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Inhalt

Study on the indoor air quality in six museums in Berlin, Tehran and Mumbai

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Abstract

Gaseous air pollution, particular matter and the corrosion potential in various locations at six museums in European and Asian cities were studied. The results from the museums in Berlin, Tehran and Mumbai showed that the differences in the individual air quality parameters depend on the outside climate and pollution levels influenced by the geographic region of the museums as well as on the pollutions generated in the vicinity by traffic, but also by technical facilities in the museum with respect to its air exchange, air exchange rates of the showcases, their construction materials and the number of visitors.

In Tehran museums most pollutants originated from outdoor fossil fuels and road-blown wind dust leading to the highest values in NO_2 and SO_2. In the Berlin and Mumbai museums visitors, construction materials of showcases and building materials are the most important sources of pollutants. Low air exchange rate in combination with internal pollutant sources caused high concentrations of the pollutants in the showcases in the museums in Berlin. In the Tehran museums the limited use of wood-based products, semi-airtight display cases and unsealed building envelops resulted in a comparable low accumulation of indoor pollutants. The corrosion potential, a parameter influenced by the pollutant levels, temperature and relative humidity, is comparably high in the museums in Mumbai and Berlin, whereas it is low in the museums in Tehran despite the presence of highly aggressive outdoor pollutants (NO_2 and SO_2) due to the low relative humidity in the museums because of the dry outdoor climate in that geographic region.

1 Introduction

The air pollutants such as indoor and outdoor gases and particulate matter in 23 locations at six museums (Table 1) in different climate zones in the European and Asian cities: Berlin (moderate seasonal climate), Tehran (warm and semidry) and Mumbai (warm and humid) were studied.

Two museums from the Staatliche Museen zu Berlin (National Museums in Berlin) of the Stiftung Preußischer Kulturbesitz (Prussian Cultural Heritage Foundation) in Berlin are the Pergamonmuseum (Pergamon Museum) and the Bode–Museum (Bode Museum) which both are located on the Museum Island in the city center in a historical urban setting. The south-west facades of the museums are adjacent to the street where tourist buses use to stop. For the period of this study there have been construction activities at the south–east of the Pergamonmuseum. There are also railway tracks in direct vicinity to the museums. Additionally, especially over summer ships powered by diesel engines take the tourists around along the river passing by the museum on the River Spree. In the locations studied in the Bode-Museum objects of the Skulpturensammlung und Museum für Byzantinische Kunst (Sculpture Collection and Museum of Byzantine Art) are on display, in the following abbreviated by BM. Location in the Pergamonmuseum occupied by the Vorderasiatisches Museum (Museum of the Ancient Near East) are abbreviated VAM and location of the Museum für Islamische Kunst, MIK (Museum of Islamic Art).

The museums in Tehran are located at two different locations in the city centre (Region 15) and North (Region 3). The Malek National Library and Museum (MNM) is located in a historical area (adjacent to the National Museum of Iran) and close to the main street. The very large market place (Bazar) is located in the Region 15. Hence this region attracts visitors and experiences heavy traffic. Bus, taxi terminals and small industries in the vicinity of this area are the main pollution sources in this region. The Reza Abbasi Museum (RAM) is likewise located in a commercial area surrounded by several very crowded streets and highways (Region 3). A main transportation terminal is close to the RAM. The specific geography of Region 3, being close to the mountains in the north of Tehran provokes the accumulation of the pollutants in this region.

The Chhatrapati Shivaji Maharaj Vastu Sangrahalaya Museum (CSMVS) is located at the Colaba region in Mumbai. It is located on a north-south stretched peninsula between the Arabian Sea /Back Bay and the Thane Creek /Mumbai Harbor. To the north of the Museum are residential areas. The southern side is occupied by a military camp, and the Navy Nagar. This area is characterized by touristic attractions. No industrial activities are located in this area but the dock area with its cargo activities contribute to air pollutions. The museum is surrounded by a green area that shelters it from the main street.

In order to evaluate the corrosion potential of the indoor air in these museums, micro climate factors in-

Table 1: The studied locations in the museums

City / museum / collection	Gallery room	Environment	Code
Berlin / Byzantine Art and Sculpture Museum / Bode Museum	Italy – Gothic	gallery	BM-R108
	Italy – Renaissance, Barroque	gallery	BM-R124
	Italy – works in Terracotta	display case	BM-R131-V
	Italy – Small Bronzes	display case	BM-R240-V
	Germany and the Netherlands – Baroque	gallery	BM-R252
Berlin / Museum of the Ancient Near East / Pergamon Museum	Archaeological finds from Assyria	gallery	VAM-R10
	Archaeological finds from Assyria	display case	VAM-R10-V
	Ishtar Gate of Babylon	gallery	VAM-R9
Berlin / Museum of Islamic Art / Pergamon Museum	Entrance hall-Introduction	display case	MIK-R1-V
	Aleppo Room – outside	gallery	MIK-R15
	Aleppo Room – inside	display case	MIK-R16-V
Tehran / Malek National Library and Museum	Coins room	gallery	MNM-R1
	Lady Ezzat Malek collection	gallery	MNM-R2
	Lady Ezzat Malek collection	display case	MNM-R2-V
Tehran / Reza Abbasi Museum	Islamic Gallery part 2	display case	RAM-R1-V
	Painting hall	gallery	RAM-R2
	Storage place – metal, painting, textile and wood	gallery	RAM-R3
Mumbai / Chhatrapati Shivaji Maharaj Vastu Sangrahalaya	Miniature Painting Gallery	gallery	CSMVS-G4
	Miniature Painting Gallery	display case	CSMVS-G4-V
	Coins Gallery	display case	CSMVS-G7-V
	Karl and Khandalavala Gallery	gallery	CSMVS-G8
	Karl and Khandalavala Gallery	display case	CSMVS-G8-V2
	Storage of textile and miniature	storage room	CSMVS-S10

cluding temperature and relative humidity, indoor and outdoor pollutants (NO_2, SO_2, O_3, acetic acid, formic acid and formaldehyde) as well as particulate matter were analysed.

2 Materials and methods

In total, 23 locations were studied, as indicated in Table 1

2.1 Measurments of temperature and relative humidity

In this project two kinds of data logger were available to measure the temperature and relative humidity over one year, apart from CSMVS in Mumbai that they were measured over 3 months. The dataloggers used were: testostor 171, The VOLTCRAFT DL-121TH USB and Lascar EL-USB-2-LCD.

