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Air Quality in Schools

Strategic Guidelines for an Integrated Approach towards indoor well-being.

Summary

Introduction

The importance of Indoor Air Quality (IAQ) and the health effects caused by excessive concentrations of harmful contaminants in indoor environments, where we spend more than 90% of our time, are widely recognised. For a general overview on this topic, see for example the document "**Air Pathway: Indoor Air Quality**", Clust-ER Greentech (2021).

To date, regulations and evaluation criteria are being developed and they set maximum concentration limits for the various harmful substances (these limits are only defined for Radon), but the **ISO EN 16000** standard (prt 1-42 in progress) provides indications on appropriate indoor monitoring criteria for human well-being. On the other hand, there are technical solutions for certain types of pollutants, characterised by varying levels of complexity, which allow **real time IAQ monitoring, with good data quality and at relatively low prices**. In addition, many solutions have been developed in recent years for **air filtration** and **abatement of potentially harmful gaseous and particulate substances**.

Among the environments that are particularly relevant in terms of occupant characteristics and the long-term impact of Indoor Air Quality are certainly school environments. As a matter of fact, schools are attended by potentially fragile subjects, in large numbers and for prolonged periods (approximately 1,000 hours per year for a secondary school pupil).

School buildings are also often energy inefficient and lack adequate air exchange and treatment facilities. For these reasons, school environments are an excellent case study for **implementing innovative IAQ systems**, and their implementation would allow to achieve long-term benefits, starting with a relatively small number of interventions.

DOWNLOAD

Air Pathway: Indoor air quality

Download the document "Air Pathway: Indoor air quality" (Clust-ER Greentech, 2021) at https://greentech.clust-er.it/documenti-e-pubblicazioni/

1. Purpose and scope

This initiative, promoted by the **IAQ Working Group - Indoor Air Quality of Greentech Clust-ER**, in collaboration with **Build Clust-ER**, intends to **provide strategic and methodological guidelines that, through an integrated approach, allow to ensure real indoor well-being in school environments**, in accordance with the necessary **energy efficiency and saving** measures.

The aim is to propose a set of **methodologies and best practices** for **construction** (low-emission materials, energy-efficient forced mechanical ventilation systems), **monitoring** (low-cost systems for indoor and outdoor air quality assessment, big data and artificial intelligence) and **remediation** (air filtration and pollutant abatement systems) that produce health benefits for occupants.

The document is addressed not only to Facility Managers[1] or HSE Managers[2] but also to school building managers (Municipalities, Provinces, Managers) and specialists involved in indoor air assessment during the design, construction, operation and use of buildings. This also includes manufacturers and distributors of products installed and/or operated in indoor environments and possible users, school managers, teachers and students who, starting from the basic elements of IAQ assessment, can draw indications for day-to-day management of equipment and environments and, at the same time, acquire notions of comfort and well-being to be implemented in general in living environments.

These guidelines, elaborated by the ClustER Greentech IAQ working group, refer to **ISO 16000-prt 40 I.A.Q.MSSt**, where the necessary steps for the correct management of air quality in confined spaces are indicated:

- **Background**: an analysis of outdoor air quality and correlation to indoor air quality
- **Diagnosis**: an analysis of equipments/installations
- **Test**: a measure of the initial situation
- **Remedy**: a possible improvement action
- **Management and Maintenance**: scheduled maintenance

[1] 💼 The Facility Manager is a professional figure in charge of the management of buildings and all those instrumental services managed by the company. He/She may be in charge of offices, shops or factories, managing their maintenance and telecommunications security, cleaning services or canteen services. He/She has wide-ranging responsibilities encompassing the strategic, analysis and control, and management-operational areas relating to instrumental real estate, technical, ancillary, general services, etc.

[2] 💼 HSE stands for Health, Safety & Environment. HSE Manager is the figure who is responsible for managing these aspects within the company's ecosystem of activities and processes.

