Degradation and conservation of granitic rocks in monuments

Protection and conservation of European cultural heritage

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MONITORED SYSTEM FOR DETERMINING ENERGY FLOWS IN GRANITES UNDER A CONTINENTAL CLIMATE.


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ABSTRACT

A system for the collection of environmental data has been adapted and assessed to gain continuous knowledge of the changes occurring in the microenvironment affecting the Cathedral Group in the city of Avila (Spain) with a view to determining its effect on the evolution of the different stone materials used in the construction of the buildings.

INTRODUCTION

The effect of sharp changes in temperature occurring between the day and the night in zones with a continental climate on the degradation of stone materials, above all when these are heterogeneous (granites sensu lato and sandstones) is well known. Photo 1 shows the deterioration produced by this phenomenon.

Photo 1: The upper part of the apse-aisle of the Cathedral of Avila, constructed of bleeding stone.
In order to quantify the different parameters involved, an environmental data collection (climatic and pollution) system was installed. The system also measures energy flows between the external environment and the surface of the stone and the transmission of this energy through the stonework in the Cathedral of Avila. The Cathedral is located in a zone with continental climate with a Mediterranean trend and a low degree of atmospheric pollution.

MATERIALS AND METHODS

The three different types of stone material most used in the zone were employed: "Avila Grey" granite, "Ochre" granite and "Red-White" granite (known as "bleeding stone" in which the red and white parts were separated because they have different mineralogical and chemical compositions and different petrophysical characteristics [García-Talegón et al., 1984; and Ihigo et al., 1984].

The system installed comprised:
1. Four energy flow cells placed on the described granite facies.
2. A SKYE sensor for the determination of relative humidity and environmental temperature.
3. Eight thermistors for measuring temperature at the surface of the granite and inside the blocks (depth 10 cm).
4. Two KIMOTO devices with two bubblers each to determine possible atmospheric pollution. All these components were situated on the high parts of the building
5. Two autonomous SKYE sensors for the determination of relative humidity and environmental temperature on the North and South faces of the inside of the Cloister (microenvironment).

In an attempt to approximate the energy flows detected by the cells to the "real" flows existing at the surface of the granite ashlar, the four cells were situated respectively on blocks of 35 x 35 x 35 cm of the different types of stone studied and covered with a 5 mm thick granite plate.

Discontinuity between the cells and the stone was avoided, or at least minimized, by using an interface composed of silicone and ZnO. The outputs of the sensors, with the exception of the autonomous ones, were connected to an automatic data collection system (Photo 2). The output signals from the relative humidity and environmental temperature sensors were also recorded continuously in the same system.

The atmospheric pollutants determined with the bubblers were SO₂, SO₃, NH₃, CO₂ and solid particles.

Scheme 1 depicts the flow cells, as well as their technical characteristics, that measure the variations in energy flows.
Photo 2: Installation of energy flow sensors.

Scheme 1: EKO model MF-130 heat flow sensor
RESULTS AND DISCUSSION

Figure 1 shows the variations in energy flow, temperature and relative humidity occurring over 24 h in the different types of stone assayed. It may be seen that as environmental temperature increases so does the energy flow absorption by the stones (Fig 1a). In the case of relative humidity, this variation is the converse (Fig 1b).

In the blocks of "Avila Grey" granite (Fig 1c) and "Ochre" granite (Fig 1d), surface and interior temperatures were controlled. It was seen that as environmental temperature increases so do these, reaching a maximum during the day at around 16.00 h and thereafter decreasing. The variations in energy flow followed an identical trend.

With respect to the maxima in flow variation reached in the different varieties of granite, the order can be said to be:

Grey granite > Red granite > Ochre granite > White granite

These variations can be explained in terms of the differences in colour and surface conditions of the different varieties of stone assayed.

The same findings are seen along most of the days studied, although the present study is incomplete and data collection continues.

Figure 2 shows the results on temperature and relative humidity corresponding to the microclimate prevailing inside the Cathedral Cloister. These data were only collected over one year (collection continues). The parameters measured were controlled by SKYE autonomous sensors on both the North and South faces. The results obtained point to appreciable differences in the monthly means of temperature and relative humidity between both faces (= 1.5°C in temperature and > 10% in relative humidity).

A low content of atmospheric pollutants, often under the detection limit, has been found in Avila.

The microclimate softens the temperature changes as observed on comparing the alterations that have appeared on the stone of the upper balustrades (outside the microclimate) where the effect of thermoclasty phenomena is well observed and those situated inside the Cloister, where the effect of temperature changes is less appreciable. In the lower parts of the Cloister, the damage is mainly due to the crystallization of soluble salts washed out of mortars by rainwater and/or due to capillary ascent from a water table strongly contaminated by different ions (SO₄²⁻, PO₄³⁻, Cl⁻, NO₃⁻, etc).
Fig. 1: Energy Flows versus Temperature and Relative Humidity.
T - Environmental Temperature; F - Energy Flows; H.R. - Relative Humidity; DT - Temperature inside stone (10 cm deep); ST - Temperature on stone surface.
O (Ocre Granite), R (Red Granite), G (Gray Granite), W (White Granite)
a) Energy Flows in 4 granitic facies versus Environmental Temperature.
b) Energy Flows in 4 granitic facies versus Relative Humidity.
c) Energy Flows versus Environmental (T) surface (STG) and inside (DTG) on Gray Granite.
d) Energy Flows versus Environmental (T) surface (STO) and inside (DTO) on Ocre Granite.
Fig. 2: Environmental data in Cloister Microclimate.
CONCLUSIONS

Although the present study is still ongoing and several aspects require confirmation, the following may be concluded:

1.- Inside the Cloister a microclimate exists that softens the climatic variations; within it there are significant differences in temperature and relative humidity between the North and South faces.
2.- On the upper unprotected parts of the building, exposed to sharp temperature changes and strong energy flows, thermoclasty phenomena are well visible.
3.- As the environmental temperature increases, so does the energy absorption by the stones, until a daily maximum is reached at around 16.00 h in the different varieties of granite studied. The inverse effect is observed in the case of relative humidity.
4.- The changes in energy flows in the different types of granite are subject to the following order:

   Grey granite > Red granite > Ochre granite > White granite

REFERENCES


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