



Indoor Air Quality in the Uffizi Gallery of Florence: sampling methodology and preliminary results

***Cristina Carletti, Gianfranco Cellai, Fabio Scieurpi, DIEF - University of Florence
Giuseppe Russo, Eike D. Schmidt, Uffizi Gallery – Florence, Italy***

Corresponding Author: F. Scieurpi, fabio.sciurpi@unifi.it



UNIVERSITÀ
DEGLI STUDI
FIRENZE

DIEF

Dipartimento di
Ingegneria Industriale



LE GALLERIE
DEGLI UFFIZI

INTRODUCTION & AIM OF THE PAPER

As Museums play an important role in society it is necessary to ensure and improve indoor air quality (IAQ) to preserve the artefacts provide well-being to visitors and staff.

It can be hard to manage the conflicts and to reach a compromise between IAQ, well-being, preventive conservation and energy efficiency, since conservation requires by definition a very stable climate with short fluctuations to reduce the process of exhibits degradation.

Most relevant pollutants inside museums are water vapour, carbon dioxide (CO₂), other inorganic pollutants, volatile organic compounds (VOCs) and biological agents.

Due to some complaints dealing with poor air quality conditions reported by the occupants, a preliminary survey in some rooms of the Uffizi Gallery in Florence was carried out.

To assess indoor temperature, relative humidity, chemical and microbiological pollutants in the museum, a methodology of investigation and evaluation of the results was defined and applied to several rooms of the Uffizi Gallery.

Results of the monitoring in the Room X containing Primavera of Sandro Botticelli are presented and discussed.

IAQ GUIDELINES

CO₂ concentration values

CO ₂ concentration	CO ₂ assessment
CO ₂ beneath 1800 mg/m ³ (1000 ppm)	Acceptable level, harmless
CO ₂ between 1800 mg/m ³ (1000 ppm) and 3600 mg/m ³ (2000 ppm)	High level
CO ₂ higher than 3600 mg/ m ³ (2000 ppm)	Unacceptable level

VOCs concentration values

VOCs concentration	VOCs assessment
< 0.200 mg/m ³	Comfort level
0.200 - 3 mg/m ³	Acceptable level
3 - 25 mg/m ³	Discomfort level
> 25 mg/m ³	Unacceptable level - toxicity

Recommended values in CFU/m³ of biological concentration

Biological pollution level	Bacterial pollution (CFU/m ³)	Mould pollution (CFU/m ³)
Very low	< 50	< 25
Low	< 100	< 100
Intermediate	< 500	< 500
High	< 2000	< 2000
Very High	> 2000	> 2000

Even if there are not specific laws for IAQ there are many technical standards, guidelines and studies that can be taken into account to establish a relationship between pollutant concentration, quality indicators and health effects or even discomfort conditions

MATERIALS AND METHODS

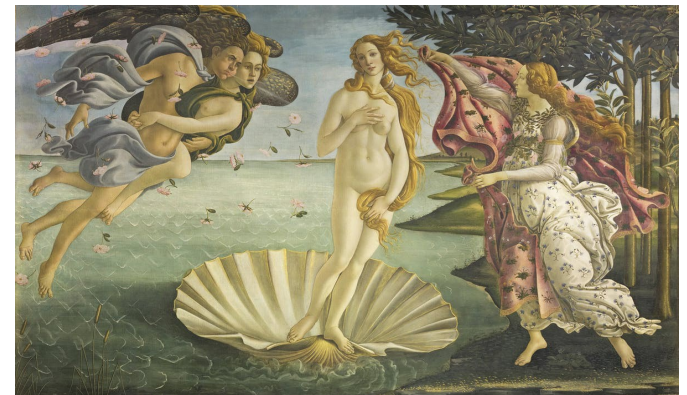
To carry on a general evaluation of the Uffizi Gallery a methodology was defined including site inspections and interviews with the technical staff (for rooms and HVAC system).

This methodology was applied on several rooms of the Uffizi Gallery, chosen according to the importance of the artworks exhibited, the number of visitors, the air conditioning system and the potential critical issues for artworks conservation and for occupants well-being related to indoor air quality:

- collection of general data
- monitoring strategies
- sampling of thermo - hygrometric parameters: air temperature, relative humidity, air velocity (measured in the room and in proximity with the air inlet/outlet grids), organic (VOCs) and inorganic pollutants (CO₂), bacteria aerosol (bacteria and moulds)
- collection of reference values for the sampled pollutants
- sampling analysis to determine chemical and microbiological pollutants
- comparison between the measured values and the recommended limit values
- critical analysis of pollutants and their correlation with possible pollution sources (HVAC system, maintenance procedures, cleaning procedures, etc.)

