2022 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
University of Calabria, Italy, October 19-21, 2022

Evaluation of the concentration of harmful air pollutants in a cultural heritage site by passive sampling

Maria Ricciardi[1], Concetta Pironti[1], Antonio Faggiano[2], Andrea Bergomi[3], Valeria Comite[3], Paola Fermo[3], Vittoria Guglielmi[3], Carlo Mariani[4], Daniele Sofia[5], Oriana Motta[1], Antonio Proto[2]

[1] Department of Medicine and Surgery, University of Salerno, via S. Allende, 84081 Baronissi, SA, Italy, mricciardi@unisa.it, cpironti@unisa.it, omotta@unisa.it
[2] Department of Chemistry and Biology, University of Salerno, via Giovanni Paolo II 132, 84084 Fisciano, SA, Italy, anfaggiano@unisa.it, aproto@unisa.it
[3] Department of Chemistry, University of Milan, Via Golgi 19, 20133 Milan, Italy, andrea.bergomi@unimi.it, valeria.comite@unimi.it, paola.fermo@unimi.it, vittoria.guglielmi@unimi.it
[4] Architect, Via Giuseppe Giusti n. 21/B, Seregno (MB), Italy; cm@carlomariani.eu
[5] Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano, Italy, dsofia@unisa.it

***Abstract* – The monitoring of the concentration of harmful air pollutants is mandatory to prevent the deterioration of cultural heritage and, at the same time, safeguard the health of visitors and workers. The present study is focused on the determination of the concentration of specific air pollutants (nitrogen dioxide and aromatic hydrocarbons, precisely benzene, toluene, ethylbenzene and xylene) in the Sanctuary of the Beata Vergine dei Miracoli (Saronno, Italy) by passive air sampling. The results of this monitoring suggest that indoor concentration of NO_2 and benzene are always higher than outdoor ones. Further investigations should be performed to assess the effective concentrations to which, not only the works of art, but also people are exposed.**

I. INTRODUCTION

The degradation of cultural heritage caused by exposure to airborne and aqueous pollutants is increasingly becoming a serious problem for cultural heritage preservation [1–5]. In fact, several pollutants such as carbon dioxide (CO_2), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) [6] have negative effects on buildings, artworks, sculptures [7], frescoes [8], paintings and so on. Not the least, the high concentration of certain pollutants in indoor environments, including sanctuaries, monument complexes and museum areas, can pose risks to human health [9–13].

Consequently, monitoring the concentration of pollutants that are hazardous to both human health and cultural heritage is essential. In particular, some pollutants can be linked to vehicular traffic such as NO_2, aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene, xylenes, namely BTEX), whereas others (e.g. CO_2 [14] and NH_3 [15]) are due to the presence of visitors.

Moreover, the indoor air quality was recently evaluated through the measurement of the carbon stable isotope ratio ($\delta^{13}C$), a parameter employed in several fields of environmental science [16–18]. Since the isotopic carbon composition varied with the concentration of pollutants, this innovative approach allowed to easily monitor the air quality in the archeological and museum sites [14,15].

Obviously, monuments located in the historic center of large cities are the main historical buildings exposed to such degrading anthropogenic emissions. As a result, the concentration of hazardous pollutants should be periodically monitored in these locations in order to safeguard the artworks contained therein and at the same time the health of workers and/or visitors.

Atmospheric monitoring can be carried out through active or passive sampling or the use of continuous monitoring stations [19,20]. Active sampling involves the use of air aspiration systems and is carried out over short periods of time, so it is not preferable for long-term monitoring activities. On the other hand, passive sampling returns time-weighted average concentrations that are useful in air quality assessment and makes it easy to carry out monitoring over long times. Passive sampling is governed by diffusive processes [21], so it relies on the principles of Fick's first law which can be expressed as:

$$J_i = -D_i \frac{C_0 - C}{l} \tag{1}$$

where J_i is the diffusive flux, D_i is the diffusion coefficient of the considered analyte, l is length diffusive path, C is the concentration of the given analyte at the end of the diffusion layer and C_0 is concentration of the analyte at the beginning of the diffusion layer [22].

