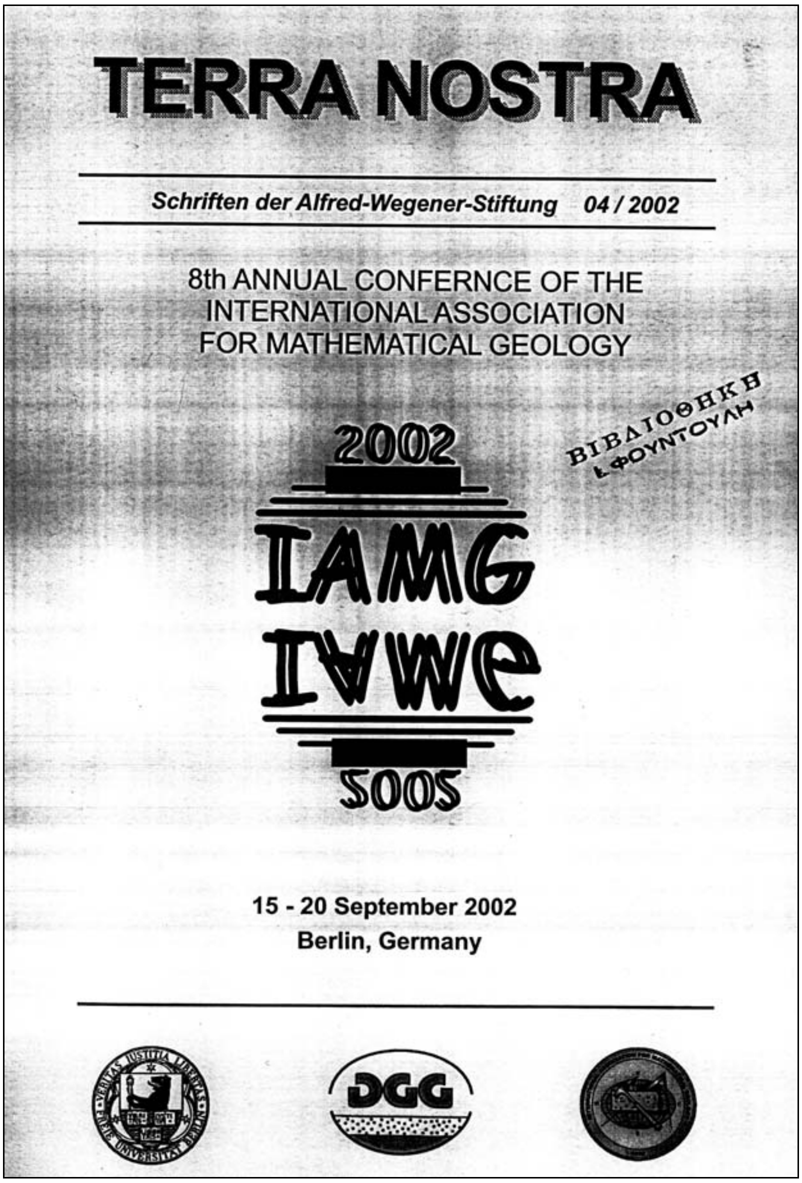
ΔΗΜΟΣΙΕΥΣΗ Νο 86



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Monitoring and Modeling the Spatiotemporal Variation of Air Temperature and Relative Humidity in Ancient Macedonian Graves in Vergina, Greece

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1. Abstract
Wall paintings in ancient grave chambers are sensitive to changes in the microclimatic conditions. This study focuses on an ancient Macedonian grave near the town of Veria in the Vergina region, southern Macedonia, Greece. Due to the rise of the ground water table as a result of intensive irrigation in the summer months, the internal atmosphere of several graves in the area is becoming very humid. The humidity in combination with the high summer temperatures causes damages to the wall paintings in the graves, especially when opening the monuments to the public. An automatic telemetric monitoring system was used to record the fluctuation of the temperature and relative air humidity inside a tomb (a small building buried in the ground) from the 4th century B.C.. Measurements were taken for a period of 12 months and recorded every 30 minutes. The results are visualised utilising a 3D modelling software system. The acquired data can be used as initial conditions and calibration data for a dynamic atmospheric model of the interior of the grave, in order to simulate the changes in case of an opening to the public.

