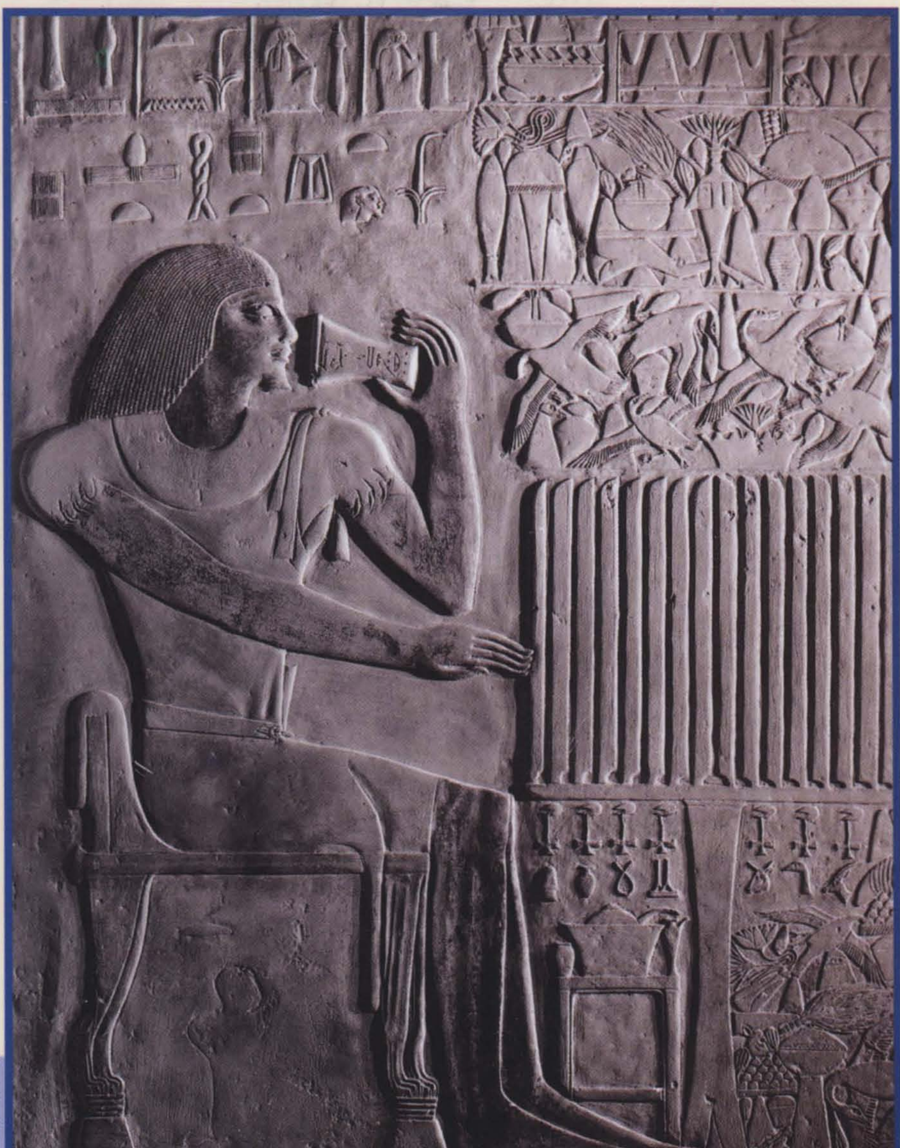
SUPPLÉMENT AUX ANNALES DU SERVICE DES ANTIQUITÉS DE L'ÉGYPTE

CAHIER N° 35

THE WORLD OF ANCIENT EGYPT
ESSAYS IN HONOR OF
AHMED ABD EL-QADER EL-SAWI

PREFACE
ZAHI HAWASS

EDITED BY
KHALED DAOUD
SAWSAN ABD EL-FATAH



PUBLICATIONS DU CONSEIL SUPRÊME DES ANTIQUITÉS DE L'ÉGYPTE

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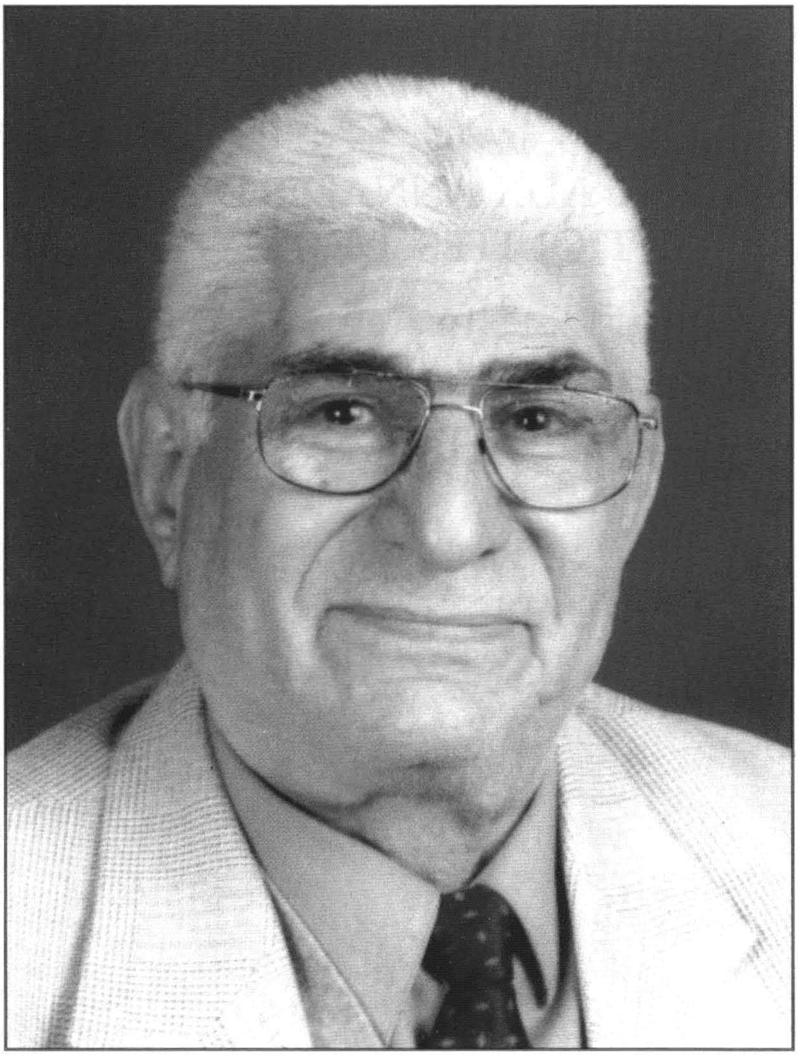
Cover Illustration:
An offering scene from the mastaba of Ptah-hotep, Saqqara.



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LE CAIRE 2006

Graphic Designer
Ezz el-Din, Magdy

Director of Printing
Safwat, Amal

(*CASAE* 35) 2006

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DE L'ÉGYPTE, LE CAIRE, 2006
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DAR EL KUTUB NO. 17679/2006
ISBN. 977-437-015-5
ISSN. 1687-4951

IMPRIMERIE DU CONSEIL SUPRÊME DES ANTIQUITÉS

THE GCI/EAO ENVIRONMENTAL MONITORING PROGRAM AT THE GREAT SPHINX OF GIZA: RESULTS AND INTERPRETATION

Frank PREUSSER, Shin MAEKAWA, Eric DOEHNE, Charles SELWITZ *

I. Abstract

An automatic environmental monitoring system was installed on the back of the Sphinx. It has been shown that both temperature and relative humidity fluctuations contribute significantly to the surface deterioration of the rock of the Sphinx.

Moreover, it has been shown that some of the gypsum on the surface is due to atmospheric pollution.

II. Introduction

In late 1989 the Egyptian Antiquities Organization (EAO) and Getty Conservation Institute (GCI) agreed to undertake a joint program of monitoring the natural environment in close proximity to the Great Sphinx to complement the other ongoing studies. This program was designed to measure air temperature, air relative humidity (R H), and air pollutants in close proximity to the Sphinx. No attempt was made to determine the degree of rising damp (ground water), and wind speed and direction were measured only in one location (on the back of the Sphinx). An environmental monitoring system was installed on the back of the Great Sphinx in May 1990 (Fig. 1). The system is an autonomous electronic sensing and data-logging device, which is powered by solar energy. All the sensors are activated once a minute, and the averaged readings over 15 minute intervals are recorded in the system.

In addition to electronically monitoring the natural environment, a set of limestone samples has been exposed on the back of the Great Sphinx since May 1990 for a preliminary assessment of the potential impact of air pollution on the rock of the Sphinx.