Several passive sampling devices are commercially available, that differ in their geometric characteristics (diffusive path and diffusive surface) and consequently on the sampling flow rate ($\emptyset_i$). This quantity is defined as the amount of pollutant the device samples in the unit of time, expressed in function of geometrical parameters as:

$$\emptyset_i = D_i \frac{S}{l} \quad (2)$$

where D_i is the diffusion coefficient of the considered analyte, l is length diffusive path, and S the diffusive surface.

The present work is focused on the determination of the concentration of different harmful air pollutants (NO_2, aromatic hydrocarbons, i.e. BTEX) in the Sanctuary of the Beata Vergine dei Miracoli di Saronno (VA) by passive sampling. Monitoring the concentration of these pollutants is critical to determine whether they can cause harm to the various artworks present in the Sanctuary, and the effect of the visitor's presence on their values.

A. Case study: The sanctuary of the Beata Vergine dei Miracoli (Saronno (VA) - Italy)

The sanctuary of the Beata Vergine dei Miracoli is located in the small town of Saronno, Varese, Italy (Figure 1).

Fig. 1. Front view of the sanctuary of the Beata Vergine dei Miracoli.

This marian sanctuary was erected in 1498 to give hospitality to the simulacrum of the "Madonna dei Miracoli", believed to be the dispenser of miraculous healings. Its construction was completed in 1525 [23]. Among the various works of art in it, the frescoes by Bernardino Luini and two large wooden scultpures ("Cenacolo" and "Compianto sul Cristo morto") by Andrea da Corbetta and Alberto da Lodi are most noteworthy (Figure 2).

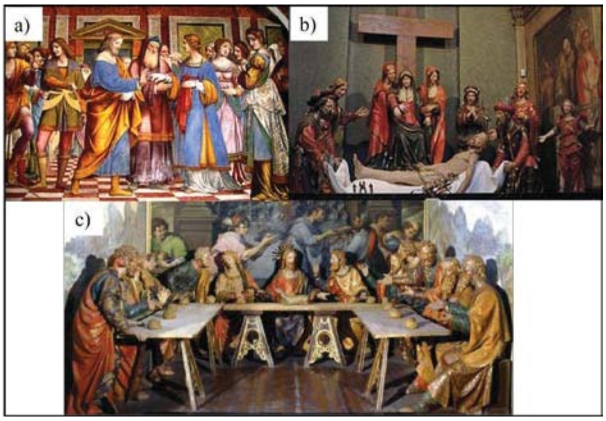

Fig. 2. a) Fresco by Bernardino Luini, "Sposalizio della Vergine"; wooden scultpures by Andrea da Corbetta and Alberto da Lodi: b) "Compianto sul Cristo morto", c) "Cenacolo".

Given the artistic richness of the Sanctuary, environmental monitoring is fundamental for the preservation of artworks to limit the degradation phenomena related to poor air quality.

II. MATERIALS AND METHODS

A. Air pollutants considered in this study

Pollutants monitored in this study are BTEX and NO_2 according to the National Institute for Occupational Safety and Health (NIOSH) methodologies, the United States federal agency for research and prevention of work-related injury and illness. The NIOSH methodologies employed for these pollutants are the following:

- N° 1500 for BTEX;
- N° 6014 for Nitrogen Dioxide.

B. Passive air sampling

The air monitoring in the Sanctuary of the Beata Vergine dei Miracoli was developed using passive samplers from April to May 2022. Radial diffusive samplers were employed. In particular, RING® devices (purchased from Aquaria S.r.l., Milan, Italy) [24,25] were used as radial diffusive samplers. Depending on the considered pollutant, different sorbent materials were employed: activated carbon for BTEX, triethanolamine for NO_2.

Five sampling points were monitored by passive sampling: three inside the Sanctuary and close to the works of art (indoor environments) and two outside it (outdoor environments). The choice of proper positions of the air quality measuring devices allows for more correct characterization of pollutant concentration [26]. For each sampling point, two diffusive samplers for each pollutant were exposed for a sampling time of 2 weeks: one from April 27 to May 11 and the other from May 11 to May 25.

