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# A CASE STUDY OF INDOOR AIR QUALITY IN A CLASSROOM BY COMPARING PASSIVE AND CONTINUOUS MONITORING

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**Abstract**

Most people is aware that outdoor air pollution can impact human health, including indoor air pollution. Human exposure to air pollutants indicate that indoor levels of pollutants may be two to five times, and occasionally more than 100 times, higher than outdoor levels. These levels of indoor air pollutants are of particular concern because most people spend about 90 percent of their time indoors. In this manuscript we monitored indoor pollutants in a school building with two different methodologies (active and passive monitoring). We demonstrated that, even if in general the registered pollutants showed concentration below the threshold defined by WHO guidelines, the active monitoring is able to catch peaks of concentrations linked to particular school activities, such as educational arts, including single emitting episodes. The use of the monitoring equipment in continuous facilitated the identification of the pollution sources in a timely manner, identifying the impact of the best management practices on the microclimate, and particularly on internal temperature and $CO_2$ concentrations.

*Key words:* active monitoring, indoor pollution, school redevelopment

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## 1. Introduction

Because of increasing traffic and industrial emissions, outdoor air quality has become of growing concern during the past 50 years. As a consequence, monitoring of outdoor air pollution has become more and more systematic in western countries, either to check that national or international standards on contaminant emissions are applied, to ensure that outdoor air quality complies with the standards in force, to inform authorities if concentrations limit value are exceeded, and/or to assess people health hazard (Blondeau et al., 2005).

Evidence has been made that city-dwellers spend most of their time in buildings (Jenkins et al., 1992; Klepeis et al., 2001) and are far more exposed to pollution indoors than outdoors. As a result, contaminant concentration measurements have been performed in various indoor environments during the past 40 years, providing more accurate information about human exposure.

In the last years public awareness about negative impacts of indoor air quality on human health was strongly increased, starting after occurrence of health problems associated with indoor air quality in building in the 1970s for occupants of commercial and institutional buildings (ASHARAE, 1999; Daisey et al., 2003; Finnigan et al., 1984; Latif et al., 2018; Mendell et al., 2007).

Poor indoor air quality at classrooms was demonstrated to exert a negative impact on children's learning performance, with absenteeism and adverse health effects such as increased risk of asthma and other health-related symptoms (Canha et al., 2013;

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EPA, 2014; Vassura et al., 2015). In schools, aerosol particles are between the pollutants that can cause the decrease of indoor air quality. Particles may be originated naturally such as by dust, salt, pollen, viruses, fungi and bacteria (Sohn et al., 2009) or from anthropogenic sources, such as industrial activity, and combustion processes (Almeida et al., 2011; Almeida-Silva et al., 2011; Canha et al., 2010, 2013; David and Kopac, 2017; Lage et al., 2014).

The WHO (2006) started a process of updating the guidelines for the 42 pollutants harmful for indoor environments and for the first time considered as integrated both the indoor and outdoor environments. According to WHO (2010), indoor pollution in schools can be traced for the presence of organic compounds such as VOCs (i.e. benzene, naphthalene, formaldehyde, toluene, xylene, styrene, trichlorethylene, tetrachlorethylene) and inorganic substances, such as $PM_{10}$ and $PM_{2,5}$ particles, carbon dioxide ($CO_2$), oxides of nitrogen ($NO_x$), carbon oxide (CO), sulfur dioxide ($SO_2$) and ozone ($O_3$). Legislative acts are developed in several European countries, in particular in France, that responded to the obligation to monitor indoor air quality in nursery schools for 32 pollutants as stated Decree 5 June 2016, relating to monitoring procedures for indoor air quality in certain establishments receiving public.

Indoor atmospheric pollution is due not only to the behavior of occupants but to a series of variables such as the diversity of pollutant concentration levels in relation to the investigated environment and depends on different factors ranging from climatic parameters and typologies of natural or forced ventilation carried out, and from the characteristics of the environment, furnishings, building materials and surface finishes (Blondeau et al., 2005). Considering all the listed aspects, indoor monitoring is complex and unique, depending on the environment.

In the countries of the European Community already sensitive to the problem in recent years various strategies have been adopted to mitigate and contain the phenomenon (Godwin and Batterman, 2007; Shendell et al., 2004; Sohn et al., 2009; Stranger et al., 2007, 2008). Recent studies show that children aged 3 to 14 are vulnerable categories as they spend 90% of their day in indoor environments, both in winter and summer and that they reveal a greater susceptibility to some typical indoor pollutants (Firestone et al., 2008; Selgrade et al., 2008).

