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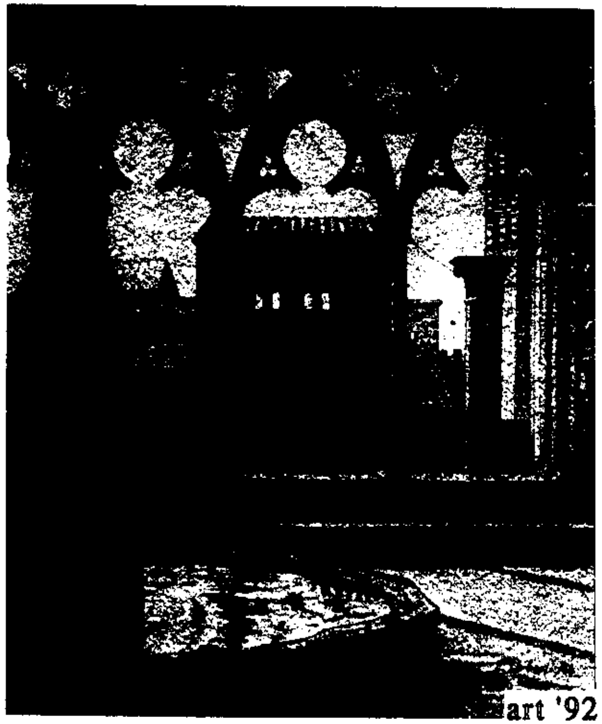

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SURVEYS FOR THE CONTROL OF INDOOR POLLUTION AFFECTING CULTURAL PROPERTY IN ITALY

Maurizio MARABELLI

Abstract

The study of indoor atmospheric pollution has attracted increasing attention in Italy since the surveys carried out in the Scrovegni Chapel, Padua, in 1977-78.

Since then, seven other sites have been analyzed, all of which demonstrate the high risk to which museum environments are subjected when there are insufficient controls over the exchange of indoor and outdoor air or over the influx of visitors, or where operating conditions in general are defective.

Together with the results of these experiments, some guidelines for future research are also offered.

1 INTRODUCTION

This paper presents the results of experiments conducted by the Istituto Centrale per il Restauro (ICR) and by other scientific institutes in Italy to study indoor air pollution as it affects cultural property. In effect, the first survey for the measurement of atmospheric pollution was expressly dedicated to the control of an indoor environment, the Scrovegni Chapel in Padua, an investigation necessary for determining the most appropriate conservation treatment for the frescoes of Giotto.

The results obtained there indicated a high incidence of certain atmospheric pollutants (sulphur dioxide and atmospheric particulate) causing the deterioration of the works of art conserved in the Chapel.

From the time of this initial investigation to the present day, research has been carried out at the following sites:

Basilica of Torcello, 1979-1980
Borghese Gallery, Rome, 1980
Camera degli Sposi, Ducal Palace, Mantua, 1982-1983
Sala del Cenacolo, S. Maria delle Grazie, Milan, 1984-1986
Church of S. Francesco, Arezzo, 1987
Sistine Chapel, Vatican Palace, Rome, 1988
Brancacci Chapel, S. Maria del Carmine, Florence, 1988-1989

The most interesting results of these investigations are summarized in the following paragraphs.

2 SCROVEGNI CHAPEL *(Cappella degli Scrovegni or Madonna dell'Arena), Padua*

The interior of the building is decorated with mural paintings (frescoes) of Giotto, completed in 1305. As early as 1963 Sayre and Majewski /1/ identified the relationship between atmospheric pollution and the deterioration of the frescoes.

A series of multidisciplinary measurements was carried out in 1977-1978, involving chemists, physicists and biologists; the results were published in 1982 /4/.

For the measurement of the pollution levels in particular /5/, two sets of samplings of the atmospheric particulate were carried out (using filters of cellulose acetate, 047 mm, 0.8 micron pore diameter) inside and outside the Chapel, during the day and at night. The campaigns were carried out in consecutive seasons: summer, autumn, winter, summer.

A Gelman flame-photometry apparatus and a Philips apparatus with a coulometric unit (continuous titration with bromine) were used to measure the sulphur dioxide.

During the day, the suspended particulate matter was found to be greater inside the building than outside, especially during the summer; the dust levels were also higher inside during the day, due to the influx of visitors, frequent opening of the entrance door, and eddies (convective air currents) caused by the incandescent lamps (figs. 1-2).

The acidity of the total suspended particulate (TSP) inside the building proved to be higher during the night, because of the prevalence of tiny acidic particles, and in winter, due to the greater concentration of sulphur dioxide and high relative humidity (RH) (fig. 3).

During the winter, the variations in the acidity of the inside particulate follow those of the outside, with a certain delay, showing, rather significantly, a substantial exchange of internal and external air /6/ (fig. 4).

Figure 5 shows the registration of sulphur dioxide concentration in winter, with the apparatus placed at the midpoint of the nave. It shows the rapid increase of sulphur dioxide following the opening of the door; with the intermittent opening of the door due to the sporadic entrance of visitors and later with the final closing of the Chapel, the concentration of the pollutant returns almost to its initial value, ca. 10 ppb (part per billion), in about four hours, due to the deposit of SO_2 on the frescoed walls. Sulphur dioxide and acidic particulate cause sulphation of the calcium carbonate, of a few percent, up to 0.1 mm of depth, but this sulphation increases to 50% into the pictorial layer, some tens of microns thick. In the areas of greatest sulphation, such as the entrance wall, the pigment layer becomes detached and falls, forming innumerable microlacunae on the surface of the painting.

Unfortunately, the environmental conservation problems are still not resolved, although some partial provisions have been adopted.

3 BASILICA OF TORCELLO

In 1979-80, three surveys were conducted (two in summer, one in winter) to measure the suspended particulate matter, sulphur dioxide and ammoniac inside the basilica of S. Maria Assunta in Torcello.

These campaigns were undertaken in order to study the detachment of the mosaics, caused at least in part by sulphation and subsequent disintegration of the mortar binding the mosaic tesserae, according to Fassina /3/.

Samplings of the suspended particulate matter were conducted only on the inside, in 24-hour cycles; the ammoniac was collected into scavenging towers containing a diluted solution of sulphuric acid.

For measuring the sulphur dioxide and the suspended particulate matter, the apparatus described in the preceding example was used.

The Basilica of Torcello is located far from the intense pollution sources of city traffic and domestic heating plants, but is affected by pollutants from the diffusion and dilution of the industrial exhausts characteristic of the Marghera coastline.

As can be seen in fig. 6 (courtesy of V. Fassina), the concentration of suspended particulate matter is higher in winter than in summer; in fact, the maximum frequency interval in winter ranges from 20 to 40 μg/mc, equal to that of the summer season, but with a pronounced skewness toward the right, that is, toward the higher values. The acidity of the TSP presents similar intervals in winter (3-4 μg/mc) and in the two summers (3-4 and 2-3 μg/mc respectively), but again the winter distribution skews toward the right.

The sulphur dioxide shows slightly higher values in winter (maximum frequency interval 10-20 μg/mc, as opposed to 0-10 μg/mc in summer), partially due to climatic "fumigation".

In the case of the ammoniac, the difference between the two seasons is more significant, with greater concentration ranges in summer (50-60 and 30-40 μg/mc) than in winter (10-20 μg/mc). The higher concentration of ammoniac corresponds to an acceleration, caused by higher temperatures, of the process of decomposition of the algae in the laguna.

While there is a high coefficient of correlation between the H2S04 and the sulphates in the TSP (0.75), the correlation between concentrations of $S0_2$ and H_2S0_4 and between $S0_2$ and sulphates is lower (0.51), perhaps partly due to an imbalance among the air-dispersed agents caused by the rapid fixation of the sulphur dioxide onto the binding mortar. The deposit of pollutants seems to take place more rapidly on the inferior parts of the mosaics, where the temperature is lower and where the effects of rising damp can also be observed. The predictable deposit of acid pollutants may cause the corrosion of the binding mortar and thus the detachment of the mosaic tesserae.

4 BORGHESE GALLERY *(Galleria Borghese), Rome*

The Borghese Museum, which houses paintings (on panel and canvas) and sculpture (in stone and metal), is located in a villa commissioned by Cardinal Scipione Borghese and erected in 1613. Measurements were conducted to verify the effect on indoor pollution of

external pollution sources (traffic, domestic heating) and internal ones (visitors) /2/. Two series of TSP surveys were conducted by ICR, one in winter and one in summer, differentiating between diurnal and nocturnal periods, and taking samplings inside and outside. Sulphur dioxide was also tested.

On the inside, two rooms from the upper floor were tested: room IX (in which Raphael's masterpiece, "The Deposition," is hung) and room XVI; the apparatus for the outdoor test was placed in the entry loggia, facing a thoroughfare. The equipment was the same used for the Padua surveys. From the graphs in figs. 710 and from other experimental results (not reported here), the following deductions can be made:

a) The pollution of the TSP is greater in winter, both outdoors and indoors, with daytime prevailing over nighttime, because of the functioning of heating plants.

b) During the brief periods under examination, a clear differentiation was not observed between indoor and outdoor TSP, except for room IX in winter (higher outdoor pollution levels).

The levels of the TSP on the inside in winter are very high, enough to cause damage to the works of art in the Gallery.

c) Inside, daytime values of the amount of dust prevail over nighttime values, both in summer and winter, due to the presence of visitors during the day.

d) Inside, the atmospheric particulate was found to be more acidic in winter, in terms of absolute value, and the percent of acidity is higher during the night. Some basic values were encountered in both winter and summer, attributed to the use of an alkaline solution for cleaning the floors.

e) The average concentration of sulphur dioxide registered indoors during the winter (ca. 30 μg/mc) is double the summer average.

During a winter experiment in which a window in one of the exhibition rooms was opened for ten minutes, the level of sulphur dioxide decreased from a peak concentration of 300 μg/mc (at the moment that the window was closed again) to 30 μg/mc (after ca. 90 minutes).

Suggestions for ameliorating the environmental conditions have been made to the Administration of the Museum.

5 CAMERA DEGLI SPOSI, DUCAL PALACE, MANTUA

The Camera degli Sposi is decorated with mural paintings (1474) by Andrea Mantegna, depicting scenes from the life of the Gonzaga family. Some of the paintings were executed in fresco;

Fassina has hypothesized a cyclical attack of calcium carbonate on the fresco surface, caused by the absorption of carbon dioxide exhaled by visitors and producing surface efflorescences, especially on the southwest wall /9/.

During peak periods, according to Fassina's estimates, more than 50 persons crowd into the small room every 5 minutes, corresponding to 600 persons per hour, and thus producing, in the four hours that the room is open daily, a total of 4200 liters of carbon dioxide every day. Fig. 11 (courtesy of V. Fassina) shows measurements of carbon dioxide in winter and in spring; in the latter period the concentrations reach as high as four times greater than the standard level. Daily peaks of visitors, up to 2500 persons, create problems for the conservation of the paintings with carbonate binder, especially when one takes into account the parallel production of water vapour (up to 1 Kg of water vapour diffused through the 400 mc of the room.)

This survey, which was accompanied by thermohygrometric measurements, is an example of the necessity to regulate the influx of the public, in order to improve the environmental conditions for conservation.

6 SALA DEL CENACOLO VINCIANO OR REFECTORY, *S. Maria delle Grazie, Milan*

The Cenacolo ("Last Supper") by Leonardo da Vinci is a mural painting executed with tempera qrassa on dry plaster (a secco), on the north wall of the refectory in the monastic complex of S. Maria delle Grazie.