III. Results

Figures 2-6 show the general climate of the site, the relative humidity, the air temperature, the calculated surface temperature, and the calculated dew point temperature for the monitoring period. The extreme fluctuations become even more apparent in the graphs for the daily data as shown in figures 7 and 8. It also has to be noted that the local environments can differ significantly between the different sides of the Sphinx (N, E, S, W, sky facing).

The measurements have shown that the air temperature, surface temperature of the rock, air relative humidity, and dew point temperature undergo great fluctuations on a daily and annual basis. Considering the potential sensitivity of the rock against thermal stresses and its salt content, this provides additional information about the deterioration mechanisms of the Sphinx. Pure sodium chloride absorbs water at or above a relative humidity of 75%. Mixed with other salts, this can occur at much lower relative humidity, 60% being a relative realistic value. Figures 9 and 10 show the duration of moisture absorption for both 75%

* Getty Conservation Institute, U. S. A.

and 60% RH for the period of September 1991 to January 1992. This data shows that the frequent high relative humidity in the surroundings of the Sphinx is potentially a key factor in the surface deterioration of the rock. The moisture absorption activates the soluble salts on a nearly daily basis. Rain and ground water, which are also other potential source for water, may however play a smaller role. To determine their significance, further studies will be required.

To obtain a qualitative first idea about the effects of air pollution on the rock of the Sphinx, Salem limestone samples (free of sulfur components and salts) were exposed on the back of the Sphinx. After 15 months of exposure, the samples had a darker appearance than the reference sample that remained at the GCI. The surfaces had a powdery character that could easily be removed by gentle rubbing. The samples showed a weight increase of 0.4-0.5% and were composed of gypsum with smaller amounts of halite. While for the moment we cannot exclude that some of the gypsum is related to SO2, the morphology suggests that the most likely source of the crust is windblown dust. This would mean that, even after removal of the salts from the rock, windblown material may rapidly add soluble salts to the Sphinx surface.

IV. Conclusion

The EAO-GCI environmental monitoring program has shown that both temperature and relative humidity fluctuation contribute significantly to the surface deterioration of the rock of the Great Sphinx. Other contributing factors, such as rising ground water and wind erosion, require additional studies.

FURTHER COMMENTS PREPARED BY

F. Preusser, Snethlage, H. Klapperich

1. On the deterioration of the Sphinx:

As frequently observed by the participants of this symposium, the weathering of the Sphinx follows the geological stratification of the rock. It is characterized by spalling, chipping, and sanding with the softer strata eroding much faster than the harder ones. This deterioration is mainly due to gypsum and sodium chloride, primarily present in the rock, and the deposition of dust, gypsum, and sodium chloride from the surroundings. The salts are activated by water. Sources of water include the humidity in the air, rain, and potentially the ground water (this would have to be verified by additional studies). The negative effects of salts and water are compounded by the action of wind and temperature variations.

2. Ongoing work

Since there are air spaces between the stone cladding and the rock of the Sphinx, there is a possibility that adverse reactions might still go on, leading to continued destruction of the rock. It seems therefore advisable to open up small portions of the cladding in one to two years to evaluate the situation behind it.

3. Proposed Additional Studies

a. Studies of the rock of the Sphinx

The following parameters should be determined in the laboratory:

Maximum capillary rise of water
Water sorption isotherms (rock and dust deposits)
Equilibrium moisture content
Sorption rates
Hygric expansion coefficient
Depth of thermal and hygric fluctuations
Desalination experiments

It should also be determined if ground water (rising damp) is a factor in the deterioration of the Sphinx through the measurement of moisture and salt concentration profiles. These measurements could be undertaken on strata adjacent to the Sphinx.

b. Consolidation (stone strengthening) experiments

While at this point it is not envisioned or proposed to do large-scale stone strengthening treatments on the Sphinx, we propose to undertake laboratory and field experiments to study the most promising stone consolidants. The field experiments could be carried out on strata adjacent to the Sphinx. While laboratory studies are good indicators of the performance of such materials, they cannot fully replace actual field studies. Since field studies require a long period of time, they should be initiated as soon as possible in order to be prepared for a potential future need for chemical consolidation. This experiment has to be planned very carefully in order to result in the greatest maximum information possible.

c. Other suggestions

The Sphinx and its surroundings should be kept free from excessive accumulations of dust and sand since they contain harmful components, such as gypsum and sodium chloride. Regular cleaning should be planned.

Provisions should be made for the removal of standing water in the surrounding of the Sphinx after a rainfall. If the water is allowed to stay there, it will penetrate the rock of the Sphinx, dissolve, transport, and reprecipitate the salts with the known destructive results.

