the use of adhesives, used for reinforcing the internal structure or glueing fragmentary parts of the fossil specimen (Table 1 and Fig. 2). This analysis allows the study of the dampening of the weather conditions by the material of the prototypes under similar conditions and the evaluation of the adhesive materials that maintain the structural stability of the specimens after the intervention.

Table 1. Ageing protocol according policy ISO 9142:2003. Based on *M. San Andrés et al.* [18]

HR (%)	T (ºC)	Time (h)
90	23	24
30	55	24
90	23	72
30	55	48
*The sample is maintained for 24h at 50% y 23ºC after the ageing cycle (168h) and before any measurements are taken and analysed.		

Fig. 2. Climatic chamber uses in the analysis of the prototypes.

Despite the available data, a climatic chamber does not reproduce real weather conditions in storage because the fluctuations are low and because the conditions ruling the test do not allow temperature measurements below 23°C. For this reason, the second test carried over from the prototypes was made under no programmed weather conditions. The prototypes and data loggers were exposed to the outdoor weather inside polyethylene boxes with a size of 60x40x40cm, protecting them only from the direct effects of weather agents (water and sun) but without altering the real changes of humidity and temperature to which the prototypes would be exposed in the collection facilities. In this test, the external weather conditions were also recorded, as there are no controlled environmental factors. A second unprotected data logger collected the outdoor humidity and temperature of the testing area. The data collection was carried out during 30 days of the year 2019, with the emplacement of the polyethylene box with the prototypes in the outdoor of the Fine Arts Faculty of the UCM (Figs. 3 and 4).

Fig. 3. Distribution of the prototypes inside a standard polyethylene box used for this study. Box base = 5cm x 1cm.

Fig. 4. Location of the standard polyethylene box with the prototypes and data loggers inside, outside of the Fine Arts Faculty of the Complutense University of Madrid.

The collected data during both tests is presented in the corresponding graphs, along with the time series of recorded environmental conditions over each prototype [9]. The overlap of the different evolution curves allows comparison between the different recorded times and also the determination of the effect of weather fluctuations in the interior of the prototypes in relation to the control curve of the outside weather record [10–18]. With the comparison between the evolution curves in the interior and the outside control, dampening capabilities are obtained for each of the proposed storage systems (prototypes).

Results and discussion

Macrovertebrate fossil conservation is subject to its location in places with specific characteristics intended to protect the collections from external conditions. Despite these specifications and dampening of external factors, especially outdoor environmental conditions, they are sometimes insufficient in order to reach environmental stability for the conservation of the collections. In this case, the reference was the external storage of the paleontological collections of the Museum of Palaeontology of Castilla-La Mancha, where the environmental conditions were measured and recorded during the year 2014 in order to evaluate the specific environmental conditions of the surroundings of the paleontological collection of the fossil site of Lo Hueco (Cuenca, Spain). The weather record of the temperature and rainfall corresponds to the outdoor data collected during the same period of time by the Cuenca station of the Spanish State Meteorological Agency (AEMET) placed in the nearby storage facilities. The outdoor measurement allows us to compare and determine the dampening capabilities against external weather conditions for the storage facilities in the same way as before (Figs. 5 and 6).