The Italian National statistical database (www.istat.it) shows that the school population (students of all orders and degrees, teaching staff excluding administrative staff) spending many hours in school environments is corresponding to around 9 million people safety and well-being in schools. The harmonization framework for health started in Europe, started in the year 2015, based on evaluation of indoor emissions from construction products for the obligation to certify indoor air quality. Recently, to comply, Italy has adopted in the year 2014 the Action Plan for environmental sustainability of consumption in the Public Administration sector, and will end in 2018 with a series of legislative acts and actions aimed at protecting the health of the population in line with what was defined in the First Accord of 27/09/2001 between the Minister of Health regions and autonomous provinces, where the Guidelines for Indoor Environments were established (National Prevention Plan).

It should be emphasized the growing interest in recent years in the monitoring of $PM_{10}$ and breathable $PM_{2,5}$, as several studies have shown that exposure to high concentrations of these pollutants are no longer due solely to the outdoor contribution. Indeed, the PM pollution is not attributable just to traffic, presence of industrial plants and/or residential thermal installations, but also to poor ventilation system inside the buildings through doors and windows, that are usually closed and to crowding itself in the indoor environments.

The aim of this paper is to propose a first set of methodological strategies for simultaneous monitoring of indoor air quality for chemical pollutants such as CO, $NO_2$, $CO_2$, Formaldehyde, Toluene, Benzene, Btex, acetaldehyde, m,o,p, xylene, acetaldehyde, acetone, styrene, chloroform, ethylbenzene, trichlorethylene, dichloromethane, tetrachlorethylene using in-situ, continuous and passive type methodology. In the same time to assess if the proposed methodology is able to identify management measures able to reduce indoor air pollutants concentrations.

## 2. Material and methods

### *2.1. The classroom*

The classroom chosen to carry out monitoring is part of a school building that has been subjected to an energy-saving reconditioning constituted by an outer coat with natural insulating material. The choice was related to some feature such as the street exposure, the solar exposure, the building material characteristics and the type of furnishings.

The selected school was located in a village in South of Italy (Mesagne), characterized by Mediterranean climate, even if is located not on the coast but 20 km from the sea. The school building was redeveloped with a vertical and horizontal intervention called “external coat insulation”, change of windows fixtures and an integrate hot water heater. The building is located far from industrial sites, out from the traffic area. During the experiment, the school community participated in a classroom training on issues related to energy efficiency and the role of indoor pollution, at the stage of detection and experimentation.

### *2.2. Monitoring activity*

The duration of monitoring was 6 months, and was organized in the following way: measurements in continuous done by $Aeroqual_1$, $Aeroqual_2$ and Capetti, and passive sampler measurements by Radiello. For indoor measurements Aeroqual$_1$, Capetti and passive samplers were located into the center of the classroom at 90 cm height, while Aeroqual$_2$ was locate close to the desk, again at 90 cm height. The Capetti measured indoor temperature, relative humidity and CO2 concentration and passive samplers indoor (Radiello) measured COV and formaldehyde. The Aeroqual$_1$ and Aeroqual$_2$ measured COV, temperature relative humidity and $CO_2$ concentration indoor.

For outdoor measurements the Capetti (to monitor temperature, relative humidity, wind speed and direction) were located on the school roof at 1.5 m height, and the passive samplers (to measure COV and formaldehyde) close to the classroom windows. For more details see Fig. 1and Table 1. The measurements duration was variable between 4 to 6 days depending on the school vacation time.

All the measurements obtained by the campaign were compared with data provided by ARPA Puglia (www.arpa.puglia.it) for pollutants and (www.eurometeo.com) for meteorological data. The both analytical systems and passive samplers were conditioned for 48h to adapt to the measurements environment, according to methodology described in ISSN, 2015. Testing averaged over 4 days was conducted between February 2017 and April 2017, considering the periods of the winter season and the spring season. The sampling cycles provided 2 reference tests (Blank), characterized by the absence of school activities corresponding to carnival holidays and Easter holidays. Other 2 tests were conducted during school day-to-day. For VOCs and Formaldehyde measurement, Radiello passive samplers and continuous analyzers were used for a week, during working days (Monday to Friday). The tests have taken into account several variables: external climate factors, green for shading, location and exposure of the classroom, classroom activities, number of attendances, adopted ventilation, school holidays, use or no of thermal conditioning in relation to different seasons, daily habits related to classroom cleaning, and finally vehicular traffic. The information on cleaning methods and the products used were obtained from interviews with the cleaning staff.