2.2 Sampling of the gaseous pollutants

The microclimate in the museums, apart from the CSMVS museum in Mumbai, was gathered over a one year (Feb. 2013 – Feb. 2014) period at intervals of 15 min. The measurements at the CSMVS museum were performed over a three-month period between winter and summer (February – May 2014) at intervals of 15 min as well.

The gaseous pollutants and particulate matter were measured twice in summer 2013 and winter 2013/14. These measurements were carried out once in winter 2014 in the CSMVS.

Sampling was performed by means of passive methods i.e. Palmes diffusion tubes for gaseous pollutants. Palmes passive sampler tubes (Palmes et al. 1976) were constructed with 71×10 mm diameter acrylic tubes fitted with airtight end-caps. Details can be found in Hadian, 2015. For each sampling campaign the tubes were exposed for 28 days. The absorbents, filters and preparation procedure were as below briefly:

Sulfur dioxide SO_2: The trapping solution was prepared by dissolving 5.60 g KOH in 50.00 mL methanol and mixed with 10.00 mL glycerol. The solution was made up to 100 mL with methanol (Salem et al. 2009). The required number of stainless steel discs (two per tube) was placed using tweezers or forceps into closed end-caps and 50 µL of trapping solution were added with a pipette into each cap. The caps with discs were left in the fume hood for two hours to dry.

Nitrogen dioxide NO_2: The required number of stainless steel discs (two per tube) were dipped in fresh 50% v/v triethanolamine (TEA)/acetone solution for few minutes. The discs then were removed using tweezers and placed on absorbent surface (filter paper) to allow the acetone to evaporate and thus to leave a fine coating of TEA (Targa & Loader 2008, Ashenden & Bell 1991).

Acetic and formic acid: The trapping solution, filter and preparation procedure were the same as for SO_2 (as

mentioned above) and according to established method by Gibson et al., 1997

Formaldehyde: The trapping solution was prepared by dissolving 300 mg twice recrystallized 2,4-dinitrophenylhydrazine (DNPH) into 10.5 mL of acetonitrile and mixing with 0.5 mL of concentrated phosphoric acid (Gibson & Brokerhof 2001, Grzywacz 2006). The filter paper disk (one for each tube) was placed using tweezers into the yellow end-caps and 60 µL of trapping solution were added with a pipette into each yellow cap. The caps with discs were left in the fume hood for two hours to dry.

2.3 Analysis of the gaseous pollutants

The collected pollutants were deliberated for analysis using the following solutions:

SO_2: Each closed end-cap was rinsed with 5 mL eluent (2 mmol/L phthalic acid mixed with 10% acetone in water) into a beaker and left in the ultrasonic bath for 10 minutes. The solution was filtered into a 5 mL flask using a 13 mm Ion Chromatography syringe by Acrodisc with a filter of 0.2 µm pore-size Supor membrane.

NO_2: The tubes were extracted by adding 3.0 mL of pre-mixed reagent solutions (1:1) including the colour reagent (sulphanilamide and orthophosphoric acid) and N-(1-naphthyl) ethylenediamine dihydrochloride (NEDD) (Targa & Loader 2008).

Acetic and formic acid: The same procedure as for SO_2. The eluent was 0.5 mmol/L H_2SO_4.

Formaldehyde: Each filter was rinsed with 2 mL of acetonitrile added with a pipette to wash the sample from the filter and was left in an ultrasonic bath for 1 minute. The solution was filtered into the 5 mL flask using a 13 mm LC Minispike syringe by Acrodisc with a filter of 0.2 µm pore-size PTFE membrane (Grzywacz 2006).

The concentration of NO_2 was measured by UV/Vis spectrophotometry (PYE UNICAM SP6-550 at 542 nm). Ion Chromatography (Metrohm 690) was used to measure SO_2, acetic and formic acid. The concentrations of acetic and formic acid were analysed through a column ofpoly styrene/divinyl benzene (PS-DVB) copolymer with sulfonic acid groups (PRP-X300, 250×4.0 mm), whereas SO_2 with a column of polystyrene/divinyl benzene copolymer with quarternary ammonium groups (PRP-X100, 125×4.0 mm). The analysis of the concentration of formaldehyde was carried out by HPLC (Merck Hitachi L-4500, Diode Array Detector and L-6200A intelligent Pump with column Eurosphere 100-5 C18, 150×4.0 mm).

2.4 Sampling of particulate matter

Passive sampling was carried out by the dust-fall method, i.e. sedimentation of the particles from air to a horizontal surface (Morawska & Salthammer 2003). Microscope glass slides with an area of 19 cm^2 were exposed for 7 days to the environment to collect sample material (Ford & Adams 1999, Troi et al. 2011).

2.5 Analysis of particulate matter

The glass slides were photographed under a microscope (50×). The grain size distribution of particulate matter was carried out through image analysis by Image-Pro Plus 5.1.2. The portable ArtTAX Pro spectrometer (Bruker) with analyses spot area about 0.1 mm (100 µm) was used to identify the elements in the dust samples. The qualification of the particles was carried out via ATR-FTIR spectroscopy in the region 4000 – 570 cm^{-1} (Perkin Elmer Spectrum 100 attached to a microscope, resolution 4 cm^{-1}) and Raman microspectroscopy (Horiba XploRA Raman-Microscope, equipped with 532 nm, 638 nm and a 785 nm lasers).

2.6 Analysis of corrosivity of the atmosphere

The concentration of ozone O_3 was estimated through latex strips (cis-poly isoprene) as dosimeter (Ryhl-Svendsen 2009). The ozone dosimeters were calibrated using accelerated aging und UV radiation and/or elevated ozone concentration (Hadian 2105).

2.6.1 Metal coupons

The corrosion potential was assessed by metal coupons (lead, silver and copper foils in 10×10 mm). They were placed at the studied locations over one year and then analysed by different methods. ESEM/EDX analysis was performed at 20 kV using a Quanta 200 ESEM (Fei) equipped with a backscattered electron detector and energy dispersive X-ray analyzer XFlash 4010 (Bruker) to identify corrosion products of metal coupons. Horiba XploRa Raman-Microscope, equipped with a 532 nm, 638 nm and a 785 nm laser was utilized to identify the corrosion products of metal coupons as well.

2.6.2 Glasslides dosimeter

Glass slide dosimeters (GSD) provided by Fraunhofer Institute for Silicate Research (ISC) (Maas-Diegeler 2013) were the second method to assess the corrosion potential in the open (the galleies) and close (showcases). These slides were placed at the museums over 3 months.

