Science of the Total Environment 536 (2015) 557–567

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A multidisciplinary approach to the study of cultural heritage environments: Experience at the Palatina Library in Parma

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HIGHLIGHTS

- An integrated system including biological, particles, microclimate and CFD analysis was applied.
- The tracing and diffusion of particles inside the room were studied.
- A wide variability in biological and particle values was observed.
- Cultural and molecular methods were combined to evaluate microbial contamination.
- Simulation results were consistent with experimental data.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 4 June 2015
Received in revised form 16 July 2015
Accepted 22 July 2015
Available online 1 August 2015

Editor: D. Barcelo

Keywords:
Cultural heritage
Biological monitoring
Particle counting

ABSTRACT

The aim of this paper is to describe a multidisciplinary approach including biological and particle monitoring, and microclimate analysis associated with the application of the Computational Fluid Dynamic (CFD). This approach was applied at the Palatina historical library in Parma. Monitoring was performed both in July and in December, in the absence of visitors and operators. Air microbial monitoring was performed with active and passive methods. Airborne particles with a diameter of ≥0.3, ≥0.5, ≥1 and ≥5 μm/m^3, were counted by a laser particle counter. The surface contamination of shelves and manuscripts was assessed with nitrocellulose membranes. A spore trap sampler was used to identify both viable and non-viable fungal spores by optical microscope. Microbiological contaminants were analyzed through cultural and molecular biology techniques. Microclimatic parameters were also recorded. An infrared thermal camera provided information on the surface temperature of the different building materials, objects and components. Transient simulation models, for coupled heat and mass-moisture transfer, taking into account archivist and general public movements, combined with the related

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http://dx.doi.org/10.1016/j.scitotenv.2015.07.105

Microclimate
Computational fluid dynamics
Particle tracing

sensible and latent heat released into the environment, were carried out applying the CFD-FE (Finite Elements) method. Simulations of particle tracing were carried out.
A wide variability in environmental microbial contamination, both for air and surfaces, was observed. *Cladosporium* spp., *Alternaria* spp., *Aspergillus* spp., and *Penicillium* spp. were the most frequently found microfungi. Bacteria such as *Streptomyces* spp., *Bacillus* spp., *Sphingomonas* spp., and *Pseudoclavibacter* as well as unculturable colonies were characterized by molecular investigation. CFD simulation results obtained were consistent with the experimental data on microclimatic conditions. The tracing and distribution of particles showed the different slice planes of diffusion mostly influenced by the convective airflow.
This interdisciplinary research represents a contribution towards the definition of standardized methods for assessing the biological and microclimatic quality of indoor cultural heritage environments.

1. Introduction

Biological particles in indoor environments, such as museums, libraries and archives, can represent a hazard both for artifacts, due to their biodeteriogenic action, and the health of operators and visitors due to their potential infectious, allergenic and toxic effects (Mandrioli et al., 2003). Every building has its own microbial ecology equilibrium, which depends on its structure, the materials used for its construction and furnishings, and the people working and visiting the building itself. People represent one of the most important sources of microbial air contamination. Skin is a natural source of microorganisms, which are released into the environment through the continuous process of desquamation. Hair is also a significant potential source of microbial contamination. Microorganisms are also introduced into the environment when people talk, cough and sneeze. However, microorganisms can also come from animals and a variety of indoor and outdoor environmental sources, contaminated materials and objects, malfunctioning ventilation systems, any activity involving the modification or renovation of buildings, which inevitably generates dust and debris, increasing microbial contamination and that of fungal spores in particular. Depending on their size, particles settle on the ground and surfaces at different rates, contaminating any surface, for example graphic collections (prints, drawings, watercolors, books, codices, photographs, paper, etc.). Surfaces can also become contaminated through contact with other contaminated surfaces. The survival and development of microorganisms in the air and on surfaces will depend on microbial structural and metabolic characteristics and the presence of favorable conditions, such as nutritional and microclimatic conditions.