Measures should be discussed to protect the Sphinx against rain, airborne dust and particles, extreme temperatures, and climatic factors leading to water condensation. While we are aware of the legitimate aesthetic and other concerns, we would strongly suggest reopening the discussion about temporarily sheltering the Sphinx until a final solution for its long-term preservation has been found.

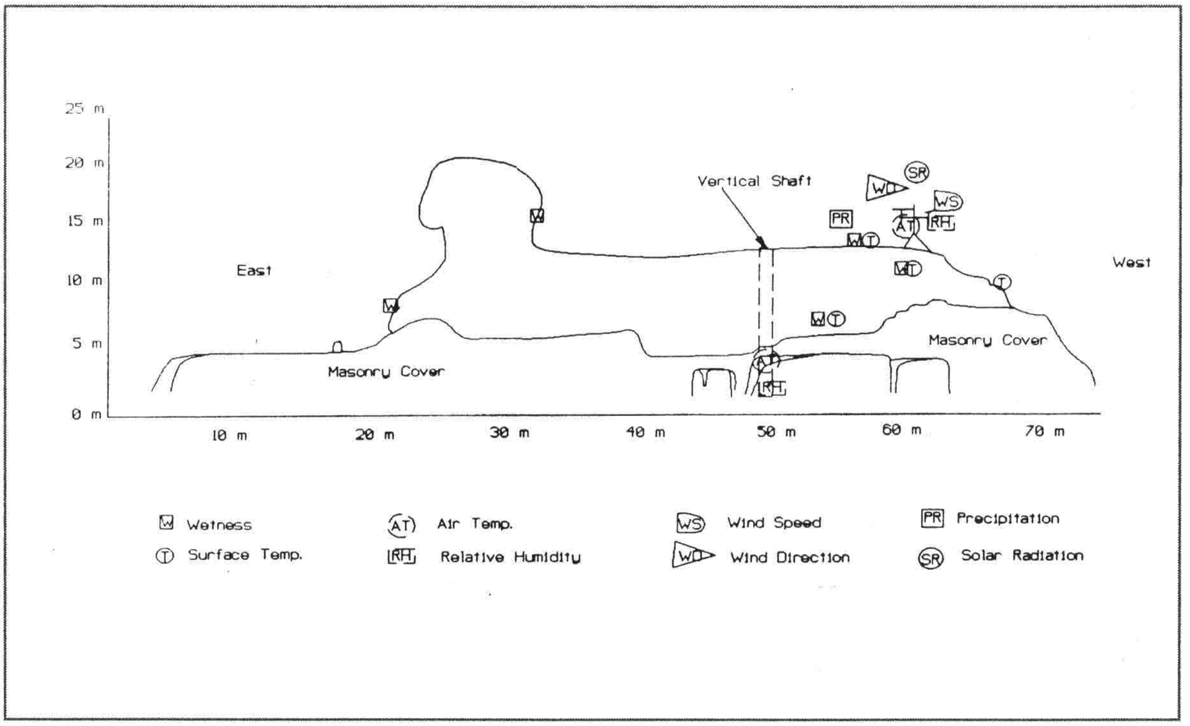

Fig. 1. Locations of Sensors on the Great Sphinx.

General Climate of the Site

	Range	Average
Air Temp.	3 - 42°C	12 - 23°C
RH	10 – 100%	50 – 68%
Wind Speed	24.6 m/s (max)	1.8 – 7.4 m/s
Solar Radiation	1.09 kw/m² (max)	0.18 - 0.31 kw/m²
Stone Temp. (exposed)	2 - 55°C	15 - 32°C
Stone Temp. (sheltered)	4 - 42°C	16 - 30°C