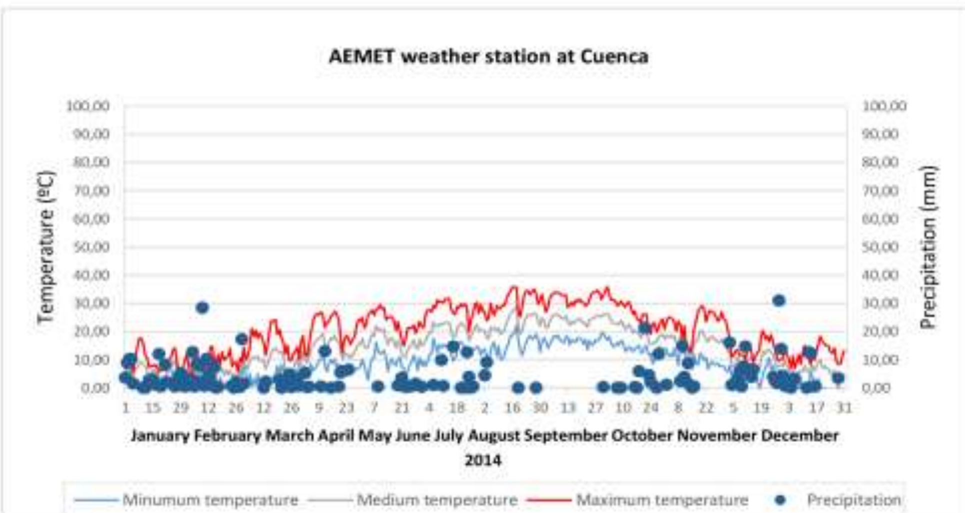

Fig. 5. Weather data record form the Cuenca station of the Spanish State Meteorological Agency (AEMET). Based on the public data collected by the station.

As expected, the storage facility produces a dampening effect from the direct effects of the weather on the paleontological collection, but it is not enough to impede the most severe fluctuations. The storage facilities avoid direct exposure to the water from rainfall but do not avoid a rise in indoor humidity caused by the outdoor humidity increase. Moreover, the outside heat produces an increase in temperature, reducing the indoor moisture concentration, and the highest peaks in temperature are correlated with the lowest humidity peaks.

The data show similitude between the temperature curves both outdoor and indoor, with only minor isolation and temperature differences inside the storage facility at the highest temperature peak (35.7ºC outdoor against 33ºC) but a better temperature in the lowest peaks (-4ºC outdoor against 1.5ºC). The humidity levels show the biggest increases in the periods of highest rainfall records, as the storage facility is protected by the rainfall, but the relative humidity conditions are still affected. The use of passive systems in order to dampen these environmental conditions indoors in the storage facility is one of the methods for controlling and reducing the range of fluctuations and maintaining them at more stable levels.

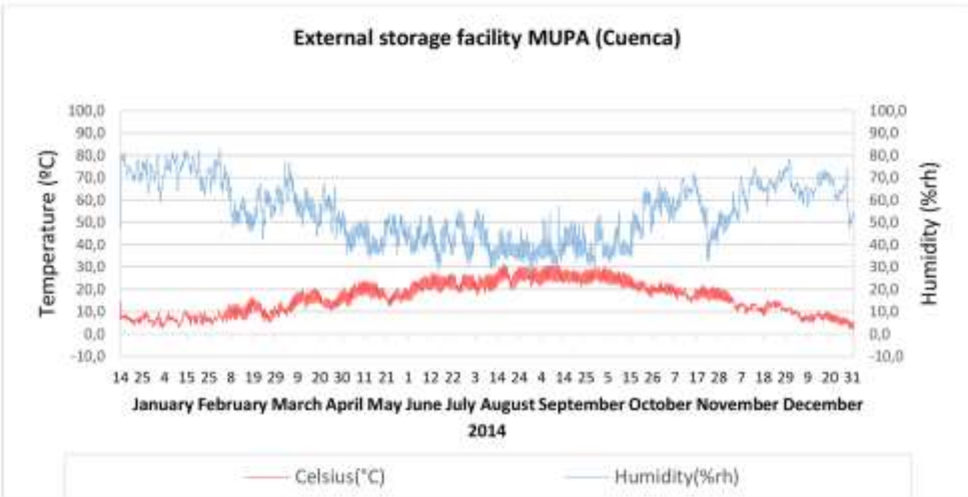

Fig. 6. Environmental data registered at the storage facilities from the Museum of Palaeontology of Castilla-La Mancha (Cuenca).