C. Analytical determinations

A spectroscopic assay on water extracts (Griess-Saltzman reaction) was employed for the detection of NO_2 using a Varian Cary® 50 UV-VIS spectrophotometer [27–29]. Calibration standard solutions in the concentration range 0.05-0.1 mg/mL of NO_2^- were prepared by successive dilution of a stock solution 1 g/L made starting from $NaNO_2$.

Chemical desorption with carbon disulfide (CS_2) was used for BTEX extraction from activated carbon. Chromatographic analysis on the obtained extracts was used for BTEX determination (Agilent Technologies gas chromatography with flame ionization detector [30,31]). Calibration curves for each aromatic hydrocarbon was recorded using standard solutions in CS_2 prepared by dilution of a standard mix in dimethyl sulfoxide (1 g/L of each BTEX).

D. Determination of air concentration

The air concentration in μg/m^3 of NO_2 was calculated using the following equation (3):

$$C\left(\frac{\mu g}{m^3}\right) = \frac{m_{NO2}}{t_{NO2}} * K \qquad (3)$$

where m_{NO2} is the mass of NO_2 in μg, t_{NO2} is the exposure time in hours and K is a constant supplied by the passive devices' vendors, with a value of 157.82 h/m^3.

For each BTEX, the air concentration (μg/m^3) was determined from the equation (4):

$$C\left(\frac{\mu g}{m^3}\right) = \frac{m_{BTEX} * 10^6}{t_{BTEX} * F} \qquad (4)$$

where m_{BTEX} is the mass of each BTEX in μg, t_{BTEX} is the exposure time in minutes and F is sampling flow rate provided by the passive devices' vendors, with values of 73, 66, 60 and 64 mL/min for benzene, toluene, ethylbenzene and xylene respectively.

III. DISCUSSION

The air concentration of certain air pollutants such as nitrogen oxides and aromatic hydrocarbons is a critical parameter for air quality and must be monitored both in indoor and outdoor environments. In this context, it is of great interest to evaluate the concentrations of these pollutants near places of artistic and cultural interest such as museums, art galleries, archaeological sites, national parks, temples, churches and sanctuaries. In fact, high concentrations of them can cause deterioration of the works of art, and, at the same time, have harmful effects on the health of workers and visitors. It should also be considered that the attendance of visitors can also affect the concentration of pollutants in indoor environments such as the Sanctuary of the Beata Vergine dei Miracoli.

Figures 3 and 4 show the average concentration of the considered air pollutants, expressed as μg/m^3, recorded by passive air sampling in the five sampling points (both indoor and outdoor) during the sampling period of 4 weeks. The values of NO_2 concentration were in the range 7-22 μg/m^3, with outdoor concentrations always lower than indoor ones (see Figure 3). This result is in line with the principle of accumulation of pollutants indoors due to poor aeration of these types of environments [32]. It also indicates that there are indoor sources of this pollutant, such as candle burning during religious rites.

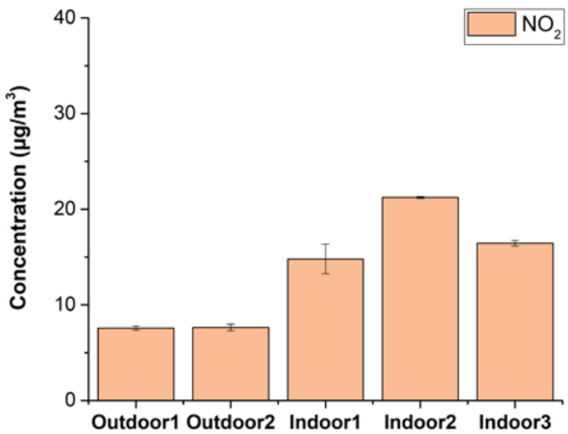

Fig.3. Air concentration of NO_2 (μg/m^3) recorded with radial passive samplers.

The recorded values are always higher than the recommended limit values for NO_2 concentration in museum environments (5 μg/m^3) to achieve proper conservation of artifacts [33], suggesting the need of proper strategy to improve indoor air quality. On the other hand, no concern for human health is posed since these values are lower than annual average regulatory limit (40 μg/m^3) of Italian law [34]. Further data will be analysed to make a fully comparison of these results with data from the ARPA (Agenzia regionale per la protezione ambientale) Lombardy control unit. Moreover, it should be noted that it is not possible to have information on any concentration spikes during the sampling period, since passive sampling returns time-weighted average concentrations of air pollutant.

