# Monitoring of bio-aerosols, gaseous and Particulate Matter (PM) pollution of Wawel Royal Castle in Krakow, Poland.

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**Abstract**
Krakow is now firmly established as one of the Europe's top tourist destinations and, at the same time, it is one of the cities with the worst air quality in Europe. The Wawel Royal Castle is of the most important museum and predominating visited attraction of the city of Krakow (in 2017, the Castle was visited by over 1.4 million tourists).
Taking this into account, and in accordance with the guidelines of European Standards, the Wawel Royal Castle has been implemented the Integrated Pest Management (IPM) for protection of cultural heritage (CSN EN 16790:2016). As a part of the preventive conservation strategy, the monitoring of Indoor Air Pollution (IAP)has been carried out in addition to the standard control of climate parameters.Air samples were collected in rooms with various intensity of tourist traffic including: State Rooms, Royal Private Apartments, as well as warehouses and conservation workrooms.
The highest concentrations of PM, selected chemical compounds and microorganismsin the air were observedin the first halls at the entrance to Castle and in some conservation workshops.
**Keywords:** cultural heritage, particulate matter pollution, microbiological contamination, air pollution, preventive conservation

## 1. Introduction

Air pollutants (mostly traffic-related compounds and PM)have negative effect not only on human health (Bernstein et al., 2008) but also on preservation of historical, archivaland library collection.A significant role in the destruction of historical matter is played by oxidizing and acidiccompounds as ozone, $SO_2$, $NO_x$ acetic acid and formaldehyde (ISO11799:2003). Another important group of deterioration agents for Cultural Heritage objects are, indirectly, bioaerosols: bacteria and molds spores.Particularly, the growth of molds is dangerous for the preservation of historical material, due to their ability to rapid mycelium biomass formation, hypha penetrationas well as chemical activity of the mycelium resulting in e.g. color or strength changesof the infected object (Sterflinger, 2010; Sterflinger and Pinzari, 2012).

## 2. Methods

### *2.1. Sample collection*

Air samples were collected inexhibition rooms (twice in every month – with and without visitors) located on ground, first and second floor of the Museum, as well as in warehouses and conservation workrooms in months: (1) June, (2) August, (3) October, (4) Decemberand (5) March. In each of the sampling periods, the following three types of sampling were obtained: (1) measurements of selected gases concentration were determined based on Fourier Transformation (FT - IR) methodswith the use of GASMET DX-4030; (2) quantitative analysis of particulate matter concentrations in the airwere determined with the use of TSI DustTrak Monitor 8533 and (3) bacterial and fungal counts in the air were determinedwith the use of MAS-100 Eco® air sampler (Merck). Bioaerosols samples (3) were collected onto diverse agar plates (50 L). Bacteria and fungi were incubated for 48 h at 37°C and 168 h at 26°C, respectively. After the cultivation, the airborne microorganisms were counted and isolated molds colonies were identified based on microscopic observation of sporulating mycelium with the use of Nikon SMZ800 binocular and Nikon Eclipse E200 light microscope.

## 3. Results

### *3.1. Gaseous and PM Air Pollution*

Our results showed seasonal variations in the concentration of PM: higher levels during the heating period (autumn - winter) both outside and inside the Museum (independently of the analyzed PM fraction). The lowest PM concentrations were found in the warehouses -rooms with limited accessibility.The highest concentrations were observed on the ground floor, at the entrance to the Museum, in the first exhibition halls available to visitors (Fig. 1).

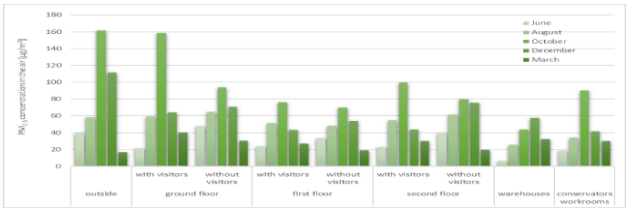


**Figure 1.** $PM_{2.5}$ concentrations in the air of the Museum rooms in diverse sampling period (the average value)

During the summer period (June-August) higherconcentration of nitric oxide, formaldehyde, carbonyl sulphide and octane, and during the heating period (October - December) higher concentrations of sulfur dioxide and acetic acid were observed (data not presented). Interestingly, relatively high concentrations of acetic acid and formaldehyde were found in some rooms of the Museum regardless of the concentrations observed outside (data not presented).

### *3.2. Concentrations of the airborne microorganisms and diversity of isolated molds*

The results demonstrated that the concentration of bacteria in the air in rooms at the entrance to the Museum (on the ground floor), were much higher than the concentration observed outside the building. Overall,in periods from August to March, in State Rooms(at the second floor), the most frequently visited exhibition on the Wawel Castle,the number of Bacteria was higherduring days with visitors comparing to days, were Museum was closed (Fig. 2) and inverse dependence was found for Fungi (Fig. 3).The lowest Bacteriaas well as Fungi concentrations, were observed in the warehouses. On the first floor, regardless of the presence of visitors, concentrationsof microorganisms were stable(Fig. 2-3).

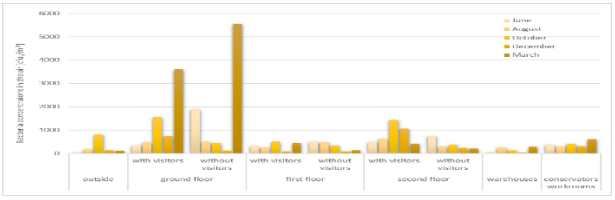


**Figure 2.** Number of bacterial colonies isolated from the air of Museum rooms (YEA agar plates)in each month

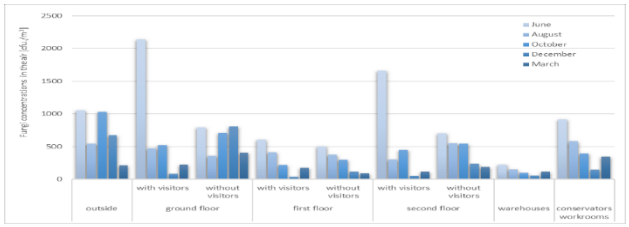


**Figure 3.** Number of molds colonies isolated from the air of Museum rooms (MEA agar plates) in each month.

Diversity of airborne Fungi showed that indoor and outdoor samples from all sampling periods were dominated by *Penicillium* and*Cladosporium*. Other generaidentified in samples with high frequency were: *Sporobolomyces*, *Alternaria* and*Aspergillus*.From the indoor samples 33 different genera of fungi were isolated.

## 4. Discussion

Our observations, that gaseous and PM pollution are infiltrated with outdoor airconfirm, that outdoor air pollution in Krakow (smog) is affecting indoor environmentsin the Wawel Royal Castle. There was no clear correlation between PM concentration and air microbial contamination levels in the Wawel Castle what was observed in other museums and libraries in Poland (Skóra et al., 2015).

The results demonstrated that in the WawelRoyal Castle andMuseum of King John's III Palace at Wilanow (both are residential museums) the dependence between bio-aerosols levels and the intensity of tourist trafficexisted (Laudy A., 2013). Interestingly, the impact on sanitary air conditions and diversity of isolated Fungi in Wawel Castle has also room predestination.

The dominant Fungi genera isolated from the air in Museum were also obtained forother museums and archival institutions in Poland (Skóra et al 2015), or in Slovak National Gallery (Pangallo et al., 2009). What is important, some *Penicillium* and *Aspergillus* species isolated from the air, have strong cellulolytic activities and could play an important role in the degradation of $CaCO_3$ in the indoor environment (Pangallo et al., 2009).

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