There is a wide variety of storage systems available, but in the current storage facility, there are eight different types: Styrofoam™, Propore®, Ethafoam®, Plastazote® polyethylene film, polyurethane foam, wood, and paperboard. Their use is determined by their physicochemical characteristics and ageing, and even the cost and weight are considered, as are sometimes the real environmental isolation capabilities. In order to consider these capabilities, the first environmental isolation study was made in a support with polyethylene film enveloping in a classroom at the Fine Arts Faculty of the UCM (Figs. 7 and 8).

Similar to the previous measurements, the environmental conditions were recorded inside the support and on the outside of the envelope to assess the differences in exposure between both records. The comparison of both records allows for the recognition of significant differences in the relative humidity, with a maximum fluctuation of 2% in the interior of the support while there is a total 22% range in the classroom. On the other hand, the temperature in the classroom does not present significant changes, and the curves show similar records between the interior of the support envelope and the classroom. However, it is necessary to take into consideration that at low temperatures in the classroom (exterior to the envelope), the system is limited by its low perspiration capacity, which could allow humidity condensation in the interior of the support.

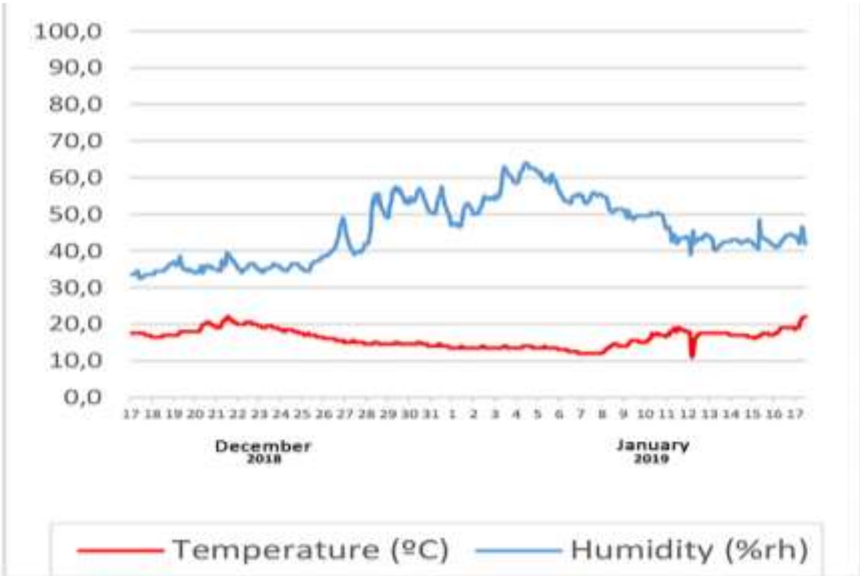

Fig. 7. Data record of the environmental conditions in the restoration classroom of the Fine Arts Faculty of the Complutense University of Madrid.

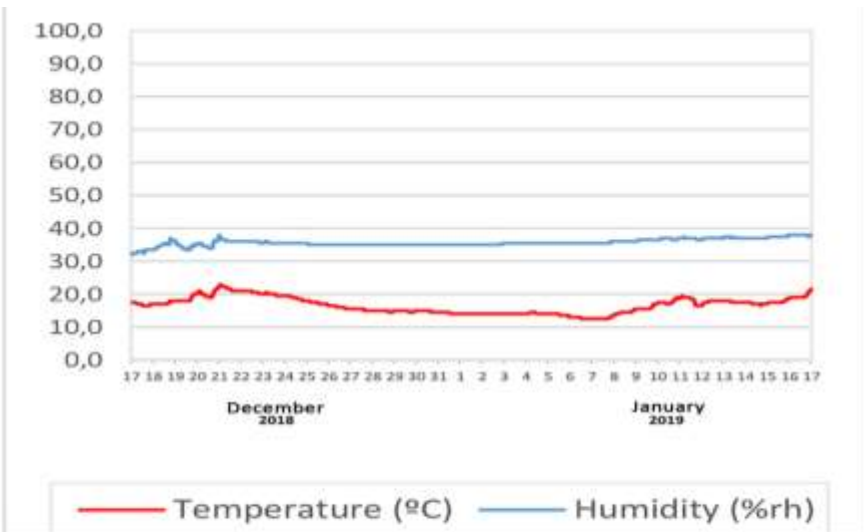

Fig. 8. Data record of the environmental conditions in the interior of the support with polyethylene film.

