Microclimate Monitoring in the Carcer Tullianum: Temporal and Spatial Gradients Evidenced by Multivariate Analysis; First Campaign

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Abstract

For the exploration and study of a hypogaeum site priority should be given to microclimate monitoring, even before starting any excavation activity. Except for fortuitous findings during the planning of excavations, recoveries, restoration and conservation monitoring of chemical and physical microclimate parameters (e.g. temperature, relative humidity, light luminance, concentrations of CO_2, CO, O_3, SOx, NOx, VOC, etc.) is desirable in order to identify their spontaneous values. Generally few sensors, sometimes only one, are applied and time series obtained, which are then analysed by means of control cards and/or univariate graphs. Contrarily in this study 15 cheap but accurate dataloggers were applied (Fig.1) for monitoring three environmental parameters every 5 minutes along a vertical axis between two environments on the ground floor and the basement (6 sensor points), along a horizontal axis in the ground floor room (3 sensor points) and in the basement along a vertical (6 sensor points) and a horizontal axis (2 sensor points). In the basement concentrations of CO, CO_2 and O_2 were measured and the two environments were not entered during the 15 days measurement campaign. Multivariate analysis aims to study the interaction with the external environment and to identify mutual variations of parameters and gradients in space and time.

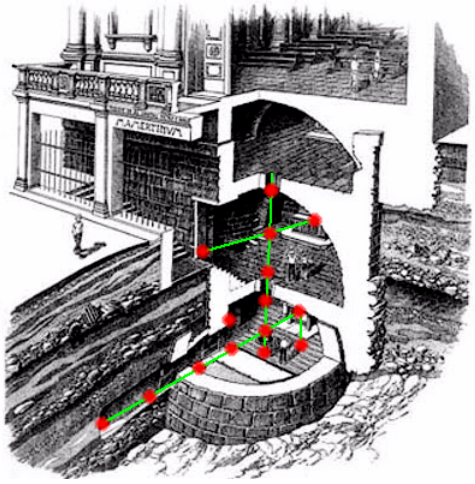


Fig.1; An ancient 3D draw of Tullianum with the sensors in red and vectors in green

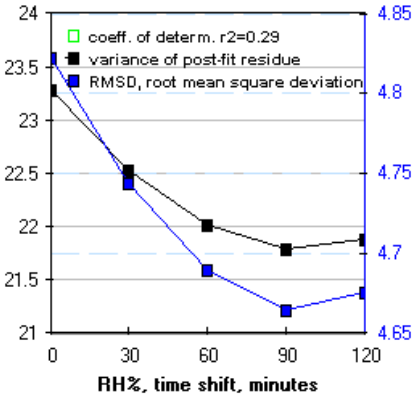
Introduction

The research environment is composed by a vertical series of rooms of which the last one, completely buried, has the floor continuously covered by some mm of water; the origin of the latter goes beyond the aims of this study. Research was conducted on this hypogaeum ambient with walls made of huge blocks of lava stone as well as on the ground floor ambient, which today is transformed in a partially buried church, accessible by a descending stair with circa 20 steps, see fig. 1 [1].

A contemporary reading of the external and the hypogaeum microclimate should allow identification of their correlation type, e.g. “Conservative Mode”, where the walls or the burring soil exclude or strongly slow down any exchange; “Selective Mode”, where some parameters are filtered by the barrier, while others are not; “Regenerative Mode”, where an independent internal microclimate is created, which instead leads to retroactive mechanisms (typical for modern living environments with high waste of energy). Identification of the spontaneous condition of the research environment is particularly important. Referring to previous Banham’s definitions [2] we can state that it is impossible to define a priori for a hypogaeum, as in our case, the time necessary to reach constancy or at least spontaneous periodicity. Spontaneous values of parameters are fundamental for a conservation project. A wall structure of stone, ceramics, glass, frescos, metals and also organic material may be conserved for centuries or millennia due to a delicate equilibrium, where a simple variation of humidity could put in danger the availability, often the mere existence of this patrimony and this can happen in a very short time range compared to the sites life-time.

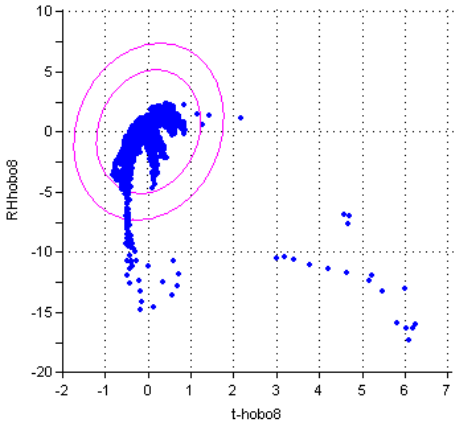
Materials & Methods

In order to verify the sensors rise time, accuracy, hysteresis, and coherence before starting our measurement campaign all 15 sensors (the Hobo U12-012 by Onset USA for RH%, °C, lux; the EL-usb2 by Lascar U.K for RH%, °C) where placed in a hypogaeum ambient similar to the one to be studied, near to each other and around two certified instruments (the EB20-THP, by Ebro GmbH, Germany for RH%, °C, mbar; a VWR cod. 61027-056, Hg thermometer AA grade for °C). This allows to estimate the sensors response to environmental variations, e.g. a coherence of 0.5 degrees allows us to regard a variation of 0.8 degrees between two rooms or along a vertical axis as significant. In the hypogaeum, at the cross of the two vectors, the concentrations of CO, CO_2 and O_2 were measured (by EL-usb-CO by Lascar U.K.; by CO_2-bta and O_2-bta, by Vernier Tech., USA). Used software were mainly free ones, like Datalab, Past, Gnumeric, Zaitun, WinIDAMS.



Results

In order to analyse the correlation between the meteorological and the microclimate data time shift techniques with the hypothesis of a propagation delay have to be applied. Usage of the simple coefficient of determination, r^2, of Pearson [3] is not sufficient, because it is influenced by the numerousness and outliers. Correlation analysis as a function of time shift was carried out by calculating all parameters of every single distribution (meteo as X axis, microclima as Y axis) and then of all parameters which indicate "correlation quality", for example: Std. Err. of Pearson's r, Variance of residue, Residue sum of squares (RSS), Root mean square deviation (RMSD), on the left Fig.2 an example for the sensor on the altar on the ground floor. Multivariate representations can be useful to study the sensors positions. Datalogger Hobo-8, placed immediately under the antique hole connecting the two environments, shows, after column centering, a distribution on the XY plane, which highlights unusual values that should be further investigated comparing with the violet ellipsoids show the variance for 95% and 99.8% as the probability limits on the right figure.



Conclusions

The availability of many measurement points, the construction of space vectors extended over several environments, accuracy and coherence of data allows detailed analysis of a hypogaeum and/or museum environment and much more information than that presentable in a short abstract can be extracted. Using only data from the 15 sensors the matrix is composed by three columns of 4299 rows for each sensor, which means 15 layers. Data elaboration is therefore much more time consuming than its acquisition and our short experience brings us to suggest caution with the usage of specific software probably designed for meteorology or electrical engineering. Preliminary results suggest to go on with monitoring using D.o.E. for sensor positioning and chemometrics methods for data analysis as PCA or PCoA.

References

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2) R. Banham, *The Architecture of the Well-tempered Environment*, Architectural Press, London (1969), ISBN 978-0226036984
3) Karl Pearson, On lines and planes of closest fit to systems of points in space, *Philos. Mag. A*, 2, (1901), 559-572