PRASSI DI RIFERIMENTO UNI/PdR 122:2022

Air quality monitoring in school buildings - Instruments, sampling strategies and measurements interpretation

Monitoraggio della qualità dell'aria negli edifici scolastici - Strumenti, strategie di campionamento e interpretazione delle misure

This document stems from the need to provide school building managers with a simplified procedure to monitor the air quality in a school building, assuring sufficient reliability and quality of the measurement. Furthermore, it supports the manager in understanding the issue, in wording requests to the test laboratory and in interpreting the test results.
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INTRODUCTION

Multiple and heterogeneous didactic-educational activities and functions are carried out in school buildings, which differ from those that characterise other types of social buildings, as the infrastructural “value” and “quality” of the premises, the adaptability, connectivity and high occupancy rate of school spaces have a strong impact on health, education, and schooling. School building managers are responsible for the health and safety of pupils/students and of the teaching personnel.

Indoor air quality in school premises (from nursery schools to kindergartens, primary, lower and upper secondary schools), both in the public and private sectors, is a critical topic from the point of view of health and learning. In order to monitor the air quality of a school building and to ascertain compliance with any legislative or regulatory limits set for the concentration of one or more pollutants in the premises, the manager may act independently or rely on a test laboratory that has the necessary equipment and skills to carry out the measurement.

This reference practice stems from the need to provide school building managers with a simplified procedure to monitor the air quality in a school building, assuring sufficient reliability and quality of the measurement. Furthermore, it supports the manager in understanding the issue, in wording requests to the test laboratory and in interpreting the test results.

This reference practice is based on the regulations in force, on the technical literature in the sector and on the experience gained in the field by the Authors and by personnel of the public and research bodies involved in its drafting.

This reference practice cannot be applied to define strategies for monitoring pathogens such as viruses (such as SARS-COV-2).

1 SCOPE

The UNI/PdR has the following unified objectives:

- define a simplified operating procedure for monitoring and checking air quality by monitoring certain indicator parameters. The procedure can be applied independently by building managers, without the support by a test laboratory;
- define the procedures, that the manager may adhere to in the event of entrusting monitoring to a test laboratory: understanding the issue, how to outsource the assignment, what parameters should be measured, assessing and interpreting the results of the outsourced tests.

The simplified monitoring procedures set out herein do not replace the standardised procedures contained in UNI/EN/ISO standards, which are still the only framework standards for test laboratories.

The main pollutants that may be found in indoor premises such as a schoolroom are described.

The reference practice is completed with:

- Annex A: School inspection questionnaire
- Annex B: Test report according to UNI CEI EN ISO/IEC 17025
- Annex C: Identification card of the instrument
- Annex D: Control card
- Annex E: Setting out the results.

The UNI/PdR does not deal with the topic of subjective analyses and perception of occupants as a parameter to describe air quality, but focuses on instrumental measurements.

2 NORMATIVE AND LEGAL REFERECES

ISO 16000-3:2011 Indoor air - Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air - Active sampling method

ISO 16000-4:2011 Indoor air - Part 4: Determination of formaldehyde - Diffusive sampling method

ISO 16000-34:2018 Indoor air - Part 34: Strategies for the measurement of airborne particles

ISO 16000-37:2019 Indoor air - Part 37: Measurement of PM2.5 mass concentration

ISO 18593:2018 Microbiology of the food chain - Horizontal methods for surface sampling

UNI CEI EN ISO/IEC 17025:2018 General requirements for the competence of test and calibration laboratories

UNI EN 12341:2014 Ambient air. Standard gravimetric measurement method for the determination of the PM10 or PM2.5 mass concentration of suspended particulate matter

UNI EN 14211:2012 Ambient air. Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence

UNI EN 15780:2011 Ventilation for buildings - Ductwork – Cleanliness of ventilation systems

UNI EN 16798-1:2019 Energy performance of buildings. Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

UNI EN 12792:2005 Ventilation for buildings - Symbols, terminology and graphical symbols in section 2 and all the standards from which the definitions have been taken or translated

UNI EN 17141:2021 Cleanrooms and associated controlled environments - Biocontamination control

UNI EN ISO 10551:2019 Ergonomics of the physical environment - Subjective judgement scales for assessing physical environments

UNI EN ISO 11665-1:2019 Measurement of radioactivity in the environment - Air: radon-222 - Part 1: Origins of radon and its short-lived decay products and associated measurement methods

UNI EN ISO 11665-4:2021 Measurement of radioactivity in the environment - Air: radon-222 - Part 4: Integrated measurement method for determining average activity concentration using passive sampling and delayed analysis

UNI EN ISO 11665-5:2020 Measurement of radioactivity in the environment - Air: radon-222 - Part 5: Continuous measurement methods of the activity concentration

UNI EN ISO 11665-6:2020 Measurement of radioactivity in the environment - Air: radon-222 - Part 6: Spot measurement methods of the activity concentration

UNI EN ISO 16000-1:2006 Indoor air - Part 1: General aspects of sampling strategy

UNI EN ISO 16000-2:2006 Indoor air - Part 2: Sampling strategy for formaldehyde

UNI EN ISO 16000-5:2007 Indoor air - Part 5: Sampling strategy for volatile organic compounds (VOCs)

UNI EN ISO 16000-15:2008 Indoor air - Part 15: Sampling strategy for nitrogen dioxide (NO2)

UNI EN ISO 16000-19:2014 Indoor air - Part 19: Sampling strategy for moulds

UNI EN ISO 16000-26:2012 Indoor air - Part 26: Sampling strategy for carbon dioxide (CO_2)

UNI EN ISO 16000-32:2015 Indoor air - Part 32: Investigation of buildings for the occurrence of pollutants

3 TERMS AND DEFINITIONS

The following terms and definitions apply for the purposes of this document:

3.1 calibration: Operation that makes it possible to determine errors in the indications of system and measurement instruments and the values of measurement samples so as to guarantee precise and reliable measurement results. The calibration process of instruments and samples consists of a comparison with a reference sample of a higher level, permitting the measurements produced to acquire the fundamental properties of metrological traceability with respect to national or international samples. (Source: Accredia)

3.2 airing: Natural ventilation by window opening. (Source: UNI EN 12792)

3.3 room with airing: Place where the air exchange is carried out exclusively by opening windows, doors or French windows.

3.4 room with mechanical ventilation system: Place where the air exchange is carried out with controlled mechanical ventilation systems, which may be centralised, spot or hybrid.

3.5 control card: Document that makes it possible to statistically ascertain the tendency of an instrument's performance over time.

3.6 test laboratory: Facility, either public or private, which operates under its own business name or within a company or a public facility, to carry out analyses, tests and diagnoses in a variety of sectors, depending on its specific customers. (Source: Accredia)

3.7 standardised procedure: Description of a measurement methodology described in a standard, for example UNI, CEN, ISO.

3.8 simplified procedure: Description of a measurement methodology not set out in a UNI, CEN, ISO standard but with acknowledged validity. The simplified procedure is described under item 7.4 and consists of a set of operations that the manager can perform independently.

3.9 manager: Natural person or entity with or without legal personality, guarantor of the cultural identity and educational project of the school and responsible for managing the school towards the Administration and users. The manager may be the head teacher, coordinator or another role.

3.10 indoor premises: Indoor premises where people live and work, for residential, recreational and working purposes. Area, room or premises that is, or are, enclosed by a roof and walls and has openings to the outdoor space, within which non-industrial activities take place.

3.11 operator: Technician who carries out the test activity.

4 SYMBOLS AND ABBREVIATIONS

4.1 SYMBOLS

Symbol	Quantity	Units of measure
CO_2	Carbon dioxide	ppm
n	Ventilation rate	Vol/h, h^{-1}
NO_2	Nitrogen dioxide	$\mu g/m^3$
TVOC	Total volatile organic compounds	$\mu g/m^3$, ppb
VOC	Individual volatile organic compounds	$\mu g/m^3$
PM10 PM2.5	Particulate matter	$\mu g/m^3$

4.2 ACRONYMS

Acronym	Term
BTEX	Benzene, toluene, ethylbenzene and xylene
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
IR	Infrared
NDIR	Non-Dispersive Infrared
PM	Particulate Matter
TVOC	Total Volatile Organic Compounds
VOC	Volatile Organic Compounds
WHO	World Health Organization

4.3 UNITS OF MEASURE

ppb	Parts per billion
ppm	Parts per million
Bq	Becquerel
CFU	Colony-forming unit

5 PRINCIPLES

Air quality is a component of the quality of indoor environments, together with thermal comfort, lighting comfort and acoustic comfort. Some pollutants are closely linked to thermal comfort parameters, as described below.

Indoor air quality is defined as acceptable when “there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority of the people exposed do not express dissatisfaction”. The subjective approach, i.e., the one that investigates the satisfaction of occupants, their complaints and their perception is a complex issue and cannot be investigated through objective measurements, which are instead the subject of this Reference Practice.

The pollutants found within a classroom may have two origins:

– Internal:
    - emitted by the materials that the structure and furnishings of the classroom are made of;
    - emitted by the metabolic activity of the people occupying the classroom;
    - emitted by the activities carried out by people within the classroom;
    - emitted by the installations if maintenance is not carried out properly.
– External:
    - road traffic;
    - gaseous emissions from civil and industrial plants;
    - widespread emissions from building sites and storage of materials outdoors;
    - natural gaseous emissions from the subsoil (e.g., radon).

The effect of indoor pollution is worse when there are other problems at the same time:

- inadequate air exchange;
- technical defects of technological systems, structures and internal elements (claddings);
- overheating (high temperature may promote the emissions of certain materials).

The pollution of an indoor environment may be controlled in two ways:

- by the manager, by independently monitoring certain indicator parameters, such as CO_2

  Advantages: low costs, control extended to the whole period of the school’s activities;

  Disadvantages: few measurable parameters, requires trained personnel;
- by the manager, by appointing a test laboratory

  Advantages: higher number of measurable parameters, greater precision of the measurement;

  Disadvantages: high costs.

In some cases, these two methods may be used alternatively, in others in combination necessarily.

Table 1 describes the parameters that may be measured independently and those that require the involvement of a test laboratory. Further details are provided under item 7.4.

Table 1 - Air quality parameters

Parameters that may be measured by the school independently	Main parameters that require the involvement of a test laboratory
- carbon dioxide (CO_2) Supplementary parameters (optional): - air temperature - relative air humidity - atmospheric pressure	- formaldehyde - VOC, TVOC - radon - particulate matter - biological measurements - NOx - …

6 PRELIMINARY TESTS AND INSPECTIONS OF SCHOOL BUILDINGS

6.1 OVERVIEW

The characterisation of the building's current state forms the basis of the assessments on the measurement approach of indoor environment quality parameters.

For an assessment of the approach to air quality measurements one may refer to standard UNI EN ISO 16000-32 which specifies the requirements for investigating buildings for the occurrence of pollutants or other harmful factors, as a basis for subsequent sampling of suspect areas and determination of the type and quantity of pollutants.

6.2 INSPECTIONS

Annex A shows an example of questionnaire to perform an inspection in a school building with the goal of assessing the air quality and parameters affecting it and technical installations.

7 INDICATORS, POLLUTANTS AND APPROACH TO MEASUREMENTS

7.1 OVERVIEW

The measurement of air quality must necessarily provide correct information and whoever performs it must therefore have specific knowledge of the techniques and the context in which it is carried out. A measurement is the result of the use of instrumentation combined with standardised procedures, but also knowledge of the variables that affect the result of the measurement and the context in which the measurement is performed.

For the purposes of proper interpretation of the data, for example measured in the same room but by different institutions, the person carrying out this interpretation must know the level of equivalence between the various measurement methods. The methods set out in the UNI, EN, ISO standards are called “reference methods”. All other methods, national or alternative, may however be used, subject to checking that the results obtained are equivalent to those obtained with the reference method (there are specific rules for this): this operation must be carried out by the laboratory that decides to use an alternative method, while the manager must ensure the laboratory has done so.