Biological risk, which is the probability that damage will occur, depends on the presence of biological hazards, and on the exposure and vulnerability of the materials and people (operators and visitors) involved. The first step in preventing such damage is a thorough knowledge of biological particles and all the factors that may affect their circulation, survival and growth in the environment, as a basis for any further preventive strategy. The monitoring of microbial contamination on the surface of heritage objects and in the air surrounding them, both from a quantitative and qualitative perspective, along with an evaluation of the microclimatic conditions, is essential for the study of environmental quality. Nowadays, the application of Computational Fluid Dynamics (CFD) allows a map of the global microclimatic conditions to be drawn, which is fundamental to the conservation of cultural heritage (Bakker, 2003; Tennekes and Lumley, 1972). Numerical models allow the prediction of damage-related processes in materials, and also knowledge of indoor air movement, air temperature and humidity distribution over time (Balocco et al., 2013).

As for the biological monitoring of air and surfaces, different methodologies and measuring techniques for biological monitoring have been adopted (Pasquarella et al., 2008), but a standardized and universally accepted methodology that can guarantee reliability, reproducibility and comparability of results is yet to be found. On the basis of experiences carried out in environments at high risk of contamination/infection (e.g. healthcare environments, food industries, spacecraft) (Guarnieri et al., 1997; Castiglia et al., 2008; Pasquarella et al., 2010, 2012a,b,c; Pitzurra et al., 2007); a working model for the evaluation of microbial air and surface contamination in cultural heritage environments has been defined (Pasquarella et al., 2011, 2012a,b,c). This model, completed with the evaluation of microclimatic parameters and CFD simulation, has been applied as a pilot study to the De Rossi Room at the Palatina Library in Parma.

To our knowledge, no study has yet adopted a multidisciplinary approach to investigate biological environmental pollution and related factors.

2. Materials and methods

2.1. Setting

The historical Palatina Library is located on the second floor of the Pilotta Building, which dates back to the late 16th century. The library was opened in 1761 and contains over 700,000 volumes. In particular, the De Rossi Room is one of the most important rooms in the Library, hosting the largest collection of Jewish manuscripts outside Israel and a number of incunabula, manuscripts from the 15th century.

The room is 6.90 m wide, 12 m long with a total volume of 496.8 m^3. It has two internal partition walls and two external walls. The smaller of these external walls, with an area of 48.28 m^2, has a central window with an area of 3.5 m^2 and is south-west oriented, and the wider external wall is 42.20 m^2 and south-east oriented. It has a cross-vaulted ceiling.

2.2. Monitoring program

Monitoring was performed during two periods of the year: July and December 2012. Air microbial sampling, particle sampling and microclimate analysis were performed at a height of 1 m (12 sampling points), 2 m (12 sampling points) and 4 m (2 sampling points) (Fig. 1). Book surfaces (spine and edge) and shelves were sampled in the two areas where the most valuable books are stored (Jewish manuscripts and incunabula). The library was closed to visitors and operators during the sampling period. Researchers performed the sampling wearing sterile protective clothing (cap, mask, gown, gloves and overshoes) (Fig. 2).

2.2.1. Biological environmental monitoring

2.2.1.1. Microbial air sampling. Microbial air sampling was carried out by active samplings, to measure the concentration of microorganisms in the air, and by passive sampling to measure the rate at which the microorganisms settle on surfaces (ISO, 14698-1; Pasquarella et al., 2008). For active samplings, a DUO SAS 360 sampler (International PBI, Milan, Italy) equipped with RODAC plates (55 mm diameter) was used. The flow rate was 180 liters per minute (L/min) and the suction volume was 200 liters (L). The sampler was placed in the monitored room at different heights above the floor and about one meter away from any physical obstacle. Results were adjusted according to the table provided by the manufacturer and were expressed as colony forming units (cfu)/cubic meter (m^3). For passive samplings, Petri dishes with a diameter of