THE UFFIZI GALLERY

The Uffizi Gallery entirely occupies the first and second floors of the large building constructed between 1560 and 1580 and designed by Giorgio Vasari. It is famous worldwide for its outstanding collections of ancient sculptures and paintings (from the Middle Ages to the Modern period). The collections of paintings from the 14th-century and Renaissance period include some absolute masterpieces: Giotto, Simone Martini, Piero della Francesca, Beato Angelico, Filippo Lippi, Botticelli, Mantegna, Correggio, Leonardo, Raffaello, Michelangelo and Caravaggio, in addition to many precious works by European painters (mainly German, Dutch and Flemish). Moreover, the Gallery boasts an invaluable collection of ancient statues and busts from the Medici family, which adorns the corridors and consists of ancient Roman copies of lost Greek sculptures.



<https://www.uffizi.it/>

SAMPLING APPARATUS

In every analyzed room of the Gallery the instruments were positioned in an appropriate location with the aim of collecting representative data and, at the same time, limiting visitors interaction and ensuring the correct fruition of the room.

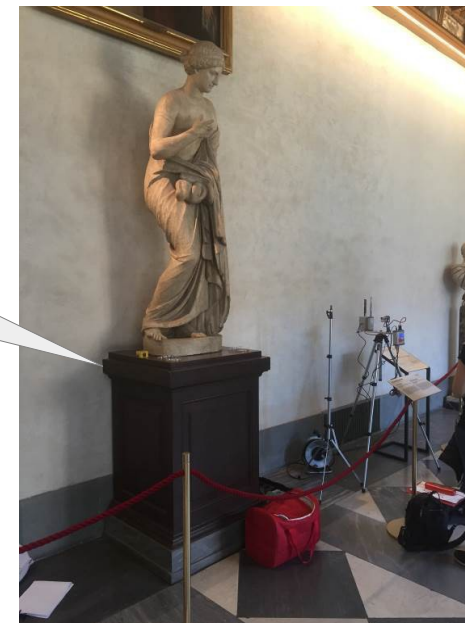
To sample environmental parameters a microclimatic station with datalogger, positioned to a high of 1.6 m from floor, was used; the data were collected every minute for 2 hours and the following parameters were measured: dry bulb temperature (t_{db}), wet bulb temperature (t_{wb}), relative humidity, air velocity and CO_2 concentration.



Microclimatic station for
 t_{db} t_{wb} v_a RH CO_2 conc.

Datalogger for
 t_{db} RH

VOCs active sampling of a 5 liters
air volume collected in nalophan bags



SAMPLING APPARATUS

The VOCs monitoring was carried on in close proximity to the microclimatic station with active sampling of a 5 litres air volume collected in nalophan bags, afterwards sent to an external laboratory to be analysed; quantitative and qualitative VOCs analysis was carried out according with Gas Chromatography-Mass Spectrometry (GC/MS) method (EPA TO-15-1999 method). For VOCs the cut-off value was settled at 1% of the air sample, as established by the CE Reg. 1272/2008.

Biological analysis (TBL and moulds) was carried on both with active and passive sampling methods. During active sampling air flow was collected with a surface air system impactor with a sampling rate of 100 l/minute positioned in close proximity to the microclimatic station, to a high of 1.60 m from floor. Sampling rate and consequently the total air volume (0.3 - 0.5 - 1m³) varied for different occupational pattern of the museum room. In order to collect information about biological pollution due to the passage of people and the air flows from the ventilation systems, the total biological pollution was also collected by passive sampling for 2 hours, using Petri dishes positioned near the microclimatic station ($\Phi=90\text{mm}$, Plate Count Agar for microbial growth and Sabouraud Dextrose Agar for mould growth). Both sample dishes (active and passive sampling) were sent to an external laboratory to be incubated at proper temperature-time range (three days at 30°C for TBL and five days at 25°C for moulds) and afterwards analysed to determine the CFU both for bacteria than for moulds according to ISS Report 13/37.

SAMPLING IN ROOM X



The Room X is located on the second floor of the museum, has a floor area of 146.34 m^2 , height of 8.93 m and a volume of 1306.82 m^3 .

The marvelous Primavera by Sandro Botticelli, a tempera painting on wood dated 1478 - 1482, is exposed in the room.

The room has only an external wall, without windows, facing east and is equipped with an HVAC system for the control of temperature and relative humidity, managed by a remote monitoring and control system.