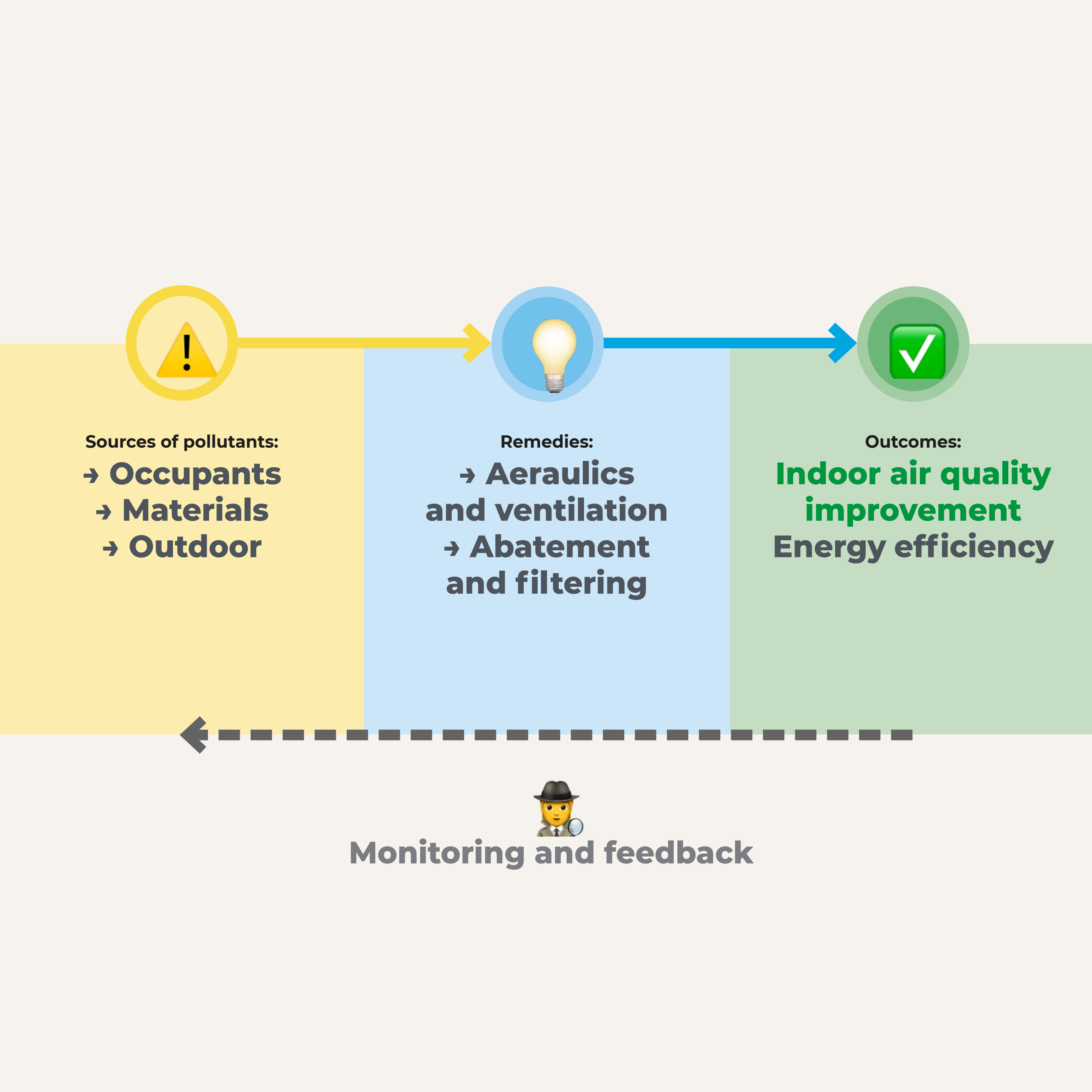

Figure 1.1: Summary diagram for proper indoor air management. For a more detailed explanation see 👉Annex 1

2. Sources of pollutants

With the exception of radon, whose origin is closely related to the lithology of the area or to building materials, for the other pollutants taken into consideration, indoor concentrations may be influenced by outdoor concentrations. For this reason, opening windows to "change the air" in a room can, in certain cases, have negative effects on the occupants. In the following paragraphs, the main sources of indoor air pollutants are described.

2.a Outdoor pollutants

Indoor ventilation is important to avoid the accumulation of pollutants from indoor sources. At the same time, the entry of air from outside, through natural ventilation (opening of windows), at particular times of the day and based on geographical location, can increase the pollution of the indoor environment, in some cases more than 50%.

This is because the outside air can be laden with harmful substances of various kinds, of biological or anthropogenic origin.