3 Results and discussion

3.1 Temperature and relative humidity

The results show that the highest values of relative humidity (57 – 72%) were measured in CSMVS and the lowest (17 – 34%) in the museums in Tehran. With the exception of the Bode Museum where the relative humidity was found fairly constant (45 – 49%), the other museums showed significant differences (average up to +/– 20%) in different seasons (Fig. 1). The average temperature in most of the locations of Berlin and Tehran Museums was between 20 – 25 °C but the temperature in the exhibition halls of Pergamonmuseum (VAM), MNM and RAM exceeded 25 °C during the warm seasons (spring and summer). The highest average temperature of all the museums (29 – 30 °C) was found at the Indian Miniature and Coin galleries in CSMVS.

The results of temperature and relative humidity show that the Bode-Museum with climate control system and low air exchange rate has the least fluctuations, Malek National Museum, despite air condition, has high fluctuations in temperature and relative humidity. Since this museum is poorly sealed, the micro climate is strongly influenced by the outdoor climate. The Pergamonmuseum

with most visitors and natural ventilation (no climate control) has also high fluctuations in temperature and relative humidity.

The temperature and humidity measurements in the display cases show similar tendencies. The airtight display cases (AER < 1 n day^{-1}) in the Bode Museum have relative constant microclimate as it can accepted in a gallery climate with few fluctuations. In the other showcases in Berlin, Tehran and Mumbai museums with relatively high air exchange rate (semi airtight AER = 1 – 10 n day^{-1}) and leaky (AER = > 10 n day^{-1}) the microclimate is influenced by the fluctuations in the outside environment.

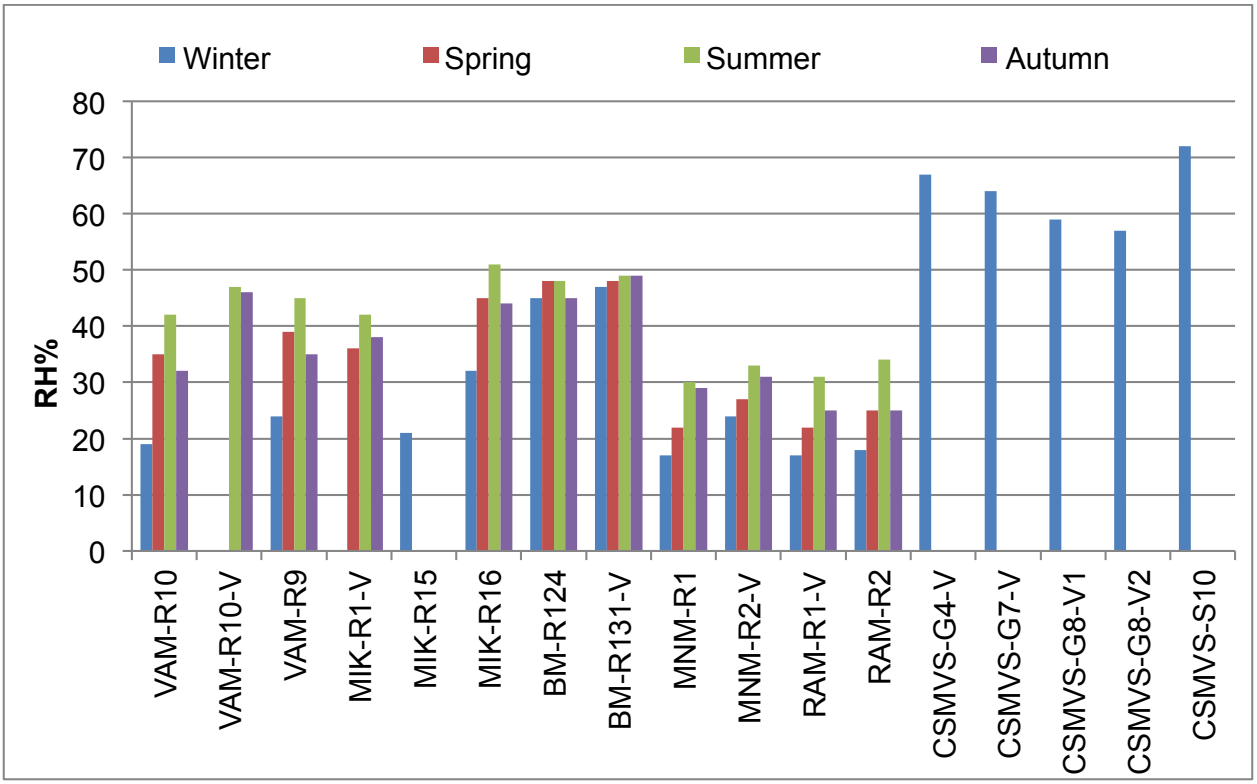

Figure 1: relative humidity in the museums (location codes refer to table 1)