	Maximum	Total
Rainfall (Sept. 91- Jan. 92)	4.6mm (in 15min)	12.7mm

Fig. 2

Annual Report of R.H., Exposed

For year 1991, Great Sphinx, Egypt, by GCI

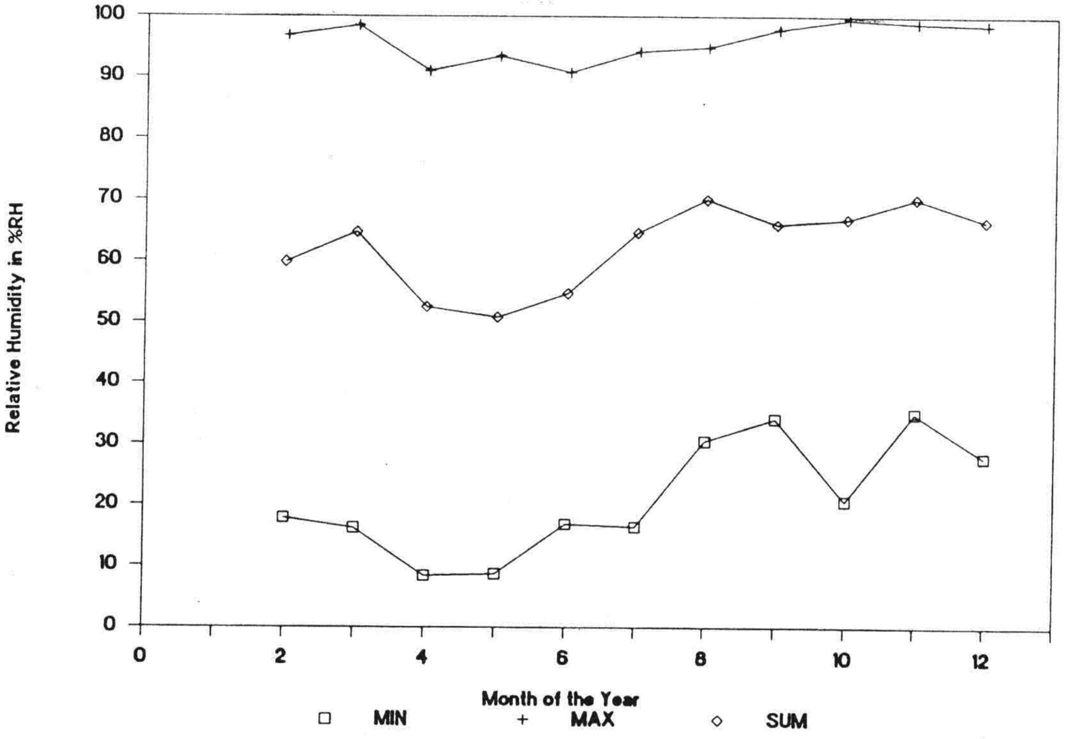

Fig. 3

Annual Report of Air Temp., Exposed

For year 1991, Great Sphinx, Egypt, by GCI

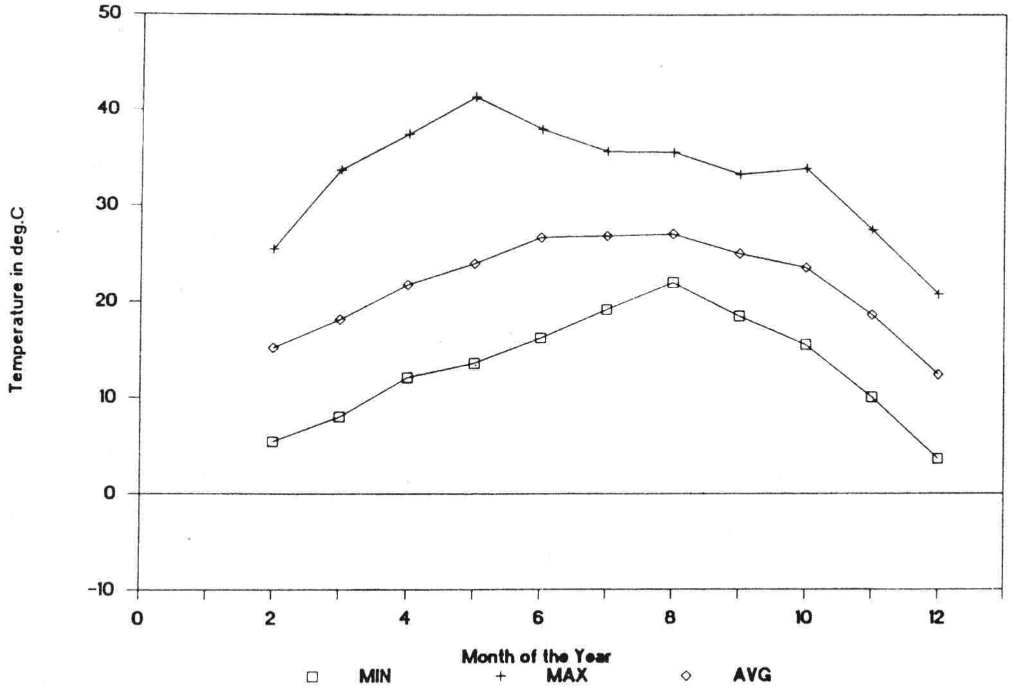

Fig. 4

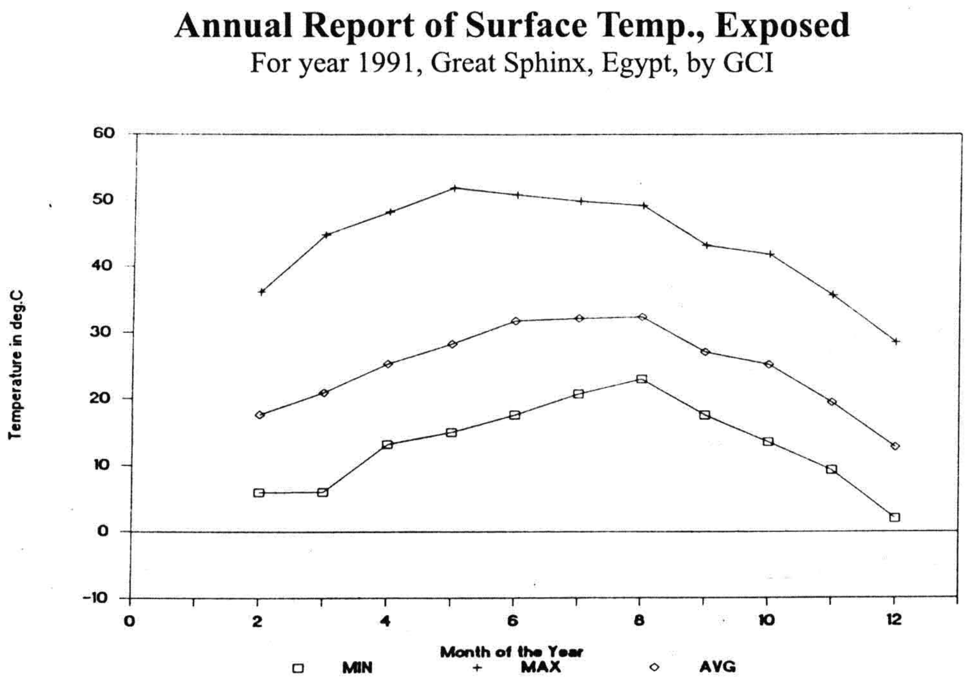
Annual Report of Surface Temp., Exposed