The main biogenic particles dispersed in the atmosphere are pollen and fungal spores, which are often overlooked but are of great importance since, in addition to generating respiratory allergies in sensitive individuals, they can aggregate with atmospheric particulate matter and increase their mass. Also present in the atmosphere are Volatile Organic Compounds (VOCs) of a biogenic nature, such as isoprene and terpenes emitted by plants, which, through oxidation, produce secondary organic aerosol, which means not emitted directly, but the result of conversion processes that take place in the atmosphere. Anthropogenic pollutants in the outdoor air consist mainly of:

- **Gaseous species**, such as sulphur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), ozone (O3), benzene (C H66), PAHs (Polycyclic Aromatic Hydrocarbons) and VOCs.
- **Airborne particulate matter:** PM10, PM2.5, PM1, ultrafine particles.

In particular, PM is a highly complex mixture, whose chemical composition depends on its size, source, residence time in the atmosphere, transport and chemical transformations it has undergone due to solar radiation and other boundary conditions. Its composition consists mainly of carbonaceous materials, including elemental carbon (EC) and organic carbon (CO) that includes, among others, compounds such as Polycyclic Aromatic Hydrocarbons (PAHs), which contribute to its toxic potential.

From an epidemiological point of view, **the PM is held responsible for diseases**, as it is capable of penetrating deeply into the respiratory system (fine particulate matter, diameter less than 2.5 µm, PM2.5), up to the alveoli (ultrafine particulate matter, diameter less than 0.1 µm, PM0.1 and nano-particles, diameter in the order of magnitude of nanometres, PM0.001) with consequent on other districts such as the circulatory system, as indicated by the World Health Organisation (WHO).

Atmospheric PM and gaseous pollutants, having an inflammatory effect on the airways of sensitive individuals, can facilitate the penetration of allergens such as pollens and their interaction with the immune system, thus causing an increase in the individual's hypersensitivity.

In the urban environment, air quality is mainly influenced by local emission sources related to human activities, such as combustion(vehicular traffic, civil heating, biomass combustion), industrial, resuspension, etc.

In the vicinity of school facilities, the passage of public and private transport, which is particularly intense at the beginning and end of educational activities, leads to a further increase of pollutants due to exhaust emissions, as well as emissions from road surface abrasion and wear (PM of various kinds). Numerous studies confirm this daily pattern of air pollutant concentrations in the urban environment, whose peaks coincide with the morning and evening rush hours.

In an urban environment, ventilation management, if done in a natural way by opening and closing windows, must be done with particular care, in order to have a real improvement in indoor air quality.

2.b Building materials

Indoor air quality inside school buildings, as for all enclosed spaces in general, is strongly influenced by the materials present within the building element, whether they are structural and part of the building itself or accessory or furnishing elements.

These elements, in fact, remain inside rooms and compartments regardless of the presence of users and occupants, 24 hours a day and, if they emit volatile substances, these pass into the air and tend to accumulate within the indoor environment. There are **many elements that emit harmful substances such as VOCs or formaldehyde**, from paints and varnishes to flooring, from coatings to adhesives used in construction, to wood panels, furniture, desks and school furniture in general. These materials continue to emit VOCs for many weeks after they have been installed, sometimes for years, and this can become dangerous in very small, overcrowded and/or poorly ventilated classrooms, especially since these substances are added to all those already present in the air for a variety of reasons.


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As far as building materials are concerned, the market and **manufacturers are moving towards reducing VOC emissions**, particularly for those elements that are installed inside the building. For example, compliance with the **CAM Decree** (Minimum Environmental Criteria)[3], necessary to have access to state incentives or to participate in public tenders, involves emission limits for these types of materials, both for total VOCs and for some specific substances that are considered more harmful (e.g. formaldehyde, styrene, etc.). Tests are carried out on material samples 28 days after packaging on the following types of product:

- paints and varnishes;
- flooring;
- adhesives and sealants;
- interior coatings;
- finishing panels;
- suspended ceilings;
- steam screens.

In order to be used in new construction or in redevelopment and renovation activities, the above-mentioned materials must comply with the limits of 👉Table 2.1 in 👉Annex 2.