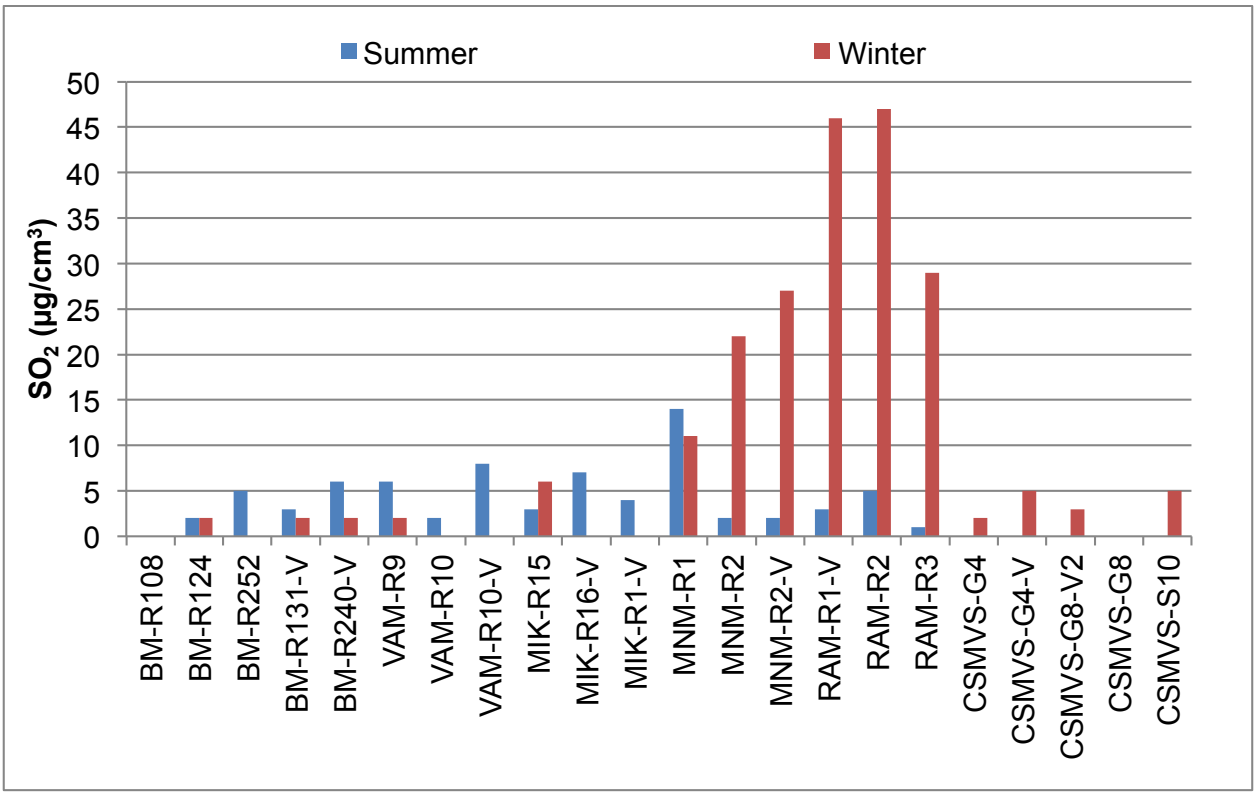

Figure 2: SO_2 concentrations in the museums (location codes refer to table 1)

3.2 Gaseous pollutants

The maximum values for the gaseous pollutants in the museums indicate the highest concentrations of NO_2 and SO_2 for the museums in Tehran, with about 60 and 75 µg/m^3 of NO_3 and 25 and 40 µg/m^3 SO_2 for NMN and RAM respectively. Compared to these values the concentrations in the Berlin museums were one third to one half of that for the NO_2 pollutant and less than 20% of that for the SO_2. The SO_2 concentration measured in CSMVS was similar to the result obtained in Berlin, but the concentration of NO_2 (40 µg/m^3) was almost as high as in Tehran museums (Fig. 2 and 3).

The maximum O_3 concentrations estimated for all museums were between 18 and 38 µg/m^3. The highest O_3 concentration was measured in CSMVS (38 µg/m³). The presence of O_3 could also be measured in the leaky showcases (2 µg/m³). The results from Aleppo room at MIK show that the concentration of O_3 inside the room (6 µg/m³) is lower comparing to outside (22 µg/m³). Typically, the least ozone concentrations (>1 µg/m³) are attributed to the enclosures with low air exchange rate such as display cases as proven through previous research (Ryhl-Svendsen 2009).

According to the results of indoor pollutants, the highest concentration of organic gaseous pollutants including acetic acid and formic acid were measured in the display cases of Berlin museum (Fig. 4 and 5). Concentrations as high as 2000 µg/m^3 for acetic acid were measured in the display case at BM and about 1000 µg/m^3 in a display case of the CSMVS. Formic acid concentrations were generally below 300 µg/m^3 with the exception of 1200 µg/m^3 measured in a display case located in the VAM. Much lower concentrations of these pollutants were measured in Tehran museums. The maximum concentrations of these pollutants in the display cases of Tehran museum (RAM) were 137 µg/m^3 for acetic acid and 299 µg/m^3 for formic acid. A relatively small amount of formic acid (< 110 µg/m^3) was measured in the exhibitions of museums in Tehran, Reza Abbasi Museum in particular (Fig. 5). As the interior decoration materials are not made of wood or plastic materials it can be assumed that the origin of the pollutants must come from outside such as industrial and vehicle pollutants (Grzywacz 2006, Hatchfield 2002).

Formaldehyde is another indoor pollutant studied that has been identified only in CSMVS (3 µg/m^3). This could be due to widespread use of the wood products such as plywood in CSMVS. Low concentrations of formaldehyde can also originate fromthe transformation of formic acid to formaldehyde (Brimblecombe 1989).

3.3 Particulate matter

The particles in the dust have various shapes, colors and sizes. The dark and small particles are mainly found in museums in Tehran, whereas the larger particles, particularly fibers, were detected in Berlin and Mumbai (Fig. 7).

The diagram of the particulate matter abundance in the museums shows that the highest amount of 4000 p/(week × slide area) was found in the CSMVS-G4 and lowest amounts of 500 p/(week × slide area) in the Bode-Museum (Fig. 6). The amount of dust in the Pergamonmuseum (collections VAM and MIK) shows no major differences subject to the location. As more people are visiting the Pergamonmuseum than the Bode-Museum, the most probable particle source is the visitor who transport the particulate matters into the museum by