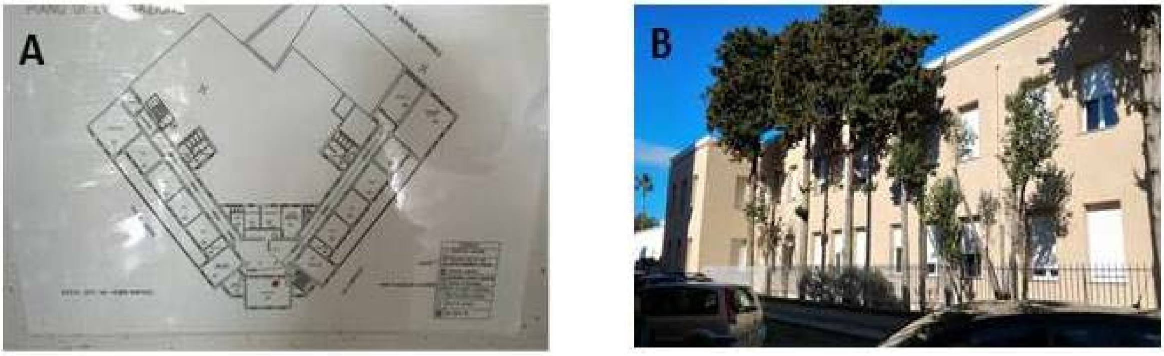



**Fig. 1.** Plan of the school (A), exterior view of the building (B)

**Table 1**. Monitoring system

| *Aeroqual sensors 1* | *Technical data range* | *Technical data Sensitivity limit* | *Technical data Resolution* | *Technical data Accuracy* |
|---|---|---|---|---|
| Electrochemical sensor for Carbon Monoxide CO | 0-25 ppm | 0.05 ppm | 0.01ppm | ≤+/-0.5 ppm |
| Electrochemical sensor for Formaldehyde $CH_2O$ | 0-10 ppm | 0.01 ppm | 0.01ppm | ≤+/-0.05 ppm |
| Semiconductor sensor for Ozono $O_3$ | 0-0.5 ppm | 0.001ppm | 0.001 ppm | ≤+/-0.08 ppm |
| Electrochemical sensor for nitrogen dioxide $NO_2$ | 0-1 ppm | 0.005 ppm | 0.001 ppm | ≤+/-0.02 ppm |
| NDIR non-dispersive infrared sensor for $CO_2$ | 0-2000 ppm | 10 ppm | 1 ppm | ≤+/-10% ppm +5% |
| PID sensor for VOC | 0-20 ppm | 0.002 ppm | 0.01 ppm | ≤+/-10% |
| Built-in temp / RH sensor | 10-125°C | | | |
| **Aeroqual sensors 2** | | | | |
| GSE electrochemical sensor for CO | 0-100 ppm | 0.2 ppm | 0.1 ppm | ≤+/-10% |
| Built-in temp / RH sensor | 10-125°C<br>and 0-100% | | | |
| NDIR non-dispersive infrared sensor for $CO_2$ | 0-2000 ppm | 10 ppm | 1 ppm | ≤+/-10% ppm+5% |
| PID photoionization sensor for VOC | 0-20 ppm | 0.02 ppm | 0.01 ppm | ≤+/-10% |
| **Capetti sensors** | | | | |
| System for the measurement of Temperature<br>Relative humidity<br>Concentration of ambient $CO_2$ | -10-60°C<br>10-90%<br>0-2000 ppm | | 0.01°C<br>1 ppm | +/-0.1°C<br>+/-5% a 25°C<br>+/-50ppm+2% |
| System for the measurement of Temperature | -40-80°C | | 0.2°C | |
| System for the measurement of wind | 0.5-70 m/s | | 0.1 m/s | 5% |
| wind direction | 0°-360° | | ≤1° | 3° |
| global solar radiation | 0-2000 W/m$^2$ | | 3 um | |
| **Radiello**<br>for HPLC e GCMS Method | www.radiello.it<br>UNI EN ISO<br>16000-annex | | | |

## 3. Results and discussion

### *3.1. Volatile Organic Compounds (VOCs) and Formaldehyde*

The study with the continuous monitoring system for VOCs was necessary to detect the activation of the sources during the period of interest and the contribution from external sources. The commercially used Aeroqual$_1$ system was calibrated respect to 100 ppm of isobutylene. therefore, the concentration of total VOC is referred to this gas. Unfortunately, the type of sensor used doesn't give sufficient and unequivocal elements to define the amount of formaldehyde, most likely due to interfering as reported in the document of the technical characteristics of the electrochemical sensor interferences for reducing gases such as alcohols.

Indeed, the results, carried out from 7 am to 1 pm school activity with continuous analysis systems, show a recurring peak for formaldehyde and VOCs coming (Singer et al., 2006) from the process of classroom cleaning (Fig. 2).