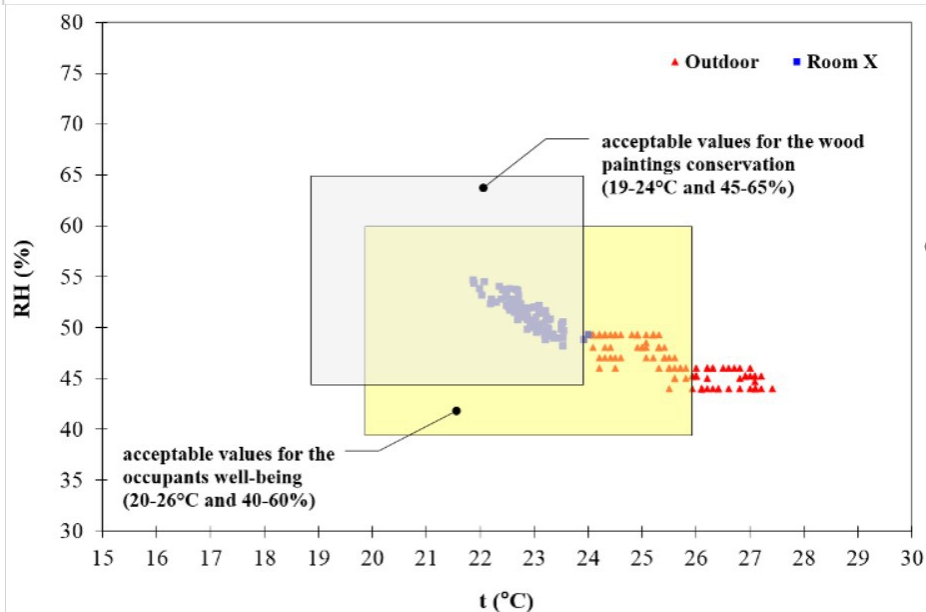
MAIN FEATURE OF PROBES	
PSYCHROMETER	
SENSOR	Pt100 (1/3DIN)
Accuracy	0.10°C (0°C); 0.13°C (20°C) 2% ($15 \div 40\%$); 1% ($40 \div 70\%$); 0.5% ($70 \div 98\%$)
Response time (T90)	90'' (operating fan)
Measure range	t_{db} : $25 \div 150^{\circ}\text{C}$; t_{wb} : $0 \div 60^{\circ}\text{C}$ RH: $0 \div 100\%$
ANEMOMETER	
SENSOR	Tungsten wire $\varnothing 9.45 \mu\text{m}$
Accuracy	0.05 m/s ($0 \div 0.5 \text{ m/s}$); 0.1 m/s ($0.5 \div 1.5 \text{ m/s}$) 4% ($>1.5 \text{ m/s}$)
Response time (T90)	0.1''
Measure range	$0 \div 20 \text{ m/s}$
CO ₂ PROBE	
SENSOR	Absorption infra-red cell
Accuracy	3% measure range
Response time (T90)	<30''
Measure range	$0 \div 3000 \text{ ppm}$

The AHU, housed in an attic room, allows the air treatment with centralized air recirculation, both for heating and cooling, and is equipped with air inlet and outlet fans with variable flow, with a nominal air flow of $8000 \text{ m}^3/\text{h}$ and a nominal air exchange rate of about 6.12 vol/h . The air inlet and outlet take place through linear grids placed under the top skylight.

SAMPLING RESULTS – ROOM X

Preliminary results of the monitoring carried out, as regards temperature, relative humidity, carbon dioxide, volatile organic compounds, total bacterial load and mould. As regards biological monitoring, the results expressed in CFU/m³ refer to active sampling, while those expressed in CFU/PT₉₀ to passive sampling of total bacterial load and mould

Monitored parameter	Minimum value	Maximum value	Average value
t (°C)	21.9	24	22.8
RH (%)	48	56	51
CO ₂ (ppm)	1312	1568	1442
Monitored parameter	Sampled value		
VOCs (mg/m ³)	0.354		
TBL (CFU/m ³)	180		
mould (CFU/m ³)	19		
TBL (CFU/PT ₉₀)	64		
mould (CFU/PT ₉₀)	3		



Values of temperature and relative humidity measured outdoor and in the Room X for the whole acquisition time compared with the acceptable values for the occupants well-being (yellow box) and for the conservation of wood paintings (gray box)

CONCLUSIONS AND FUTURE DEVELOPMENT

Data collected in the Room X of the Uffizi Gallery of Florence suggest a general agreement with the acceptable limit values, excepted for CO₂ that exceeded the recommended limit value of 1000 ppm.

For VOCs the substances with the greatest presence within the environment were the class of aldehydes, followed by that of alcohols.

As regards the microbiological parameters, the total bacterial load concentration is to be considered in the intermediate level pollution category, while the mould concentration is to be considered in the low pollution category.

The future development of the research involves a deepen analysis of the IAQ inside the Uffizi Gallery. As regards VOCs, an investigation should be carried out to underline the relationship between some specific pollutants and the pattern of use and maintenance of the museum, for example achieving cleaning, paints, varnishes, glues and disinfectants products composition to determine the presence of specific pollutant classes.

This information can be useful to determine specific VOCs Threshold Limit Value concentration both as Time Weighted Average (8 hours) for the staff and as Short-Term Exposure Limit (15 minutes) for the visitors. As for the biological pollution specific bacteria and moulds can be sampled in order to underline potentially dangerous pollutants both for occupants and the exposed objects. Moreover, an analysis of the hygienic maintenance of HVAC ductwork should be studied in deep.



Thank you for your attention

The Authors would like to acknowledge the museum staff for providing support and co-operation during the process of collecting data and the IDIS Laboratory Florence for the collaboration in the analyses of chemical and microbiological monitoring.