Concerning BTEX (see Figure 4), concentrations of toluene, ethylbenzene, and xylenes are similar between outdoor and indoor environments, with values in the ranges 0.2-2 μg/m^3. Indeed, benzene concentrations in indoor environments are much higher than those recorded in the outdoor ones, becoming close to the annual average regulatory limit (5 µg/m^3) of Italian law [34].

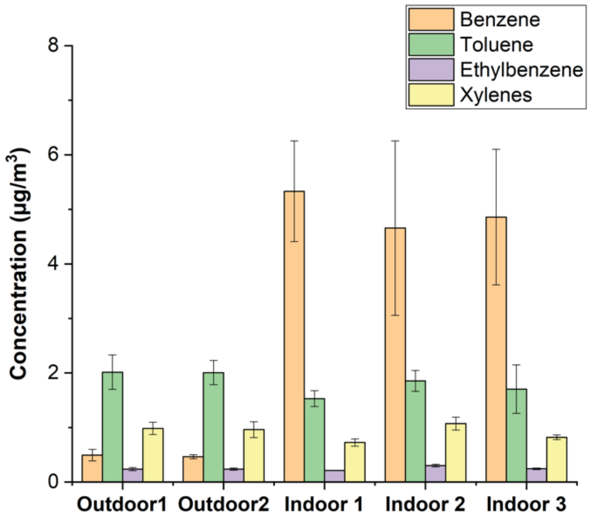

Fig. 4. Air concentration of BTEX (µg/m^3) recorded with radial passive samplers.

It is worth noting that on the base of benzene/toluene (B/T) ratio it is possible to make some hypotheses on possible sources for these pollutants [35]. In outdoor environments this ratio is lower than 1, indicating that sources of BTEX are industrial activities and vehicular traffic. Whereas, in indoor environments B/T ratio is greater than 1, suggesting incense and candle burning as main sources [36–38].

As reported in literature, the indoor concentrations of certain pollutants can be higher than outdoor ones, posing a risk for human health [35,39]. In fact, exposure to high concentrations of air pollutants is linked to the onset of disease in humans [40]. These results can be considered serious problems for the health of visitors and workers, and for the preservation of works of art, so further studies need to be conducted to evaluate its sources to prevent these high concentrations.

IV. CONCLUSION

In view of the artistic richness of the Sanctuary of the Beata Vergine dei Miracoli, air pollution monitoring is essential for the preventive conservation of the works of art and assess the exposure risk for workers and visitors. The air concentrations of nitrogen dioxide and benzene, toluene, ethylbenzene and xylene (BTEX) were measured by passive air sampling. Indoor concentrations of NO_2 and benzene are always higher than outdoor ones, whereas those of toluene, ethylbenzene and xylene in the two types of environments are similar. This is only a preliminary study and other parameters should be taken into account to fully assess the air quality in this sanctuary.

V. REFERENCES

[1] F. Di Turo, C. Proietti, A. Screpanti, M.F. Fornasier, I. Cionni, G. Favero, A. De Marco, "Impacts of air pollution on cultural heritage corrosion at European level: What has been achieved and what are the future scenarios", Environmental Pollution, vol.218, November 2016, pp. 586-594. https://doi.org/10.1016/j.envpol.2016.07.042.

[2] C. Pironti, M. Ricciardi, O. Motta, Y. Miele, A. Proto, L. Montano, "Microplastics in the Environment: Intake through the Food Web, Human Exposure and Toxicological Effects", Toxics, vol.9, No.9, September 2021, pp. 224. https://doi.org/10.3390/toxics9090224.

[3] M. Ricciardi, C. Pironti, O. Motta, Y. Miele, A. Proto, L. Montano, "Microplastics in the Aquatic Environment: Occurrence, Persistence, Analysis, and Human Exposure", Water, vol.13, No.7, April 2021, pp. 973. https://doi.org/10.3390/w13070973.