2. Introduction
A number of important Macedonian graves from the 4th to the 2nd century B.C. are located in the Vergina region of southern Macedonia, near the modern city of Veria (Drougou & Saatsoglou-Paliadeli, 1999). These tombs are small structures, made from sandstone, buried in the ground. Due to the rise of the ground water table resulting from intensive irrigation in the summer months, the atmosphere inside the grave chambers is becoming very humid. Increased humidity in combination with the high summer temperatures causes damages to the wall paintings in the graves. This damage is likely to be exacerbated when opening the monument to the public, because of sudden drying of the walls. To investigate the fluctuations of temperature and relative humidity inside the grave, a pilot study was carried out in Evridiki's tomb, which dates back to the 4th century B.C. (Fig. 1). For recording the microclimatic parameters, an automatic telemetric monitoring system was installed. 14 sensors were placed inside the grave, one outside of the grave and one in the ground. In addition to that, a rain gauge was put up. Measurements were taken for a period of 12 months and recorded every 30 minutes. On the base of these data, simulations of the changes caused by an intended opening to the public should be run, in order to evaluate the consequences of such a decision.

3. Modelling Approach
To model and visualise the measurements, the 3D CAD software package SurpacVision for geoscientific modelling was employed (SSI, 1995a, 1995b). Firstly, a 3D geometric model of the grave building was constructed and the locations of the sensor points were incorporated into it (Fig. 2). Then, for modelling of the spatial distribution of temperature and relative humidity in the interior of the grave, a 3D block model was set up. This approach is a direct analogue to the generation of property models for geological objects (Houlding, 1994). A minimum block size of 0.25×0.25×0.25 m was selected to obtain sufficient spatial resolution. The block attributes (temperature and relative air humidity) were estimated by interpolation from the sensor measurements. Interpolation was carried out by Inverse Distance Weighting.

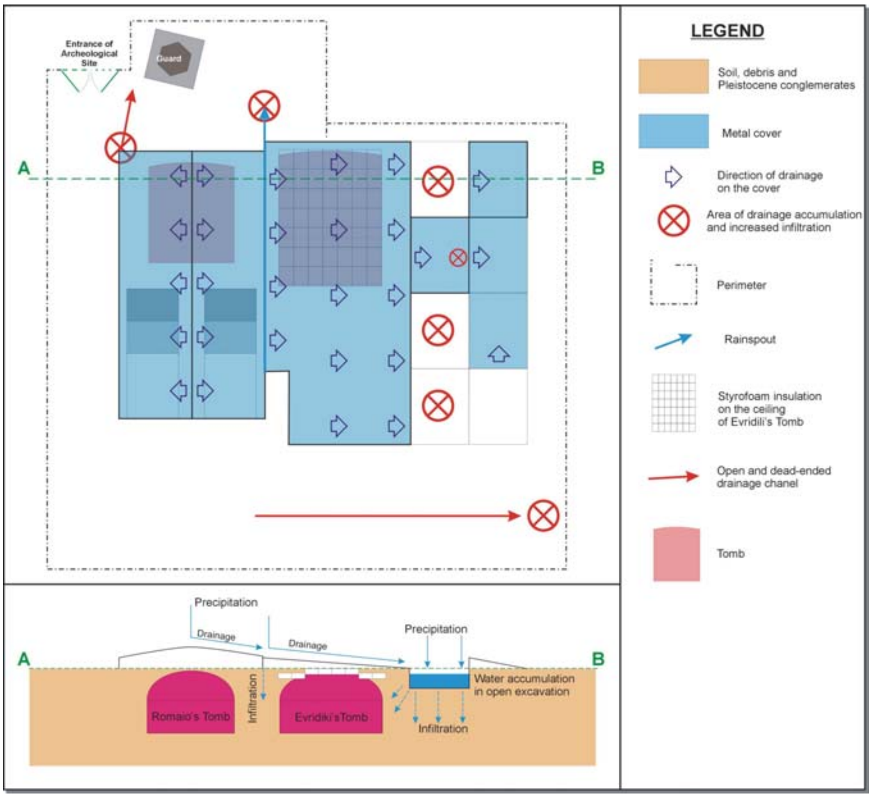
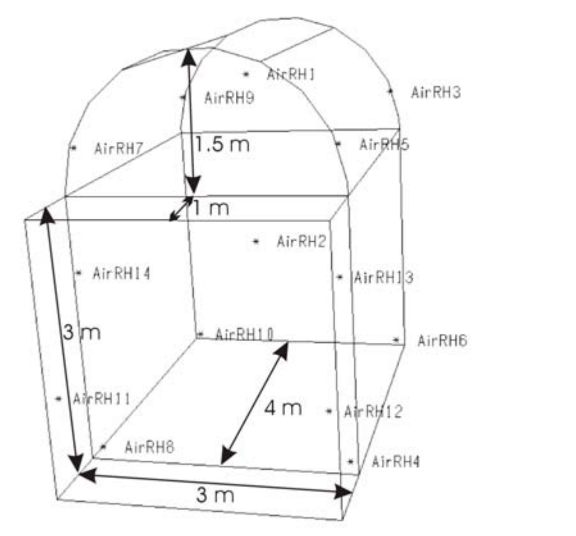