Executed between 1435 and 1437, the Cenacolo already showed extensive opacity of its surface in 1517-18, probably owing to high environmental humidity. It is evident that acidic pollutants exercise a secondary role on a tempera painting; nevertheless, the accumulation of dust and air-dispersed carbon particles can seriously darken and soil the surface. From preliminary examinations of cross-sections of the painting, it was determined that "dirt," composed of dust and degraded surface consolidants, had covered the original pigments and the layers of overpaint, even penetrating into the craquelure.

In order to measure the level of dust in the room and to take steps to improve the environmental conditions for conservation, plans were made for campaigns of microclimatic measurements, of anemometric mapping, of sampling of the suspended particulate matter, and of the continuous measurement of sulphur dioxide.

Summary data from the campaigns conducted by the Chemical Laboratory of the Istituto Centrale per il Restauro (I.C.R.) in 1984-86 are reported below /8 e 10/, refining the preliminary results obtained by Girelli and Rolla /7/.

The I.C.R. undertook two surveys of the suspended particulate matter, using Metricel Gelman filters DM/450 047 mm, 0.45 micron in diameter. The samples were taken both indoors and outdoors, differentiating between winter and summer and between daytime and nighttime.

The atmospheric particulate was analyzed for: acidity, such as H_2SO_4; water-soluble calcium ions, ammonium ions, chlorides, nitrates, nitrites and sulphates; specific conductivity of the aqueous extracts. Fig. 12 represents the comparison of indoor and outdoor TSP concentrations during the summer period, showing a high level of dust during the day; the daytime indoor values (between 250 and 400 µg/mc) are about four times greater than the corresponding outdoor values, except for days when the room is closed to the public, in which they return to normal levels. During the winter (fig. 13), the same situation is repeated, with lower peak concentrations (between 200 and 300 µg/mc).

In addition, the dust levels are higher in the daytime than in the nighttime in both measurement seasons and in both the environments. Indoors, this phenomenon is primarily due to the "visitor effect" and to the use of incandescent lamps (which produce eddies) during the day, while outdoors it can be attributed to the greater stillness of the air and to the absence of vehicular traffic at night.

The higher acidity of the atmospheric particulate in winter as opposed to summer, both in absolute value and as a percentage value, indoors and outdoors, can be attributed to the operation of heating plants during the cold weather. Indoors the atmospheric particulate is more acidic during the night, in both seasons, because of the prevalence of the finer and more acidic particulate matter.

With respect to the sulphur dioxide, continuous parallel measurements conducted during the winter, outside and inside (near the painting), showed outdoor concentration values fluctuating between 40 and 100 ppb, while the indoor pollution along the north wall can be considered negligible (10-15 ppb).

The campaigns were completed by thermohygrometric measurements in both seasons and by the mapping of the air currents inside the room using a hot-wire anemometer.

From the examination of the resulting data and from the comparison of the concentrations of indoor pollution not only with those of the environment immediately outside the church but also with sites characterized by heavy traffic elsewhere in the city, it was possible to deduce, without a shadow of doubt, that the dust levels inside the room surpassed the highest outdoor dust levels both in summer and in winter and should be attributed primarily to the influx of visitors.

A plan for climatisation and filtration is now in progress, under the supervision of ICR.

7 SISTINE CHAPEL *(Cappella Sistina), Vatican, Rome*

The restoration of Michelangelo's paintings in the vault of the Sistine Chapel was begun in June 1980 and is still in progress. Again in this case the treatment was preceded by a series of analyses, directed by the Vatican Laboratories, which confirmed the presence of a thin layer of dirt underneath the repaintings and restoration glazes (velature) /12/.

Soot from the candles once used to illuminate the vast chamber had caused the formation of a fine deposit of carbon particles on the fresco surfaces; control measurements of the air-dispersed pollutants were undertaken in 1988 to determine the current environmental conditions, as there had been a radical change not only in the pollution sources but also in the operational conditions of the Chapel, now open to visitors from all over the world.

The measurements and samplings of the pollutants were taken at the vault level, on the scaffolding erected for the restoration; the TSP sampling was carried out in four daily intervals, corresponding more or less to morning-afternoonevening-later at night /14/.

The resulting TSP data for two summer days and two winter days are summarized in tables 1 and 2 (courtesy of A. Bacaloni, in press), from which one can ascertain that the level of dust is higher during the daytime than during the nighttime, because of the influx of visitors, with peaks (400 μg/mc) that are definitely dangerous. In addition, during the same periods, measurements were taken of five other gaseous pollutants (hydrochloric acid, nitrous acid, nitric acid, sulphur dioxide, and nitrogen dioxide); in the case of the nitrogen dioxide, higher concentrations were found in winter, due to the emission of polluted air into the Chapel from a defective heating unit.

A project for climatization of the Chapel that takes into account these experimental results is now in progress.

8 BRANCACCI CHAPEL *S. Maria del Carmine, Florence*

The restoration of the mural paintings of the Brancacci Chapel in Florence took three years. These paintings constitute a large cycle, executed between 1425 and 1485 by Masolino, Masaccio and Filippino Lippi. Because of the decision to improve the conservation conditions by installing an air-conditioning system, precautionary measurements of the inside and outside air in the church were needed, so that the design of the installation would meet the conservation requirements and, above all, would include adequate systems for air filtration (if necessary).

The surveys for measurement of the pollution and for microclimatic controls were carried out by experts from Syremont, who have prepared a report now in press /15/. Thanks to the courtesy of the director P. Parrini, we are able to communicate in advance some of the most important findings.

The summer campaign (9-12 August 1988) revealed a limited concentration of TSP (average daily value of 69.4 ug/mc). The concentration of the suspended particulate matter topped off at decidedly abnormal values in winter, during the Christmas period, with values higher than those registered outside; the peaks of concentration were reached during the day (ca. 800 ug/mc) /13/. In a later period, the TSP levels decreased, closer to 100 ug/mc, only to rise again to between 100 and 200 ug/mc around Easter (fig. 14, courtesy of P. Parrini et al.).

The level of sulphur dioxide in the church, monitored during the late winter of 1988-89, was close to zero, while the indoor level of nitrogen oxides was comparable to the outdoor level, although slightly lower. The difference encountered between these two pollutants indoors can be explained by the fact that the reaction between sulphur dioxide and calcium carbonate prevails, thermodynamically, over the reaction of NOx with calcium carbonate.

Finally, concentrations of carbon dioxide up to ca. 700 ppm, much higher than natural averages, were registered when the church was full of worshippers.

9 CHURCH OF S. FRANCESCO *Arezzo*

The scientific results from the study and conservation of the cycle of mural paintings depicting the Legend of the True Cross, executed by Piero della Francesca between 1453 and 1464 on the walls of the main apse chapel of S. Francesco, were recently illustrated and discussed in a symposium held in Arezzo in March 199 0 (11) .

The mural paintings are severely damaged by efflorescences derived partly from the extensive use of cement as a consolidant. The diffuse presence of gypsum on the surface, however, may also be partly caused by the deposition of sulphur dioxide and TSP.

Samplings of the indoor suspended particulate matter (over a 24-hour period) were carried out in May and December 1987; sulphur dioxide was also measured indoors in December. Tables 3 and 4 (courtesy of L. Marchetti) summarize the results, including acidity, conductivity of the aqueous extracts of the particulate, and sulphur dioxide. The particulate concentrations are not very high, with summer prevailing over winter. Strangely enough, the total acidity in summer is greater than in winter, while the soluble salts (see the conductivity measurements) are greater in winter.

The average value of the sulphur dioxide is 22 ug/mc, not a very high value, but one for which the observations already made about the Brancacci Chapel are applicable.

The Istituto Centrale per il Restauro and the Chemical Laboratory of the Soprintendenza ai Beni Artistici e Storici di Venezia are currently coordinating a new campaign of indoor and also outdoor TSP and S02 measurements, for a better understanding of the processes of deterioration.

10 OBSERVATIONS AND CONCLUSIONS

From this schematic review, one may draw some considerations useful both for future research and for better conservation strategies.

a) From a methodological point of view, particularly meaningful data were gathered by taking parallel samples indoors and outdoors and by making a distinction between a diurnal period (generally corresponding to the hours open to the public and to the hours of greatest vehicular traffic) and a nocturnal one.

The measurements were extended through at least two seasons of the Italian climate, corresponding to summer and winter.

b) The chemical agents analysed most frequently were the suspended particulate matter and sulphur dioxide; it was also very useful to determine the acidity and the water-soluble cations and anions in the suspended particulate matter, as well as the total soluble salts (by conductivity measurements of the aqueous extracts).

Data processing of the necessary correlations should, in future, take into consideration absolute as well as percent values, calculating, if possible, the average, the median, the maximum frequency interval, the maximum and the minimum value. Coefficients of correlation should also be calculated for the various concentrations, to compare concentrations of cations, anions, suspended particulate, and acidity.

c) It would be useful in the future to measure more frequently the concentration of nitrogen dioxide, an agent found in buildings located near heavy flows of traffic.

Another necessary measurement would be that of the "black smoke" (percent of carbon particles in the dust), taken directly from the particulate collected on the filter, using reflectance spectrophotometry.

d) Simpler and less expensive passive-capture methods should be developed and standardized, permitting more extensive testing of museum environments.

These tests should be practically compulsory in cases where there is a high volume of visitors or where there are functioning air-conditioners, which can, in certain cases, increase significantly the internal concentrations of air-dispersed pollutants.

It would be highly opportune, in this context, to establish an international commission to regulate sampling and measurement methods and to define standards for indoor air quality.

e) All of the cases under examination have shown a high level of indoor dust, always in concomitance with the daily influx of the public.

A low indoor concentration of sulphur dioxide is not necessarily a reassuring sign, because of the high affinity of this pollutant with calcium carbonate.

Measurements of the microclimate (air and wall temperatures, RH and SH of the air) and anemometric maps have proven to be very useful for determining the mechanisms of transport and deposit of the pollutants inside and thus for suggesting corrective methods to contain the pollution. Although, in the interests of brevity, it is not possible to report here the relevant results, one should not underestimate the importance of the microclimate in the encouragement or retardation of the effects of indoor pollution.

f) In conclusion, the general picture is one of situations at risk, permitting us to identify solutions, often easily achieved, to ameliorate the quality of the environment.

Only in this way it will be possible in the future to achieve an effective conservation policy, that goes beyond the common logic of restoration at any price, sometimes without removing the causes of the deterioration.

g) The logic that forms the basis for the future expansion of indoor pollution studies is also cognitive, as is summarized very effectively by Briblecombe (13). According to this author, the objectives of research should comprise:

- measurement of the velocity of deposition of gaseous pollu-

tants and particulate on various common types of fragile materials;
- study of the "internal" causes producing indoor pollutants and of the chemical transformations that may involve certain polluting agents in confined spaces;
- the achievement of a better understanding of the chemical reactions induced by pollutants in various materials;
- the definition of critical danger levels for various pollutants in the indoor environment, in relation to the materials to be conserved.

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TABLE I - Concentrations of pollutants (in µg/mc) in the Sistine Chapel in winter

Sampling times	14:30-20:30	20:45/2:45	3:00/9:00	9:15/15
Particulate material, winter 88-1	256	73.0	106	40
Nitrogen dioxide, winter 88-1	29.2	33.7	39.1	29
Sampling times	**18:00-24:00**	**24:05/6:05**	**6:10/12:10**	**12:15/18**
Particulate material, winter 88-2	121	104	323	28
Nitrogen dioxide, winter 88-2	14.5	25.0	11.0	32

TABLE II - Concentrations of pollutants (in µg/mc) in the Sistine Chapel in summer

Sampling times	18:00-24:00	24:00/6:00	6.00/12.00	12.00/18.00
Particulate material, summer 88-1	110	92	221	18
Nitrogen dioxide, summer 88-1	17.9	10.1	8.9	35
Particulate material, summer 88-2	97	—	183	15
Nitrogen dioxide, summer 88-2	21.7	15.4	17.2	9.