For year 1991, Great Sphinx, Egypt, by GCI
Temperature in deg.C
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
Month of the Year
MIN
MAX
AVG

Fig. 5

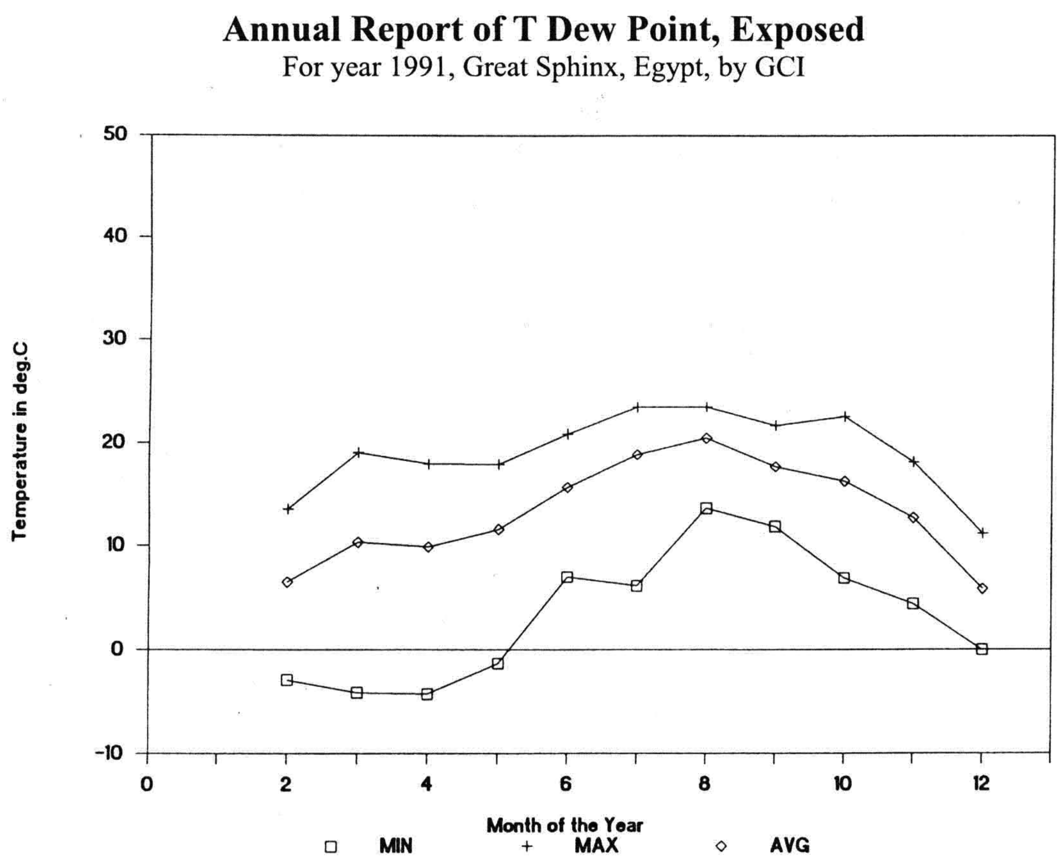
Annual Report of T Dew Point, Exposed
For year 1991, Great Sphinx, Egypt, by GCI
Temperature in deg.C
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
Month of the Year
MIN
MAX
AVG