Fig. 1. Location of the study area and site description



Sensors within the throne chamber	
AirRH1, AirTemp1	In the middle, at a height of 4 m.
AirRH2, AirTemp2	In the middle, at a height of 2 m.
AirRH3, AirTemp3	3.5 m. height, 10 cm from the wall
AirRH4, AirTemp4	10 cm. height, 10 cm from the wall
AirRH5, AirTemp5	3.5 m. height, 10 cm from the wall
AirRH6, AirTemp6	10 cm. height, 10 cm from the wall
AirRH7, AirTemp7	3.5 m. height, 10 cm from the wall
AirRH8, AirTemp8	10 cm. height, 10 cm from the wall
AirRH9, AirTemp9	3.5 m. height, 10 cm from the wall
AirRH10, AirTemp10	10 cm. height, 10 cm from the wall
Sensors within the antechamber	
AirRH11, AirTemp11	1.1 m. height, 10 cm from the wall
AirRH12, AirTemp12	1.1 m. height, 10 cm from the wall
AirRH13, AirTemp13	2.2 m. height, 10 cm from the wall
AirRH14, AirTemp14	2.2 m. height, 10 cm from the wall
Outdoor sensors	
AirRHEx	Air humidity Sensor.
AirTempEx	Air temperature Sensor.
SoilHumE	Surface soil humidity Sensor.
SoilTemE	Soil temperature Sensor.
RainGauge	Precipitation Sensor.

Fig. 2. Wire frame model of the tomb and positions of the internal sensors

4. Temporal fluctuations

Figs. 3 and 4 show the temporal fluctuation of temperature in the grave's main chamber, in the outside air and in the surrounding soil. The variation of the relative humidity inside the main chamber is illustrated by Fig. 5. A comparison of the amount of rain and the soil humidity is presented in Fig. 6. It is obvious that the fluctuations of the environmental parameters in the tomb are following the general trend of the outside temperature, not being influenced by daily fluctuations. The relative air humidity reaches saturation 100% with the

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temperature rise and remains very high even in the cold months, slightly falling in the colder period to 98%.