[4] L. Montano, C. Pironti, G. Pinto, M. Ricciardi, A. Buono, C. Brogna, M. Venier, M. Piscopo, A. Amoresano, O. Motta, "Polychlorinated Biphenyls (PCBs) in the Environment: Occupational and Exposure Events, Effects on Human Health and Fertility", Toxics, vol.10, No.7, July 2022, pp. 365. https://doi.org/10.3390/toxics10070365.

[5] V. Desauziers, D. Bourdin, P. Mocho, H. Plaisance, "Innovative tools and modeling methodology for impact prediction and assessment of the contribution of materials on indoor air quality", Heritage Science, vol.3, No.1, September 2015, pp. 28. https://doi.org/10.1186/s40494-015-0057-y.

[6] C. Pironti, M. Ricciardi, O. Motta, M. Venier, A. Faggiano, R. Cucciniello, A. Proto, "Sulphurous air pollutants and exposure events of workers in thermal-mineral springs: a case study of Contursi Terme (Salerno, Italy)", Environ. Sci. Pollut. Res., 2022. https://doi.org/10.1007/s11356-022-22432-y.

[7] M. Ricciardi, A. Faggiano, C. Pironti, O. Motta, M. Carotenuto, V. Comite, P. Fermo, A. Proto, "Analysis of PAHs (polycyclic aromatic hydrocarbons) and other main components in black crusts collected from the Monumental Cemetery of Milan (Italy)", Proc. of International Conference on Metrology for Archaeology and Cultural Heritage 2021, vol. 2204, pp. 012027. https://doi.org/10.1088/1742-6596/2204/1/012027.

[8] M. Ricciardi, C. Pironti, O. Motta, R. Fiorillo, F. Camin, A. Faggiano, A. Proto, "Investigations on historical monuments' deterioration through chemical and isotopic analyses: an Italian case study", Environ. Sci. Pollut. Res., vol.29, No.20, April 2022, pp. 29409–29418. https://doi.org/10.1007/s11356-021-15103-x.

[9] C. Pironti, M. Ricciardi, O. Motta, A. Faggiano, Y.

Miele, A. Fiorentino, R. Cucciniello, A. Proto, "Evaluation of air pollutants in thermal-mineral springs: a case study of Agnano (Naples, Italy) and Contursi Terme (Salerno, Italy)", Proc. of International Conference on Metrology for Archaeology and Cultural Heritage 2021, vol. 2204, pp. 012021. https://doi.org/10.1088/1742-6596/2204/1/012021.

[10] C. Pironti, M. Ricciardi, A. Proto, R. Cucciniello, A. Fiorentino, O. Motta, "Correlation of indoor air quality and stable carbon isotope ratio of CO2 in historical monuments of Italy: A case study", Proc. of International Conference on Metrology for Archaeology and Cultural Heritage 2020, pp. 635–639.

[11] M. Ricciardi, C. Pironti, O. Motta, R. Fiorillo, F. Camin, A. Proto, "Chemical and isotopic investigations on the deterioration of the Monumental Complex of S. Pietro in Corte in Salerno (Italy) caused by the rising waters", Proc. of International Conference on Metrology for Archaeology and Cultural Heritage 2020, pp. 646–650.

[12] O. Motta, C. Pironti, M. Ricciardi, E. Bolzacchini, L. Ferrero, C. Rostagno, R. Cucciniello, A. Proto, "Indoor air quality monitoring with stable carbon isotope ratio of CO2 in Museum Environments: Study for the Leonardo da Vinci's "Last Supper,"" Proc. of International Conference on Metrology for Archaeology and Cultural Heritage 2020, pp. 651–656.

[13] A. Schieweck, T. Salthammer, "Indoor air quality in passive-type museum showcases", Journal of Cultural Heritage, vol.12, No.2, April-June 2011, pp. 205–213. https://doi.org/10.1016/j.culher.2010.09.005.

[14] C. Pironti, M. Ricciardi, A. Proto, R. Cucciniello, A. Fiorentino, R. Fiorillo, O. Motta, "New analytical approach to monitoring air quality in historical monuments through the isotopic ratio of CO2", Environ. Sci. Pollut. Res., vol.29, No.20, April 2022, pp. 29385–29390. https://doi.org/10.1007/s11356-020-12215-8.