Prototype analysis

The materials employed in the making of the different storage systems present specific isolating capabilities; however, after a while, this characteristic decays due to the effects of their own environmental conditions. For this reason, the prototypes were exposed to artificially accelerated ageing conditions without controlled environmental conditions, with the objective of simulating the real ageing and variation of the environmental conditions.

Analisys of the climatic chamber test

In this section, we present the results after two cycles of artificial ageing applied to the selected prototypes. In addition, here is presented the comparative study of the different results of the environmental records and the maximum fluctuations between maximum and minimum conditions (Figs. 9 and 10, and Table 2).

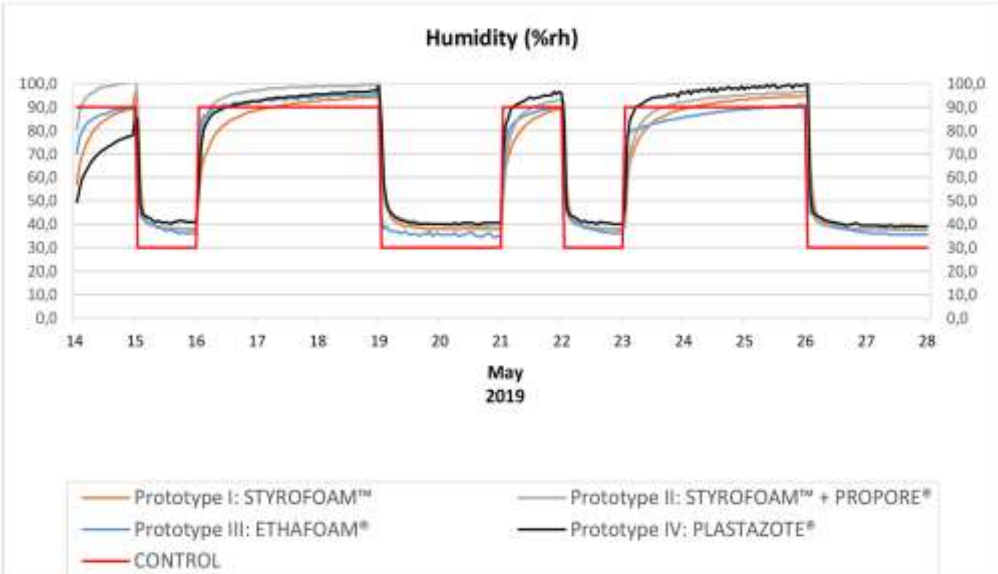

Fig. 9. Humidity data recorded in the climatic chamber test.