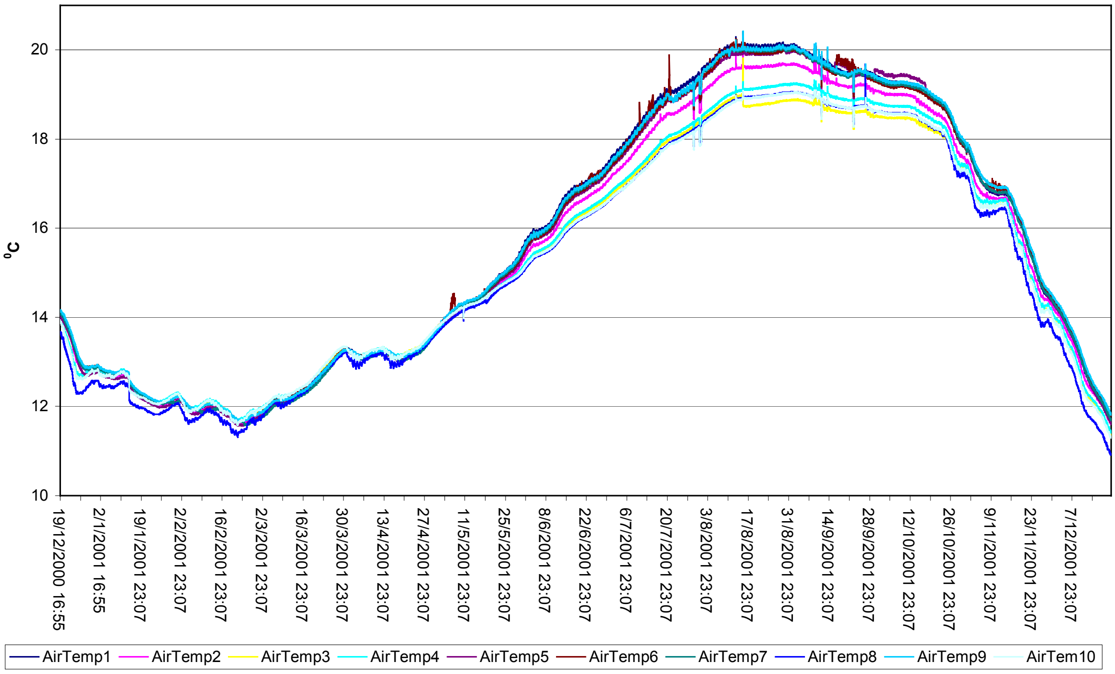

Fig. 3. Temperature in the main chamber

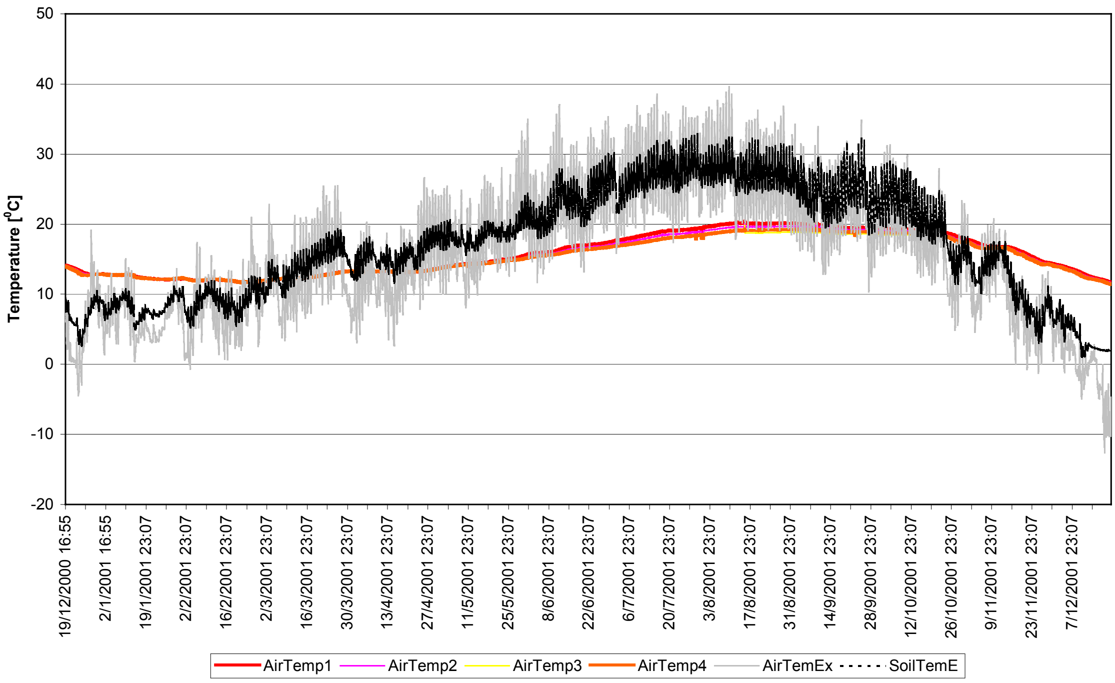

Fig. 4. Comparison of inside temperature, external air temperature and soil temperature