TABLE III - Measurements taken inside the church of S. Francesco, Arezzo

		TSP (µg/mc)	Sulphuric acid (µg/mc)	Conductivity (µS/cm.mc)
May	11	130	5.1	39
	12	133	5.6	43
	13	119	4.8	37
	14	143	4.3	30
	15	111	4.5	27
	16	136	5.8	28
	17	120	7.0	42
	18	101	7.5	38
	19	91	7.3	31
	20	126	5.9	26
	21	96	7.0	27
	22	127	8.9	29
Average		120	6.1	33

TABLE IV - Measurements taken inside the church of S. Francesco, Arezzo

		SO_2 (µg/mc)	TSP (µg/mc)	Sulphuric acid (µg/mc)	Conductivit (µS/cm.mc)
Dec.	3-4	19	91	4.8	45
	4-5	13	82	4.8	45
	5-6	22	96	5.4	38
	6-7	11	77	4.9	33
	7-8	19	103	4.7	36
	8-9	32	89	5.6	35
	10-11	13	70	4.4	32
	11-12	15	79	4.9	31
	12-13	35	80	5.9	39
	13-14	49	91	4.7	45
	14-15	18	87	5.2	40
	15-16	41	88	5.4	51
	18-19	14	97	4.6	63
	19-20	16	105	4.7	57
	20-21	16	103	5.4	49
	21-22	14	103	5.6	62
	22-23	24	85	8.4	69
Average		22	90	5.3	45

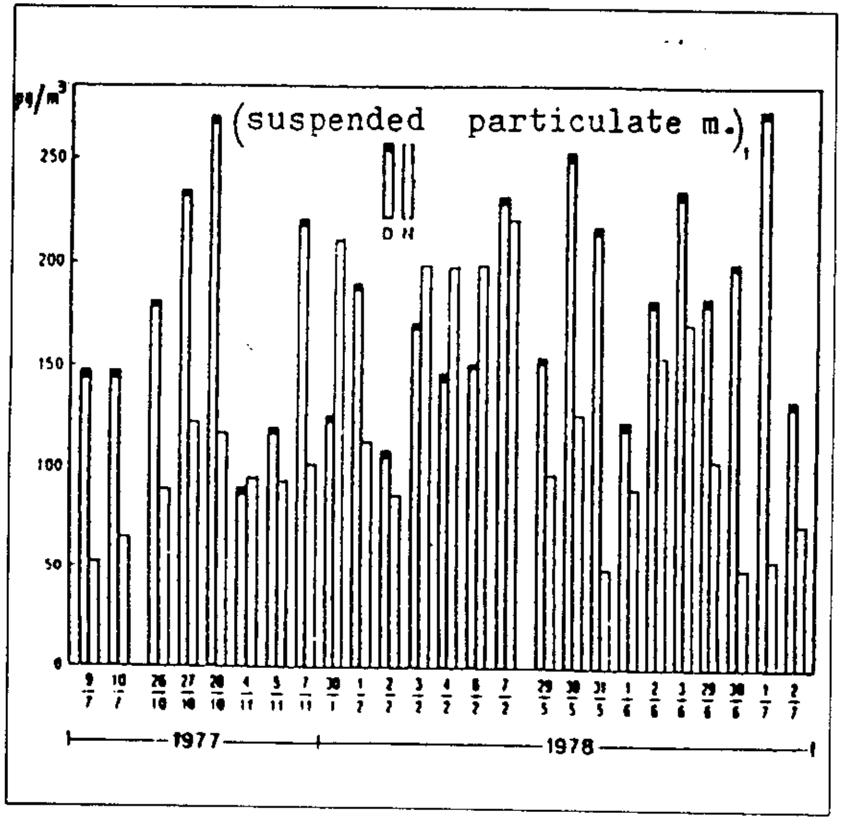


Fig. 1. TSP inside the Scrovegni Chapel: comparison of day (D) and night (N)

Fig. 2. TSP sampled inside (I) and outside (O) the Scrovegni Chapel during the day

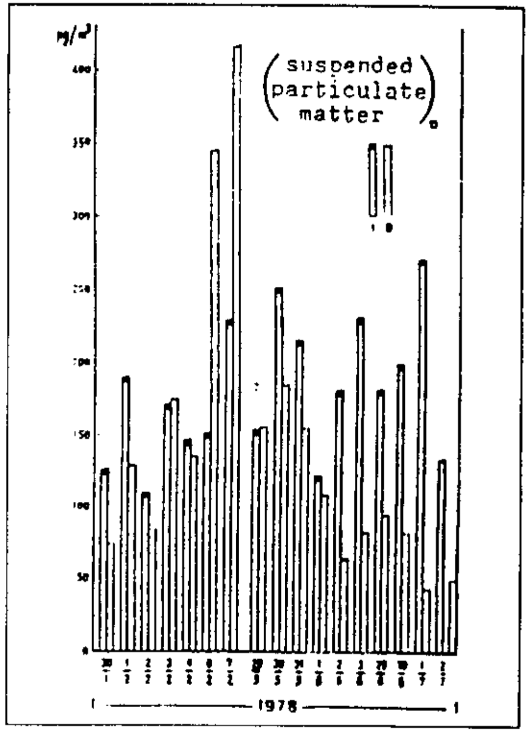
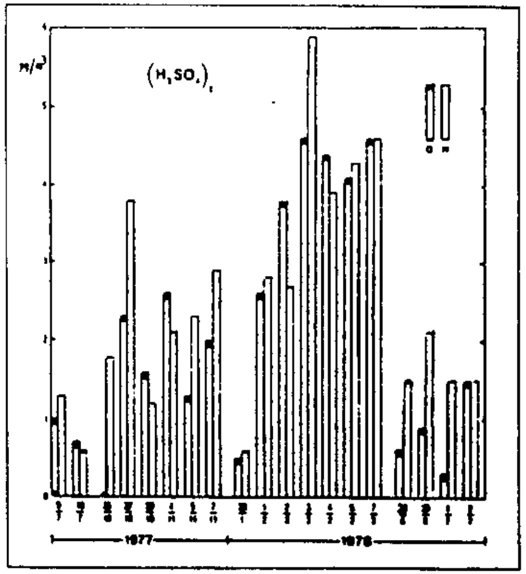
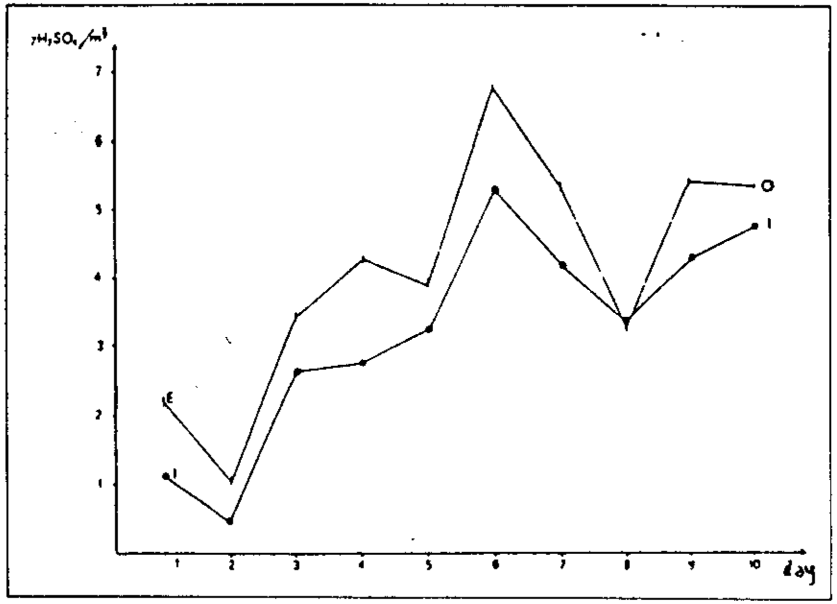


Fig. 3. Acidity of the TSP inside the Scrovegni Chapel: comparison of day (D) and night (N)





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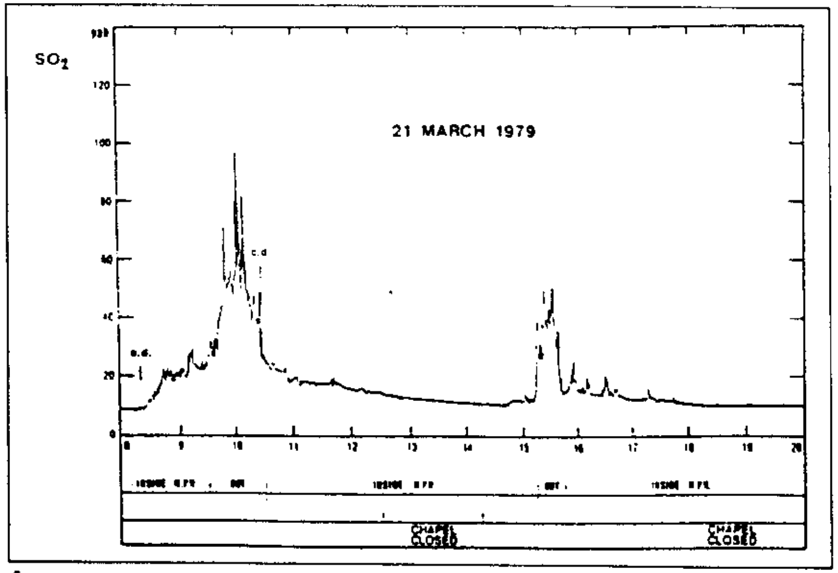

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Fig. 4. Acidity of the TSP (24 hours) sampled inside (I) and outside (O) the Scrovegni Chapel in winter

Fig. 5. Registration of the concentration of sulphur dioxide in the Chapel, measured at mid-point nave (M.P.N.), 21 March 1979

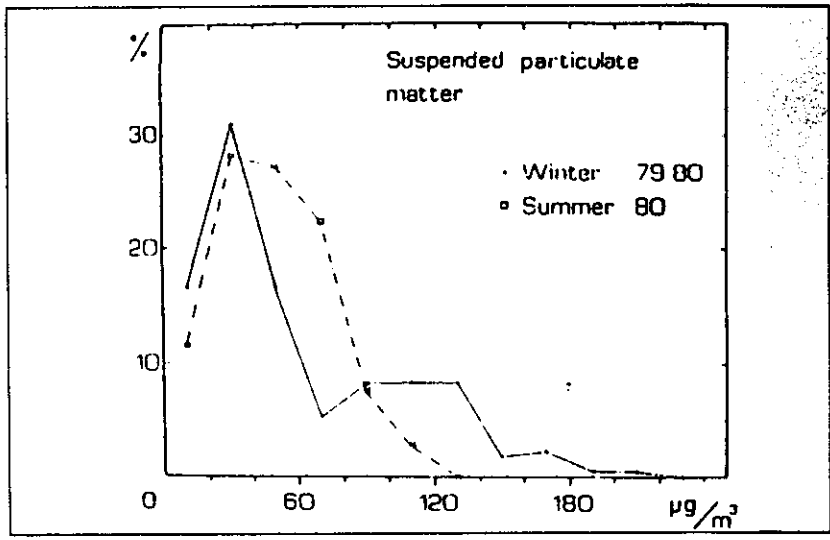


Fig. 6. Basilica of Torcello: distribution of the frequency of the concentration of the suspended particulate matter in winter and in summer, indoors