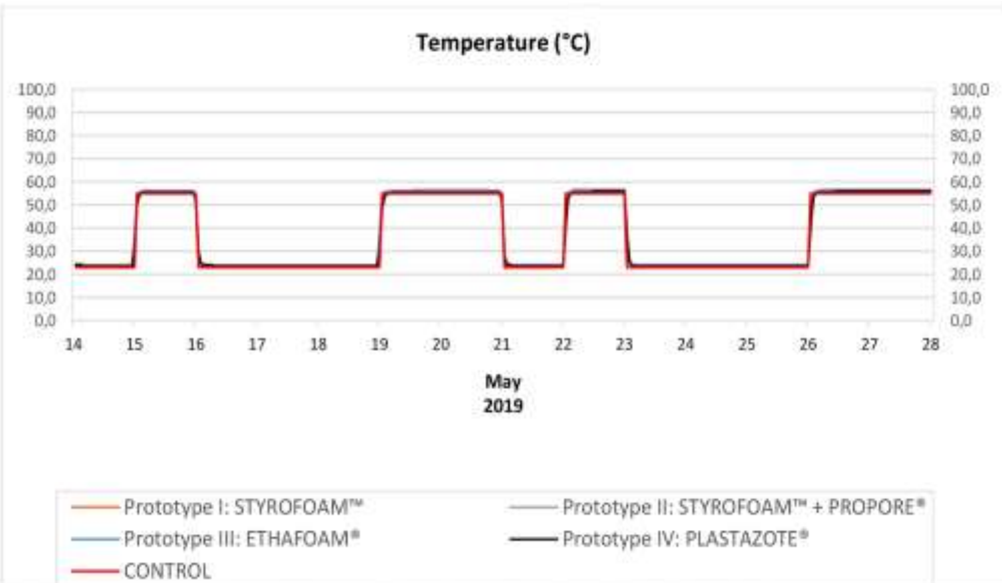

Fig. 10. Temperature data recorded in the climatic chamber test

From the different records, it can be observed that the fluctuations have not been significant, as the values do not depart greatly from the measurements by the climatic chamber (control).

Table 2. Comparative between the recorded data in the two different ageing cycles in the climatic chamber.

Humidity (%rh)				
Data	P. I	P. II	P. III	P. IV
Mean	78,8	88	83,3	79,3
Maximum	101	105,5	96,5	103
Minimum	37,5	37,5	34,5	39
Absolute fluctuation	63,5	68	62	64
Daily fluctuation max./min.	61,5	65	60,5	61,5
	0,5	1	2	0,5
Horly fluctuation max./min.	31	45	53	50
	0,5	0,5	0,5	0,5
Temperature (ºC)				
Data	P. I	P. II	P. III	P. IV
Mean	37,7	37,6	37,7	37,3
Maximum	56,5	56,5	56,5	56
Minimum	23,5	23,5	23,5	23,5
Absolute fluctuation	33	33	33,5	32,5
Daily fluctuation max./min.	32,5	32,5	32,5	32,5
	0,5	0,5	0,5	0,5
Horly fluctuation max./min.	24	24,5	25	25
	0,5	0,5	0,5	0,5

The humidity values show slightly greater absolute fluctuations, with values ranging from 63.5% to 68%, while the temperature shows similar results, and the absolute fluctuations range from 32.5ºC to 33.5ºC only. However, if each test is analysed specifically:

- The Prototype I and II (Styrofoam™ and Styrofoam™ + Propore®, respectively) present similar results in the temperature with no differences in the fluctuation, with the Prototype I mean temperature of 37.5ºC against the Prototype II mean temperature of 37.6ºC. Both prototypes reach the dew point (condensation) with 100% relative humidity while the temperature reaches its minimum peak. However, the Prototype I allows a more gradual increase in moisture, and its evolution is more gradual than that of the Prototype II, which has a rapid absolute fluctuation from 63.5% to 65%, respectively. The moisture loss is similar in both prototypes.

- The Prototype III (Ethafoam®) traces a temperature curve with similar minimum and maximum values as other prototypes shown before. The relative humidity does not exceed 100% while reaching close values to those measured in the climatic chamber. It is possible that these values are reached by the deterioration and loss of resistance of the adhesive film that glues together the layers of the materials, allowing interchange with the external environmental conditions between the joints but not through the foam material. Despite this prototype's initial adequate dampening capabilities, the values of the last cycles indicate that it could not be considered reliable enough.

- The Prototype IV (Plastazote®) traces a similar temperature curve as in other prototypes, with an absolute fluctuation of 32.5ºC, 0.5ºC less than the other materials. The relative humidity produces an ascending trend in the two cycles with higher minimum values than in other materials; the dew point of 100% humidity is only reached during the last ascending sequence.