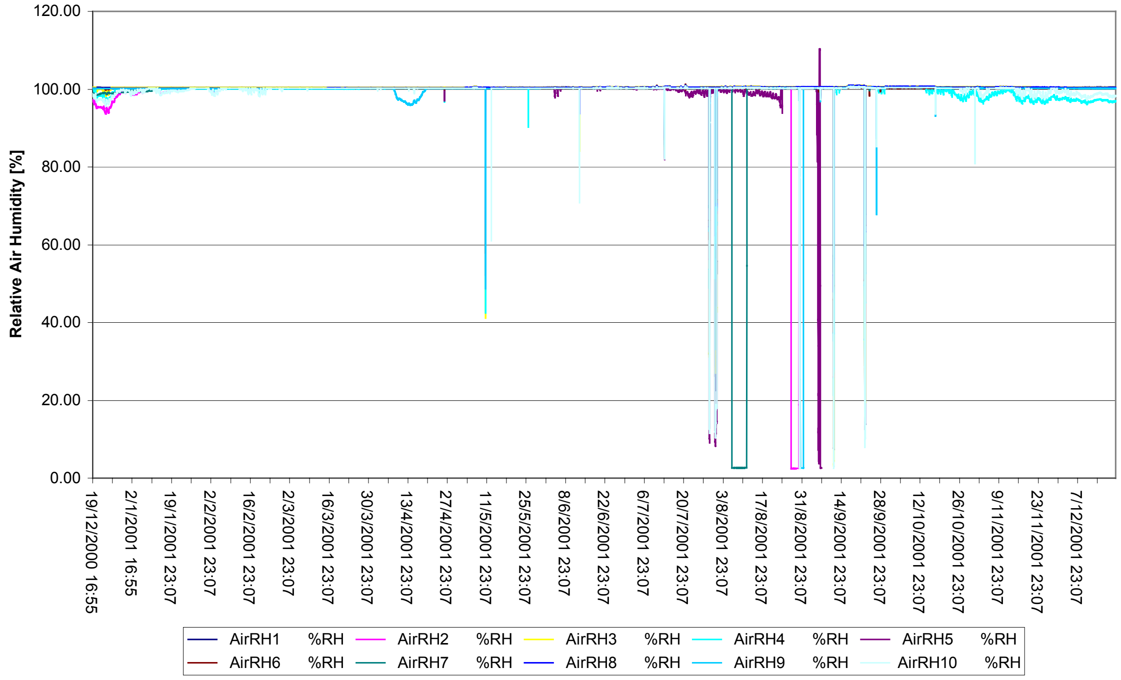

Fig. 5. Relative air humidity in the main chamber (small values between 3/8 and 28/9 indicate sensor problems due to the continuously saturated air)