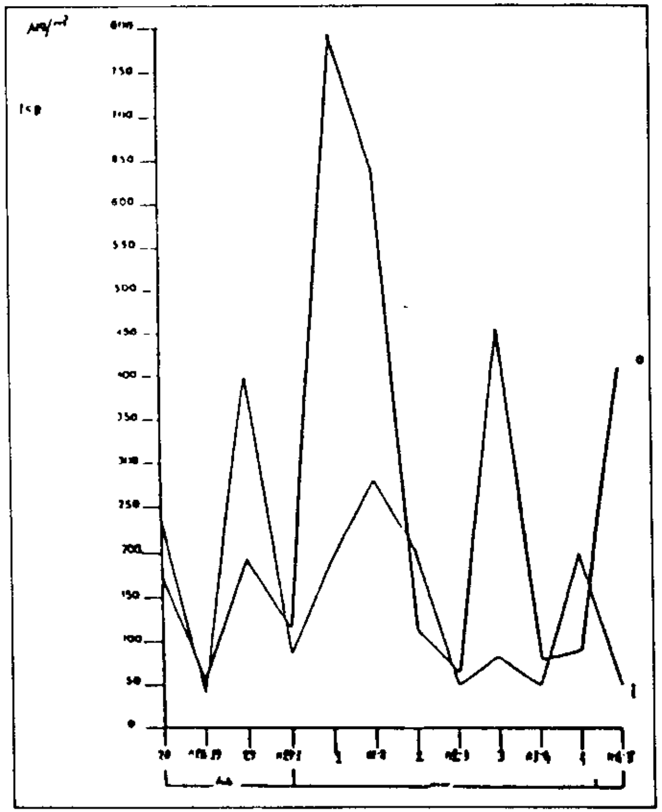


Fig. 7. Borghese Gallery, room IX (i): TSP measured in winter, compared with TSP outdoors (o)

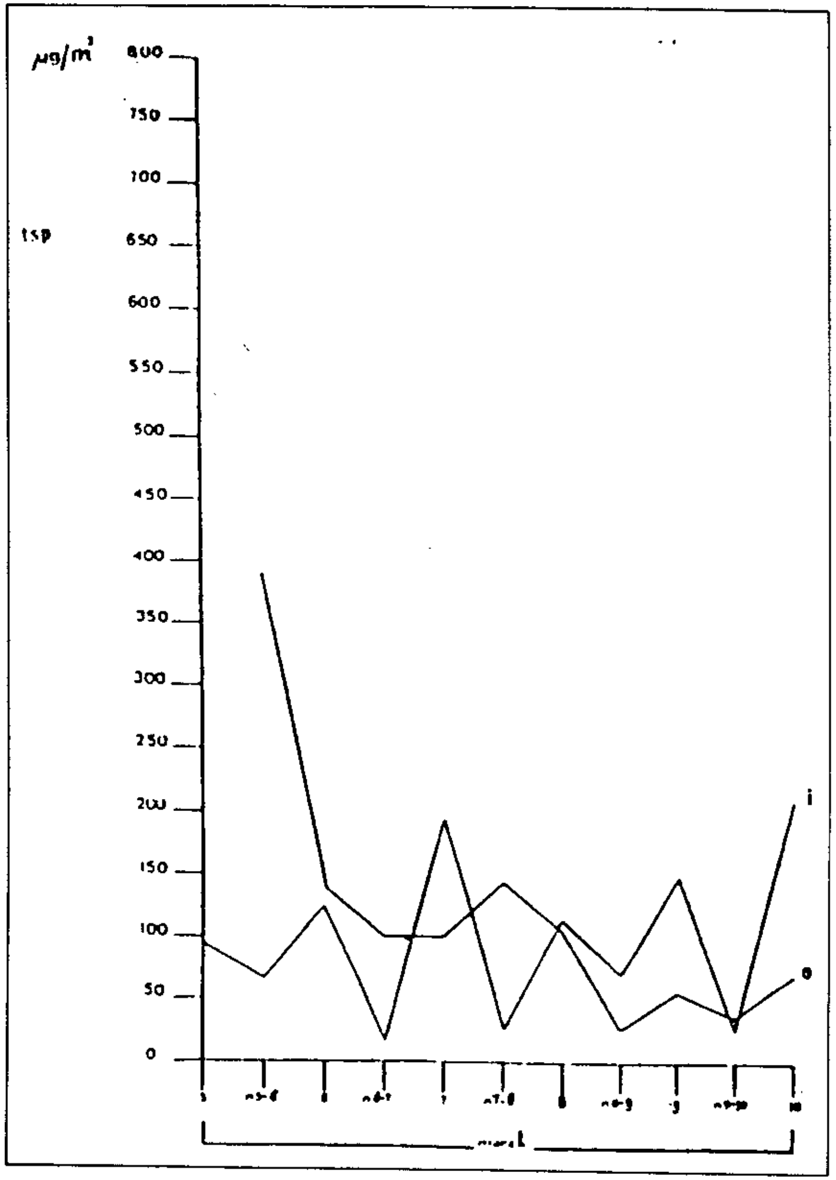


Fig. 8. Borghese Gallery, room XVI (i): TSP measured in winter, compared with TSP outdoors (o)

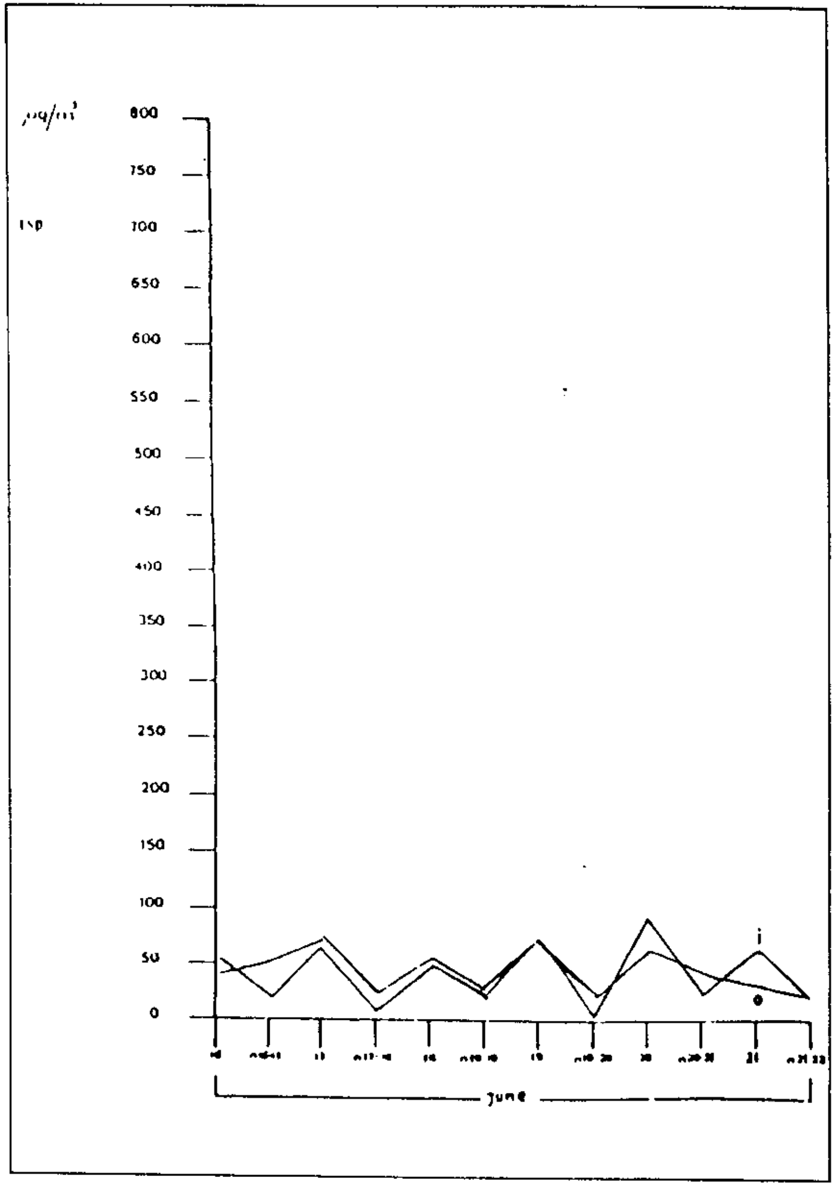


Fig. 9. Borghese Gallery, room IX (i): TSP measured in summer, compared with TSP outdoors (o)

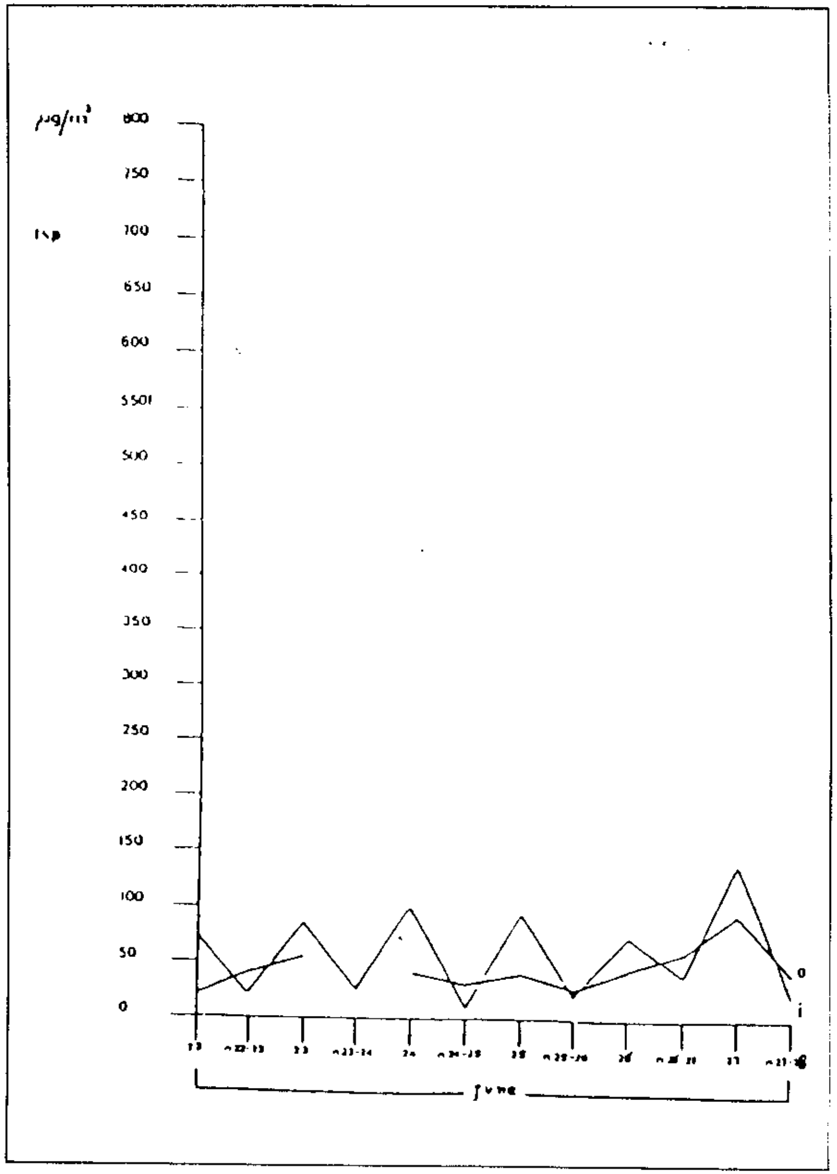


Fig. 10. Borghese Gallery, room XVI (i): TSP measured in summer, compared with TSP outdoors (o)

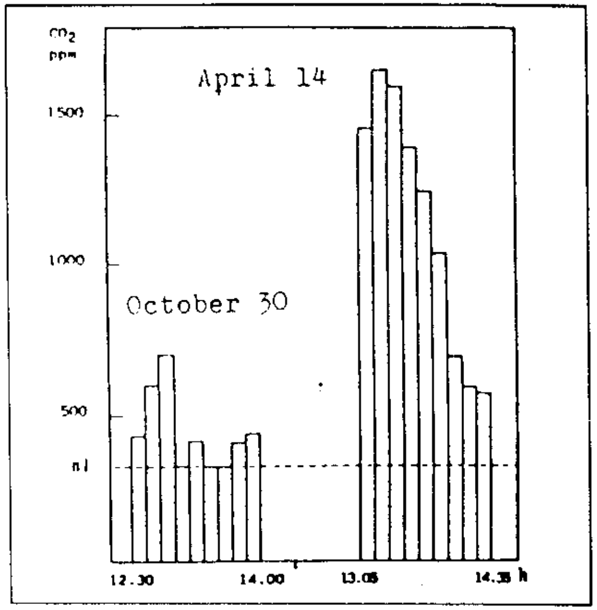


Fig. 11. Camera degli Sposi: CO_2 concentrations on two days of the year, compared with the "normal" level (n.l.).