The test method describes the techniques that make it possible to measure a physical or chemical parameter that characterises the air quality of an environment. Essentially, these techniques have two approaches, described below. According to the pollutant/indicator, only either direct or indirect measurements or both may be adopted.

- Indirect measurement, in this case the substance to be measured is first concentrated on a suitable medium (vial, filter, solution) then determined at another time. The indirect measurement is more sensitive, precise than the direct one, the result obtained represents the average concentration of the pollutant in the time it took to collect it (30 min, 1 hour, etc.). One disadvantage of the indirect measurement is that it is not well suited to short time collection and its use is more expensive than the direct measurement.
- Direct measurement, typical of automatic instruments where the result of the measurement is obtained in a very short time (seconds). The direct measurement is sometimes less sensitive than the indirect one but has the advantage of obtaining the trends of a pollutant’s

concentration over time. In direct measurement, it is important for the instrument to be able to measure the event at the same time as it happens.

7.2 UNITS OF MEASURE

The main units of measure and related conversions are described for the following parameters referred to indoor air: temperature, humidity, pressure, gas concentration, ventilation rate.

7.2.1 TEMPERATURE

The most widespread unit of measure is the degree Celsius (symbol °C), whereas the unit of measure of temperature in the International System (IS) is the Kelvin (symbol K). The conversion between degrees Celsius and Kelvin is as follows: T [K] = T [°C] + 273.15

7.2.2 HUMIDITY

The most widely used parameter is relative humidity, defined as the ratio of amount of water vapour present in a given volume of air to the maximum amount of water vapour that volume can hold at saturation (this evaluation must be made at a specific temperature). Relative humidity is expressed as %.

The parameter that correlates relative humidity and temperature is defined as specific humidity. It is defined as mass of water vapour in a unit mass of moist air, i.e., the ratio of mass of water vapour to the mass of dry air contained in the same volume of moist air. Specific humidity is expressed in kg_v/kg_{da}, where the subscript *v* indicates the vapour, while *da* dry air.

7.2.3 ATMOSPHERIC PRESSURE

Physical quantity that expresses the ratio of the weight force of the air column weighing on a surface to the measurement of the area of said surface. In the international system it is measured in pascal (Pa). The instrument that measures it is the barometer.

7.2.3.1 Difference in pressure (or differential pressure)

The pressure difference between the interior (of the building) and the exterior depends on the thermal gradient and on the difference between the interior and exterior air density. In the absence of other forces (such as wind) and assuming no chimney effect, when the inside is warmer than the outside, the base of the building has negative pressure compared to the outside and the upper part has positive pressure compared to the outside. If the internal air is colder, the opposite is true. This phenomenon is strictly linked to the migration of radon gas from the ground to the interior of the building. The pressure differential is expressed in Δp.

7.2.4 GASES IN AIR

The concentration of polluting gases in air is generally expressed in:

- ppm: parts of pollutant per million of parts of air. 1 ppm = 1000 ppb
- ppb: parts of pollutant per billion of parts of air. 1 ppb = 1/1000 ppm
- mg/m^3: milligrams of pollutant per cubic metre of air
- $\mu g/m^3$: micrograms of pollutant per cubic metre of air
- Vol%: concentration of a pollutant expressed as ratio on the air volume

- Bq/m^3: Becquerel per cubic metre of air, it expresses the radioactivity of a gas
- Fibre/litre: number of fibres per litre of air.

The following equations are used for the conversion of the units of measure:

Table 2 - Conversion of concentrations

Gas	Conversion at 25°C
CO	1 ppb = 1.146 µg/m³
CO_2	1 ppb = 1.800 µg/m³
HCHO	1 ppb = 1.228 µg/m³
NO_2	1 ppb = 1.882 µg/m³
O_3	1 ppb = 1.963 µg/m³

7.2.5AIR CHANGE RATE AND FLOW RATES

The air exchange rate is the speed at which all the air inside a room is replaced by airing or ventilation. It is calculated as the mass of air exchanged with regards to the total volume of the room in question and is indicated in the time interval of one hour.

The units of measure used to describe air exchange in indoor premises are:

- flow rate: m^3/h, L/s/person, L/s/per area
- ventilation rate: vol/h, h^{-1}

7.3 INDICATORS AND POLLUTANTS

The main indicators and pollutants of air quality are described below in the Tables. A description, the details for measurement and an example of how to set out and read the data are provided.

Guide to reading the tables and graphs
The values set out in the graphs must be read as an example of graph, according to Annex E on how the measurements are set out. Therefore, the graphs are examples and must not be taken as reference of limits or guiding values to be adhered to. The units of measure of each parameter are set out on the axes, for further details refer to the description provided after the graphs.

Measurement uncertainties
Each measurement is characterised by an error, which must be estimated and associated to the result of the measurement preceded by the sign ±. The error in measurement associated to the result is referred to as "measurement uncertainty". The approach to the estimate of the measurement uncertainty is a complex mater, covered by several standards, the main one of which is the ISO/IEC Guide 98-3:2008.

Duration of monitoring
The duration of monitoring is linked to their objectives, the characteristics of the instruments and the results obtained.

Table 3 - Carbon dioxide

What is it	CO_2 is a colourless and odourless gas, a waste product of cellular respiration: it is produced by man with breathing. It is also produced by combustion processes. It is the main indicator of air quality. Although at low concentrations CO_2 is not a pollutant, it is measured because it makes it possible to easily quantify the concentration of indoor pollutants.
Sources	The main source of emission of CO_2 in school premises is people.
Aims of monitoring	– Evaluation of air quality in environments occupied by people; continuous monitoring. – Determination of the features of airing/ventilation of the room. – Assessment of air exchange strategies. – Checking for improvement solutions (openings, ventilation systems...). – Comparison with regulatory values.
Units of measure	ppm (references: UNI EN 16798-1 and UNI EN ISO 16000-26).
Measurement principle	Infrared (IR) or non-dispersive infrared (NDIR) analysers.
Technical standard of reference	Standard UNI EN ISO 16000-26 describes how to plan measurements of carbon dioxide pollution.
What the monitoring report must contain (for measurements performed by a test laboratory)	In addition to the contents set out in Annex B (which refer to standard UNI EN ISO 16000-26), the following additional information might be collected, which improve an understanding of the monitoring data: – number of pupils/students (hour by hour); – specifications and operation of the ventilation system (if any); – - opening/closing of windows/doors.
Duration, details of the measurement period and operative indications for monitoring	– Duration: at least 1 week with one weekend. – Measurement interval: 1 minute. – Position: adhere to UNI EN ISO 16000-26: installation between 1.0 – 1.5 metres from the floor as a height that is representative of the air breathed by occupants. The measurement instruments must be placed away from heat sources (heating systems, irradiation) and from the openings/nozzles of the ventilation systems. Figure 2 shows an example of correct placement.
Influence with other parameters	Yes: ventilation rate, air temperature.
Regulatory or legislative limits	Standard UNI EN 16798-1 describes the concentration limits according to the comfort categories. The value of 1200 ppm (800 + 400) ppm is assumed as reference for good air quality in school buildings. The value of 400 ppm is taken as reference of the outdoor CO_2 concentration failing monitoring data (Source: UNI CEN/TR 16798-2).

Figure 1 - Example of setting out CO_2 data

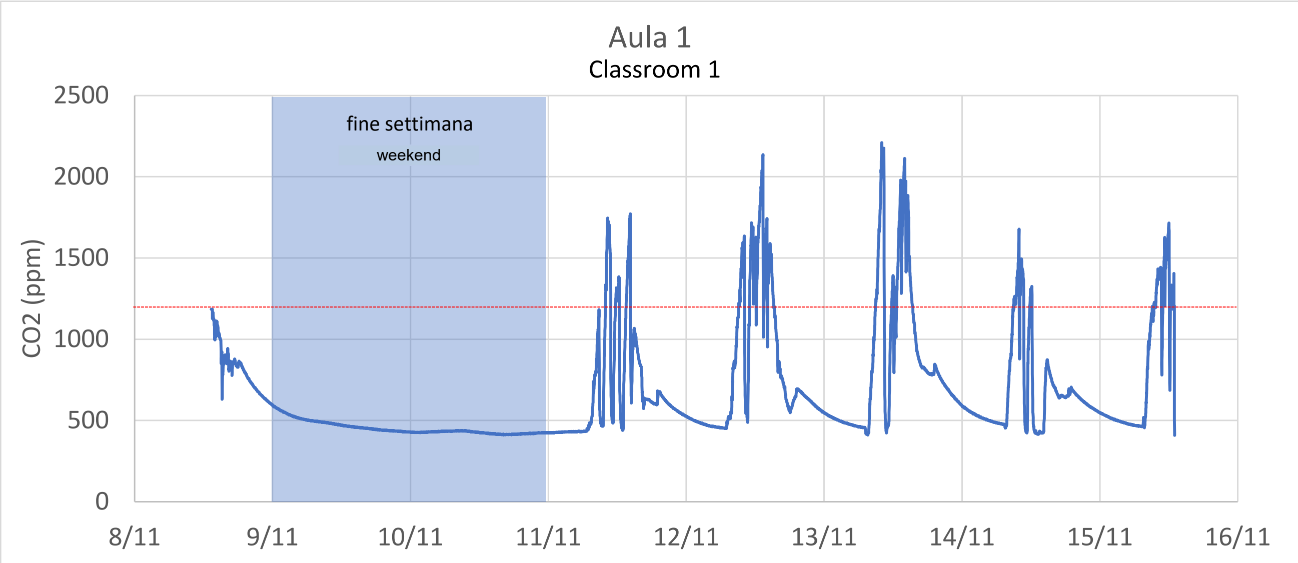


Figure 1 shows an example CO_2 concentration graph. The following elements are important to aid in reading the graph:

- title (for instance room where the measurement was taken) and unit of measure;
- representative time interval (in the graph, one week of measurement highlighting the weekend; it is possible to detail an individual day of measurement);
- regulatory limits considered (with relevant reference). The limit in the graph is 1200 ppm (UNI EN 16798-1, Class II).