The detergents, mostly degreasers, are composed by, alcohol, limonene, sodium hypochlorite, methylchlorothiazolinone, methylisothiazolinone, thus the amplitude peak became more evident when the cleaning procedure was carried out in form of aerosol. An important peak, was recorded during school activities in one specific day with an increase in VOCs concentration ranging around 240 μg/m$^3$, determined by the presence of a leather bag and in proximity of the chair, in presence of a fixative jar left open, used for art activities (Fig. 2).

Fig. 3 shows the different information obtained by passive and active measurements for both VOC (a) and $CH_2O$ (b). In the comparison periods, the VOCs selected have values lower than the main WHO references (WHO, 2006) defined by different European countries.

High importance is attributed to the location of the sensors inside the classroom, indeed the two different set of measures (continuous, located close to the desk and passive, located in the middle of the classroom) explains the different levels of pollutants detected. In addition, the active system was in the vicinity of the clean desk with the detergents.

In general, the concentrations observed do not present particular criticisms as compared to the limit values set by the European Community Generally, but is to be noticed that higher level of both pollutants were observed with active sampling methodology as compared to passive one in all the monitoring periods. Furthermore, passive methodology was not able to catch the peak of VOC registered by the active measurements. Fig. 4 shows a comparison between indoor and outdoor measurements of respectively formaldehyde, toluene and acetaldehyde in the main square and acetone and m,o,p-xylene in the small box in four weeks.

Very low differences, statistically insignificant, are present between indoor and outdoor measurements in all the sampling weeks. Generally, acetone and xylene show very lower values in comparison to the main pollutants. The concentration of some substances, such as styrene, chloroform and others are below the limit of detection of the instrument, as detected in Fig. 5.

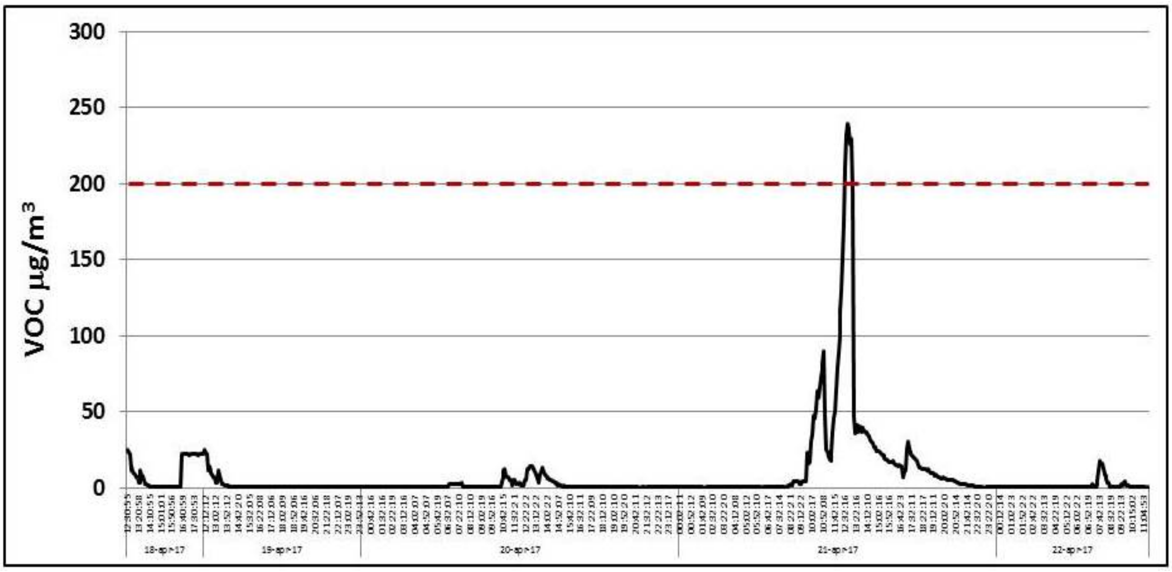
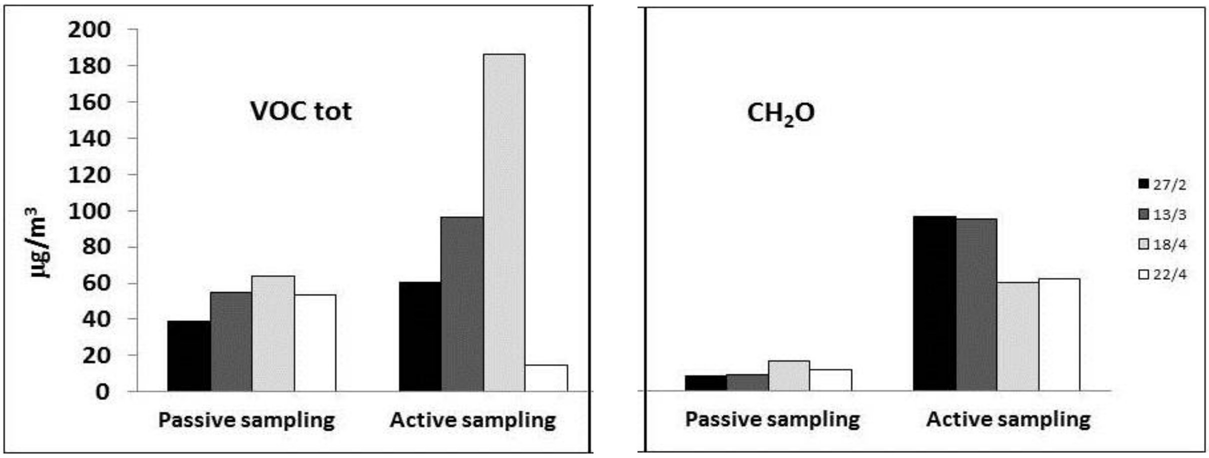