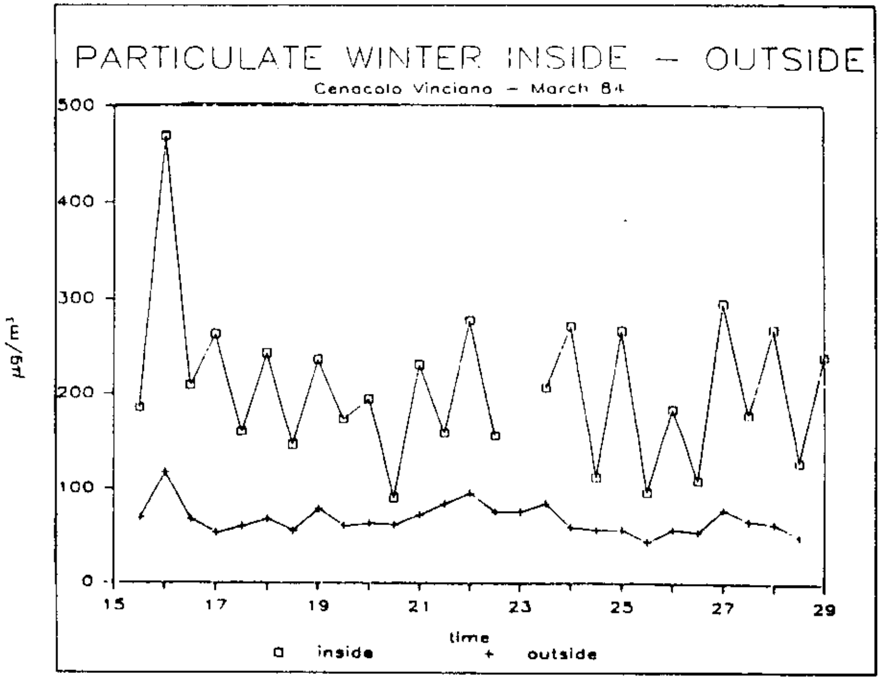
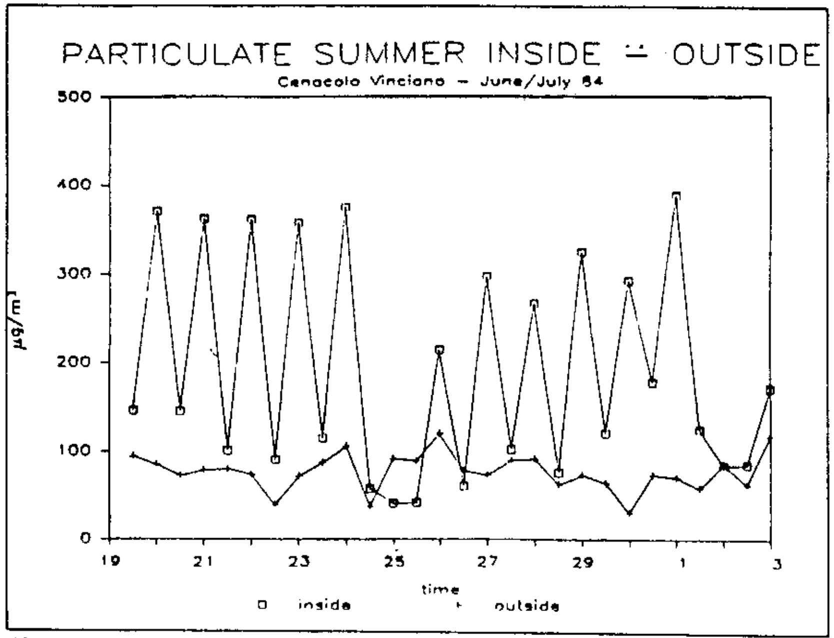


Fig. 12. Concentration of the particulate inside and outside the Sala del Cenacolo in winter.



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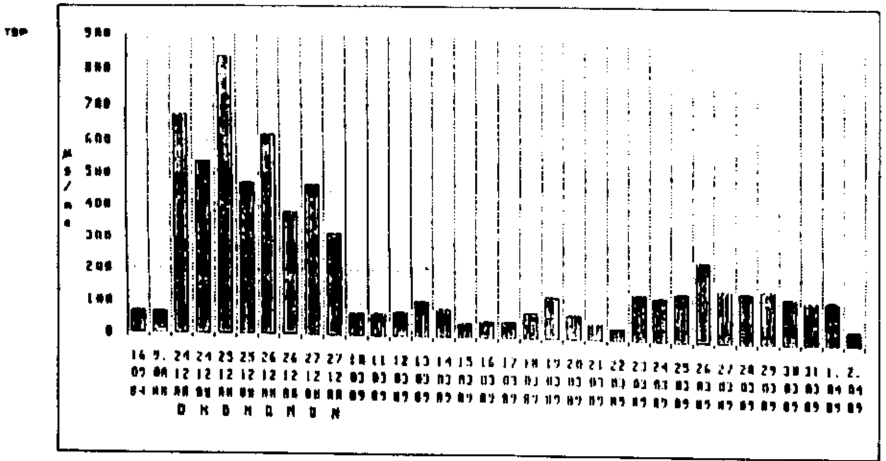

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Fig. 13. Concentration of the atmospheric particulate inside and outside the Sala del Cenacolo in summer

Fig. 14. Concentration of the TSP inside the church of S. Maria del Carmine during a winter-spring period

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Conservation of Works of Art

METODI DI CONTROLLO MICROBIOLOGICO DEGLI AFFRESCHI: L'ESEMPIO DEL RESTAURO DELLA CAPPELLA SISTINA

Riccardo Montacutelli
Gianfranco Tarsitani
Oriana Maggi
Nazzareno Gabrielli

Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V., Berlin
4. Internationale Konferenz Zerstörungsfreie Untersuchungen an Kunst- und Kulturgütern
4th International Conference on Non-Destructive Testing of Works of Art

A. Giovagnoli, M. Marabelli, Rom

St. Ciriaco Cathedral in Ancona: the air pollution campaign for the study of stone decay

Die Kathedrale St. Ciriaco in Ancona: Einfluß der Luftverschmutzung auf den Steinzerfall

ABSTRACT

The decay of stone sculptural elements and slabs of the façade and of the stone slabs of the interior of the Ancona Cathedral has required a survey of the main pollutants inside the monument (soluble salts of TSP and SO_2) for two seasons (summer and winter).
The study has been integrated by recording some microclimatic parameters outside and inside the church , measuring surface temperatures of some areas of the façade and determining the inside -outside air exchange rate.
As conclusion of the research, an hypothesis of the stone decay has been formulated.

INTRODUCTION

The aim of this research was to correlate the damage of stone elements of St. Ciriaco Cathedral in Ancona with the microclimatic trends and the air pollution agents inside and outside the monument.
St. Ciriaco (XII C.), placed on the top of an hill in front of the harbour and facing SW, is decorated with a protiro and two lions carved in "Rosso di Verona". The spiral columns of the protiro and the columns of the portal are carved in "Proconnesio"marble; walls are lined and covered with limestone slabs from "Conero" stone. All typical patterns of decay are clearly on view: darkening due to SPM capture, detachments of powdered and flaked Calcite, rain water drippings and yellow patinas. Inside the church diffuse forms of decay are detachment of stone (powdered and flaked) and accumulation of salt efflorescences, overall in correspondence with slab joint.

ANALYSIS OF ALTERATION FORMS

The results of XRD are summarised in the tables 1 and 2.
Outside the monument Gypsum is the normal form of alteration; the yellow patina contains a lot of amorphous material (probably an organic coating). Indoors efflorescences are constituted of Thenardite, while stone flakes and powder contain Halite; Gypsum is quite always present.

METHODOLOGY AND EQUIPMENTS FOR THE ENVIRONMENT CONTROLS

Two campaigns were carried out in summer and winter for two weeks, monitoring the following parameters:
1- T and RH in 9 sites indoors and in 3 sites outdoors. Measurements were carried out during the day with an electronic equipment; at the same time 5 thermohygrometers were operated for a continuous registration of T and RH (fig.1 , respectively sites 1 -12 and sites 13-17).
2 - Surface temperature of the protiro and of the portal columns (at maximum in 10 points), with an IR thermometer (fig.2).
3 - Solar radiation and radiation perpendicular to the church front.
4 -Rate of inside-outside air exchange using a gas tracer (SF_6); the gas was pumped inside the church in 9 sites and the corresponding concentrations were registered at fixed intervals.
5 - Concentration of sulphur dioxide and SPM indoors and outdoors,operating respectively an UV fluorescence analyser and a sequential sampler.

MICROCLIMATIC MEASUREMENTS

The surface temperatures of the church front are reported in figg. 3,4. In summer the maximum T was reached in the first afternoon, except the capital (fig. 1 point 7) of a column which was irradiated up to 6:30 h. p.m. The highest temperature registered was 38,5°C; some temporaneous inverted trend of T was due to the shadows of the architecture. During this season the heating of the front was mainly due to sun radiation (values not reported here).
On the contrary in winter (fig. 4) the heating of the surface was caused overall by thermal convection from the warmer air. In three days at the early morning T values under 0 °C were measured, corresponding also to condensation and fog events.
In summer the average range of outside temperatures was 23-30°C; the inside temperature fluctuations were very reduced, at maximum between 23,5 and 27,7°C. As it concerns RH the maximum values were between 50 and 90 percent outdoors and 60-80 percent indoors; in correspondence the minimum intervals were 30-60 percent and 40-70 percent.
In wintertime the outside daily T excursion was very reduced and the inside one too; it was always $T_{in}>T_{out}$ (about 4°C).

SULPHUR DIOXIDE AND SPM MONITORING

In summertime the half-hour values of SO_2 concentration monitored in the two sites were very low (the average value under 5 ppb) with a few ones above 7 ppb indoors and above 12 ppb outdoors. During wintertime the values inside the church were correspondent to zero line, due to the constant closure of the entrance door, while outdoors the same were between 1 and 6 ppb, with peaks reaching at maximum 52 ppb.
The SPM was sampled in two periods (8a.m.-8p.m./ 8p.m.-8a.m.).In summer outdoors it was day concentrations = ~ night concentrations, while inside the church night concentrations were>day concentrations (figg.5,6)
In winter outdoor concentrations were always>indoor concentrations (figg. 7,8).
The concentration range of max. frequency was 326-425 μg/mc inside and outside the church in summer, in winter the same was 26-125 μg/mc indoors and 326-425 μg/mc outdoors.