Figure 2 - Example of placement of CO_2 meters

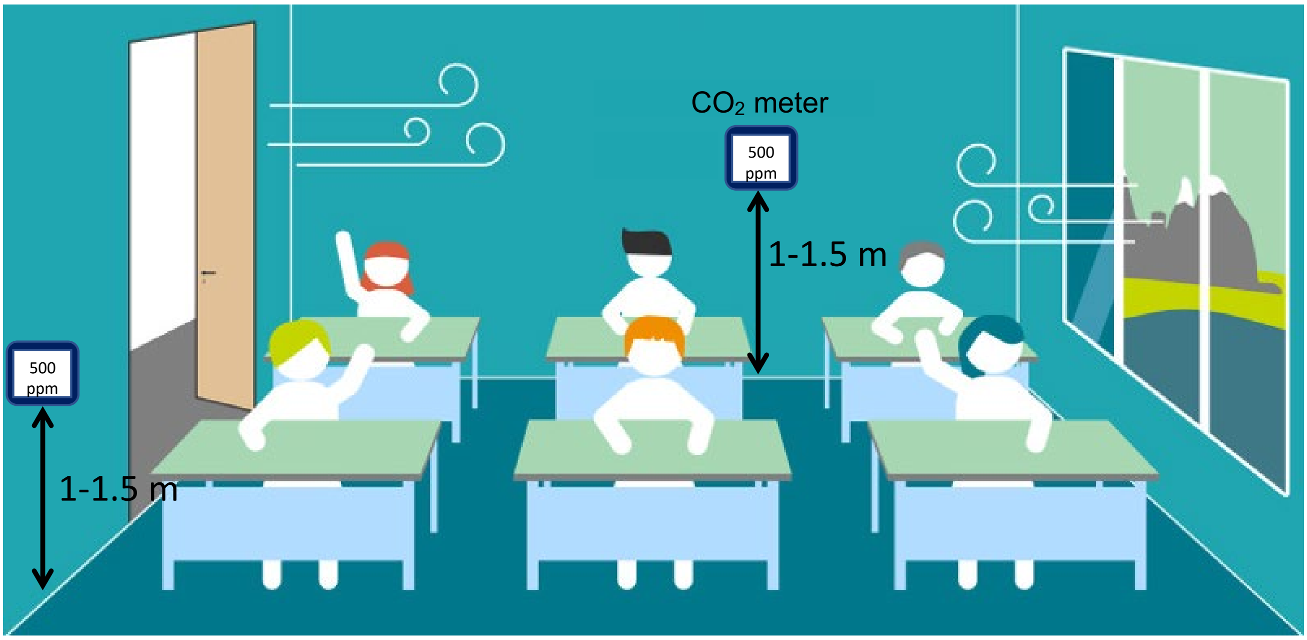


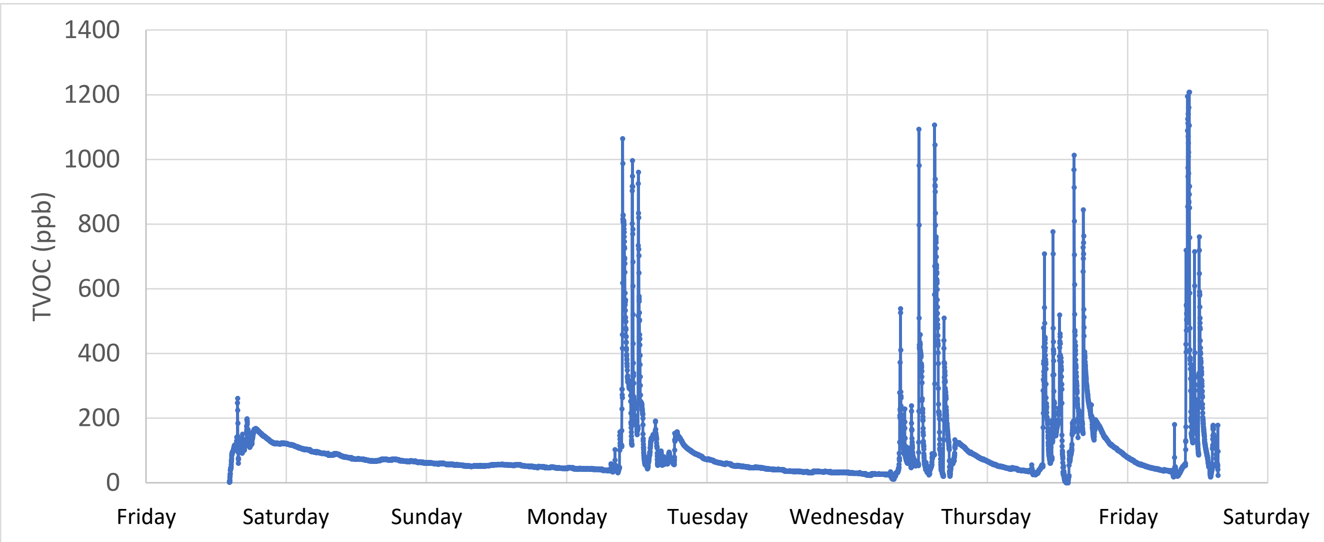
Figure 2 shows two examples of placement of CO_2 measuring instruments. The placement also refers to the measurement of other parameters such as temperature and relative humidity, if measured with a single instrument.

Table 4 - VOC and TVOC

<table>
<tr><td>What they are</td><td colspan="2">The class of volatile organic compounds – VOCs – includes various compounds that have different physical and chemical behaviours, but that have high volatility in common. These compounds are characterised by the presence of organically bound carbon. They are gaseous pollutants that may come from outdoors or from internal sources: aliphatic, aromatic and chlorinated hydrocarbons, aldehydes (e.g., formaldehyde), terpenes, alcohols, ethers and ketones, BTEX (benzene, toluene, ethylbenzene and xylene).
The sum of individual volatile organic compounds is defined as TVOC or total volatile organic compounds. These are many groups of compounds, which are difficult to determine individually, therefore sometimes it is preferred to determine them as the sum of all the compounds.
A detailed list of the sources of individual VOCs is set out in information Annex B of standard UNI EN ISO 16000-32.</td></tr>
<tr><td>Sources</td><td colspan="2">The internal sources of indoor premises are as follows:
– the materials that the building envelope and furnishings are made of;
– the people present;
– the activities performed.
The external sources are:
– motorised traffic;
– emissions of conveyed civil and industrial flows.</td></tr>
<tr><td rowspan="3">Aims of monitoring</td><td colspan="2">As with other pollutants, the purpose of the measurement is to optimise ventilation and/or filtration so that a given pollutant is not present in concentrations that are either harmful or that may cause discomfort.</td></tr>
<tr><td>VOC</td><td>Determination of the concentrations of individual VOCs</td></tr>
<tr><td>TVOC</td><td>Continuous evaluation of TVOC concentrations</td></tr>
<tr><td>Units of measure</td><td colspan="2">$\mu g/m^3$, ppb</td></tr>
<tr><td rowspan="2">Measurement principle</td><td>VOC</td><td>Sampling with adsorbent cartridges, passive samplers or canisters, gas chromatography determination</td></tr>
<tr><td>TVOC</td><td>As per VOC then summed up</td></tr>
<tr><td>Technical standard of reference</td><td colspan="2">UNI EN ISO 16000-5</td></tr>
<tr><td>What the monitoring report must contain (for measurements performed by a test laboratory)</td><td colspan="2">The relevant parameters must be specified while planning the monitoring. The measured parameters must be indicated in the report together with the measurement uncertainty.
The results of a VOC measurement with gas chromatography must be reported for each individual compound, expressed in concentration and associated with the measurement uncertainty.
When passive samplers are used, the conversion formulas used to calculate the result must be specified, including diffusion coefficients and absorption rates.
The analysis by individual compound does not make it possible to identify all the VOCs present, therefore the sum will be underestimated. The TVOC analysis reduces all VOCs into a single signal associated to a reference VOC (e.g., isobutylene). The different response of the individual compounds to the</td></tr>
</table>

	reference VOC means that also in this case, the result will be under- or overestimated. Low molecular mass aldehydes, amines and highly polar VOCs can be excluded and must therefore be determined separately using suitable methods.	
Control over the quality of the measurement and instrumentation	The measurement requires specific instruments and skills, that can be provided by test laboratories. Test accreditation is a guarantee of reliability for the result.	
Duration, details of the measurement period and operative indications for monitoring	VOC	For rooms with airing, should one wish to observe the contribution of materials: air the rooms intensely for 15 minutes, after which all openings must be closed for 8 hours (optimal if during the night). Sampling must be performed with closed doors and windows. To obtain information on the effectiveness of hourly intensive airing, the room is aired intensively after sampling by opening doors and windows for 5 min. The doors and windows are closed again and after waiting for 1 h a further sample is taken. For premises with mechanical ventilation: switch the system on at least 3 hours before the start of measurement. Note down operation of the system.
	TVOC	Continuous measurement: Use the premises for normal activities. No preparation is required prior to measurement.
Influence with other parameters	Yes: temperature and relative humidity and ventilation rate (Source: UNI EN ISO 16000-5).	
Regulatory or legislative limits	Standard UNI EN 16798-1 sets out the limits on material emissions; there is no specific limit for TVOC concentration in air. There are guide values set by the WHO and by non-Italian bodies (such as the German Umweltbundesamt).	

Figure 3 - Example of setting out TVOC data



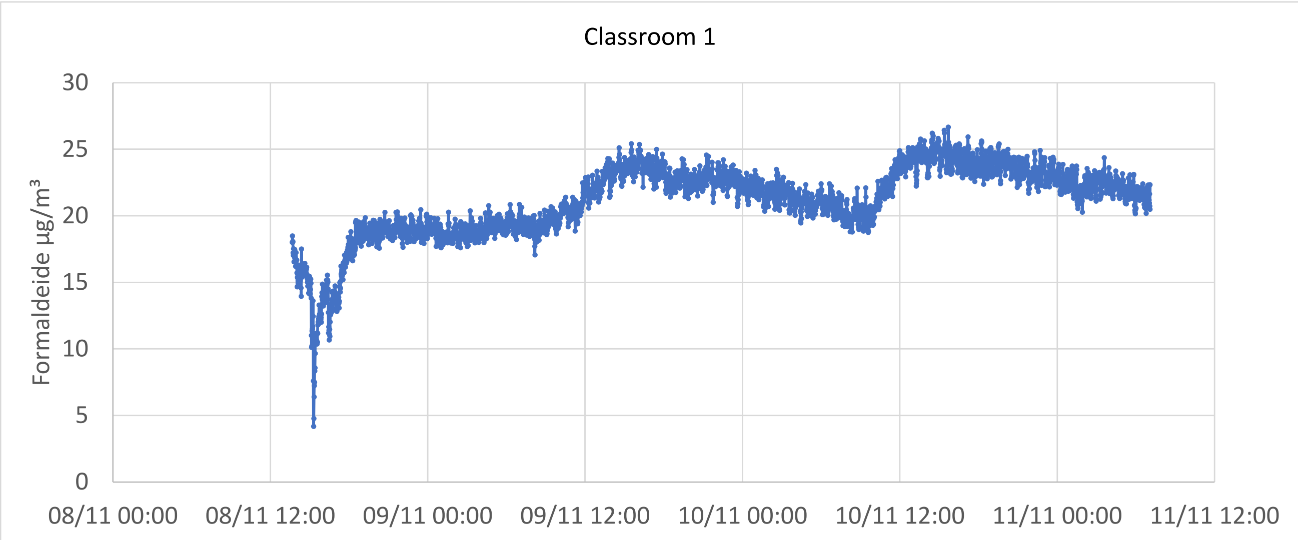
The graph shows the TVOC trend (expressed in ppb) under continuous monitoring in a classroom.

Table 5 - Formaldehyde

What is it	Among the most widespread and well-known volatile organic compounds (VOC), colourless gas with a pungent and irritant odour. According to IARC it is a group A1 carcinogenic product, that is the main reason for searching for it and for the existence of a legal limit. Used in the chemicals industry, in the manufacture of interior design objects and in cleaning products. Many construction products contain formaldehyde, specifically, it is used for the production of resins, which in turn are used for the production of chipboard and wood-based materials, glues, insulation products, etc. Formaldehyde is released even after many years from the adhesives which contain it.	
Sources	In addition to being a product of combustion (tobacco smoke and other sources of combustion), it is also emitted by urea-formaldehyde resins used for insulation and by resins used for chipboard and plywood, for upholstery, carpets, curtains and other textiles treated with anti-crease treatments and for other furnishing material and melamine foams.	
Aims of monitoring	Spot monitoring: checking concentration for compliance with legislative limits. Continuous monitoring: assessment of changes over time in formaldehyde concentration as the temperature and other parameters change, such as the ventilation rate of the premises. Other purposes (UNI EN ISO 16000-2): – - checking the effectiveness of decontamination operations.	
Units of measure	μg/m³, mg/m³, ppm	
Measurement principle	There are various methods to measure formaldehyde. Essentially, they meet different needs and may be broken down into short-term measurements with active sampling, long-term measurements with active or diffuse samplers, continuous measurements: – high performance liquid chromatography (HPLC), DNPH treated tubes; – air sampling with a detector, reaction with a reagent, analytical determination (according to ISO 16000-3).	
Technical standard of reference	UNI EN ISO 16000-2 ISO 16000-3 (short-term monitoring – 1 hour)	
What the monitoring report must contain (for measurements performed by a test laboratory)	– Environmental conditions during the measurement (temperature, relative humidity) – Placement of the instrumentation – Checking the conditioning carried out in the hours prior to the measurement under balanced conditions – Settings and operation of ventilation systems, if any	
Duration, details of the measurement period and operative indications for monitoring	Spot measurement (short-term monitoring)	For rooms with airing: air the rooms intensely for 15 minutes, after which all openings must be closed for at least 8 hours (optimal if during the night). Sampling must be performed with closed doors and windows. For premises with mechanical ventilation: switch the system on at least 3 hours before the start of measurement. Note down operation of the system.