**Fig. 2.** Indoor total VOC measurements (April 18-22)




(a) (b)

**Fig. 3**. Comparison of total VOC (a) and $CH_2O$ (b) measurements obtained by passive sampling and active sampling methodology in four different days

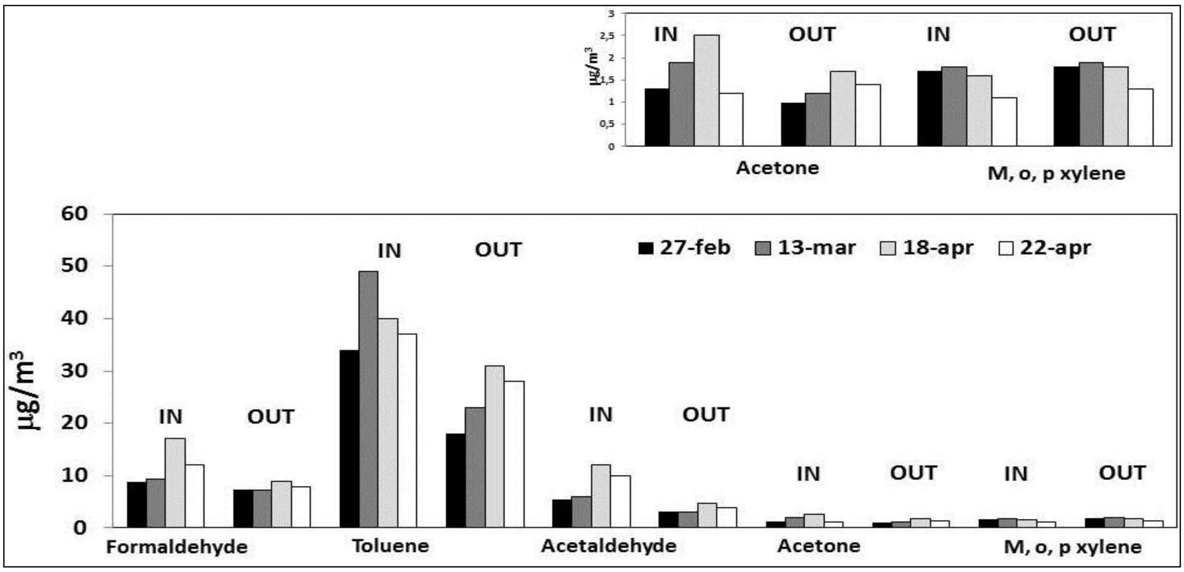



**Fig. 4** Comparison of indoor (IN) and outdoor (OUT) pollutants obtained by passive sampling in four different weeks

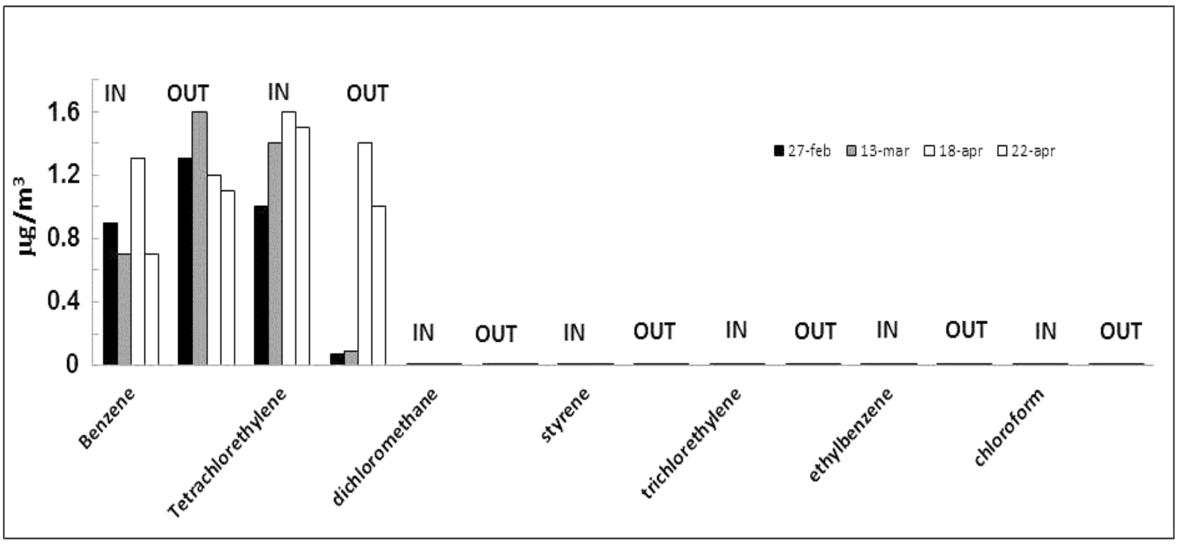



**Fig. 5**. Comparison of indoor (IN) and outdoor (OUT) pollutants obtained by passive sampling in four different weeks

*3.2. Temperature and $CO_2$*

The temperature increases according to the number of attendances in the classroom and decreases in pauses with the absence of students, end-of-activity or in relation to the type of ventilation (Daisey et al., 2003; Satish et al., 2012; Shendell et al., 2005) used. In Fig. 6 we showed the temperature trends into the classroom in a normal day, from measurements in the middle of the classroom. The maximum indoor temperature doesn't exceed the value of 23°C, even if the temperatures monitored in the proximity of the chair (data not shown) were higher than 26°C, thus well above the limits suggested by the 2013 dlgs74. In the spring period, during hot and sunny days, the same temperature registered is 23°C at the end of the morning or in the warmer hours, and this highlights the weight of the contribution of the thermal plants. The temperature profiles show that in the presence of activities within the class the temperature increases faster and more consistently when all the fixture is closed (Fig. 6). When the windows are opened in Vasistas mode or totally opened, the temperature curve decreases proportionally. The same happens if the inner door is opened in the corridor (Fig. 6). During the interruption of school activities (Carnival and Easter holidays), the temperature profile measured within the class follows the increase observed in the outdoor temperature.

The $CO_2$ measurements in the classroom recorded values even higher than 2000 ppm, during the start of the activity, at the time of return from the gym, especially in winter more than in spring, where it is customary to keep the windows open. Moreover, an analysis of the period from 18 to 22 April showed how a significant increase in $CO_2$ was due to the strong winds that avoid the opening of the windows in the classroom, as shown in Fig. 6.