The very high values of SPM concentration outside in the two seasons and the decrease of SPM concentration inside the church during the winter closure suggest a very substantial contribution of marine aerosol in correspondence with the local NW prevalent wind.
In order to verify this hypothesis a comparison was made between concentration ratios of significant ions of sea water and the same ratios corresponding to the samples of SPM. The calculated values (not reported here) indicate a significant enrichment in NaCl and a secondary contribution of calcium and sulphate ions to the formation of the inside particellate.The same conclusion is valid for the outside samples. As it regards the winter season the same trend is confirmed nothwistanding some anomalous values.

INSIDE-OUTSIDE AIR DIFFUSION PROCESSES

With the aim of measuring the inside-outside air exchange rate a gas tracer (SF_6) was pumped into the church in 9 locations carrying out 34 concentration measurements in 24 h.
An homogeneous distribution was reached after 5 h., with closed doors.
The equation linking concentration and time is:

$$C_t = C_0(1-r)^t$$

and also

$$r = 1-(C_t / C_0)^{1/t}$$

where

C_t = tracer concentration (ppb) at time t (minutes)
C_0 = tracer concentration (ppb) at the beginning
r = exchange factor.
In this way it was calculated that nearly 6 h. elapsed before the concentration reached 50 percent of its initial steady-state level. Opening the door doubled air exchange rate.

CONCLUSIONS

The results of this research are:
- the identification of the deterioration products of stone materials inside and outside the monument
- the identification of inside and outside microclimatic trends
- the evaluation of the indoor- outdoor air exchange rate
- the evaluation of the internal and external concentrations of SPM and SO_2

Some conclusions can be drawn:
A relevant air exchange rate was calculated in particular cases; in fact the rate increased twice with open doors or with increased infiltration due to wind pressure. It means that a high flux of marine aerosol can penetrate inside the church and scavenge onto the stone slabs. An accumulation of marine SPM is also possible obviously on stone surfaces outdoors in sheltered exposure.
In summer SPM concentration inside St. Ciriaco reached a daily peak of 480 μg/mc and a value of 273 μg/mc during the night : some high nocturnal values with closed doors were caused by the cleaning of the church floor in the early morning
Very high values of SPM concentration are evident outdoors for the two seasons (up to a max. of 738 μg/mc).
By comparison of the ratios Cl^-/Na^-, SO_4^{-2}/Na^+, Cl^-/Ca^{+2}, Cl^-/SO_4^{-2} corresponding to sea water and to SPM, a conspicuous contribution of the

marine soluble salts to SPM formation is clearly evident.This explains also the formation of Halite and Thenardite on the inside surfaces.
Gypsum can derive from three different sources : as a reaction product of SO_2 with Calcite; as a component of SPM ; for solubilization and transport of Gypsum from cement, used for wall consolidation.
SO_2 concentration nowadays is very reduced, also if it has been very wasteful in the recent past.
The external surfaces present the typical patterns of the decayed calcareous stones: black crusts, rain erosions, rain drippings etc.
Diffuse decohesion (as powder or flakes) is present indoors and also outdoors in correspondence with surface crystallisation of soluble salts. The RH equilibrium values regulating the phase systems solid Halite-Halite saturated solution-water vapour and Mirabilite-Thenardite-water vapour are respectively 75,5% and 82%. These values are included in the variation range of RH inside St Ciriaco, so causing the cyclic dissolution and crystallisation of soluble salts and consequently a progressive stone decay.
At last it was possible to detect events of condensation and freeze-thaw cycles.
Starting from these experimental data a project for a better conservation of the monument has pointed out and illustrated to the Soprintendenza delle Marche in Ancona

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A very important help has been offered by Maria Pia Micheli, for having promoted the surveys.

TABLE 1 : Outdoor samples

Zone	N°	Sample	Calcite	Dolomite	Quartz	Gypsum	Halite	Thenardite	Feldspars	Amorphous mat.
Front portal / Left spiral column - Capital	[illegible]	Detached Calcite Flake	++		±	+				
Front portal / Left spiral column - Shaft	[illegible]	Disintegrated Calcite Black crust	++		±	±				
Façade / Left spiral column - Shaft	[illegible]	Disintegrated Calcite Black crust	++		±	+				
[illegible]	[illegible]	Detached Calcite Flake	+	++					±	+
[illegible]	[illegible]	Yellow material in black crust	++							
Slabs	[illegible]	Yellow material in black crust	++							+
Façade / Slabs on the right	[illegible]	Disintegrated Calcite Black crust	++							
Right side portal / Right pillar	[illegible]	Disintegrated Calcite Black crust	++			±				
Façade / Left pillar	[illegible]	[illegible]								

[illegible]

TABLE 2: Indoor samples

Zone	N°	Sample	Calcite	Dolomite	Quartz	Gypsum	Halite	Thenardite	Feldspars	Amorphous mat.
Counterfaçade / Slabs on the left		White efflorescence	++					++		
Left wing / Left central pillar - Shaft	[illegible]	Disintegrated Calcite Flakes	++			++		±		
Left wing / Left central pillar - Capital	[illegible]	White efflorescence	+			±		++		
Left wing / Apse outer [illegible]	[illegible]	Detached Calcite Powder and flakes	±		±		±			
Left wing / Left arch [illegible] Slabs	[illegible]	Disintegrated Calcite Flakes	±		±	±	±			
Left wing / Wall apse [illegible]	[illegible]	Detached Calcite Powder and flakes	±		±	±	±			
Left wing / Wall apse [illegible]	[illegible]	Detached Calcite Powder and flakes	±		±	±	±			
Left wing / Wall apse - Slabs	[illegible]	Disintegrated Calcite Black crust	±			±	±			
Left wing / Apse - Slabs	[illegible]	Disintegrated Calcite Powder	±		±		±			
Left wing / Apse - Slabs	[illegible]	Disintegrated Calcite Flakes	++		±					

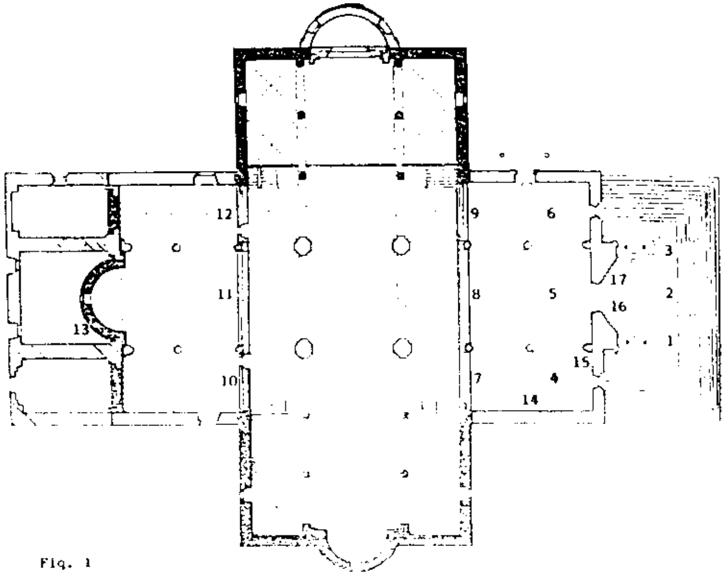
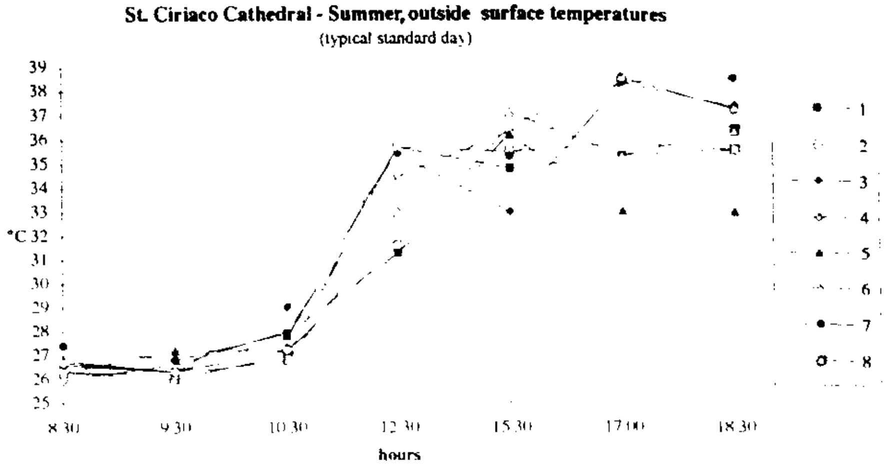


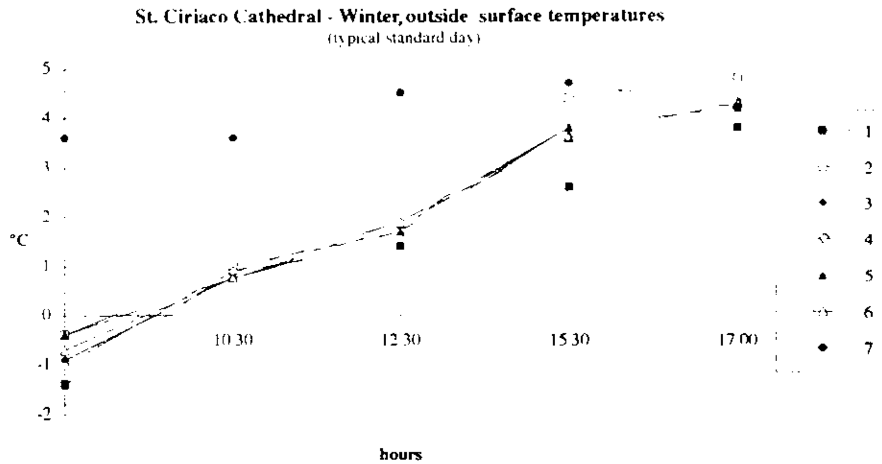
Fig. 1

 Fig. 2



1 = ext. left column, capital
2 = ext. left column, base
3 = ext. right column, capital
4 = ext. right column, base
5 = int. left column, capital
6 = int. left column, base
7 = int. right column, capital
8 = int. right column, base

Fig. 3



1 = roof
2 = top of the Protiro
3 = left column, capital
4 = left column, base
5 = right column, capital
6 = right column, base
7 = air temperature