Outdoor analyses

In this section, we present the results of the outdoor test during one month, from April 13 to May 13 of 2019, with measurements under non-controlled environmental conditions in the outdoors of the Fine Arts Faculty of the UCM, applied to all the selected prototypes. The results are compared with the public weather data available for the Ciudad Universitaria (CIU) station of AEMET, placed nearby the Fine Arts Faculty of the UCM in Madrid. The recorded data in the prototypes are the fluctuations in maximum and minimum at several different time intervals (Figs. 11, 12, and 13, and Table 3).

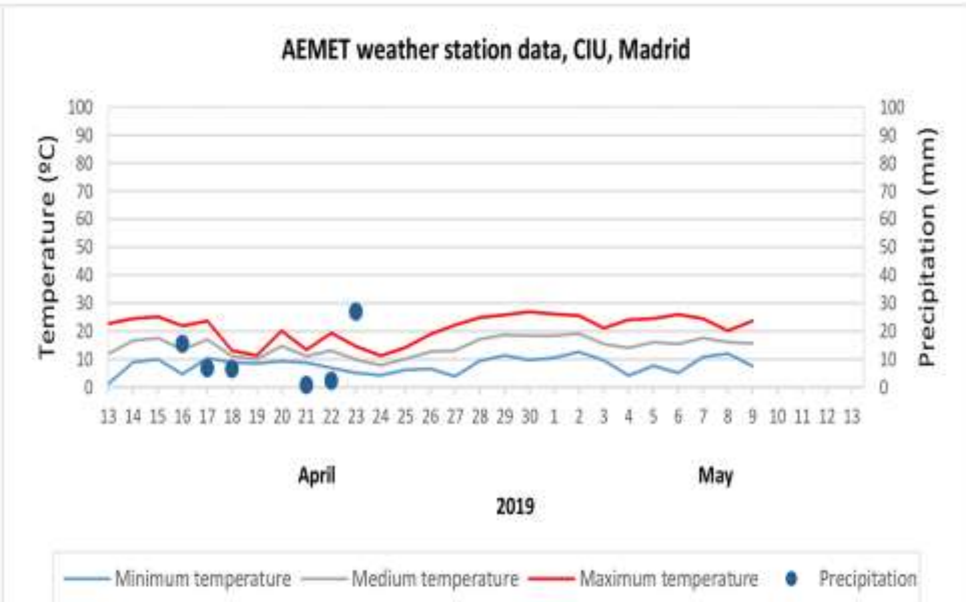

Fig. 11. Weather data record from the Ciudad Universitaria (CIU, Madrid) station of the Spanish State Meteorological Agency (AEMET). Based on the public data collected by the station.

The comparison of the available public data from the AEMET weather station and the data obtained by the data loggers shows congruence between rainfall peaks and the highest relative humidity peaks detected in the interior of the prototypes. The data show that the differences inside the protecting standard polyethylene box do not alter the test results from the outdoor conditions, with only a small amount (mean 2ºC) of dampening from the prototypes inside the box to the outdoor environmental conditions.