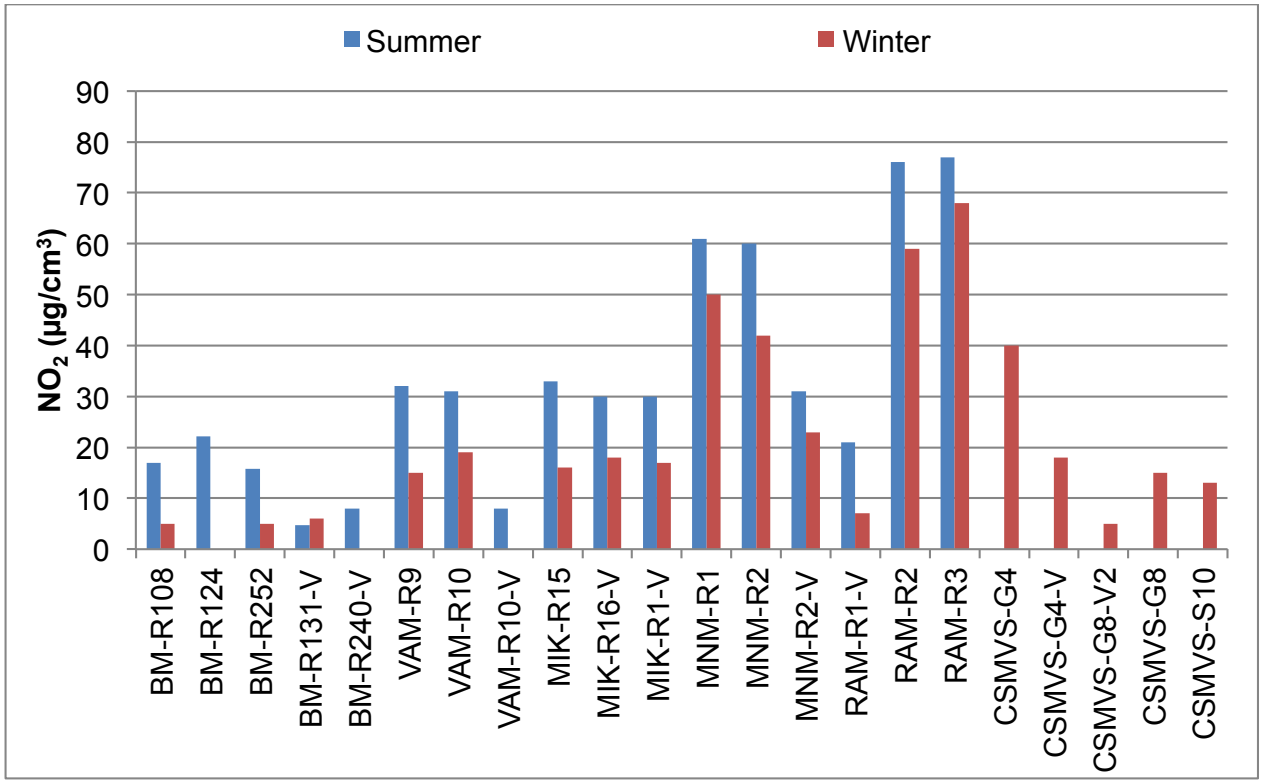

Figure 3: NO_2 concentrations in the museums (location codes refer to table 1)

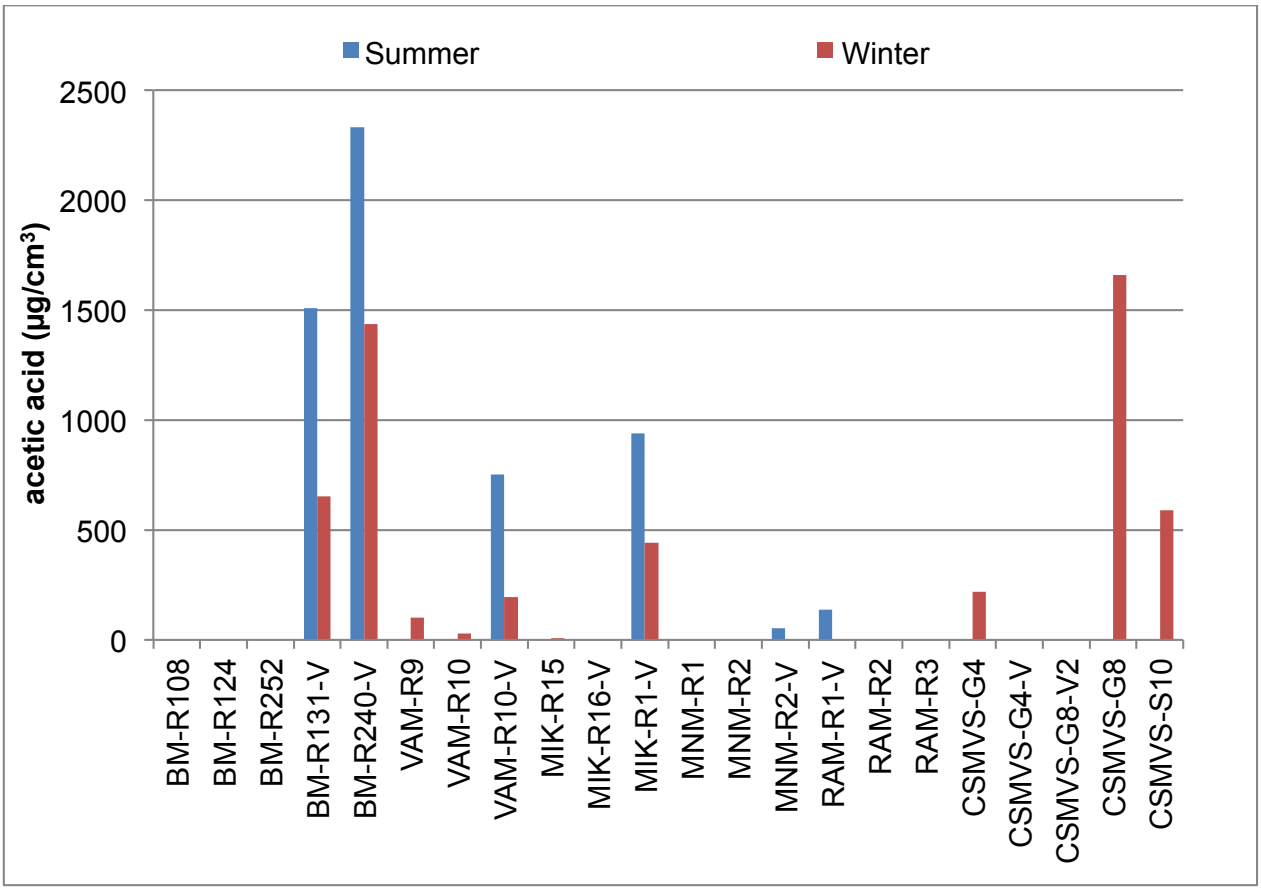

Figure 4: acetic acid concentrations in the museums (location codes refer to table 1)