Fig. 4

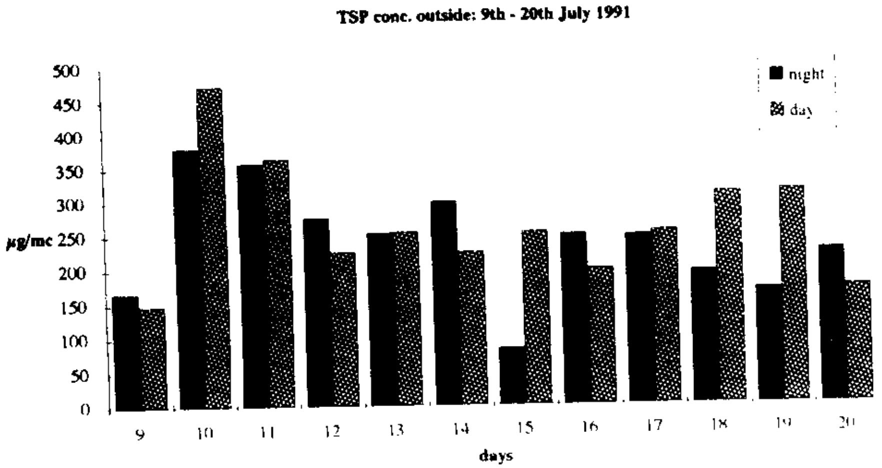


Fig. 5

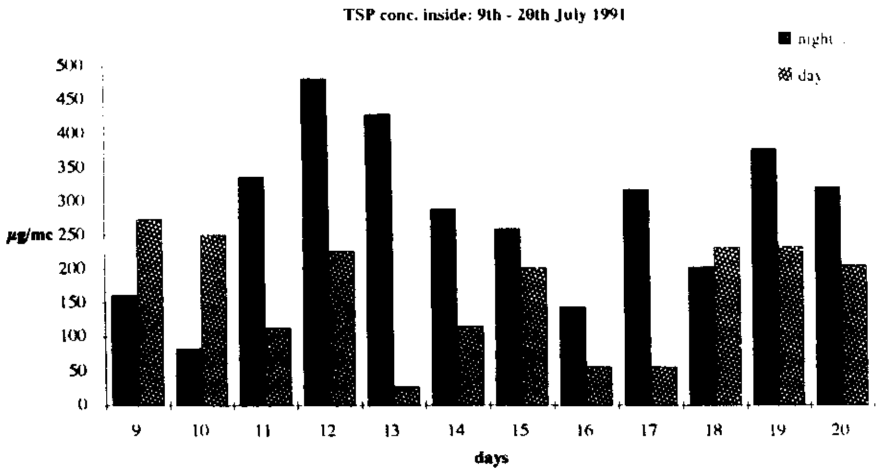


Fig. 6

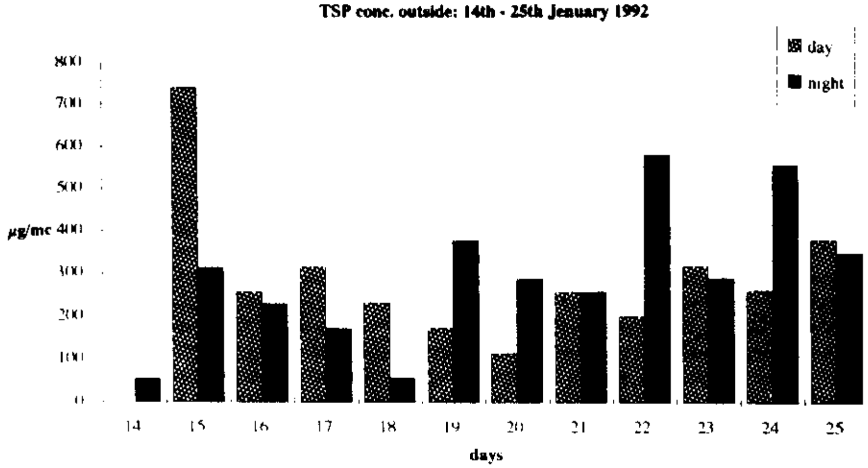


Fig. 7

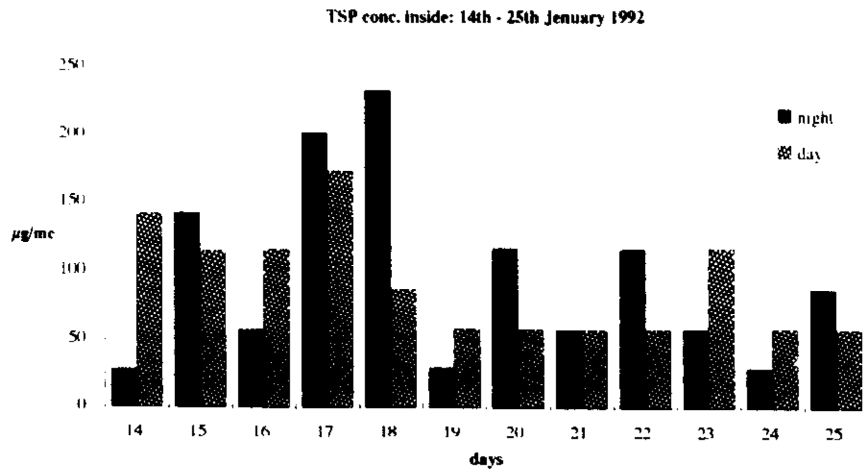


Fig. 8

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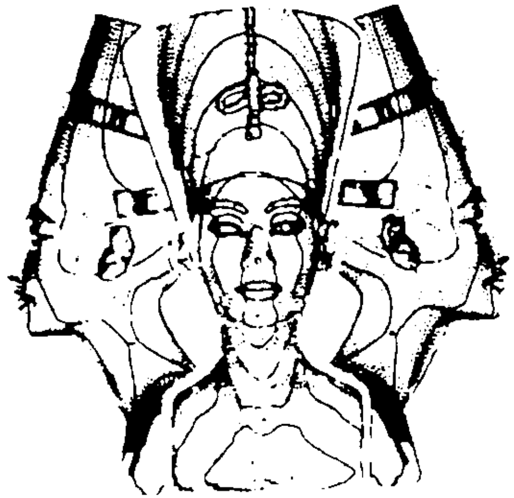
BAM	**SMB**	**AIPnD**	**ICR**
Bundesanstalt für Materialforschung und -prüfung	Staatliche Museen zu Berlin Preußischer Kulturbesitz	Associazone Italiana Prove non Distruttive Monitoraggio Diagnostica	Istituto Centrale per il Restauro



4th International Conference Non-Destructive Testing of Works of Art

4. Internationale Konferenz Zerstörungsfreie Untersuchungen an Kunst- und Kulturgütern

Berlin 3. - 8. Oktober 1994

Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V., Berlin
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4th International Conference on Non-Destructive Testing of Works of Art

S. Lorusso, Viterbo; M. Marabelli, Rom; M. Genova, Segrate-Milano

Conservation in museums: environment and energy ressources

Konservierung in den Museen: Umwelt und Energiequellen

1 INTRODUCTION

The conservation of historical, artistic and archaeological materials as well as books and archives in museums, libraries and storage areas is closely linked to the temperature and humidity in the rooms, the level of lighting and indoor biological and chemical pollution Relative humidity and temperature levels suitable for proper conservation can be determined on the basis of the nature of the material involved The average level of well-being determined experimentally in terms of temperature and humidity, though with exceptions for special cases, has been set at 50-60% relative humidity and a temperature of 18-20°C, also in relation to visitor comfort

Relative humidity affects the chemical, physical and mechanical properties of the material, as well as the likelihood of attack by microflora (fungi and bacteria) or insects of organic type material

The various phenomena of condensation on microporous surfaces should also be taken into consideration, special attention must therefore be paid to heating systems and the procedures by which air exchange takes place

The lighting factor is of particular importance inside museums, since the higher frequency radiations verging on the visible spectrum (i e ultraviolet) may lead to damage For example, in the case of cellulose or protein-based material (parchment), U V rays trigger the rupture of chemical bonds which may lead to significant colour change phenomena (often yellowing) or increased fragility Infrared rays are equally dangerous, since they may overheat and dry out porous materials Light also has a range of effects on the possibility of biological attack on museum materials High humidity (especially in storage areas for archeological artifacts) can lead to local microflora proliferation (cyanobacteria, microscopic algae, moss etc)

Lighting may inhibit the attack of some fungi and organisms (e g some stages of cellulose-eating insects); this means, for example, that it is advisable to provide daylight lighting levels for at least a few hours per day in book storage areas.

The significance of the role of external pollutants in the attack on materials depends on the amount and quality of outdoor pollution, the amount of exchange between the indoor and outdoor environment and the nature of the material on display and their state of conservation.

With regard to the use of new technologies in museums, the correct use of energy is of fundamental importance, since energy saving should also be implemented when safeguarding the work of art.

This research has two major goals
1. The first goal is to survey the museum complex selected for the study in order to optimise the sampling;
2. The second goal concerns the sampling campaigns and the analysis of data related to this museum

2. CHOICE OF THE MUSEUM

In the first stage of research, the museum environment considered to be in some way representative of the overall situation in Italy (artifacts consisting of various materials, conserved in an old building) was identified as the Villa Giulia National Museum in Rome

There were various reasons for this choice, based mainly on

a) The variety of the type and composition of the artifacts,
b) The large area of the museum,
c) The location of the museum in an urban area with heavy traffic,
d) The sixteenth century building adapted for use as a museum,
e) The large number and variety of energy-consuming installations

3. ENERGY ASPECTS

In order to quantify energy requested in a museum we must take into account the diversification of consumption throughout the day and throughout the year, and verify areas where demand is not always predictable because of the lack of planning in energy use. The dispersion of power due to old electrical systems may also be significant. In programmes for the updating and rationalising the systems, close attention must be paid to the particular nature and use of each room, and thus the need for the correct conservation of the works of art, together with the need to create a comfortable environment, suitable for the correct enjoyment and appreciation of the items on display. Table 1 shows the subdivision by category of power-consuming equipments in the Villa Giulia Museum.

The highest energy consumption of the museum complex is due to energy used for heating in the winter and for air conditioning in the summer, as well as for air conditioning in the offices

Table 1- Approximate electrical power (kw) of the Villa Giulia Museum complex, subdivided by sector

Sector	Summer Season	Winter Season
Lighting	22	30
Air conditioning	60	8
Heating		40
Photography Dept	30	30
Restoration Workshop	8	8
Cafe, WC, miscellaneous	30	30
Total	150	146
Total real consumption considering dispersion of electrical system	180	178

It should also be pointed out that air conditioning and heating of the different areas of the museum is not homogeneous and not provided by the same system. This means that there is a division of the production and distribution of energy with potentially higher losses. Taken as a whole, the equipments require a higher amount of energy than is actually supplied by the ENEL.

This occurs at seasonal peaks. Nevertheless, even under the most favourable conditions, the energy demand may verge on the maximum limits of the installations. A new heting system using methane gas has been completed. With this new installation, heating can be provided for some areas of the museum only. For example, this will allow the offices to be disconnected from the display areas, which could thus be heated during evening opening hours.

It should also be pointed out that some areas of the museum (e.g. the store-rooms) are not heated, and the microclimate is therefore directly related to outdoor climatic conditions.

With regard to lighting in the Villa Giulia Museum, various types of fl orescent, halogenous and incandescent lights are currently used in the display a :as, while incandescent bulbs and neon tubes are used in the offices and other rooms

4. MONITORING OF THE INDOOR AND OUTDOOR ENVIRONMENT

In the indoor areas the effects of air pollution are often considerable. The amounts of pollution are related directly to the outdoor situation, but also to indoor factors (combustion sources, tobacco smoke, emissions from materials, display cases and structures, human respiration and perspiration etc)

In this research, including the sampling and analysis of pollutants inside and outside the museum, the procedure consisted in a series of tests subdivided into two periods of 15 days each, corresponding to two seasonal situations, i e the summer and the autumn seasons. Tables 2 and 3 show the equipment used and the main measurements carried out

Table 2 - Monitoring the indoor and outdoor environment at the Villa Giulia Museum

a) Mobile Laboratory equipped for the automatic detection of

- SO_2
- NO
- NO_2
- H_2S
- O_3
- CO
- THC nm (total non-methane hydrocarbons)
- TSP (total suspended particulate)
- Meteorological parameters (temperature, solar radiation, wind direction and velocity, relative humidity, atmospheric pressure)

b) Indoor monitoring unit for:

- SO_2
- NO
- NO_2
- H_2S
- O_3
- CO
- THC nm
- TSP
- Microclimatic parameters (air temperature, radiating temperature, relative humidity, air velocity)

5. ENERGY AUDIT

The Villa Giulia complex uses fuel oil for the heating system, gas for services and heating, and electricity for lighting and mechanical equipments.