Fig. 6

Daily Maximum, Minimum & Average Temperature
Sky & West Back Facing Surface of the Great Sphinx

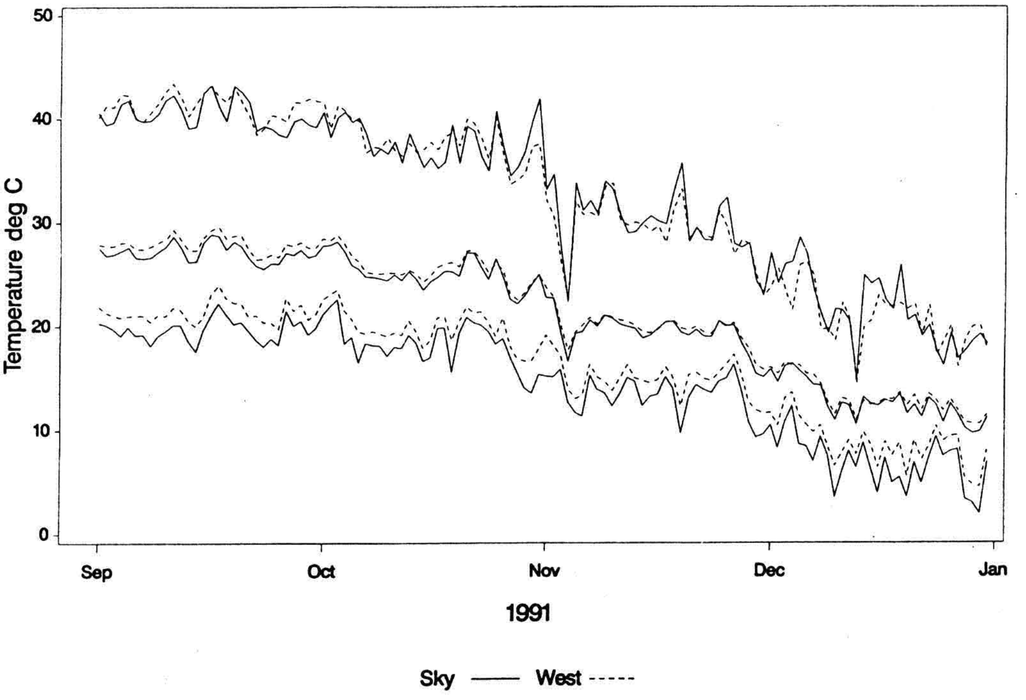

Fig. 7

R.H. at Sky Facing Surface
Sept 1991, the Great Sphinx, Egypt, by GCI

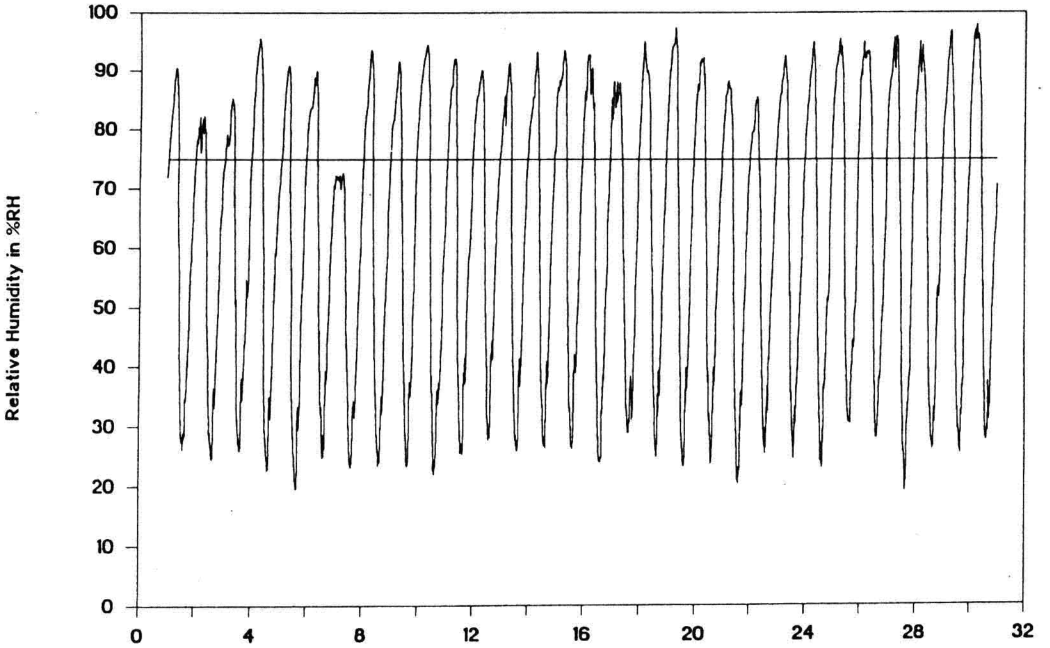

Fig. 8

Duration of Moisture Absorption at the Surface

(Sept. 91 – Jan. 92)

	Above 60% RH	Above 75% RH
Low Mid (N)	14 hrs	7 hrs