Another widely used classification in Europe, as well as a reference also in Italy, is the one indicated by the French Regulation on VOCs for building materials[4]. This regulation makes it **compulsory to affix a label with the VOC emission class** on most construction products installed indoor, as well as on flooring, coatings, paints, insulation, doors and windows, etc. In this case, VOC emissions are classified according to a scale of four classes from A+ (very low emissions) to C (high emissions).

In 👉Annex 2, the 👉Table 2.2 lists the substances that are investigated to determine their class and emission limits.

Finally, building materials can sometimes be a source of Radon, in indoor environment: some rocks often used in construction, such as tuff, and some building materials contain a significant amount of uranium, the progenitor of Radon.

2.c Chemicals

Additional sources of indoor contamination in schools are due to the presence of chemicals in cleaning products, room odourisers /smellers, insecticides and also in teaching materials and stationery.

Many of these substances are toxic and can be absorbed through the skin and lungs with harmful effects on occupants' health. Unfortunately, there is no perception of this risk and the lack of rules is causing the continuous increase of a huge number of chemicals whose effects on human health are unknown. Those most commonly found in cleaning products are: alcohol compounds, acidic and basic Chlorine compounds, Ammonia, hydrocarbons derived from oil refining.

[3] CAM Minimum Environmental Criteria, updated by Ministerial Decree no. 256 of 23 June 2022 and published in GURI no. 183 of 6 August 2022:: 🔗https://gpp.mite.gov.it/PDF/GURI%20183%20 06.08.22%20-%20Allegato%20Edilizia.pdf

[4] 🏛 25/3/2011 Official Journal of the French Republic `Decree No.2011 - 321 of 23/3/2011`.

Further indoor contaminants are those contained in products used for school activities such as glues and adhesives, and also in the use of work tools such as printers, plotters and photocopiers. The substances of interest here are VOCs, ozone, formaldehyde and dust.

Trace concentrations of flame retardants, phthalates, perfluoroalkyl substances and synthetic fragrances (terpenes) have also been found in numerous indoor air quality studies.

2.d People present in the environments

The very people who occupy indoor environments can be considered sources of pollution that increase the level of risk linked to air quality. Flu contagion or the transmission of pathogens via aerosols (air clouds that we emit in the exhalation phase) are some of the effects produced by the presence of several people in the same environment.

Recent scientific literature has been enriched - responding to the COVID-19 emergency - with material correlating the effects of breathing (increased CO_2) with the risk of spreading pathogens within environments.

The increase of CO_2 in a confined environment used by people is, in fact, essentially related to breathing activity; as the CO_2 content rises, the probability of one individual inhaling the same air emitted by another becomes higher and higher..

If one person is found to be a carrier of an airborne pathogen, the viral quanta emitted during exhalation can be correlated with the CO_2 content emitted that mixes with the air present. In an enclosed environment occupied by people, the CO_2 content correlates with the air exchange rate, which affects the likelihood of pathogen transmission.

The air quality of an environment is also closely related to the ability of pupils to maintain concentration during school lessons. It has been observed that high levels of CO_2 in indoor environments cause low concentration levels and severe complaints such as headaches and nausea (👉**Figura 2.1**).