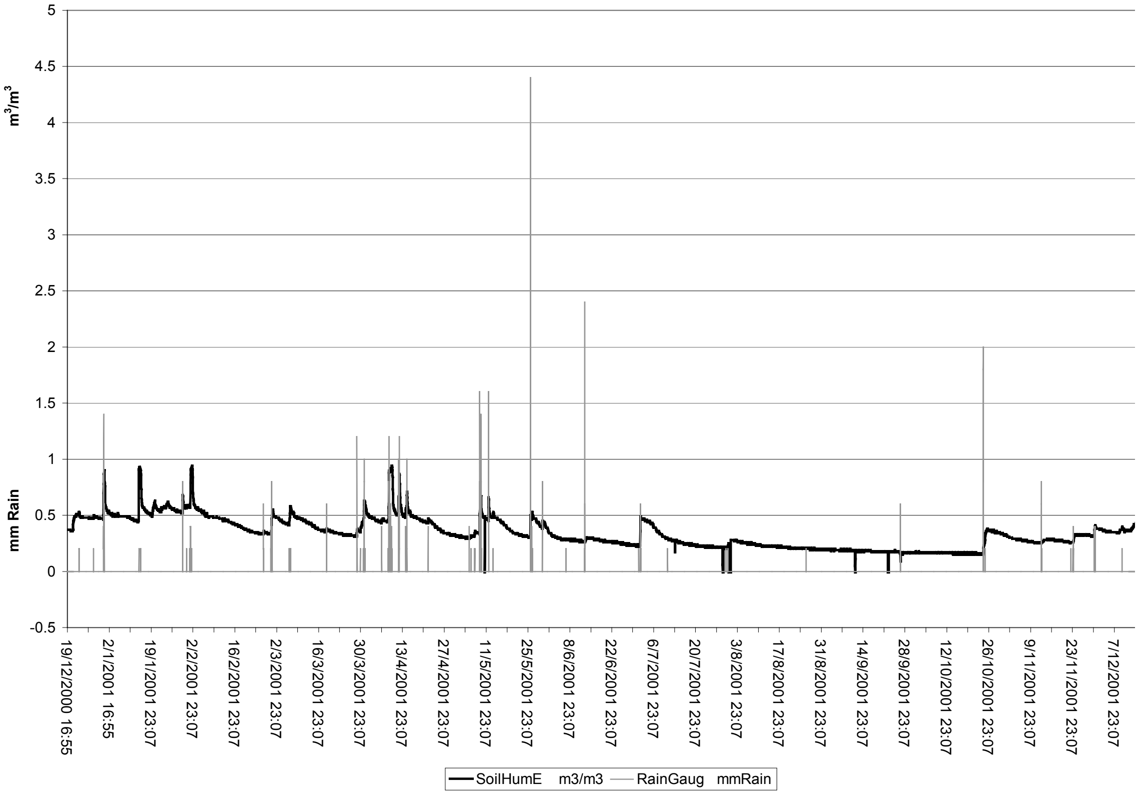

Fig. 6. Precipitation compared to soil humidity

5. Visualisation of spatial distribution of temperature and relative humidity

The block models were colour-coded in order to recognise hot or wet parts of the buildings, especially on the walls with paintings. Examples are given in Figs. 7 and 8, which depict the conditions inside the grave on January 1 and February 1, 2001.

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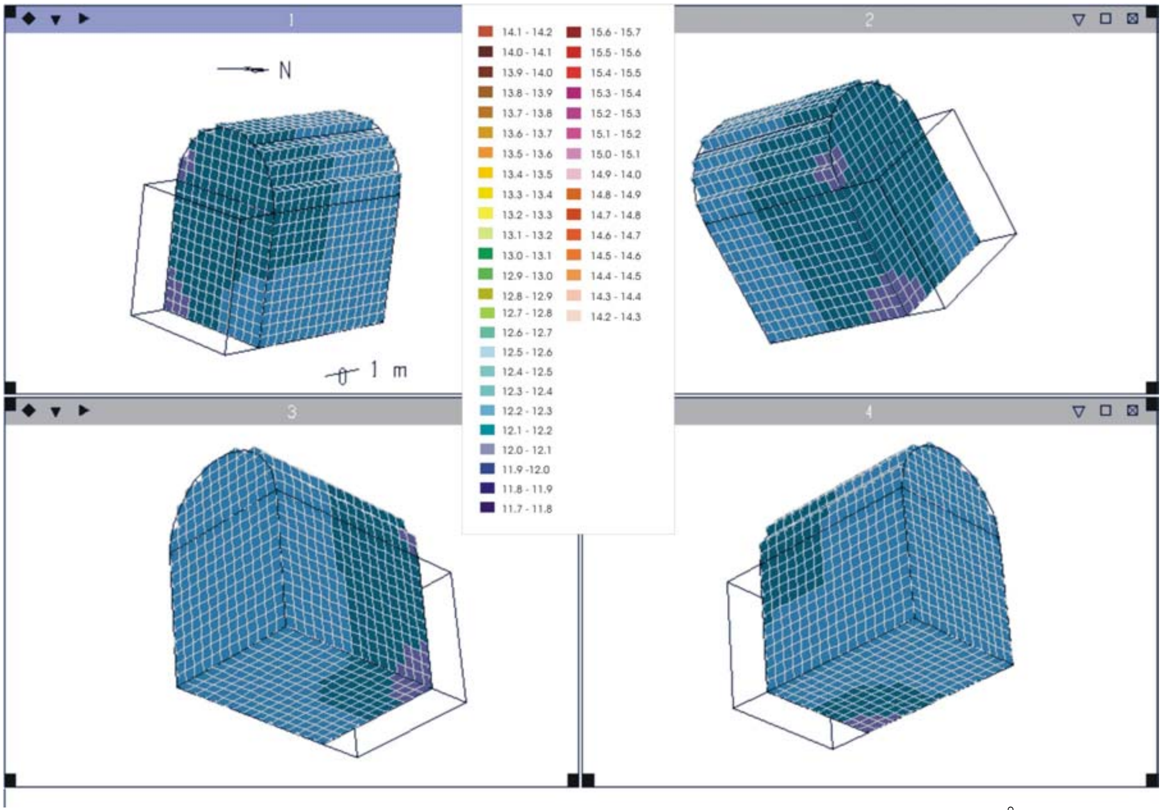