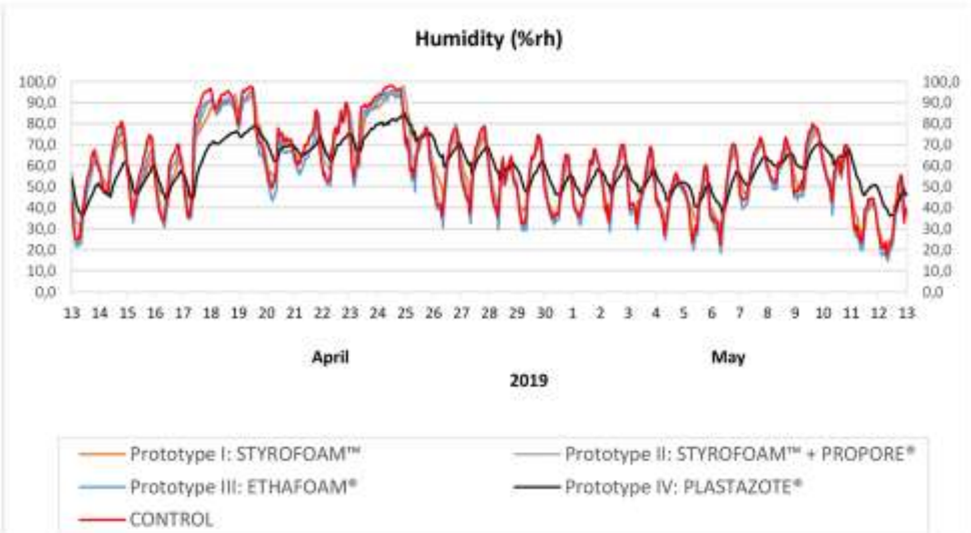

Fig. 12. Data of relative humidity recorded during the outdoor test at the Fine Arts Faculty of the Complutense University of Madrid.

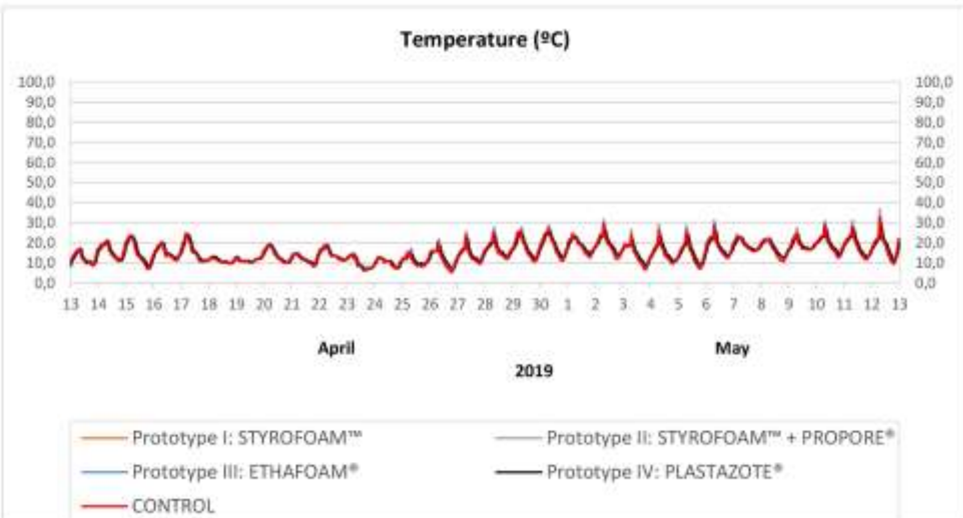

Fig. 13. Data of temperature recorded during the outdoor test at the Fine Arts Faculty of the Complutense University of Madrid.

More specifically, the curves obtained present a series of fluctuations much more marked than the previous analyses that allow an improved analysis of the effects of extreme environmental conditions (in relative humidity and temperature) in each studied prototype:

- The Prototype I and II (Styrofoam™ and Styrofoam™ + Propore® respectively) present little differences in the temperature absolute fluctuation; Prototype I stands at 15.2ºC while Prototype II stands at 15.3ºC, and both of which exceed the values of the control data logger. These peaks are representative of an overheating of up to 2ºC in the prototypes, as the material did not isolate properly from the heat but, instead, produced a small-scale greenhouse effect in the interior of the prototype. The humidity of both prototypes reaches a peak of 98%

relative humidity, near the dew point. In this case, the material of the prototypes is a good isolating medium capable of dampening the incorporation of moisture from the outdoors inside the prototype. Prototype I presents a steadier increase in humidity than Prototype II, with a damping effect of up to 8% and a peak of relative humidity fluctuation of 76% and 82.5%, respectively, with a similar moisture loss in both prototypes.