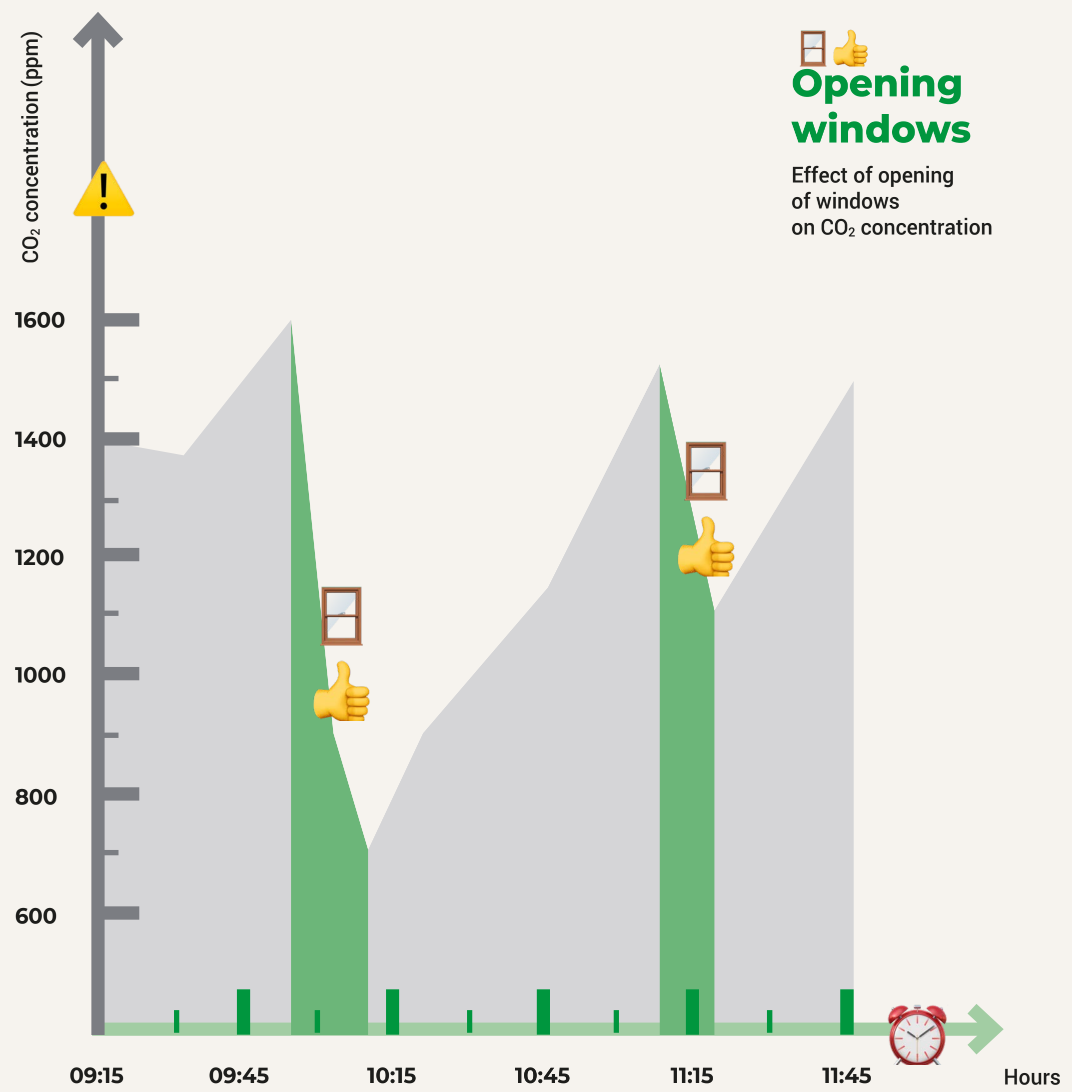
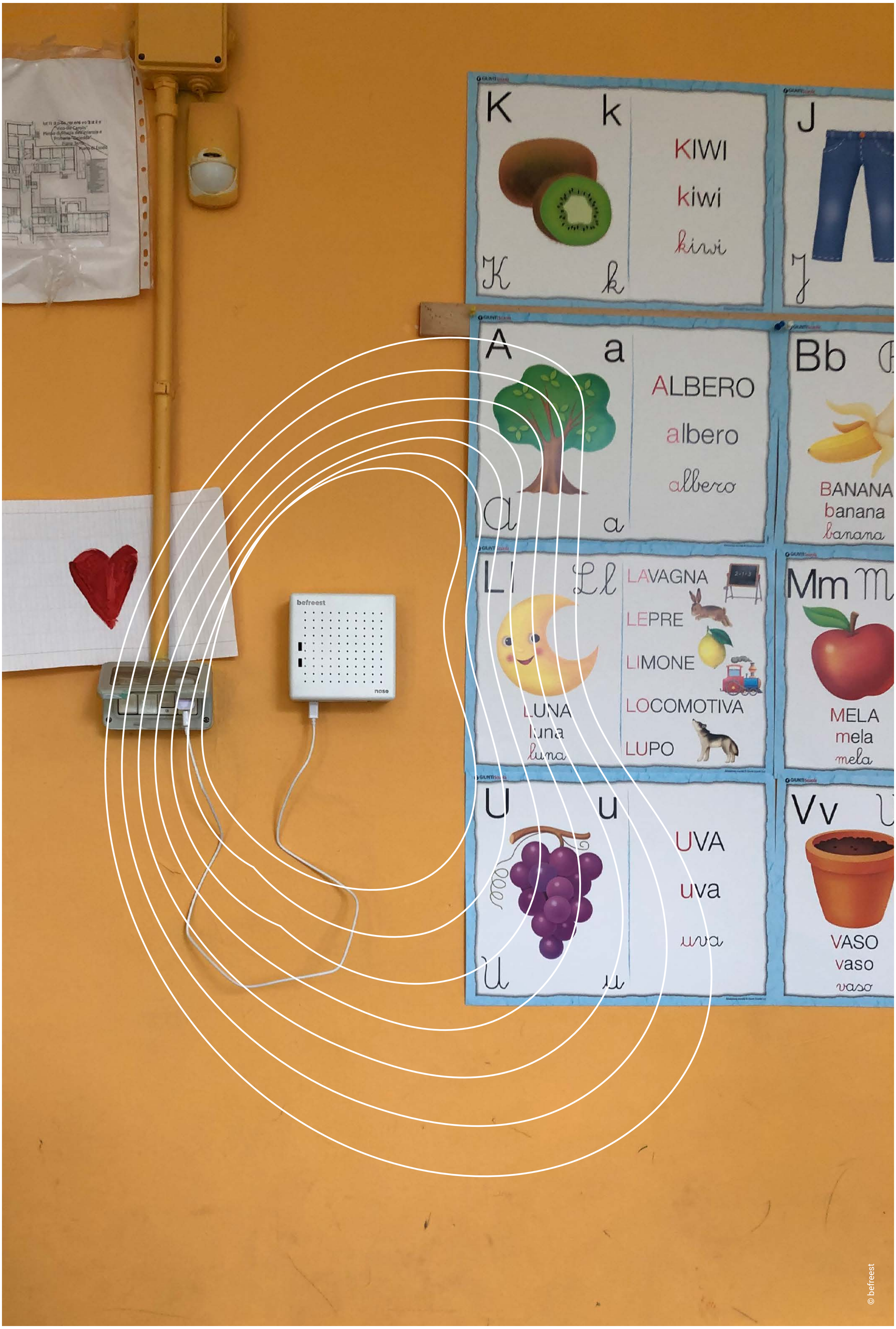