Fig. 7. Temperature distribution on February 1, 2001, 13:00 h. (11.8 – 12.1 °C)

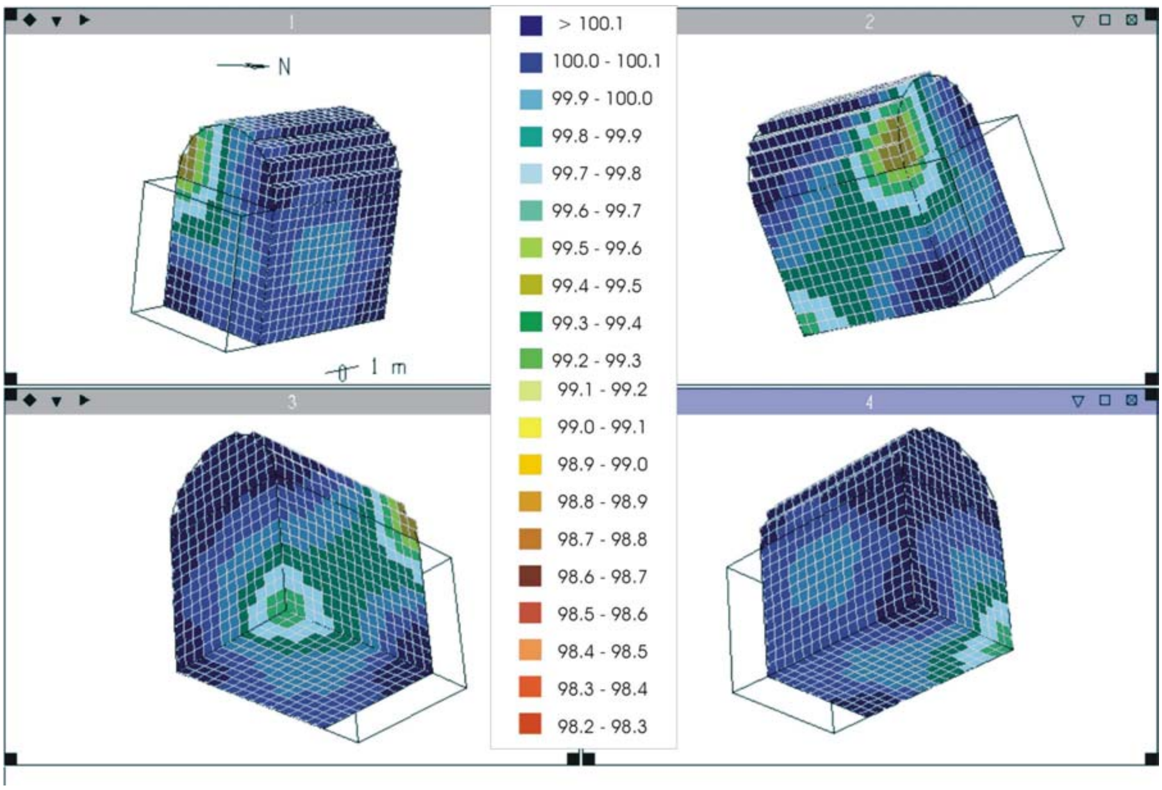

Fig. 8. Relative humidity distribution on January 1, 2001, 13:00 h (>99.4%)

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6. Conclusions

The generated 3D models describe the fluctuation of temperature and relative humidity in the interior of the grave by a number of time slices. They are offering a basis for developing a dynamic air temperature/relative humidity simulation model. Such model can be used to simulate the effects of a permanent presence of people in the building on the internal micro-climate. It could be of great help to assess the impact of the microclimatic changes on the condition of the wall paintings. In addition to that, it can provide crucial information for restorers and help them to gain a better understanding of the erosional processes on wall paintings in burial chambers. The results obtained by dynamic modelling of the climatic conditions inside the grave will also provide the necessary scientific support for the decision on opening the monument to the public. Our measurements have shown that even stay of only two persons in the tomb for about one hour led to a temperature rise of about 3 degrees.

7. Acknowledgments

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