Energy consumption and the amounts corresponding to each category are shown in Table 4. The data refer to 1991 and are based on the utilities bills. The

Table 3 - Instruments used in environmental monitoring

Pollutants	Equipment employed
- SO_2	UV fluorescence
- H_2S	Oxidation and detection as for SO_2
- NO, NO_2	Chemiluminescence
- O_3	UV absorption
- CO	Infrared
- THC nm, CH_4	Flame ionization
- TSP	Weight (°)
Meteorological data (outdoors)	**Instruments**
- Temperature	Thermocouples
- Sunlight	Sun radiation meter
- Wind direction	Wind vane
- Wind velocity	Anemometer
- Relative humidity	Hygrometer
- Atmospheric pressure	Barometer
Microclimatic parameters (indoors)	**Instruments**
- Temperature	Dry bulb thermometer
- Radiating temperature	Globothermometer
- Relative humidity	Dry and wet bulb thermometer
- Air velocity	Hot wire anemometer

(°) Cellulose acetate filter (d = 47 mm, porosity 0 45 nm, aspiration flow = 1 m^3/h)

table shows that with regard to heating, fuel oil should be replaced by natural gas for obvious reasons of impact on the environment as well as a better management and control of consumption in the heating system.

With regard to electricity, the problem is more complex due to the following reasons:

- There are two types of electric power contracts supplied at different prices (one at 30 kw and one at 15 kw);
- In particular, the contract for the 15 kw power supply was replaced by a 60 kw power supply contract in August 1991;

- Despite this change, a penalty has always been charged for the customer electricity demand exceeding the contract amount;
- The existing electrical system, on the basis of current regulations, should be redesigned and rebuilt, since for demand exceeding 30 kw ENEL requires a transformer station complying with its specifications.

In the context of the optimisation of consumption and thus of energy savings, the contract with ENEL should be revised to provide for separate supplies at different hours in accordance with the requirements of the museum.

Table 4 - Consumption and energy costs in lire at the Villa Giulia Museum in 1991

Energy Source	Kcal	kWh	Monthly average	Total penalties	Total cost
- Fuel oil	278 3 x 10^6				40,850,000
- Methane gas	34 2 x 10^6				5,986,000
- Electricity 15 kW contract (Jan.-Jul '91)		49,310	418,000	3,000,000	12,274,120
60 kW contract (Aug -Dec '91)		108,240	520,000	2,500,000	25,262,000
30 kW contract (Jan -Dec '91)		94,950			16,004,000

The solutions to be adopted for a correct use of energy resources should take into account both energy and economic factors, as well as the possibility of practical implementation in the context of the building involved, which is an historical monument subjected to various types of constraints. Considering these factors, we can identify aspects common to all museum complexes
- The predictable and quantifiable peak periods of energy consumption,
- The need for unifying energy distribution,
- The increase in energy consumption over time due to various factors (the extension of display areas, lighting improvements, the extension of areas with heating and air conditioning)

There follows a set of proposals which could be considered at least as a partial solution of these problems

- Optimisation of consumption by the reduction of energy dispersion,

- Choice of different lighting devices according to the specific requirements,
- Use of timers and cells for some equipment;
- Installation of solar panels for small equipment or for preheating;
- Use of cogenerator heating installations producing both heat and electricity (solutions of this type, initially employed in large installations, industries, municipalities and hospitals are now also being used in small communities leading to considerable economy and energy savings);
- Setting up a CIB (Computer Integrated Building) system.

In particular, the use of integrated management systems leads to museums where system integration results in lower running costs, greater flexibility of the use of installations and a more effective microclimate management for the works of art

There are four categories of functions liable to integration

- Environment management
- Security and protection of the works of art
- Telecommunication systems
- Systems and instruments for providing information to users

From the energy point of view the use of a CIB system leads to a insignificant rise in energy consumption. For the Villa Giulia Museum, estimated power consumption is less than 5 kW, also taking into account the automation of the air conditioning system

6 ENVIRONMENT ASSESSMENT

Following experiments carried out on the indoor and outdoor environments of the Villa Giulia Museum complex, the following evaluations can be made

1) Pollution detected outside the museum shows typical urban patterns with pollutants directly related to vehicle emissions

2) Because of local characteristics there is no overall accumulation of pollutants in the area considered. Nevertheless, at certain times of the day there may be high amounts of pollutants originating from vehicles

3) In general, the parameters detected outside the Museum did not exceed the air quality standards during the two monitoring periods. Nevertheless, some episodes occurred in which ozone and carbon monoxide exceeded standard levels

4) A constant difference was observed between pollutants measured outdoors and indoors (outdoor pollutants exceeded indoor ones)

Experiments highlighted causes of diffusion from the outside to the inside which differed according to the time of day
- In the early morning, opening of doors and windows (close correspondence

between outdoor and indoor levels);
- During the day, closing of doors and windows (diffusion related to visitor flow);
- In the evening and on days when the museum was closed, slower diffusion and greater difference between indoor and outdoor levels.

5) With regard to different pollutants, changes in the indoor- outdoor ratio may occur also because of the effects of adsorption or reaction with materials in the display rooms.

a) In particular, there is a low indoor-outdoor correlation for CH_4 in autumn
b) With regard to H_2S, the low outdoor amounts are decreased indoors by a possible adsorption of materials in the Museum, thus making the indoor-outdoor ratio non-significant.
c) It should be pointed out that the good indoor-outdoor correlation of SO_2 in the autumn is not the same in the summer, due to disturbance which may be caused by the air conditioning.
d) With regard to NO_x, there is a good correlation in autumn and less so in the summer
e) With regard to TSP, in the summer the indoor values are almost constantly lower than the corresponding outdoor values, in the autumn, this is sometimes due to the rain.

6) The comparison between the TSP, SO_2, NO_2 and O_3 data recorded in the summer and autumn monitoring in the Villa Giulia Museum and the threshold levels suggested for museums and archives is shown in Tables 5-6. This comparison shows that the average amounts of SO_2 and particulate recorded are lower than the threshold levels for museums and archives, while average levels of NO_2 and O_3 are higher

Microclimatic monitoring shows a limited level of temperature variation over 24 hours, while relative humidity levels may fluctuate significantly. The temperature and humidity patterns obtained in a dynamic simulation model have a satisfactory correspondence to temperature and humidity recorded experimentally.

7. CONCLUSIONS

The following measures could be useful to improve air quality inside the museum:

a) To air the rooms at times which do not coincide with maximum pollution levels, especially NO_2 and O_3;
b) To control airtightness of the area before the entrance to the display rooms;
c) To provide an air conditioning system for the Museum with the chemical filtering of pollutants as gas and TSP. In some room it was ascertained that the lack of this filtering led to a dangerous accumulation of the pollutants.

The structure of the Villa Giulia Museum can ensure a good microclimate for

the artifacts stored there, on condition that.

a) Improvemements are made in the daily airing procedures in the Museum.
b) For the skylights, suitable double glass should be used in order to reduce significant daily temperature fluctuations due to direct sunlight, this should lead to a reduction in energy consumption of approximately 15%

Table 5 - Comparison between values detected in the summer season and maximum threshold levels for air quality in museums and archives

($\mu g/m^3$)	Min	Max	Average	Threshold Museums	Threshold Archives
SO_2	0 56	31 9	8 25	10	1 0
NO_2	2 65	116	43	10	4 7
O_3	7 7	141	31 9	2	25 5
Particulate	25	100	47	-	75

Table 6 - Comparison between values detected in the autumn season and maximum threshold levels for air quality in museums and archives

($\mu g/m^3$)	Min	Max	Average	Threshold Museums	Threshold Archives
SO_2	0 2	25 8	4 3	10	1 0
NO_2	14	196	54 7	10	4 7
O_3	2 9	19 3	4 9	2	25 5
Particulate	1	74	28	-	75

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Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V., Berlin
4. Internationale Konferenz Zerstörungsfreie Untersuchungen an Kunst- und Kulturgütern
4th International Conference on Non-Destructive Testing of Works of Art

J. Leißner, Würzburg

Kann eine Schutzverglasung zur Verminderung der korrosiven Belastung für bemalte Innenseiten von Bleiverglasungen des 19. Jahrhunderts eingesetzt werden?

Do protective glazings reduce environmental stresses at the front side of 19th century stained glass windows?

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1. Einleitung

Fortschreitende Schäden an bemalten historischen Glasfenstern sind schon seit langem zu einem drängenden denkmalpflegerischen Problem geworden. Sie erfordern die intensive Beschäftigung mit den Schadensvorgängen und Schadensursachen sowie, darauf aufbauend, die Erforschung und ständige Überprüfung der Konservierungsmethoden und ein frühzeitiges Erkennen von Schädigungspotentialen. Notwendige Voraussetzung dafür ist eine enge Zusammenarbeit zwischen Materialwissenschaftlern, Denkmalpflegern und Restauratoren. Bisher beschränkten sich Untersuchungen und Schutzmaßnahmen fast ausschließlich auf die Glasfenster des Mittelalters. Es ist deshalb um so mehr begrüßenswert, auch die Glasfenster des 19. Jahrhunderts mit einzubeziehen, deren Glassubstrate zwar ungleich weniger verwittern als mittelalterliche Scheiben, deren Probleme (vor allem Malschichtverluste etc.) dennoch einer fachgerechten Konservierung bedürfen.
Vor diesem Hintergrund ist diese Untersuchung an Buntverglasungen des 19. Jahrhunderts zur Abschätzung des Einflusses von Schutzverglasungen als ein wichtiger Schritt zu wissenschaftlich fundiertem Datenmaterial zu werten.
Mit der sogenannten Glassensormethode [1-3] können die korrosiven Belastungssituationen, wie sie an unterschiedlich geschützten/konservierten Originalscheiben auftreten, erfaßt und direkt miteinander verglichen werden. Die Glassensoren registrieren nicht nur die Temperatur- und Feuchtesitutation, sondern auch weitere Einflüsse wie Schadstoffe, Schmutzablagerungen, Mikroorganismen und besonders die komplexen synergetischen Effekte.

Deutsche Gesellschaft für
Zerstörungsfreie Prüfung e.V.

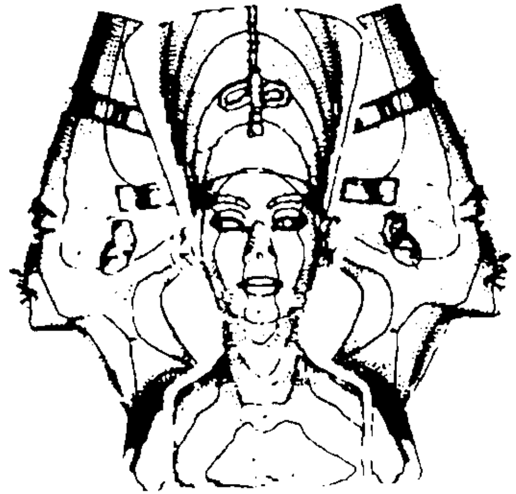
Berichtsband 45, Teil 1

BAM Bundesanstalt für Materialforschung und -prüfung

SMB Staatliche Museen zu Berlin Preußischer Kulturbesitz

AIPnD Associazone Italiana Prove non Distruttive Monitoraggio Diagnostica

ICR Istituto Centrale per il Restauro



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