Figure 2.1: Graph illustrating actual data acquired in classrooms by Proambiente as part of the CO_2-Lab project https://www.consorzioproambiente.it/it/progetti/in-corso/270-cool-co2-lab"

Changing the air when the CO2 content rises above risk thresholds is the action that significantly reduces the risk of the spread of aerosol-borne pathogens within enclosed spaces. However, it must be verified with which actions the air exchange is carried out, as the introduction of air from outside must take place in the absence of additional risks.

In fact, in cases where rooms are in contact with busy roads or in urban areas compromised by pollution, the intake of air from outside would lead to a systematic deterioration of indoor air quality (intake of PM, NOx, benzene, etc.). It is therefore necessary to always check the quality of the outside air, making sure that opening windows does not produce the opposite effect to that desired, increasing indoor risks rather than reducing them.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3. Methods for measuring pollutants

For the measurement of the main pollutants, there are different types of sensors that differ in cost, technological simplicity and reliability of results:

Level I sensors are low-cost, easy-to-use devices that provide real-time indication of critical situations and elements. These sensors, due to their low cost and the response provided in real time, are **suitable to be used to feedback ventilation and/or air filtration systems**, allowing them to be **optimally used** according to actual needs;

Level II and III sensors are certified instruments that offer better data quality and performance and therefore at a significantly higher cost.

3.a Level I sensors

Current availability in terms of low-cost sensor technology, wired-wireless communications, local and remote (cloud-based) computing resources, allow for modular systems for IAQ and indoor comfort monitoring with the concepts of **interoperability** and **customisation** at their core.

Interoperability allows the developed system to exchange information with other systems, for example:

→ **Ventilation/ filtration systems** (e.g. for feedback and/or control via standard MODBUS, RS485 or wireless IoT communications);
→ **Remote platforms** (e.g. for data management and processing via web services accessible from PCs, tablets, smartphones);
→ **Local platforms** (e.g. for the management of the monitoring system via hotspots or interfaces on the local network);
→ **Monitoring systems** o outdoorpollutants (e.g. for the feedback and control of a ventilation/filtration system by combined processing of indoor and outdoor data).