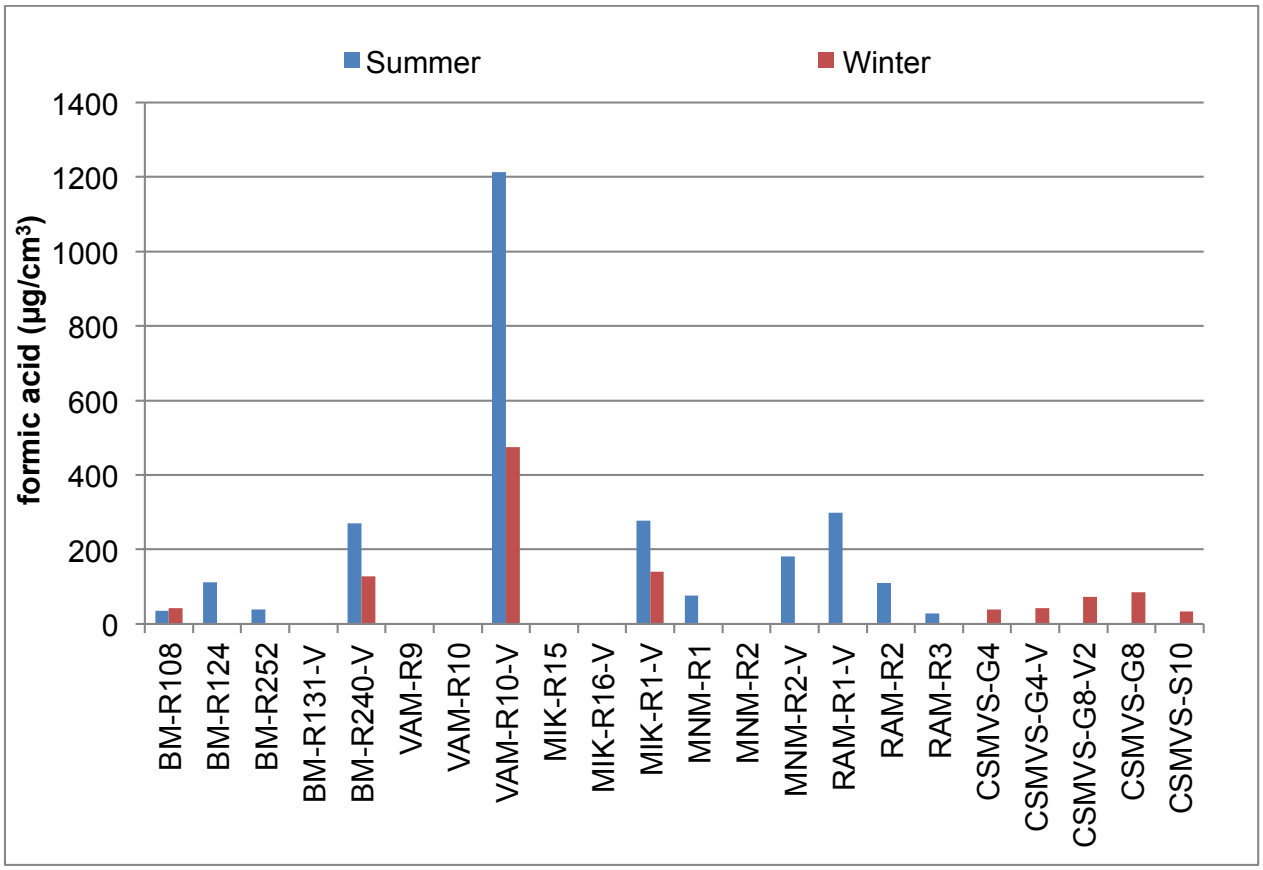

Figure 5: formic acid concentrations in the museums (location codes refer to table 1). The locations at the museum in Berlin (VAM and MIK) and Mumbai (CSMVS) in winter and Tehran in summer were not measured and the others without value were not detectable

their shoes and especially their clothes. Consequently, the dominating particle type found in the dust samples from the VAM and MIK are fibres (Fig. 7). The highest amount of dust in Tehran was recorded in the places with high AER or in the vicinity of the openings. This shows that the source of the dust is in the outside environment. In the CSMVS a big difference in the amount of dust was observed in gallery CSMVS-G4 compared to other locations (Fig. 6). The high air exchange in this gallery by natural and mechanical ventilation as well as high level of visitors in this gallery seem lead to the high accumulation rate. Small particles (probably inorganic material) and fibres have been found the dust samples from CSMVS-G4.

The results of ATR-FTIR spectroscopy show that besides fibers, the main components of the dust samples are silicate and calcium carbonate. Moreover, the elemental analysis by μXRF shows that in addition to the main elements (Fe, Ca, Si). Furthermore, the elements S and Cl were found in the dust samples. These elements play an important role in the surface corrosion of metal (Wiesinger et al. 2010, Weichert et al. 2004). The chlorine in the durst at the CSMVS museum in Mumbai comes probably from the nearby sea (Mouratidou and Samara, 2004) and in the museum in Tehran from the salt desert (Dasht-e Kavir). For the museums in Berlin these sources can be excluded leaving salts for de-