		Indicative duration: between 30 minutes and several hours. The Circular Letter of the Ministry of Health does not provide indications on the duration of the measurement.
	Continuous measurement (long-term monitoring)	Use the premises for normal activities. No preparation is required prior to measurement. Indicative duration: 2 days. This measurement is very complex and must be evaluated in specific situations.
Influence with other parameters	Yes: temperature (internal and external), humidity and ventilation significantly affect the test result.	
Regulatory or legislative limits	Circular Letter of the Ministry of Health no. 57 of 22 June 1983: formaldehyde concentration limit: 0.1 ppm = 123 μg/m³. World Health Organisation: formaldehyde concentration limit: 100 μg/m³.	

Figure 3 - Example of setting out formaldehyde data under continuous monitoring

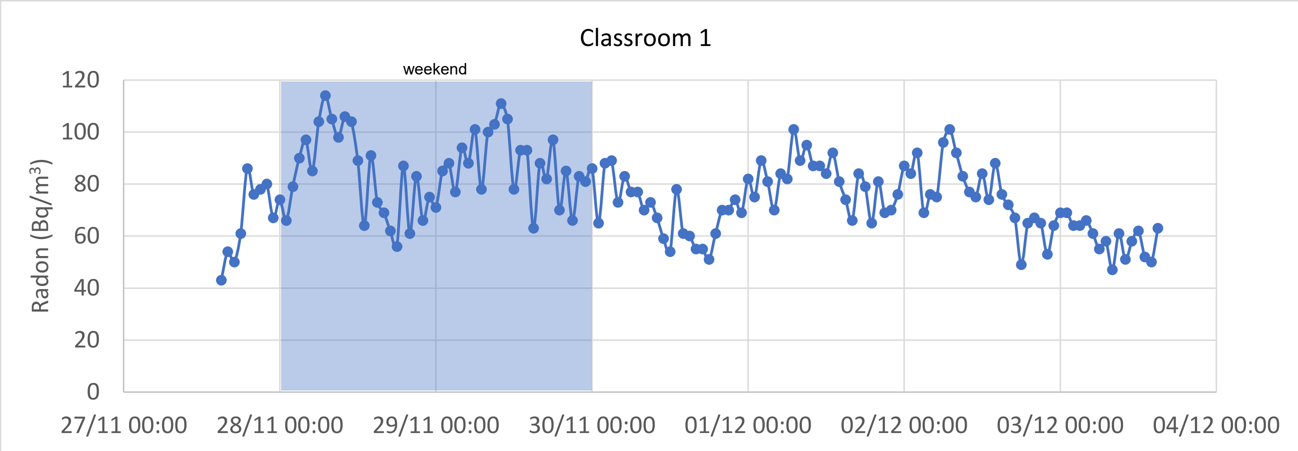


The graph shows continuous winter time monitoring of a classroom in a kindergarten during a weekend. The variation of the concentration is linked to the changes in room temperature.

Table 6 - Radon

What is it	Colourless and radioactive noble gas of natural origin, product of uranium decay. Found in the earth's crust, Radon penetrates buildings through cracks, crevices or open points in the foundations.	
Sources	The main source of Radon in buildings is the rocks underneath the building and the soil up to the surface, from which radon gas propagates. Construction materials may be a secondary source.	
Aims of monitoring	– Annual monitoring: checking concentration for compliance with legislative limits. – Continuous monitoring lasting less than one year: assessment of the concentrations in the premises at the time of their use; assessment of changes over time in the concentration of radon as the temperature and other parameters vary, such as the ventilation rate of the premises. Other purposes: – - checking the effectiveness of remediation operations.	
Units of measure	Bq/m^3	
Measurement principle	Passive systems: – Nuclear track detectors (also referred to as *dosimeters*) – Electret monitors Active systems: – Gas detectors (ionisation chamber) – Scintillation detectors (Lucas cells) – Semiconductor detectors (Silicon)	
Technical standard of reference	UNI ISO 11665-1 UNI ISO 11665-4 (passive sampling) UNI ISO 11665-5 (continuous measurements) UNI ISO 11665-6 (spot measurements)	
What the monitoring report must contain (for measurements performed by a test laboratory)	– Placement of the measurement instrumentation. – Condition of the premises (presence/absence of ventilation systems etc.), number of openings. – Plan.	
Duration, details of the measurement period and operative indications for monitoring	Passive sampling	It. Legislative Decree 101/2020 sets 1 year for the measurement.
	Continuous measurements	The measurement period varies according to the monitoring objectives, from 1 week to longer periods.
Influence with other parameters	Yes: temperature and ventilation rate.	
Regulatory or legislative limits	It. Legislative Decree 101/2020: maximum reference level expressed in terms of yearly average value of the radon activity concentration in air: 300 Bq/m^3 (school buildings are included under workplaces). This value is a reference level, that is, it is recommended to intervene to reduce concentrations even when the limit is not reached, but close.	

Figure 4 - Example of setting out radon data



Variations in radon concentrations in a school during a winter week.

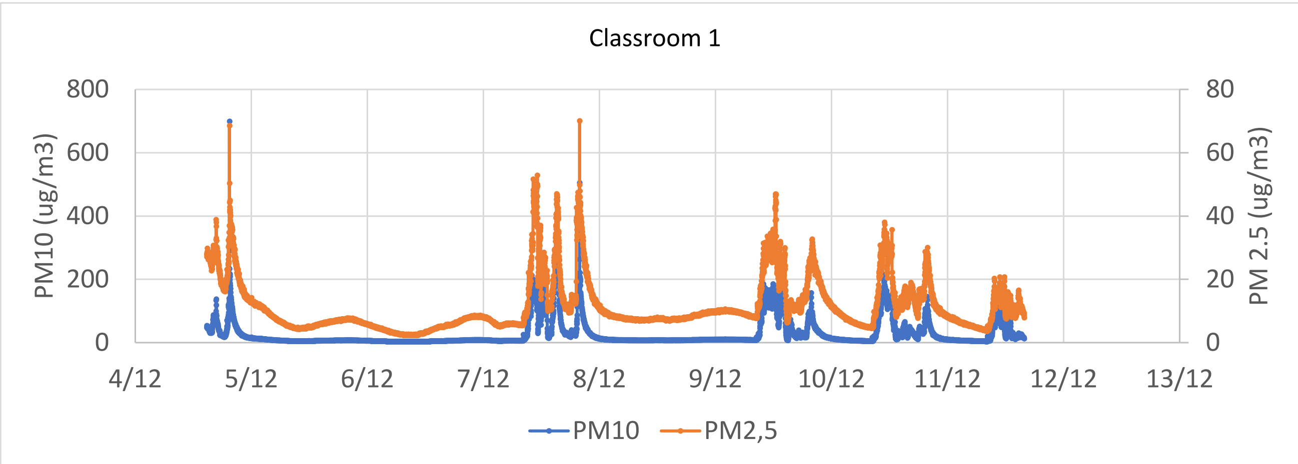
Table 7 - Dust (particulate matter)

What is it	'Dust' refers to all airborne solid particles that remain suspended for a sufficient time to affect the respiratory tract. The acronym PM, "Particulate Matter" is followed by a number indicating the diameter of the particle, which may range from 10 micron or micrometres (1 micron = 1 millionth of a metre). PM10 is also called thoracic fraction because, passing through the nose, it is able to reach the throat and trachea (located in the first part of the respiratory system). The smallest particles (with diameter less than 2.5 micron) are called PM2.5 or respirable fraction can penetrate even deeper into the gas-exchange region of the lungs.
Sources	Indoor: combustion (fireplaces and stoves for heating and for cooking), peeling of the skin, release from building materials and furnishing items, lifting of dust linked to various activities, poor maintenance of air conditioning systems. Outdoor: exhaust gases produced by means of transport with petrol and diesel engines (cars, buses, trucks, mopeds, etc.), lifting of dust from road surfaces, combustion deriving from heating systems and chimneys for use of biomass and diesel fuel.
Aims of monitoring	– Identify the main indoor and outdoor sources of pollution linked to PM10 and PM2.5 and its chemical characteristics and estimate the relevant contributions; – carry out the collection of specific information to support the decision-making processes of the competent subjects, when assessing the exposure of occupants to PM10 and PM2.5 and to toxic substances, with reference to the various lengths of time spent in a given indoor environment; – assess compliance with guide or reference values set by the competent Authorities or by international Organisations (e.g., WHO).
Units of measure	$\mu g/m^3$

Measurement principle	Continuous measurement	Laser diffraction analyser
	Spot measurement	Gravimetric method: determination of the mass concentration of suspended particulate matter through filtration on filters and weighing thereof by means of a scale. Only for total dust.
Technical standard of reference	UNI EN 12341 (gravimetric method): PM10 and PM2.5 ISO 16000-34 ISO 16000-37(PM2.5)	
What the monitoring report must contain (for measurements performed by a test laboratory)	See Annex B.	
Control over the quality of the measurement and instrumentation	Standard UNI EN 12341 contains all the essential procedural indications. Specifically, this standard describes: – the construction and performance specifications with which the sampling heads must comply (inertial impactors for selective "cut-off" of the PM10 and PM2.5 fraction), the suction lines, the supports for housing the filters, the suction systems; – the procedures for treatment, transport, conditioning and storage of filtering membranes; – the requirements of the analytical scale and the procedures for gravimetric determination; – the quality control and assurance procedures; – - the criteria for measuring and expressing the results.	
Duration, details of the measurement period and operative indications for monitoring	In order to define the time period of observation, one needs to refer to the guide values, established by the competent Authorities or contained in the WHO guidelines (2021). Indeed, should one wish to compare the concentration obtained with a reference guide value, the duration of monitoring must be the same as the time associated to the guide value (for PM10 and PM2.5 it is nominally 24 hrs). If, on the other hand, the sampling duration is less than the duration set forth by the guide/reference value, but is chosen based on school activities, use of the premises by people, or the activation of internal sources, the measurement provides an indicative value that will be useful to identify and estimate the possible contributions to the contamination levels of a given room, induced by the activity of the individual sources in operation at the time of measurement. It is therefore necessary to acquire information on the presence/absence of occupants and what actions they carry out at the premises, on the operation/activation of mechanical ventilation and heating systems, etc. In any case, the parameters and conditions of use of indoor premises for which the measurements may be deemed representative must be specified.	

	The frequency of measurements is scheduled in relation to the objective of monitoring, taking into account the activities, source(s), possible time variations (hourly, daily, monthly, seasonal), the microclimate variables. The PM10 and PM2.5 samplers to be used in sampling activities must comply with the specifications of standard UNI EN 12341.
Influence with other parameters	Yes: ventilation rate.
Regulatory or legislative limits	The WHO guide value updated in 2021 for exposure of the population to PM2.5 on a yearly basis is 5 μg/m³, whereas the daily one is 15 μg/m³. For exposure of the population to PM10, the WHO's annual guide value is 15 μg/m³ whereas on a daily basis it is 45 μg/m³. According to the WHO 2021 guide, the guide values defined for PM10 and for PM2.5 in ambient air are also applicable to indoor environments.

Figure 5 - Example of setting out particulate matter data



The graph shows the trends of PM10 (in blue, with values to be read on the axis on the left) and PM2.5 (in orange, with values to be read on the axis on the right).

Chart 8 - Nitrogen oxides

What is it	Nitrogen oxides are: nitrogen dioxide (NO2) and nitrogen monoxide (NO); these can be found in ambient air as a red-brownish gas, with a pungent odour and they are highly toxic.
Sources	In indoor environments, the sources of NO2 consist of kitchen stoves, stoves, heating systems with internal boilers and environmental tobacco smoke. An outdoor source is road traffic and the presence of garages or covered parking lots, since NO2 is also contained in the exhaust gases of vehicles. A further source is the ducted gaseous emissions of civil and industrial installations.
Aims of monitoring	Determine and quantify the presence of nitrogen oxides.
Units of measure	μg/m³, ppm
Measurement principle	UV ultraviolet chemiluminescence.