Low Mid (S)	11 hrs	5 hrs
High Rear (N)	17 hrs	10 hrs
High Rear (S)	11 hrs	4 hrs
High Rear (W)	14 hrs	8 hrs
Sky Facing	14 hrs	11 hrs

*Duration by hours/ day

Fig. 9

Weekly Percentage of Hours above 60% and 75% RH

Low Middle Surface of the Great Sphinx

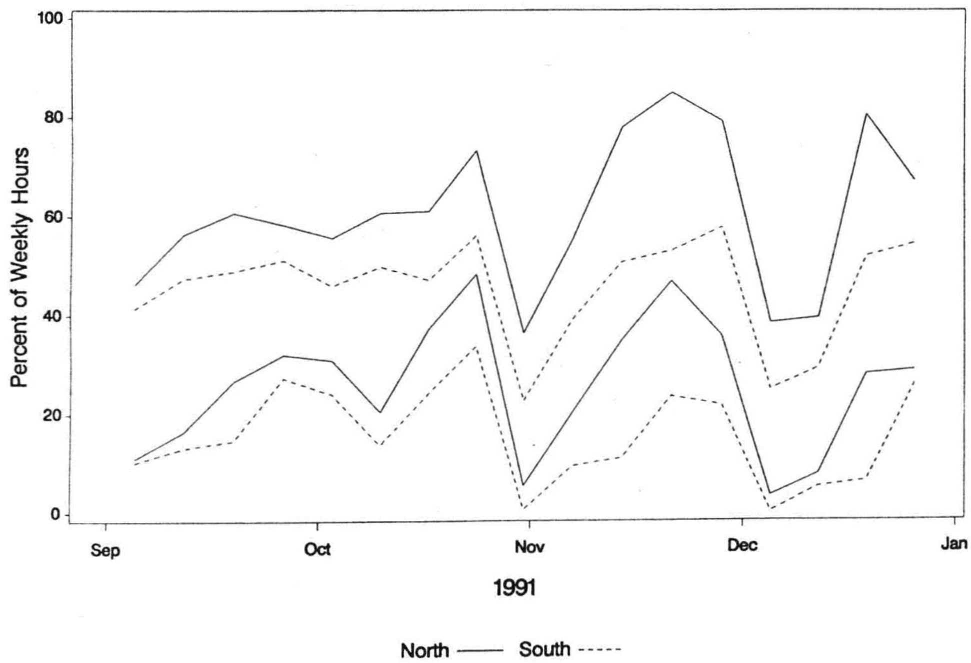

Fig. 10

ISBN. 977-437-015-5
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