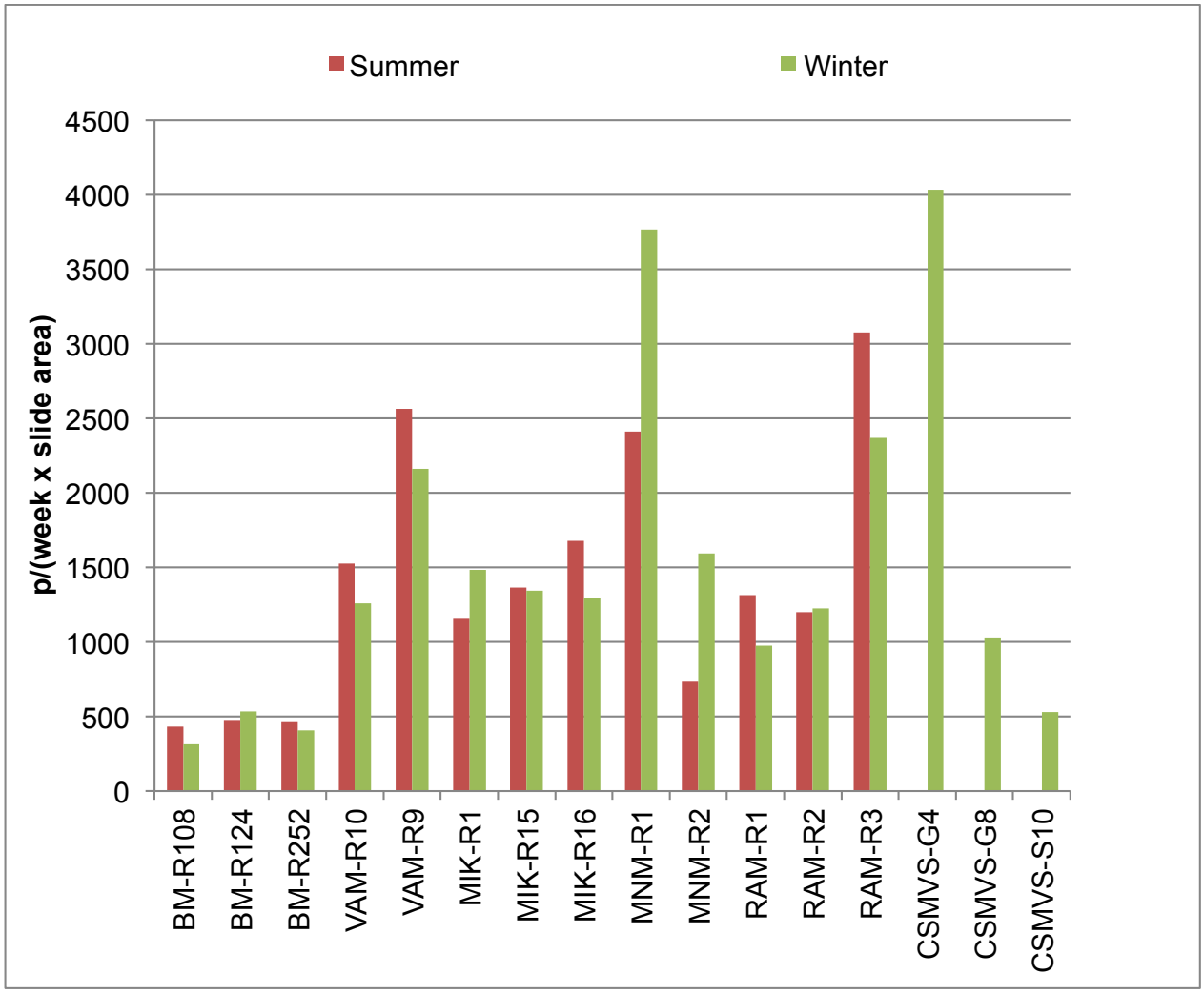

Figure 6: dust abundance in the museums (particles / (week × slide area))

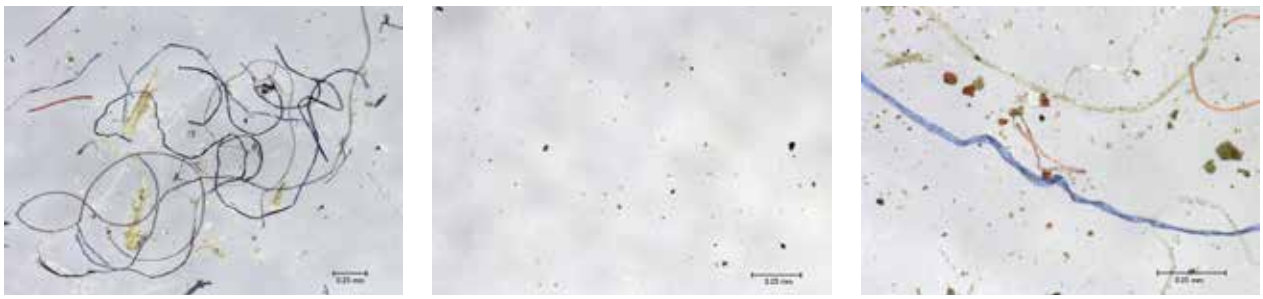

Figure 7: the morphology of particulate matters in the museums (scale: 0.25 mm), samples: VAM-R9, MNM–R1 and CSMVS-G4 from left to right

Table 2: chemical analysis of particulate matters gathered from the studied museums

analysis	major component	minor component
compound (ATR-FTIR)	silicate, calcite	organic materials
element (µXRF)	Fe, Ca, Si	S, Cl, Ti, Zn, Cu
compound (Raman)	carbon black / amorphous carbon	–

icing of roads in winter (Ferm et al. 2006, Worobiec et al. 2010) or industrial emissions as possible sources. The two elements Cu and Zn, which are traces in some samples (particularly from MIK and RAM), are mostly enriched in fine particles known as outdoor pollutants from traffic and fossil fuels for domestic and industrial proposes (Zhang et al. 2010). Another study has shown that the concentration of indoor K, Zn and Al can be contributed to emissions from heating systems introduced by eroding air-tube and fuel-chamber (Kontozova et al. 2005).

The presence of carbon could be identified in almost all museums. Typically these particles come from an outside source such as diesel fuels for some vehicles and industries (Grieken & Worobiec 2011). These particles in Berlin and Mumbai may originate from diesel fuels of ships (refer to introduction).

Some exceptions in the dust samples were observed, e.g. small and relatively regular particles in the dust samples taken from the Bode Museum. The elemental analysis with ESEM shows Na and Al as the main elements. These particles could originate from the gas filter (activated alumina and sodium bicarbonate ($NaHCO_3$) as impregnant used in some the old air conditioning (Tetreault 2003). The particles can be released from disintegrated filters and reach the rooms via the air flow.

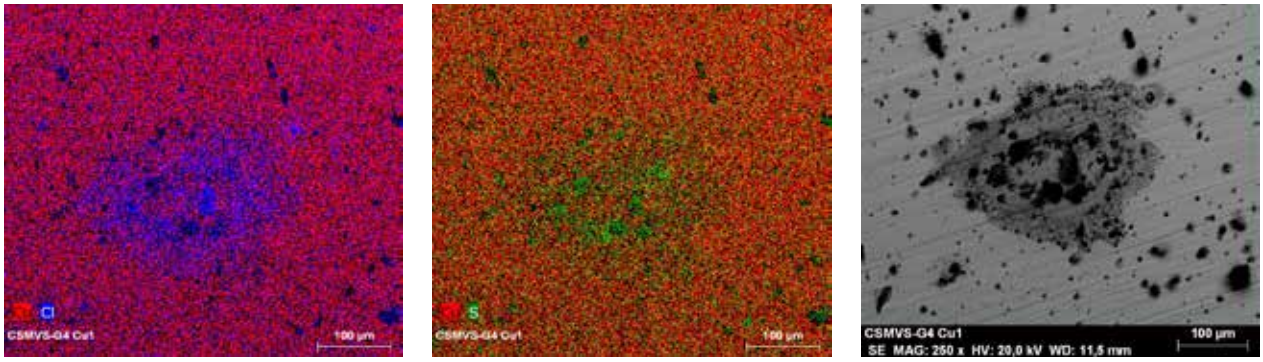

Figure 8: The elemental mapping (SEM-EDX) of a black spot on the copper coupon at the gallery CSMVS-G4 shows a combination of **Cu**–**Cl** (left) and **Cu**–**S** (middle), (scale 100 µm)