[15] O. Motta, C. Pironti, M. Ricciardi, C. Rostagno, E. Bolzacchini, L. Ferrero, R. Cucciniello, A. Proto, "Leonardo da Vinci's "Last Supper": a case study to evaluate the influence of visitors on the Museum preservation systems", Environ. Sci. Pollut. Res., vol.29, No.20, April 2022, pp. 29391–29398. https://doi.org/10.1007/s11356-021-13741-9.

[16] C. Pironti, R. Cucciniello, F. Camin, A. Tonon, O. Motta, A. Proto, "Determination of the 13C/12C Carbon Isotope Ratio in Carbonates and Bicarbonates by 13C NMR Spectroscopy", Anal. Chem., vol.89, No.21, September 2017, pp. 11413–11418. https://doi.org/10.1021/acs.analchem.7b02473.

[17] C. Pironti, O. Motta, M. Ricciardi, F. Camin, R. Cucciniello, A. Proto, "Characterization and authentication of commercial cleaning products formulated with biobased surfactants by stable carbon isotope ratio", Talanta, vol.219, November 2020, pp. 121256. https://doi.org/10.1016/j.talanta.2020.121256.

[18] C. Pironti, M. Ricciardi, O. Motta, F. Camin, L. Bontempo, A. Proto, "Application of 13C Quantitative NMR Spectroscopy to Isotopic Analyses for Vanillin Authentication Source", Foods, vol.10, No.11, October 2021, pp. 2635. https://doi.org/10.3390/foods10112635.

[19] V.P. Campos, L.P.S. Cruz, R.H.M. Godoi, A.F.L. Godoi, T.M. Tavares, "Development and validation of passive samplers for atmospheric monitoring of SO2, NO2, O3 and H2S in tropical areas", Microchemical Journal, vol.96, No.1, September 2010, pp. 132–138. https://doi.org/10.1016/j.microc.2010.02.015.

[20] F. Karagulian, M. Barbiere, A. Kotsev, L. Spinelle, M. Gerboles, F. Lagler, N. Redon, S. Crunaire, A. Borowiak, "Review of the Performance of Low-Cost Sensors for Air Quality Monitoring", Atmosphere, vol.10, No.9, August 2019, pp. 506. https://doi.org/10.3390/atmos10090506.

[21] J.N. Cape, "The Use of Passive Diffusion Tubes for Measuring Concentrations of Nitrogen Dioxide in Air", Critical Reviews in Analytical Chemistry, vol.39, No.4, October 2009, pp. 289–310. https://doi.org/10.1080/10408340903001375.

[22] R.H. Brown, "The use of diffusive samplers for monitoring of ambient air (Technical Report)", Pure and Applied Chemistry, vol.65, No.8, (1993), pp. 1859–1874. https://doi.org/10.1351/pac199365081859.

[23] P.M.L. Gatti, "Il Santuario della Beata Vergine dei Miracoli di Saronno", ISAL (Istituto per la Storia dell'Arte Lombarda), Cinisello Balsamo, 1996.

[24] O. Motta, R. Cucciniello, R. La Femina, C. Pironti, A. Proto, "Development of a new radial passive sampling device for atmospheric NOx determination", Talanta, vol.190, December 2018, pp. 199–203. https://doi.org/10.1016/j.talanta.2018.07.088.

[25] O. Motta, R. Cucciniello, C. Scicali, A. Proto, "A study on the applicability of zinc acetate impregnated silica substrate in the collection of hydrogen sulfide by active sampling", Talanta, vol.128, October 2014, pp. 268–272. https://doi.org/10.1016/j.talanta.2014.04.031.

[26] D. Sofia, N. Lotrecchiano, A. Giuliano, D. Barletta, M. Poletto, "Optimization of Number and Location of Sampling Points of an Air Quality Monitoring Network in an Urban Contest", Chemical Engineering Transactions. vol.74, May 2019, pp. 277–282. https://doi.org/10.3303/CET1974047.