Technical standard of reference	UNI EN ISO 16000-15 UNI EN 14211
What the monitoring report must contain (for measurements performed by a test laboratory)	When diffusive samplers are used, the conversion equation used to calculate the result must be reported. In measurement results, numerical data are usually set out so that the last decimal place (significant position) simultaneously reflects the order of magnitude of the measurement uncertainty.
Influence with other parameters	Yes: ventilation rate.
Regulatory or legislative limits	The WHO guide value updated in 2021 for exposure of the population to NO_2 on a yearly basis is 10 µg/m³, whereas the daily one is 25 µg/m³.

Table 9 - Biological agents (airborne)

What is it	Airborne organic particles in the order of micrometres, often linked to other, larger particles, consisting of dust mites, biological materials, bacteria (e.g., legionella), viruses, fungi (moulds and yeasts), pollen. The microbiological parameters for basic quantitative analysis are as follows: – psychrophilic bacterial load bacteria with growth around 22°C (range 15-25°C), considered to be indicators of environmental microbial contamination; – mesophilic bacterial load bacteria with growth around 37°C (range 25-40°C), considered to be indicators of contamination of human or animal origin; – fungal load including moulds and yeasts, very important environmental indicators, as they are very often related to high humidity and dustiness, low ventilation and poor air quality.
Sources	Microorganisms are ubiquitous and able to live and reproduce using a multitude of substrates. In indoor environments such as schools, the microbial contribution depends above all on the entry and movement of people and objects. Moreover, the features of indoor air quality may be influenced by the movement of air circulation, also coming from the outside and, to a lesser extent, by the peculiar features of the materials in the environment itself (furnishings, paints and wall coverings, etc.) which, over time, may release substances or particles into the environment.
Aims of monitoring	In school premises, the risk due to the presence of biological agents is mainly of an infectious and allergic nature, depending on the content of bacteria, viruses, fungi, pollen and other components of organic origin in the bioaerosol. The pathways of exposure to hazardous conditions for people's health are mainly linked to inhalation and/or contact with contaminated air/surfaces. The sampling and analysis of bioaerosol, in addition to allowing the biological features of the air to be assessed, is also an indispensable tool for preventing health risks for the population in general and for the school population in particular. The main objective is therefore to assess the bacterial and fungal contamination.

<table>
<tr><td>Units of measure</td><td colspan="2">CFU/m³ of air (Colony-Forming Units per cubic metre of air)
MPN/m³ of air (Most Probable Number of Microorganisms per cubic metre of air)</td></tr>
<tr><td rowspan="2">Measurement principle</td><td>Sampling by sedimentation or gravimetric</td><td>The microorganisms, conveyed by airborne particles (PM), are collected by deposition on the surface of a plate (Petri dish) of known size, exposed to air for predetermined times and containing a suitable culture medium. After appropriate incubation of the plates, the number of colonies grown is counted and the measurement is expressed as a number per unit of surface. This method does not allow the number of microorganisms detected to be correlated to a known volume of air and is influenced by the degree of ventilation and by the air humidity of the sampled environment.</td></tr>
<tr><td>Sampling</td><td>By suction, it is possible to convey a certain amount of air directly onto a solid nutrient substrate suitable for microbial growth or into a liquid medium to be analysed later.
It measures the concentration of microorganisms present in the bioaerosol of the sampled air volume with an appropriate instrument and reduces to the minimum the differences in bacteria distribution.</td></tr>
<tr><td>Technical standard of reference</td><td colspan="2">UNI EN ISO 16000-19:2014 Sampling strategy for moulds
UNI EN ISO 14698-1:2004 Biocontamination control
Unichim Method 1962-2:2006 Workplaces – Microbiological air contamination (Bacteria and fungi) Determination by means of an active sampler by orthogonal impact
ISTISAN 20/03 Reports Indoor air quality in school environments: monitoring strategies of chemical and biological pollutants</td></tr>
<tr><td>What the monitoring report must contain (for measurements performed by a test laboratory)</td><td colspan="2">In addition to that set out in Annex B, the report must contain:
– type and characteristics of the indoor environment and situation at the time of collection (e.g., after classes, after cleaning the premises etc.);
– activities carried out therein;
– outdoor characteristics.</td></tr>
<tr><td>Duration, details of the measurement period and operative indications for monitoring</td><td colspan="2">Having to correlate the microbial concentration and the possibility of its inhalation during exposure, the samplers must be placed at an average height of 1.5 m from the ground to simulate an average height of the human upper respiratory tract. In the case of monitoring in school premises in the presence of children (kindergartens and primary schools), the height of sampling must be reduced to 1 m. Furthermore, the samples must be taken near the centre of the room to be monitored and at a distance of not less than 1 m from walls, doors and windows.</td></tr>
<tr><td>Influence with other parameters</td><td colspan="2">Yes: ventilation rate, temperature, relative humidity of air and interstitial (in masonry).</td></tr>
</table>

Regulatory or legislative limits	The variability due to the receptivity and individual response to the risk of microbial infection is such that it does not make it possible to define exposure limits accepted by the international scientific community and that can be used as threshold values. The reference values set out in the INAIL, ISS and WHO Guidelines may be used. The reference values must be framed against the context under study and considered over time based on the features of the environment being monitored.

Figure 6 - Results of the measurements set out in table format

Description of point	Collection date	Parameter	Conditions	MPN/m^3
External	31/08	Colonies at 22°C	After cleaning	**120**
External	31/08	Colonies at 36°C	After cleaning	**65**
External	31/08	Moulds	After cleaning	**460**
Section	31/08	Colonies at 22°C	After cleaning	**85**
Section	31/08	Colonies at 36°C	After cleaning	**80**
Section	31/08	Moulds	After cleaning	**268**

The table sets out the concentrations of bacterial and fungal load, in a classroom and outdoors.

Table 10 - Biological agents (on surfaces)

What is it	In indoor environments, surfaces may be an ideal substrate for the growth of bacterial flora. I this context the contribution of microorganisms and nutritional elements required for their sustenance can occur by direct contact as well as by sedimentation of indoor airborne particles. Other surfaces that might need to be tested are those of ventilation systems (ducting).	
Sources	As per biological agents (air).	
Aims of monitoring	– Check proper cleanliness of indoor surfaces such as desks, chairs, handles, bathrooms. – Check the condition of ventilation ducts.	
Units of measure	Colony-Forming Units (CFU) per cm^2 Colony-Forming Units (CFU) per plate	
Measurement principle	Microbiological method	It refers to the sponge, flexible slide, contact slide and swab method.
Technical standard of reference	ISO 18953 (for surfaces) UNI EN 15780 (for ventilation ducts)	
What the monitoring report must contain (for measurements performed by a test laboratory)	As set out above for air sampling.	
Duration, details of the measurement period and operative	For surfaces: sampling may be performed by placing the Petri dish containing the culture medium suitable for the growth of microorganisms to be detected against the surface to be monitored (or the flexible slides).	

indications for monitoring	As an alternative, one may use the swabs or moistened sterile sponges, by rubbing them on the area to be sampled. In the case of kits ready for use, the manufacturer's instructions must be followed. For ventilation ducts: UNI EN 15780.
Regulatory or legislative limits	Guidelines of INAIL "Microbiological surface contamination in workplaces" (2017). To assess the contamination condition of surfaces in school environments, two analytical procedures may be used that are already used in other fields for the determination of microorganisms on surfaces: the contact plate technique (e.g., Compact Dry, Rodac Weight, Maxi Contact Plate) and the swab technique (Source: ISTISAN Reports 20/3).

Figure 7 - Results of the measurements set out in table format

Description of point	Collection date	Parameter	Conditions	CFU/plate
Room 3: central desk	31/08/2021	Total aerobic mesophilic load	After cleaning	**12**
Room 3: central desk	31/08/2021	Moulds	After cleaning	**1**
Room 3: teacher's desk	31/08/2021	Total aerobic mesophilic load	After cleaning	**5**
Room 3: teacher's desk	31/08/2021	Moulds	After cleaning	**0**

Table 11 - Asbestos

What is it and sources	Asbestos is a generic, commercial term that groups a set of minerals belonging to the class of amphiboles and serpentines, chemically made up of hydrated calcium and magnesium silicates. Thanks to its properties, asbestos has been widely used in industry since 1930, either pure or mixed with other materials, for instance combined with cement to form asbestos-cement (for the production of tiles, flat and corrugated sheets, ducts and pipes, etc.) or with other chemical substances, to produce thermal or acoustic insulation. The presence of asbestos alone does not always pose a risk; it may become so if the material that contains it is degraded or damaged in such a way as to disperse its fibres in the surrounding environment, for example due to mechanical stress, thermal stress, water washout or even just vandalism. Although It. Law 257/1992 prohibited the use and production of asbestos and materials containing asbestos, the risk of exposure to this mineral still remains, since most of the materials containing asbestos are located in public buildings, schools and even in residential buildings built prior to 1980. (Source: Asbestos in schools mapping project, Lazio 2015). The main sources in school buildings are: – vinyl asbestos floors; – insulation behind radiators; – plaster; – boiler gaskets; – paints.

Legislative framework	From the point of view of identifying asbestos in schools and relevant responsibilities, one needs to consider the main implementation provision, It. Ministerial Decree 06/09/1994. This Decree describes how to identify the materials containing asbestos, the ensuing management tasks for risk mitigation and the methods to be implemented should one intend to clean up and remove said materials.
Details and aims of monitoring, procedure to be adhered to in the event the presence of asbestos is suspected	It is often difficult to tell whether roofs, slabs, tiles, pipes, ducts or other materials really contain asbestos as they can look very similar to the ones without asbestos. The age of the building is a good clue because the use of asbestos has been prohibited in Italy since 1994. That is why it can be inferred that a building, built or completely renovated after 1994, no longer contains asbestos materials. In the other cases one needs to use the services of an expert, who in some cases will need to analyse the suspected material. By itself, the presence of asbestos in a building does not pose a danger to the health of the occupants, provided that the material is in good condition and is not tampered with, punctured, cut or damaged in any way. However, in the event the material has been damaged due to normal wear, weathering or tampering, there might be a risk of fibres being released, which is a serious hazard for people's health. The managers of buildings where materials containing asbestos have been found are obliged to assure continuous monitoring thereof. The reclamation of materials containing asbestos generally involves a risk, of a professional nature for the personnel in charge of the removal, as well as an environmental one, connected to the methods of waste disposal of the material and possible contamination of the areas involved in the operation. In the event of reclamation, very strict provisions must be complied with, in order to prevent a hazard (see It. Ministerial Decree 6 September 1994).
Units of measure and monitoring	Fibres/litre Based on the risk minimisation principle, the concentration of airborne asbestos fibres must be less than 1000 respirable fibres per litre. It is important to underline that monitoring the ambient air makes it possible to measure the concentration of fibres only at the time of sampling. Therefore, the results must be considered as being tantamount to additional information and cannot replace a detailed assessment that includes all external factors.

7.3.1 OPENING/CLOSING OF WINDOWS AND DOORS

By monitoring the position of windows and doors, one acquires information to characterise school premises. By correlating the opening/closing data with the pollutant concentration data, it is possible to describe the air exchange rate according to the type and quantity of openings.