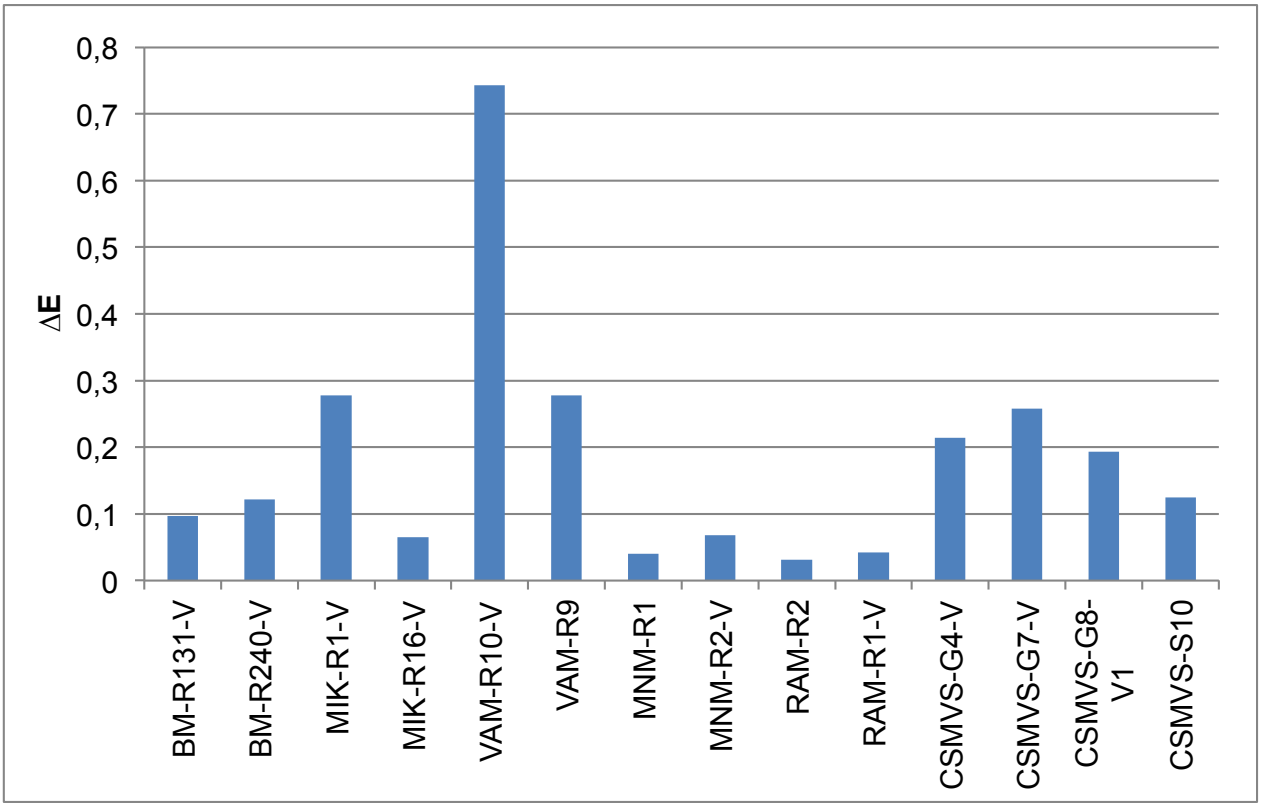

Figure 9: corrosion potential in the museums as determined by glass sensor dosimeters (GSD)

3.4 Corrosion potential in the galleries and showcases

The results of metal coupons used to evaluate the air quality and the corrosion potential show that the strongest corrosion of silver coupons occurs in the areas where a lot of visitors, dust and high humidity fluctuations were found. These locations are in the Pergamonmuseum and the CSMVS. Sulphur and chlorine ions were identified as corrosion products on the silver coupons. The airtight showcases with low AER (eg. BM-R240-V, BM-R131-V and MIK-R1-V) prevent silver coupons from tarnishing.

Unlike silver coupons, lead coupons corroded more heavily in the showcases, particularly in the museums in Berlin and Mumbai. Sometimes, the corrosion products produce a matte surface (BM-R240-V) or even a white powder layer (VAM-R10-V) on the coupon. Analytical results of the corrosion produce by Raman spectroscopy showed acetate, formate and hydrocerussite caused by acetic and formic acids. These results indicate that the air tightness of a showcase can have an undesired effect on the concentration of pollutants and the corrosion rate if an emission source is present in the showcase (Calver et al. 2005, Thickett et al. 2005).

Copper coupons corrode usually only at very harsh conditions. However, in three locations in the CSMVS and MIK museums (CSMVS-S10, CSMVS-G4 and MIK-R15) corrosion products were observed as black spots and brown stain. The copper corrosion products were identified by ESEM as sulfur and chlorine compounds (Fig. 8). These elements were observed as well in the dust samples from these locations.

Glass sensor dosimeters (GSD) from the Fraunhofer Institute for Silicate Research were additionally used to evaluate air quality in the museums by the corrosion potential. The results show that the corrosion potential in museums in Berlin and Mumbai are higher than in museums in Tehran (Fig. 9). Despite the high concentrations of SO_2 and NO_2 as outdoor pollutants in the museum in Tehran, the corrosion potential was found to be lower than in Berlin and Mumbai due to the low moisture. The main cause for the high corrosion potential in the display cases of the museums in Berlin and Mumbai are indoor pollutants and humidity.

4 Conclusion

In a summary, the measurements made in the museums indicate that the highest concentrations of outdoor pollutants (sulphur dioxide and nitrogen dioxide) can be found in the museums of Tehran and the lowest in the Bode Museum in Berlin. The origins of these pollutants are fuels from traffic and industries. The concentrations of ozone in the museum are influenced by outdoor sources. The pollutant enters the enclosure through the air exchange. In the airtight showcases the ozone concentration is close to zero whereas in rooms with high air exchange rate or natural ventilation a higher concentration of ozone is measured. The highest concentrations of organic gaseous pollutants such as acetic and formic acids were found in the museums of Berlin and Mumbai. Wood and plastic products used in the display cases and interior decoration could be the origin of these contaminations. Another reason for the high concentration of these pollutants is very low air exchange rates of the showcases. Additionally, copper as well as silver coupons placed in all museums proved the presence of sulphurous pollutants such as H_2S causing deterioration. The presence of aggressive particles like chloride ions and soot were also found in all museums. Surprisingly, the lowest corrosion potential as detected by glass sensor dosimeters (GSD) corresponds to the museums in Tehran while the highest measured concentrations of outdoor gaseous pollutants (NO_2, SO_2, O_3) do occur in these museums. Since the relative humidity has an important role in the corrosion processes the low level of relative humidity (≤30%) in the Tehran certainly reduces the corrosion potential despite the presence of high amounts of NO_2 and SO_2.. Furthermore, except for the Bode-Museum in Berlin, high levels of particulate matters were found in all museums. Many fibres were found the Pergamonmuseum and in the CSMVS corresponding to the large number of visitors. The amount of fine particles from combustion, including motor vehicles, was higher in Tehran museums compared to other museums.

5 Acknowledgement

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