Customisation makes it possible to combine interoperability with the possibility of integrating sensors for Level I monitoring with specific solutions with improved performance (e.g. PID Photo Ionisation Detectors for measuring concentrations of VOCs), increasing data quality and data reliability within a single system, an added value in sensitive environments such as schools, which is also necessary in view of the release of future regulations governing the continuous monitoring of parameters that set indoor air quality. The main Level I sensors for monitoring IAQ are:

→ **CO_2 sensor** based on or photoacoustic or NDIR dual channel operating principle, reliable over the long term and to be calibrated periodically by exposing it to outdoor air (with a known CO_2 value). Accuracy (±30ppm) suitable for Level I applications;
→ **TVOC sensor** based on the MOX (I level) or PID (I-II level) operating principle. The latter, at a higher cost, is not affected by the presence of interfering agents such as NO, NO2, CO, is insensitive to humidity variations, and provides greater sensitivity and greater linearity in response;
→ **PM sensor** (PM1, PM2.5, PM10) effective for the measurement of PM1 and PM2.5, with lower accuracy for PM10. It suffers from high relative humidity levels. There are alternative technological solutions that could provide better performance in the future;
→ **Radon sensor** based on the detection of alpha particles from radon decay. It allows to detect the amount of radon present in a room and to signal the level of risk or to implement mechanised ventilation systems for air exchange;
→ **Sensor of T and RH%** (Temperature and Relative Humidity). There are dozens of sensors on the market with comparable performance that can be integrated into IAQ systems.

From the point of view of platforms, data interchange technologies (Cloud, API, MQTT) allow to integrate information also from different producers and thus allow greater freedom of choice between different producers. This aspect, however, does not always meet with the favour of different manufacturers, who often build proprietary and isolated information environments.

In order to increase the performance and reliability of Level I systems for IAQ, the data provided by sensors should be continuously correlated with each other and, regularly, with Level II or III instruments on site (the use of sample gas cylinders for expeditious calibration activities should also be considered), or in a controlled atmosphere in the laboratory, in order to apply corrections enhancing data quality from a quantitative point of view.

3.b Level II and III sensors

Level II and III sensors refer to instrumentation that, compared to Level I sensors, is characterised by a **higher cost as well as often considerable complexity of use**. These are therefore instruments that require the intervention of specialised figures, useful for carrying out short or medium-term measurements characterised by **excellent data quality**, certifiable according to various reference standards. Moreover, measurement with Level II and III instrumentation in some cases takes place 'off-line', through on-site sampling and subsequent analysis in analytical laboratories. The higher data quality is thus evident but, at the same time, also the **impossibility of using Level II and Level III measurements for real-time feedback and control of ventilation or air filtering systems**.

Level II and III sensors are therefore mainly used in the **initial assessment** of air quality in buildings, in order to plan upgrades, and in **periodic reviews** to assess and manage the functioning of installed aeraulic systems.

To describe in an illustrative manner the difference between Level I and Level II/III methods, we can consider the example of the measurement of volatile organic compounds VOCs. **A good Level I sensor** is indeed able to reliably and reproducibly measure the concentration of **total volatile organic compounds**, i.e. of all VOCs, which canbe molecules of various types. For example, listing some of them in ascending order of harmfulness: alcohols, perfumes/odourants, terpenes, aromatic compounds and formaldehyde. A Level I sensor may therefore be able to provide the concentration level, without specifying the relative content of individual compounds, more or less harmful. **A Level III** method, based on bag or cartridge sampling, followed by a gas/mass analysis at an analytical laboratory **will be able to identify and provide the concentration of each individual molecule**, in mixtures composed of even hundreds of different molecules. The analytical superiority of the Level III method is therefore evident, but also how this type of measurement, which is expensive and off-line, is not useful for real-time feedback of aeraulic ventilation or filtering systems.

The opposite example, again by way of illustration, concerns the measurement of the concentration of CO_2. This is in fact a very specific single molecule, which is a useful indicator of its presence in an environment, being a product of exhalation. The most commonly used measurement methods (non-dispersive infrared and and allow the CO_2 measurement with excellent reliability at a cost of a few tens of euros per sensor. Therefore, Level II and Level III methods are generally not required for CO_2 quantification.

In many cases, the quality of a Level II or Level III measurement depends on both the operator skills and the equipment reliability. For a more in-depth discussion of the specific issues of calibration, recalibration and data quality, see from 👉Annex 3.