Table 12 - Parameters, instrumentation, references and details for measuring air quality (*summary*)

Measurement parameter	Instrumentation *details*	Needs/ absence of occupants	Duration and details of the measurements	Reference standards on sampling or legislative framework	Reference standards on limits or legislative framework
CO_2	Analyser, station, datalogger *Continuous measurement*	Presence	Measurement interval: 1 minute	UNI EN ISO 16000-26	UNI EN 16798-1 and CEN/TR 16798-2
VOC	Canister *Spot measurement*	Absence	30 min – 2 hours	UNI EN ISO 16000-5	Limits for certain VOCs
TVOC	PID *Continuous measurement*	Absence/ presence	Duration of monitoring: hours/days		
Formaldehyde	DNPH tubes *Spot measurement*	Absence[1]	30 min – 2 hours	UNI EN ISO 16000-2 ISO 16000-3 ISO 16000-4	Circular Letter of the Ministry of Health no. 57 of 22 June 1983
Radon	*Continuous measurement*		Measurement interval: 10 minutes	UNI ISO 11665-1 UNI ISO 11665-5 (continuous measurements)	
	Dosimeters *Spot measurement*		1 year	UNI ISO 11665-1 UNI ISO 11665-4 (passive sampling)	It. Legislative Decree 101/2020
Dust (PM_x)	*Continuous measurement*		Measurement interval: 10 minutes	UNI EN 12341 ISO 16000-34 ISO 16000-37(PM2.5)	
	Spot measurement	Absence/ presence	30 min – 2 hours		
Nitrogen oxides (NO2)	*Continuous measurement*			UNI EN ISO 16000-15 UNI EN 14211	
Biological tests	Microbiological sampler *Spot measurement*	Absence	Duration of the measurement: 15 minutes per each room	UNI EN ISO 16000-19 UNI EN ISO 14698-1 Unichim method 1962-2:2006	INAIL, ISS and WHO Guidelines
Asbestos		Absence		It. Ministerial Decree 06/09/1994	It. Ministerial Decree 06/09/1994

[1] UNI EN ISO 16000-2: it can be performed with presence of people.

7.4 APPROACH TO MEASUREMENTS, INSTRUMENTATION AND QUALITY CONTROL OF THE DATA

Air quality measurements may be carried out:

- by an accredited test laboratory, according to standard CEI EN ISO/IEC 17025;
- by a non-certified test laboratory, a professional, an agency, as set forth by the ISO 16000 series.

In their turn, the measurements may also be performed by using an instrument that is either:

- compliant with the technical standard of reference;
- non-compliant.

For measurements made with instrumentation that does not comply with the technical reference standards, indications are provided below to perform scheduled tests in order to ensure the quality of the measurement for some air quality parameters and indicators. It is possible to acquire data on the parameters described below also through building management and adjustment systems: also in this case, in order to ensure the quality of the data, the tests set out under Item 7.4.1 must be carried out.

Performing measurements with reliable instrumentation or systems and the result of which is controlled is essential in order to ensure the quality of monitoring.

Many commercially available instruments and systems cannot be calibrated by the user, most of the times they come with a declaration of conformity produced by the manufacturer and any subsequent calibration may entail costs that exceed the value of the instrument itself. Checking the operability of an instrument, however, is crucial and must be done at set time intervals, because any device loses its calibration over time. Instruments for measuring temperature, relative humidity, atmospheric pressure and carbon dioxide can be easily checked by the user, as often as needed.

Independent monitoring (i.e., that which may be carried out by the school building manager) of air quality parameters (CO_2, temperature, relative humidity, and pressure) entails certain essential procedures and knowledge:

1. **Recording the equipment**

   A basic principle for data quality assurance is recording the equipment. Every measurement device installed should be associated with a unique identification code, this code must be displayed on the instrument and on an Identification card that records its whole history. The minimum information to be recorded is set out in Annex C.

2. **Units of measure**

   The instruments for measuring air quality use units of measure to express the result, it is important to become familiar with the units of measure and be able to compare the results of different measurements only if expressed with the same unit of measure. For instance, it is not possible to compare a concentration expressed in $\mu g/m^3$ with one in ppb or vol%, before doing so the units of measure must be converted to the same one. Details on the conversions are described in Paragraph 7.2.4.

3. **Checking the instrumentation**

No measurement is reliable unless the operability of the instrument used has been ascertained prior. Every instrument must be checked during use, at set intervals.

Simplified procedures for calibration and checking are provided in Annex D.

4. **Control cards**

The control card is described in Annex D.

5. **Placement of the equipment, measurement conditions**

An environmental measurement must represent the context where it is carried out, e.g., a thermometer installed on the ceiling of a classroom does not represent the temperature perceived by the occupants of the classroom. In this case the thermometer will show a higher temperature than that at head height. A standardised measurement method contains all the information required on placement of the equipment and conditions to be complied with to carry out the measurement. An example of instrumentation placement is shown in Figure 2.

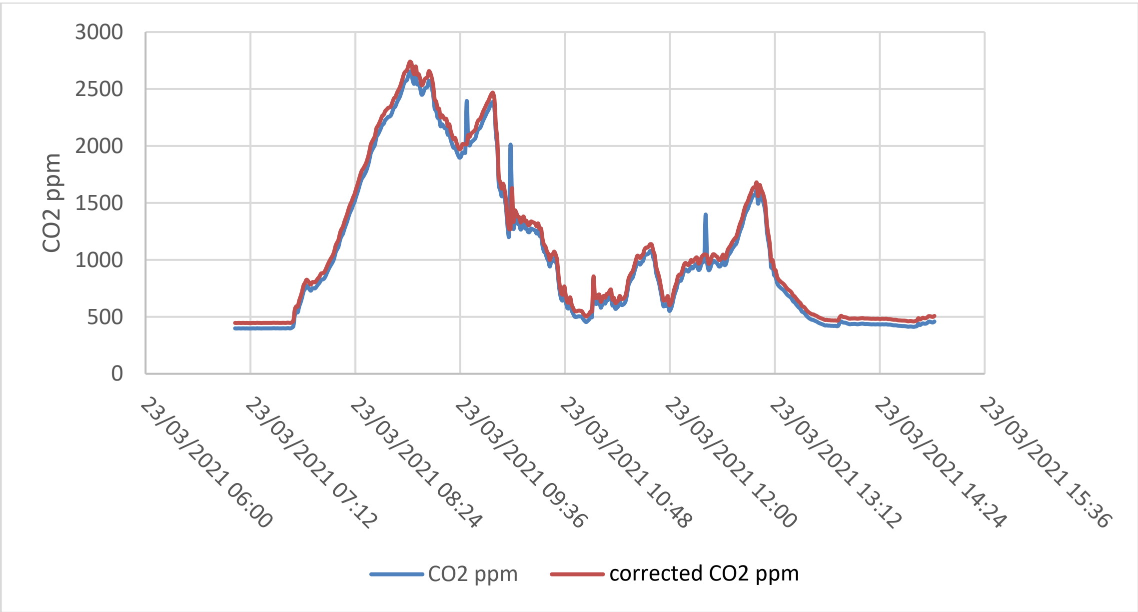
6. **Measurement and data recording**

A monitoring system consists of the instrument and the software that acquires and records the data, the necessary assessments cannot be carried out without the records. The recording criterion is not random, each manufacturer adopts its own, e.g., minute average (recommended), average of several minutes (5,10, 15...), spot value of a minute or several minutes (e.g., the last acquired value of 15 min.). It is important to know how the instrument software acquires the data.

7. **Data validation and processing**

The raw measurement data acquired by software are not ready to be interpreted, they need to undergo an important operation first: validation. Validation is a "cleaning" operation, where the data that stem from instrument anomalies, drifts or tampering are removed.

Figure 8 - Example of data validation



The graph above shows the raw data (blue) and the validated data (red), cleaned up from peaks due to tampering.

The following knowledge is required in order to contract out the measurement on air pollutants to a test laboratory:

A. **Identification of the test laboratory**

   Identifying a test laboratory to carry out specific tests is difficult. It may be useful to refer to the web page of ACCREDIA: www.accredia.it, databases, search test laboratories. Or refer to the local environment agency, local health authority to ask for advice.

B. **Accreditation**

   An accredited test laboratory meets the general requirements for the competency of test laboratories and calibration defined by standard ISO/IEC 17025. An accredited test laboratory warrants its competency in carrying out certain tests. In Italy, the single accreditation body is "ACCREDIA".

C. **Measurement methods**

   The standardised measurement methods are documents that describe all the required procedures to perform a given test. In the contract stage, it is important for the test laboratory to declare to the client what measurement method will be applied. Tables from 1 to 9 show the references for each pollutant.

D. **Test report**

   This is the final document that contains the result of the measurement and all the information required to characterise it. The test report is drawn up by the laboratory that carried out the test. The information must be clear and allow the client to understand it and to be apprised of all the activities carried out.

For the parameters that must be measured by a test laboratory, such as volatile organic compounds and formaldehyde, the use of professional instrumentation is critical. The main problem is that very small quantities are measured with sensors that are not sufficiently sensitive. For instance, many commercial sensors for measuring formaldehyde have a measurement range from 0 to 5 ppm. It has been observed that in an indoor environment, the limit value of formaldehyde that must not be exceeded is 0.1 ppm. To do that, the sensor should therefore be so sensitive as to accurately detect a concentration of at least 0.05 ppm (100 times smaller).

Therefore, sensitivity is the main problem of these instruments and consequently also selectivity, that is, the ability to "isolate" the signal of the substance sought from that generated by other "interfering" substances – the smaller the quantity to be measured, the higher the weight that the interfering substances may have on the result.

In a classroom, when the concentration of formaldehyde is properly measured following renovation or refurbishment with new furniture, if the conditions do not change, it can be expected to remain so for years. The same principle applies to volatile organic compounds where, bar special cases, the pollution produced by the activities carried out by people and by the people themselves is much greater than that caused by the furnishings and structure. Therefore, when the activity carried out is known, the VOC emission will not change significantly over time. If these pollutants are measured properly once and the ventilation rate required for concentrations to be low is known, then the measurement of CO_2, temperature and air humidity alone are enough to monitor the air quality in the premises.

If there is a need to measure the concentration of certain special pollutants in a room, the best strategy is to request the support of a test laboratory, which must have the appropriate equipment and knowledge. In this event, however, basic knowledge is still required, in order to assess the activity carried out by the appointed laboratory.

The first step to measure an airborne pollutant is the application of a standardised test method, i.e., the procedure to be implemented, the technique, the specifications of the equipment, the materials to be used. The test methods are drawn up and issued by national and international bodies such as UNI, EN, ISO, their application is not mandatory unless required expressly by the legislative framework. However, it is important for the laboratory to apply them, for instance in the event that the data measured in the same room by different institutes need to be compared. If different methods have been used and the level of equivalence between methods is not known, interpretation will also be difficult. Any other method may be used nevertheless, after ascertaining that the results obtained are equivalent to those obtained with the method of reference. The matter is governed by specific regulations.

Therefore, the test method to be applied must be determined, by agreement with the appointed test laboratory.

The test method describes the techniques that make it possible to measure a physical or chemical parameter that characterises the air quality of an environment. Essentially, these techniques have two approaches:

- indirect measurement, in this case the compound to be measured is first concentrated on a suitable medium (vial, filter, solution) then determined at another time;
- direct measurement, typical of automatic instruments where the result of the measurement is obtained in a very short time (seconds).

The indirect measurement is more sensitive, precise than the direct one, the result obtained represents the average concentration of the pollutant in the time it took to collect it (30 min, 1 hour, 1 year, etc.). Furthermore, indirect measurement is not well suited to short-term sampling.

The direct measurement is sometimes less sensitive than the indirect one but has the advantage of obtaining the trends of a pollutant’s concentration over time, which for instance, in the case of CO_2, may be very important data.

The method also determines what environmental variables affect the test result.

7.4.1 CONTROL OVER THE QUALITY OF THE MEASUREMENT PERFORMED INDEPENDENTLY

The procedure to check the quality of the instrument and of the measurement entails two steps:

- recording the characteristics of the instrument (an example of identification card is provided in Annex C);
- assessment and systematic control of the data provided by the instrument through periodic recording of the output data (Annex D).

Annex D provides an example of control card to check the quality of the measurement. This document makes it possible to evaluate over time the performance of the instrument, keeping it under control.