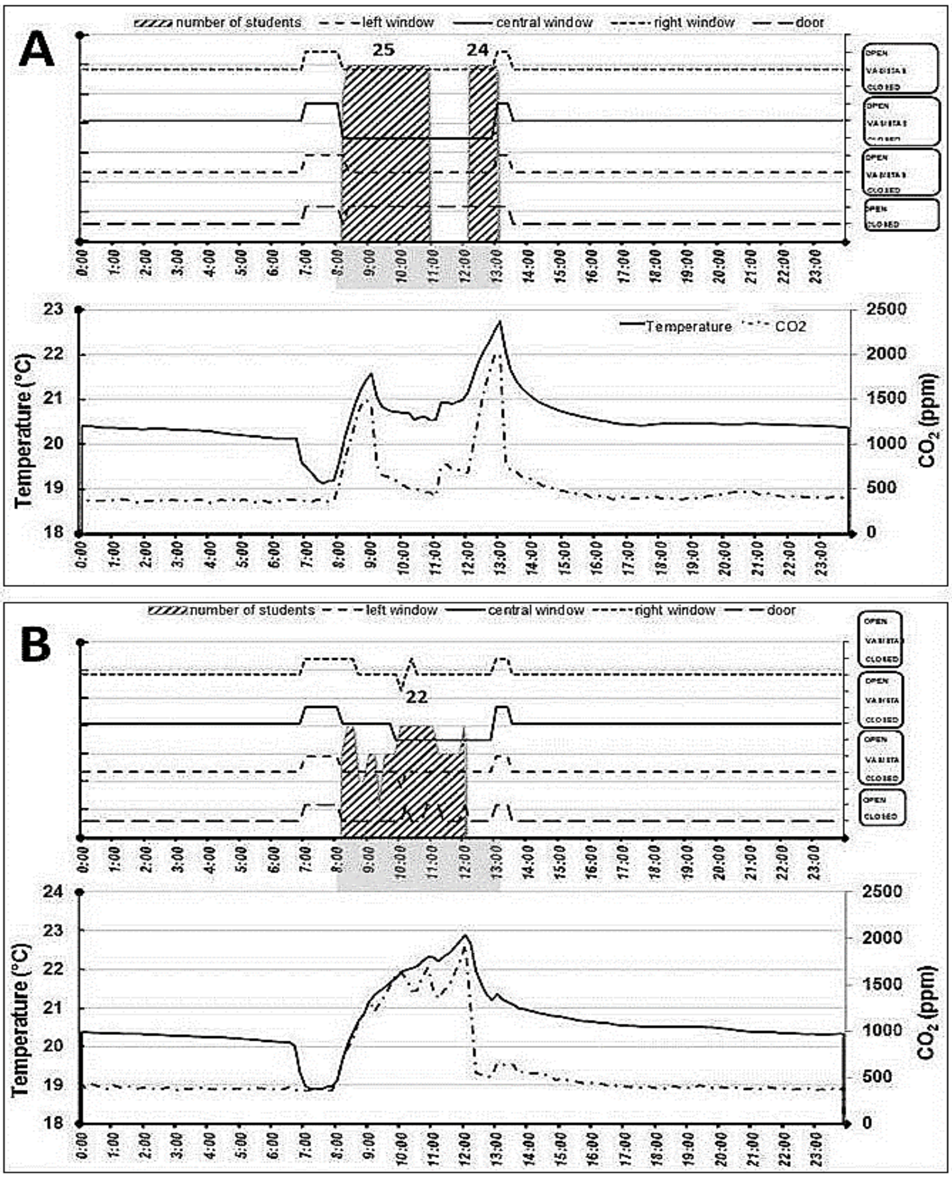



**Fig. 6**. Temperature and $CO_2$ measurements during two different days, 15th March (A) and 16th March (B) as related to number of students into the classroom and opening and closure of the three different windows and the door

*3.3. Relative humidity*

The relative humidity trend follows the same pattern as temperature, increases in classroom activity when windows and door are locked (data not shown). Moisture decreases with the opening of the windows while the opening of the door generally produces a dampening of the rapidity of the moisture increase. From data analysis, however, recorded values follow the external trend and do not generally exceed 55%, in line with dlgs n ° 74 of 16/4/2013, on days not rainy or humid as those characterized by winds typical of the Mediterranean climate.

*3.4. CO, $NO_2$, $O_3$*

There were no significant increases in the level of CO, but just a sufficient recurrence at the start and end of school time as shown in Fig. 7, probably due to vehicular traffic and to the discharges from thermal plants. The values generally not exceeding 2 ppm still remain below the expected limits or guide values. Immediately before the start of school activities there is an increase in the concentration of 0.02 ppm of $NO_2$ compared to a baseline level.

During the activity there is usually a reduction in concentration and the opening of doors or windows always appears to have the same effect. The oscillations found are still included within the limits and the guide values taken into the reference. It is assumed, as shown in Fig 7 that a short variation can be attributed to the discharges of vehicular traffic in the presence of sunny days. The pollutant concentrations into the environment don't exceed the current WHO guideline values to protect public health (WHO, 2006). The monitoring carried out did not reveal any particular criticisms in the measurement of ozone, whom concentrations appear, however, affected by the aperture of the windows. However, the ozone levels remain within the limits of the experimental tolerance, as shown in Fig 7. From temporal trends shown in Fig 7 it appears clear that the school area is not affected by significant traffic levels.

The results shown above demonstrated that the communication and the interactive training can be considered as an effective scientific tool to be included in the experimental campaigns and in the protocols to prevent and mitigate the emissions of indoor pollutants in the daily living environment.

Indeed, during the experiment together with the experimental measures, the students were involved in the achievement of results, by compilation of appropriate sheets, reporting information on the classroom attendance, frequency and type of opening of the windows and doors.

Comparisons of total VOC levels across studies can be problematic due to differences in definition, sampling times, measurement, and analysis (Zhang et al., 2006), and examination of specific VOC species is often more informative.