- The Prototype III (Ethafoam®) presents a temperature curve with maxima and minima that exceed by 1ºC the values of the control data logger at some points. The humidity curve does not exceed 100% relative humidity but instead presents values at 5% under the control curve that vary over time, coming closer to the values of the outdoor control data logger each following day. On the contrary, the minima reach values inferior to those from the control data logger, reaching up to 6% below the control minima. This indicates that its dampening capabilities are worse than the ones obtained for Prototype I and II. While the maximum temperatures are below the values obtained for those prototypes, the minima are lower, and the fluctuations described by the evolution of the curve are bigger, even bigger than the fluctuation of the outdoor control data logger.

- The Prototype IV (Plastazote®) presents a curve that moves away even from the recorded values for the climatic chamber analysis and presents more stable values than the other prototypes, with an absolute fluctuation of humidity of 49.5% and a temperature of 23ºC only. The temperature follows the same type of curve described by the control data logger, but with the maxima and minima dampened by 6% (=below the maxima and above the minima). The relative humidity shows more significant fluctuations but maintains stable levels with only 25% of the absolute fluctuation differences. The maximum and minimum relative humidity values are reached much more gradually as they slow down the effect of the external environmental conditions.

Table 3. Comparative between the recorded data during the outdoor test in the outdoor of the Fine Arts Faculty of the Complutense University of Madrid

Humidity (%rh)				
Data	P. I	P. II	P. III	P. IV
Mean	59,5	59,8	57,2	59,3
Maximum	98	98	95,5	85
Minimum	22	15,5	14,5	35,5
Absolute fluctuation	76	82,5	81	49,5
Daily fluctuation max./min.	39	42,5	49,5	22
	7	8	11,5	5
Hourly fluctuation max./min.	12,5	12,5	21	5,5
	0,5	0,5	0,5	0,5
Temperature (ºC)				
Data	P. I	P. II	P. III	P. IV
Mean	15,3	15,2	15,2	15,3
Maximum	36,5	36,5	32	29,5
Minimum	6	6	5	6,5
Absolute fluctuation	30,5	30,5	27	23
Daily fluctuation max./min.	24	25	22,5	17
	3	3,5	2,5	3
Hourly fluctuation max./min.	13,5	13,5	10	10
	0,5	0,5	0,5	0,5

Conclusions

Based on the analysis of the main types of supports used in the conservation of macrovertebrate fossils, the following conclusions can be drawn:

The environmental conditions are dampened by the proper storage facilities of the Lo Hueco collection, but some fluctuations may pose a risk for fossil conservation.

In an uncontrolled environment, the packaging and supporting structures of the fossils dampen environmental conditions, particularly humidity and temperature variations. When there is a greater fluctuation in these conditions, the material that composes the structure dampens the action of the external agents, maintaining the stability of the interior of the support where the fossil specimen is stored. The prototype made with Platazote® presented a condensation effect under the climate chamber test, but in an environment without controlled parameters that permit the creation of an internal microclimate in the support, the values showed more stability with less variation. On the other hand, the prototypes made with Ethafoam® and Styrofoam™ present graded fluctuations but are incapable of reducing them significantly. The use of protective films such as Propore® should be limited only to the contact area with the foam, as it can produce an accumulation of moisture in the interior, exceeding the external values of humidity.

Based on the lack of active controlled environmental conditions of temperature and humidity in the storage facilities where the fossils of the Lo Hueco site are stored, the data that best fits this scenario are the outdoor measurements with no environmental control. The comparisons in the outdoor test allowed us to conclude that the Prototype IV made of polyethylene Plastazote® is the storage system that presents the best characteristics, the best ageing response, and better control of the external environmental conditions. The isolating capabilities of this material avoid the direct impact of the external environment as well as easing its effects, which represent a risk factor in the conservation of the fossil collections.

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