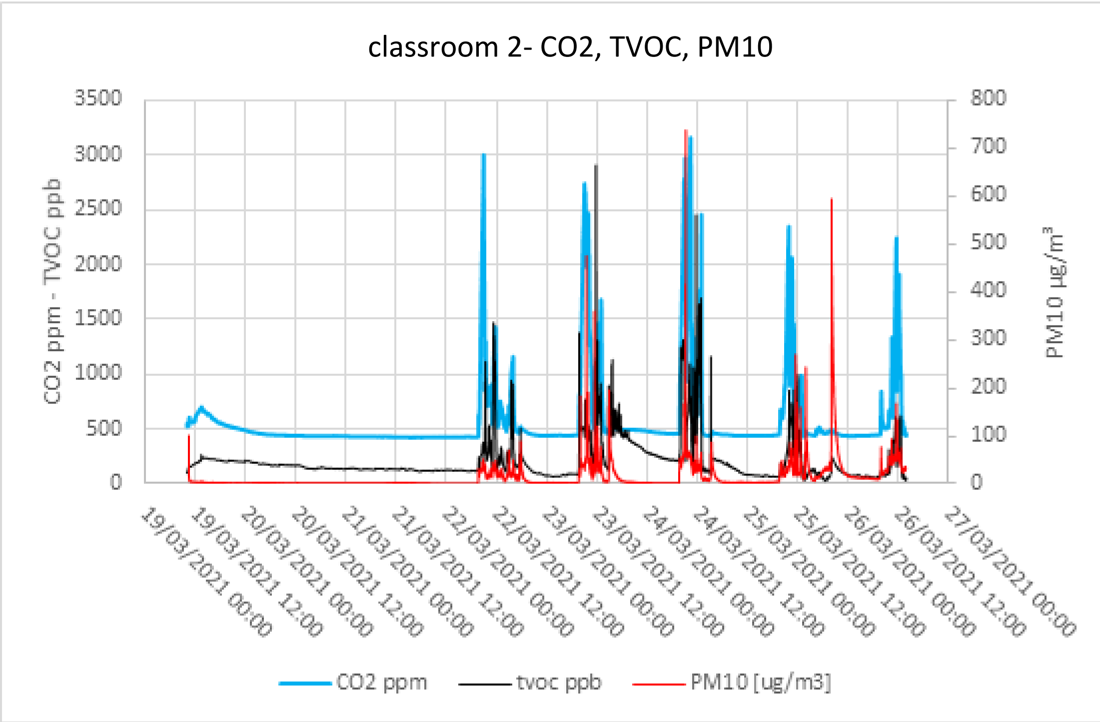
Table 13 - Air quality parameters

Parameters that may be measured by the school independently	Main parameters that require the involvement of a test laboratory
- carbon dioxide (CO_2) Supplementary parameters (optional): – air temperature – relative air humidity – atmospheric pressure	- formaldehyde - VOC, TVOC - radon - particulate matter - biological measurements - NOx - …

The measurement of the temperature and relative humidity of air may be useful, for instance to assess the opening of doors and windows in case of airing. That is why it is recommended to monitor the temperature and relative humidity of air with the same measurement interval.

The choice of CO_2 as the main indicator of air quality is corroborated by the extensive scientific and regulatory literature (such as UNI EN 16798-1). By way of example, a graph is provided for comparison (Figure 10), showing how the CO_2 concentrations have a similar trend to those of TVOC and PM10.

Figure 9 - Comparison between CO_2, TVOC and PM10



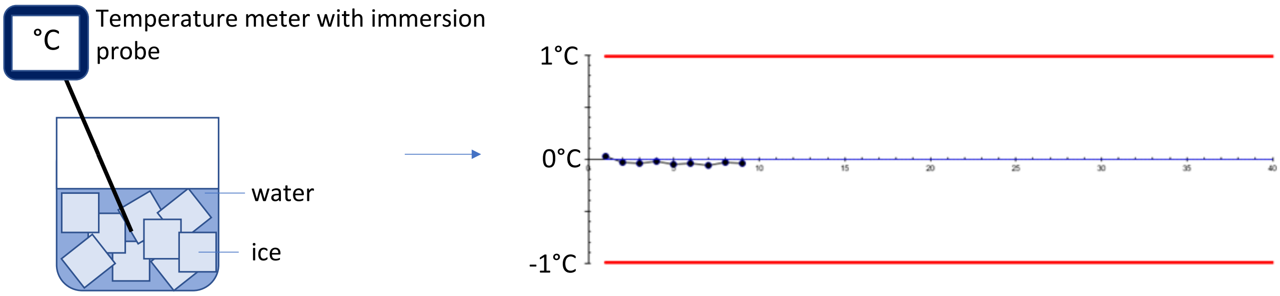
7.4.1.1 Simplified procedures for instrumentation control for measurements performed independently

The control procedures for the following parameters are described below:

- air temperature
- relative air humidity
- atmospheric pressure
- carbon dioxide.

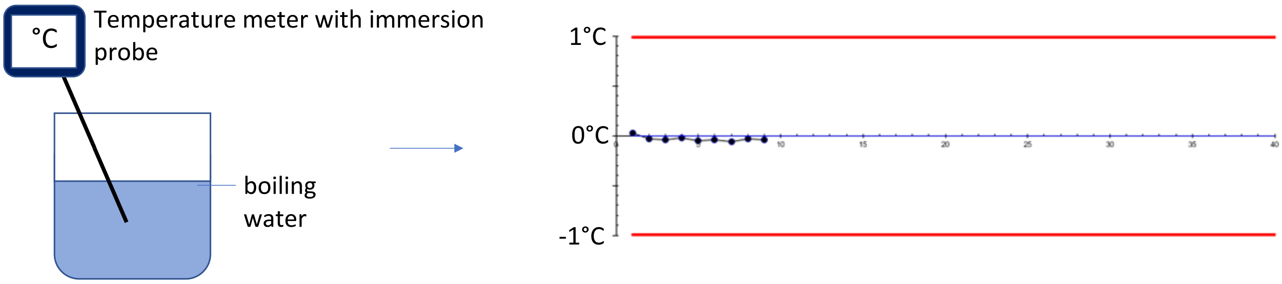
<u>Air temperature</u>
The sensor is immersed once in melting ice (a glass full of ice cubes covered with water) and once in boiling water to obtain the value 0°C and 100°C with good approximation. The sensors fitted in the instruments for measuring air temperature often cannot be immersed in a liquid; an immersion thermometer can then be used, calibrated as described above and then the other sensors can be checked by comparison.

Figure 10 - Procedure for controlling the instrumentation for temperature measurements performed independently. Immersion in ice



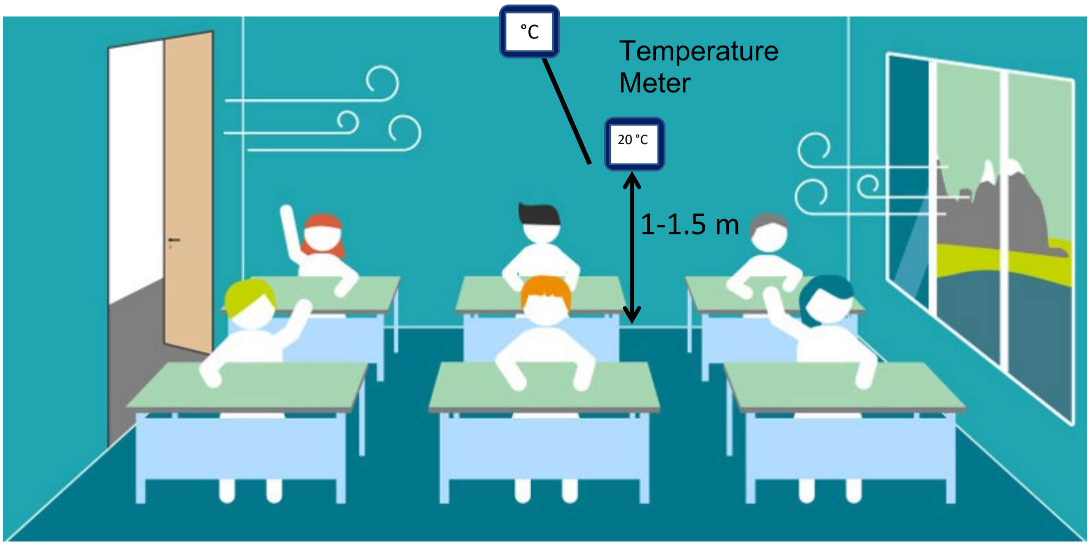
The deviation or acceptance limit must be ± 1°C.

Figure 11 - Procedure for controlling the instrumentation for temperature measurements performed independently. Immersion in boiling water



The deviation or acceptance limit must be ± 1°C.

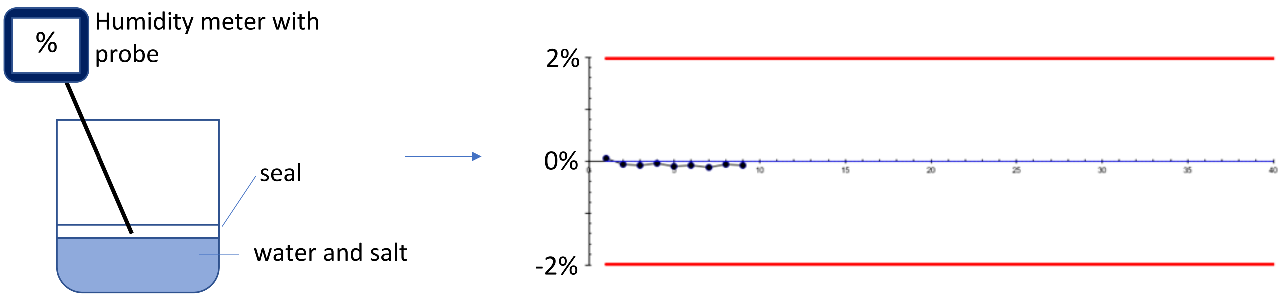
Figure 12 - Comparison with instrument placed in the classroom



The deviation or acceptance limit must be ± 2°C. The differential between the value indicated by the control instrument (immersion thermometer) and that of the environment being monitored will be compared.

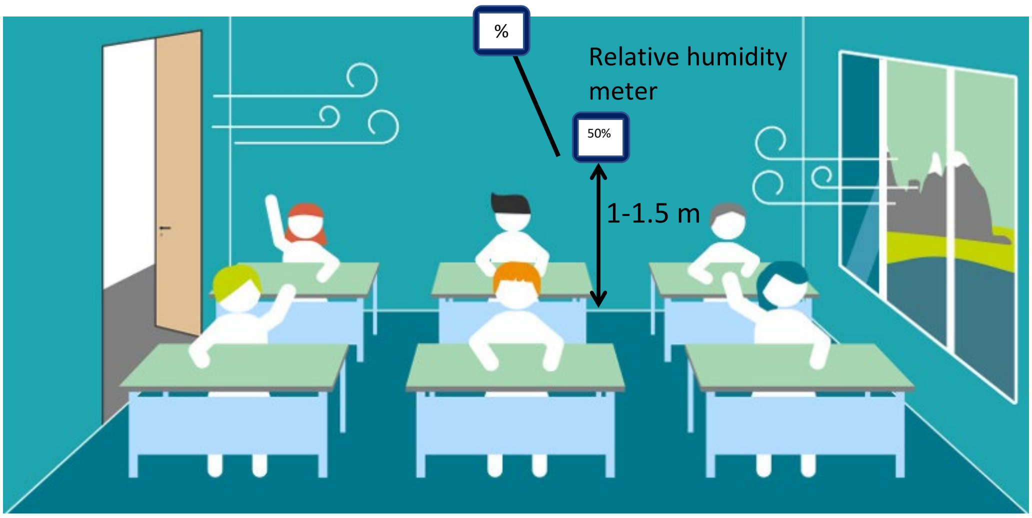
Relative air humidity: calibration by means of a solution of saturated salts.
A sufficient, albeit incomplete, check of a humidity sensor can be carried out by exposing the sensor to a hygroscopic gel first (such as silica gel which is affordable and easily available) and then to a saturated solution of table salt. In this way there will be two control points: one close to zero and one close to 75% relative humidity. Two plastic jars can be adapted with minimal manual ability, one for the gel and the other for the salt-saturated solution, half of the jars will be filled with the gel or solution, the sensor is inserted in the upper half (without immersing it). As for the temperature, also in this case it might be more practical to procure an instrument with probe that is suitable to be inserted in the hole of a jar, then use it to compare the sensors installed in the various rooms.