[27] M. Ricciardi, R. Cucciniello, J. Barrault, A. Faggiano, C. Capacchione, A. Proto, "A step towards bio-surfactants: Monoalkylglyceryl ethers synthesis

through glycidol alcoholysis with long-chain alcohols catalyzed by Al(OTf)3”, Sustainable Chemistry and Pharmacy, vol.17, September 2020, pp. 100281. https://doi.org/10.1016/j.scp.2020.100281.
[28] A. Faggiano, M. Ricciardi, A. Fiorentino, R. Cucciniello, O. Motta, L. Rizzo, A. Proto, “Combination of foam fractionation and photo-Fenton like processes for greywater treatment”, Separation and Purification Technology, vol.293, July 2022, pp. 121114. https://doi.org/10.1016/j.seppur.2022.121114.
[29] A. Faggiano, M. Ricciardi, A. Proto, “Catalytic Routes to Produce Polyphenolic Esters (PEs) from Biomass Feedstocks”, Catalysts, vol.12, No.4, April 2022, pp. 447. https://doi.org/10.3390/catal12040447.
[30] F. Della Monica, M. Ricciardi, A. Proto, R. Cucciniello, C. Capacchione, “Regioselective Ring-Opening of Glycidol to Monoalkyl Glyceryl Ethers Promoted by an [OSSO]-FeIII Triflate Complex”, ChemSusChem, vol.12, No.15, July 2019, pp. 3448–3452. https://doi.org/10.1002/cssc.201901329.
[31] M. Ricciardi, L. Falivene, T. Tabanelli, A. Proto, R. Cucciniello, F. Cavani, “Bio-Glycidol Conversion to Solketal over Acid Heterogeneous Catalysts: Synthesis and Theoretical Approach”, Catalysts, vol.8, No.9, September 2018, pp. 391. https://doi.org/10.3390/catal8090391.
[32] Y. Hu, B. Zhao, “Relationship between indoor and outdoor NO2: A review”, Building and Environment, vol.180, August 2020, pp. 106909. https://doi.org/10.1016/j.buildenv.2020.106909.
[33] D.M. 2001. Decreto Ministeriale 10 maggio 2001. Atto di indirizzo sui criteri tecnico-scientifici e sugli standard di funzionamento e sviluppo dei musei (Art. 150, comma 6, D.L. n. 112/1998).
[34]D.L. 2010. Decreto Legislativo 13 agosto 2010, n.155. Attuazione della direttiva 2008/50/CE relativa alla qualità dell’aria ambiente e per un’aria più pulita in Europa.
[35] P. Ielpo, C. Mangia, G. de Gennaro, A. Di Gilio, J. Palmisani, A. Dinoi, A. Bergomi, V. Comite, P. Fermo, “Air Quality Assessment of a School in an Industrialized Area of Southern Italy”, Applied Sciences, vol. 11, No.19, September 2021, pp. 8870. https://doi.org/10.3390/app11198870.
[36] A. Manoukian, E. Quivet, B. Temime-Roussel, M. Nicolas, F. Maupetit, H. Wortham, “Emission characteristics of air pollutants from incense and candle burning in indoor atmospheres”, Environ. Sci. Pollut. Res., vol.20, No.7, July 2013, pp. 4659–4670. https://doi.org/10.1007/s11356-012-1394-y.
[37] S.-C. Lee, B. Wang, “Characteristics of emissions of air pollutants from burning of incense in a large environmental chamber”, Atmospheric Environment, vol.38, No.7, March 2004, pp. 941–951. https://doi.org/10.1016/j.atmosenv.2003.11.002.
[38] W. Tirler, G. Settimo, “Incense, sparklers and cigarettes are significant contributors to indoor benzene and particle levels”, Ann. Ist. Super. Sanità, vol. 51, No.1, February 2015, pp. 28–33. https://doi.org/10.4415/ANN_15_01_06.
[39] M.A. El-Hashemy, H.M. Ali, “Characterization of BTEX group of VOCs and inhalation risks in indoor microenvironments at small enterprises”, Science of The Total Environment, vol.645, December 2018, pp. 974–983. https://doi.org/10.1016/j.scitotenv.2018.07.157.
[40] N. Lotrecchiano, L. Montano, I.M. Bonapace, T. Giancarlo, P. Trucillo, D. Sofia, “Comparison Process of Blood Heavy Metals Absorption Linked to Measured Air Quality Data in Areas with High and Low Environmental Impact”, Processes, vol.10, No.7, July 2022, pp. 1409. https://doi.org/10.3390/pr10071409.