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Acute episodes of black carbon and aerosol contamination in a museum environment: Results of integrated real-time and off-line measurements

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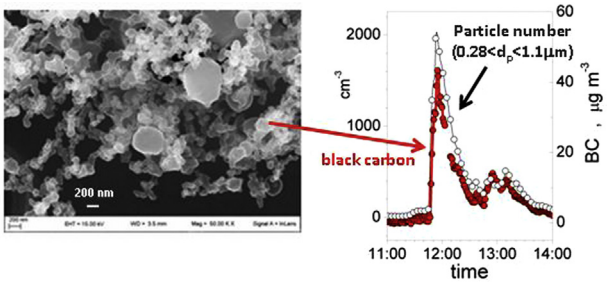
HIGHLIGHTS

- Air quality monitoring of a museum by integrated on-line and off-line techniques.
- Seasonal indoor versus outdoor comparisons.
- Indoor black carbon pollution episodes characterised at high temporal resolution.
- Black carbon and aerosol revealed specific size distributions.
- Identification of the indoor combustion source and measurement of the remediation.

GRAPHICAL ABSTRACT



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ABSTRACT

Aerosol size distributions together with black carbon and ozone concentrations have been recorded simultaneously at high temporal resolution (1 min) for three seasonal campaigns in a museum environment. The aerosol measurements were essential to individuate acute episodes of black carbon intrusions, generated every day at meal times from a wood-burning oven located in an adjacent restaurant. This case study provided the opportunity to further investigate and characterize in details the properties of the airborne particles generated by the combustion episodes. Specifically, real-time data have been discussed and integrated with off-line chemical analyses of aerosol samples including chromatographic and SEM-EDX techniques. All the events of elevated particles concentration evidenced the presence of fresh carbonaceous particles (chain-like aggregates and tar balls) with relatively large size (200–400 nm) typical of biomass combustion processes. These have been associated also with high levels of PAH and low carbon number n-alkanes. Finally, this study found that the operation of the wood oven, even if located in an adjacent building, elevated the particle number concentration and BC mass from 4 to 20 times higher than the background values inside the museum.

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1. Introduction

In the last decade indoor pollution has become a hot topic in aerosol science with an increasing number of papers dealing with the monitoring, the characterization and the evaluation of human exposure and health effects in the living and working environments (Morawska and Salthammer, 2003; Morawska et al., 2013). In museum environments the question of indoor contamination and pollution is even more important for the implications on both human health and artwork conservation.

Typically, museum environmental monitoring and control are based on conventional measurements of thermo-hygrometric values and on long-time averaged measurements of atmospheric pollutants' concentration (Grøntoft et al., 2010). Thermo-hygrometric parameters are used to provide a first indication of the museum air quality and of the impact of the outdoor environment on the indoor microclimate. For this reason they are usually recorded in museums to routinely check the efficiency of the air control systems (Camuffo et al., 2001). Previous surveys report measurements of thermo-hygrometric values integrated with the characterization of gaseous pollutants, microbiological contaminants and, with a less extent, particulate matter (Camuffo et al., 2001; Daher et al., 2011; Gysels et al., 2004; Krupinska et al., 2012; Schieweck et al., 2005). Particulate matter (PM) air pollution is an emerging concern for its variable extent of risk for cultural heritage. Coarse PM deposition has long been studied for soiling of surfaces exposed outdoor (De Bock et al., 1996; Nazaroff and Cass, 1991), while fine PM is mostly charged for chemical damage (Grau-Bové and Strlič, 2013). Black carbon (BC) and ozone are also very important. Black carbon, the light-absorbing component of aerosol, is an impure form of near-elemental carbon with a graphite-like structure mostly originated by anthropogenic combustion processes and internal combustion engines (Bond et al., 2013). Black carbon is typically associated with the fine (<1 μm) particle fraction, with distinct agglomeration morphology that can be readily recognized under the scanning (SEM) or transmission electron microscope. In the past, the attention on black carbon in cultural heritage was mostly addressed to the effects of soiling and darkening of outdoor surfaces (Ghedini et al., 2006); much less is known about indoor air pollution and surface reactions prompted by deposited BC particles (Grau-Bové and Strlič, 2013). Ozone is a strong oxidant and its reactivity has a direct impact on the degradation of organic artists' materials (Grosjean et al., 1994; Bonaduce et al., 2013). Ozone is originated outdoor and in controlled indoor environments, like museums, O_3 concentration generally exhibits dependence from outdoor–indoor exchanges and can be used to estimate the extent of outdoor atmospheric pollutants infiltration (Cavicchioli et al., 2013).