Figure 13 - Procedure for controlling the instrumentation for relative humidity measurements performed independently



The deviation or acceptance limit must be ± 2%.

Figure 14 - Comparison with instrument placed in the classroom



The deviation or acceptance limit must be ± 2%.

Atmospheric pressure: the data may be obtained from the website of the closest airport or weather station. One needs to pay attention because the pressure value indicated by airports always refers to sea level, a conversion must therefore be applied to bring it to the proper altitude.

Carbon Dioxide: the external concentration of CO_2 can be taken as reference, with good approximation – in an urban environment, without excessive traffic, it is around 450 ppm.

Temperature, relative humidity, atmospheric pressure and carbon dioxide, measured with type 2) instrumentation, the condition of which has been checked as described above, and which is therefore able to provide reliable and useful information on air quality within lived-in premises. The check performed must be systematically documented: an example is provided in Annex C.

ANNEX A

(informative)

SCHOOL INSPECTION QUESTIONNAIRE

A.1 OVERVIEW

This Annex provides a guideline on the information to be collected prior to and during monitoring. This information may be supplemented with specific information. This questionnaire has been built upon standards ISO 16000 and ISTISAN Reports.

Date	
People present	
Questionnaire filled in by	

School name	
Address/number	
No. of floors (above ground/basement)	
Contact information of person in charge	
Useful contact telephone numbers for the school	

A.2 USE, SPACES AND STRUCTURE (FOR EACH BUILDING – EXTENSION/SCHOOL/INTENDED USE)

Hours of use		
No. of classes		
No. of students		
Canteen	yes ☐	no ☐
Gym	yes ☐	no ☐
Laboratories	yes ☐	no ☐
Other rooms		
Special rooms		
Maintenance		
Cleaning of the premises	(hours, responsibility, …)	
Wireless available	yes ☐	no ☐

A.3 CHARACTERISATION OF CLASSROOMS (FOR EACH BUILDING – EXTENSION/SCHOOL/INTENDED USE)

Classroom height	
Windows (describe)	
Furnishings	
Equipment	

A.4 CHARACTERISATION OF THE BUILDING

Year of construction	
Year of renovation	
Environment around the building	Rural ☐ Urban ☐ City centre ☐ Light traffic ☐ Heavy traffic ☐ Industrial estate ☐
Exposure	North ☐ South ☐ West ☐ East ☐
Energy class	
Walls	Insulation: yes ☐ no ☐
Doors and windows	PVC: wood ☐ aluminium ☐ Date of installation: Glazing: single ☐ double ☐ triple ☐

A.5 INSTALLATIONS

Fuel	Methane ☐ LPG ☐ Diesel fuel ☐ Biomass ☐ Other ☐
Renewables	Photovoltaic ☐ Thermal solar ☐
Heating	
Cooling	
Heat generation	Boiler ☐ Heat Pump ☐ District heating ☐ New old
Supplementary heating	(electric heaters, wood, pellet stove, …)
Cold generation	Heat Pump ☐ Chiller ☐ New old
DHW generation	Resistance boiler ☐ Boiler ☐ Heat Pump ☐ District heating ☐
Emission	Heating elements (radiators) ☐ Radiant floor system ☐ Radiant ceiling system ☐ Fan heaters ☐ Ducted system ☐
Regulation	
CMV	Centralised ☐ Individual room ☐
CMV – heat recovery	yes ☐ no ☐
Consumptions (bills)	High expenses ☐ Low expenses ☐
Lift	yes ☐ no ☐
Periods of installation use	Heating Cooling CMV

A.6 FINISHES

Classroom walls	Plastered covered with ..
Walls of other rooms	Plastered covered with ..
Walls …	Plastered covered with ..
Classroom floors	In wood ceramic/stoneware PVC …
Floors of other rooms	
Floors …	

A.7 PROBLEMS IN RECENT YEARS

Mould	(where?)
Stale air	(where?)
Odours	
Dry eyes	
Discomfort	
Temperatures	(low/high)
Radon	
Formaldehyde	
High CO_2	
Other	

A.8 MONITORING AND TESTS ALREADY PERFORMED?

Take photos of: floor plans (fire safety), classrooms, common areas, envelope, installations.
Instrumentation to bring: Laser distance meter, Camera.
Documentation to be requested: system maintenance.

ANNEX B

(informative)

TEST REPORT ACCORDING TO UNI CEI EN ISO/IEC 17025

The test report on the air quality measurement performed by a test laboratory must include the following. In addition to which, the Tables under Items 7.3 detail additional specific data for each indicator and pollutant.

- Title;
- the name and address of the test laboratory;
- the place of execution of laboratory activities, including those carried out at the school or at sites outside the permanent premises of the test laboratory, or in temporary mobile locations thereof;
- a unique identification to recognise all the parts that make it up as integral parts of the complete report, and a clear identification of the end of the report;
- the name and contact information of the client;
- identification of the method used;
- the description, unique identification and, where necessary, the conditions of the object;
- the date of receipt of the object(s) undergoing the test, and the date of sampling, when it is critical for the validity and use of the results;
- the date(s) of execution of the laboratory activity;
- the date of issuance of the report;
- the reference to the sampling plan and to the sampling method used by the test laboratory or other body, when this information is relevant for the validity or use of the results;
- a statement certifying that the results only refer to the objects that underwent the test, calibration or sampling;
- the results, where appropriate providing the units of measure;
- additions, deviations or exclusions from the method;
- identification of the person(s) who authorise(s) the report;
- clear identification of the results originating from external providers.

In addition to the listed requirements, the test reports must include the following, where necessary for the interpretation of the results:

- information concerning particular test conditions, such as the environmental conditions;
- declaration of conformity to requirements or specifications;
- the uncertainty of measurement set out in the same unit of measure of the measurand or in relative terms with respect to the measurand itself (for instance as a percentage) when:

    - it is significant for the validity or use of the test results;
    - it is required by the client, or
    - it affects the conformity to a specification limit;
- where appropriate, opinions and interpretations;
- further information that might be required by specific methods, authorities, clients or groups of clients.

When the test laboratory is responsible for sampling, the test reports must comply with the requirements listed below, where necessary for the interpretation of the test results.

ANNEX C
(informative)

IDENTIFICATION CARD OF THE INSTRUMENT

C.1 OVERVIEW

This Annex sums up the information to be collected relating to instruments for measuring air quality (such as CO_2 meters) and the parameters of indoor premises (such as thermometers, hygrometers, ...).

C.2 IDENTIFICATION CARD OF THE MEASURING INSTRUMENT

Owner	

Instrument name	
Model/type	
Serial number	
Software/Licence no.	
Manufacturer (address, contact information)	
Distributor (address, contact information)	
Date of purchase/receipt	
Date of commissioning	
Person in charge of the instrument	
Condition at the time of receipt (new, used, reconditioned)	
Identification/serial number	
Location	
Card filled by (name, date and signature)	
References on calibration, certificates	

ANNEX D
(informative)

CONTROL CARD

D.1 OVERVIEW

This Annex describes the contents of the control card for the instrumentation used to check the operability of a measuring instrument. The objective of this document is to ensure the data provided by the measuring instrument is correct within the acceptance limit.

D.2 CONTROL CARD OF AN INSTRUMENT

Identification/serial number	
Description of what needs to be checked	
Acceptance limit	

No.	date	Reference value	Reading value	Acceptance limit
1				
2				
3				
..				

ANNEX E

(informative)

SETTING OUT THE RESULTS

E.1 OVERVIEW

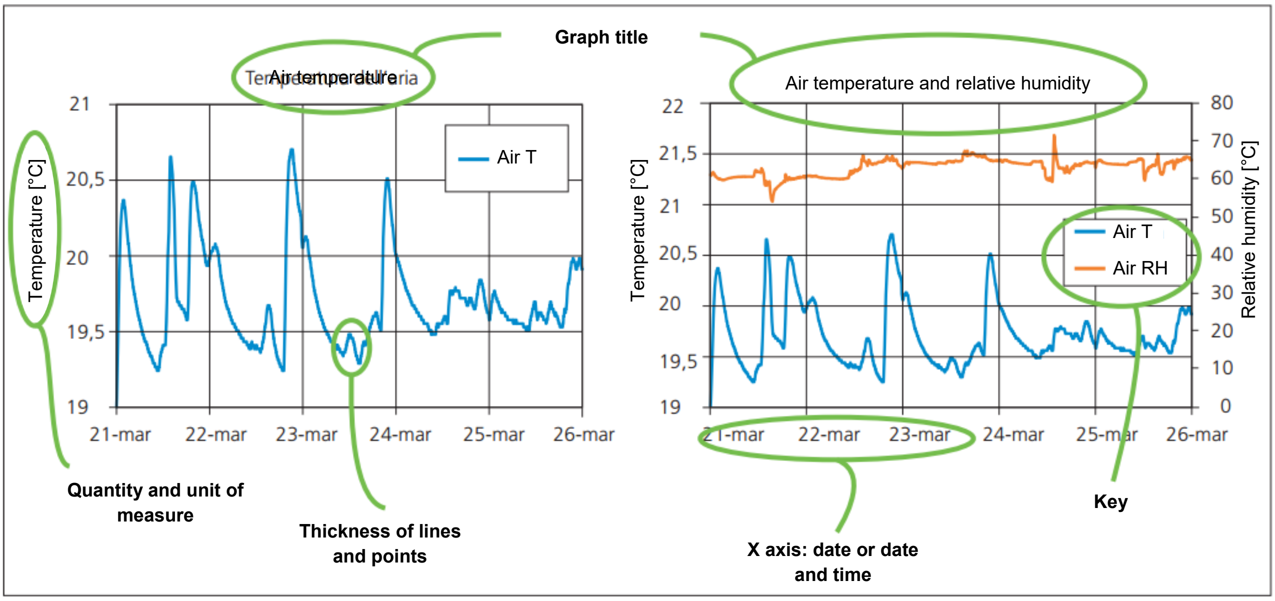
This Annex provides information and examples to set out the results of the monitoring on air quality and other parameters. The objective of this Annex is to improve the legibility and interpretation of the measured data.

E.2 CONTINUOUS MEASUREMENTS

Essential aspects to ensure proper reading of the data:

- use an appropriate scale (maximum and minimum value must be chosen according to the data. In the temperature graph in Figure E.1 the minimum value is 19 and the maximum one is 21 °C);
- the thickness of lines and points must be appropriate for reading – if too thin, they might be difficult to read, if too thick some data might often overlap hence get lost;
- the horizontal and vertical grid makes reading easier;
- colours: to make it easier to read graphs for colour-blind people, it is recommended to use easily recognisable symbols;
- the ordinate axis must be legible. If a date is shown, it is important to highlight the time of day one refers to (i.e., whether the data refer to midnight, midday or another time);
- when several monitoring days are set out (on the X axis), it might be useful to highlight school days as well as Saturdays and Sundays;
- by selecting one part of the data (for instance working hours for an office), it is possible to make reading and interpretation easier, avoiding to include data that are irrelevant for the analysis;
- for two-variable graphs, overlapping the data of the two parameters must be avoided, adapting the two scales (for instance in the graph on the right in Figure E.1, the temperature scale was increased: the maximum value went from 21 to 22°C).

Figure E.1. Example of setting out continuous series of data



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