The current study showed an increase in total VOC levels during cleaning activities, artistic activities with solvents, paints and in particular with closed windows. The decrease in total VOC levels is associated with the increase of ventilation due to the windows. These results, and the outdoor levels suggest that the indoor sources are more effective than the outdoor sources. Ultimately, it can be stated that the site investigated after energy redevelopment intervention during the observation period shows levels of concentration of VOCs and Formaldehyde below the European limits. Some criticalities are reported, however, in this study relatively to some microclimatic parameters, such as temperature and $CO_2$ concentration. Indeed, high values of $CO_2$ concentrations were recorded during school activities, with levels reaching concentrations above 2000ppm. These values are in agreement with the $CO_2$ levels registered by Pegas et al., 2010.

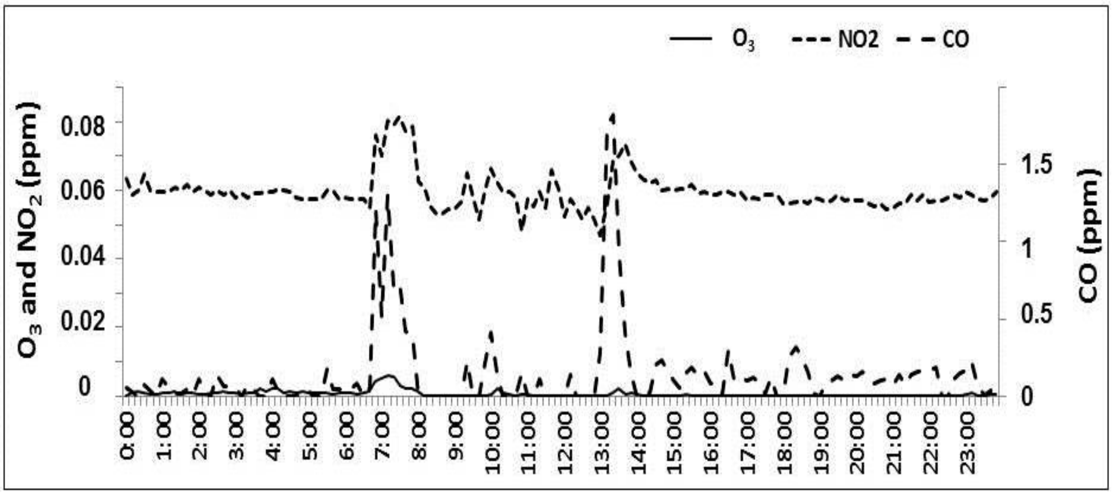



**Fig. 7.** Temporal trend of $O_3$ (solid line), $NO_2$ (short dashed line) and CO (high dashed line) during a single typical day

Good practices were suggested to decrease the high levels, through natural ventilation by regular window openings. This allowed to reduce the $CO_2$ value during the activities. To this purpose, management procedures have been identified in order to mitigate the effects consciously. Firstly, the total aperture of windows and doors for short periods rather than set the windows in the Vasistas mode for longer periods of time. The importance of ventilation of the rooms were demonstrated in the past. Indeed, the type of ventilation (mechanical ventilated or natural ventilated) plays a major role on ventilation rates in primary schools (Canha et al., 2013; Dimitroulopoulou, 2012) demonstrated the importance of ventilation during winter, comparing a Finnish school, not very much ventilated during the cold winter and a Portuguese school. Other critical points are the cleaning activities and specific arts education activities during in the school time.

## 4. Conclusions

To further improve the air quality one of the suggested actions is to not perform the room cleaning procedures using detergents in aerosol mode as highlighted by Fig. 2 for $CH_2O$, (period 27/02 and 13/03), but using the cleaning products directly on a wet cloth as reported in the spring period (18/4 and 22/4) where there is a decrease in the pollutant concentrations.

The monitored results and comparisons with the methodologies already recognized and reported in for the determination of VOCs showed the effectiveness of the integrated approach proposed for quantitative and limited surveillance of air quality in order to be able to minimize the issues related to indoor pollution in short time through the conscious management of natural ventilation. In this particular case, the use of the monitoring equipment in continuous facilitated the identification of the pollution sources in a timely manner, identifying the impact of the best management practices on the microclimate, and particularly on internal temperature and $CO_2$ concentrations.

The limitation of this work is the relative low number of measurements, due to limited funding availability. The study is to be considered as a starting point to develop the appropriated methodology for indoor air pollution monitoring into the classroom.

The authors in the future through other case studies, already in the pipeline, propose to implement the sensor network and to develop a prototype of the Artificial Neural Network to make the measures less and less invasive and to demonstrate the effectiveness in the surveillance action to promote the use in all indoor environments.

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