Indoor pollution inside museums is mostly due to the permeation and diffusion of pollutants inside the building (Lopez-Aparicio et al., 2011). Environmental monitoring activity inside museums is generally based on long-time averaged measurements from fixed instrumentations (Camuffo et al., 1999; Daher et al., 2011; Krupinska et al., 2012). This approach tends to underestimate the processes especially in the case of acute contamination episodes. The latters, for their great intensity, both in mass and in number, and sharp localization in space and time, require high time resolution and portable measurement devices (He et al., 2004).

In this work we report on the detailed characterization of the phenomenology producing a strong contamination condition in a relevant museum painting collection in Umbria (Central Italy). The study was organized in three consecutive seasonal monitoring campaigns based on real-time measurements by portable instrumentations integrated with off-line chemical analysis of PM and gaseous pollutants. The results revealed intense air pollution episodes that would have remained totally undetected without this study, with consequences on artwork conservation and human health.

2. Materials and methods

2.1. The sampling site

The "Galleria Nazionale dell'Umbria" extends over the second and the third floor of a XIIIth century building located in the historical centre (traffic-restricted area) of the medium sized town of Perugia (about 160.000 inhabitants) in central Italy. This historic part of the town is frequented by tourists and is served by many restaurants and pizzerias with wood-fired ovens. The museum has a medium visitor flow with the exception of occasional increases in coincidence with special events (concerts, conferences, temporary exhibitions, etc.).

The analytical campaign was focused on the third floor, containing mainly Italian paintings from the XIIIth–XVth centuries. The expositive area is organized in about twenty interconnected rooms over a circular route (Fig. SM1 in the Supplementary Material). The building is roughly north-south (N–S) oriented. The east side is almost linear and shows a long sequence of windows, while the west side is much more irregular. The museum entrance is in the E side and opens directly on the main staircase of the building which is also used as access way to several public offices located at the other floors.

Visitors exit through a new external closed staircase, protected by glass walls. In order to improve microclimatic conditions, the part of the historical building housing the museum has been restructured. The museum is provided with an air conditioning and filtering system based on a centralised HVAC (Heating, Ventilating, and Air Conditioning) unit which runs a set of AHUs (Air Handling Units) equipped with EU4 filters for microclimate control. Windows have screens to filter solar radiation.

2.2. On-line instrumentation and sampling strategy

The study consisted of three seasonal indoor sampling and measurement campaigns (1 week each) performed in July 2012, November 2012, and February 2013. These key periods have been chosen to compare two opposite situations, and the transition between them: summer, when the solar forcing is higher and air conditioning system works at maximum power, and winter, when the heating system is on.

Measurements and samplings were concentrated in two rooms (Rooms 11 and 21) with peculiar location in respect to the main entrance and distinct typology of the exposed objects and furnishing. Namely, Room 11 (R11 in the following) contains one of the most important paintings of the collection (the "*Polittico di S. Antonio*" by *Piero della Francesca*) and lies in the inner part of the exhibition area (south-east side). Conversely, Room 21 (hereafter R21) is in the north-west side and opens on the main hall of the entrance. The room is also known as the "*Cappella dei Priori*" and was the boardroom of the town in 15th century. It is decorated with a fresco painting cycle by *Benedetto Bonfigli* and is furnished with a wooden stall; the ceramic tiles of the floor are protected from visitors by a carpet.

On-line instruments have been used for data acquisition both in a fixed and a mobile mode of operation in order to investigate possible differences in the environmental parameters through the museum and in particular in R11 and R21. Specifically, a fixed monitoring station was placed in R11. It was equipped with an Optical Particle Counter (OPC; FAI Instruments) and a meteorological station (HOBO U12 T/RH Data Logger). The OPC has 22