It is important to note that **for some types of substances of interest, to date, no level I instrumentation exists** which makes essential to perform an initial, and possibly periodic, assessment of the situation with Level II and III methods.

One example is **bioaerosols**, or Primary Biological Air-Borne Particles (PBAPs): these air-borne particles, come from biological organisms including microorganisms (bacteria, fungi, viruses) and fragments of biological, animal and plant materials, such as pollen and/or specific allergens and pathogens.

Exposure to bioaerosols can have important effects on health, especially on sensitive individuals such as children. It is usually necessary to characterise the type of PBAP for the presence of infectious microorganisms, such as identifying genus and species of allergenic fungi and bacteria. For this reason, bioaerosol measurement methods usually involve an initial sampling phase of atmospheric particulate matter (which includes bioaerosol), followed by specific analysis methods in the laboratory, including, for instance, a microscopic analysis of cultured bacteria and fungi or of individual particles, biological antigen/antibody tests or chain reactions of the polymerase (PCR). This often requires manual methods that can be costly and time-consuming.

Indoor bioaerosol concentrations depend on both outdoor and indoor sources, including the individuals present and their health conditions.

Since possible sources do not emit bioaerosols continuously, and the variability of environmental conditions also strongly influences the presence, transport and diffusion of biological agents in indoor environments, the quantity and quality of biological agents observed in different environments are never the same, and even within the same room, wide changes in qualitative and quantitative characteristics and concentrations are observed over time[5].

Finally, we would like to mention the **Level II sensors for Radon**, the so-called ionisation chambers. These instruments, which guarantee very high sensitivity and frequent sampling (even every 10 minutes), mainly consist of a volume of air bounded by metal walls and are capable of detecting the electrons produced by ionisation by radon and its decay products.

As far as the measurement of Radon concentration is concerned, it is worth mentioning nuclear trace detectors, which are by far the most widely used instruments in this field. These are passive instruments that allow the average concentration to be measured over long periods of exposure, typically six months. At the end of the exposure period, these detectors are analysed under an optical microscope and the average Radon concentration is obtained using appropriate correction factors.

[5] (ISTISAN Report 15/4, 2015)

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4. Aeraulics

Confined environments, especially school environments, require continuous and constant air changes in order to eliminate or control pollutants, keeping them within permitted values, thus ensuring better health for students and the people working in them, teachers and school staff.

The use of aeration or natural ventilation, meant as the occasional opening of windows, has proven to be only partially effective in these environments, characterised by the continuous presence of many people. In addition to this aspect,

natural ventilation entails other disadvantages including high heat loss in wintertime and therefore higher operating costs, the entry of cold air that reduce people's comfort, as well as the entry of uncontrolled pollutants (fine dust and allergens) and exposure to external noise.

In order to solve these problems, the use of **Controlled Mechanical Ventilation (CMV) systems** or more generally **aeraulic systems** can be very helpful. These systems, equipped with appropriate **filtration** of the incoming air, allow a continuous and controlled change of indoor air and can guarantee the thermal control of the environments (winter heating and summer cooling), the control of relative humidity, while also optimising energy consumption.

Aeraulic systems involve the intake of clean air from outside and the simultaneous expulsion of stale air from rooms. In this way, it is possible to dilute and remove pollutants present in the indoor environments, limiting the concentration within the values required by regulations. Outside air must be introduced into the rooms in the least polluting conditions possible. For this reason, air intakes must be positioned at a height of at least 3 metres above the ground and 5 metres away from the expulsion, adding **suitable filtration systems** before the air intake.

In addition to the effects on IAQ, aeraulic systems can control the conditions of **thermo-hygrometric comfort** of the people inside, thanks to the presence of heating and/or cooling 'batteries' that allow them to cope with internal thermal loads. Actually, these systems take on the role of **indoor air-conditioning systems**, completely replacing (or, in some cases, complementing) traditional hydronic systems (radiators, fan coils, radiant panels) or summer air conditioners. In classrooms, moreover, the large number of people present at the same time is the cause of a strong production of vapour, which leads to an increase in relative humidity in the environment, if this is not adequately ventilated. Relative humidity values above 60-70% can lead to favourable conditions for the **proliferation of bacteria** as well as worsening olfactory respiration, also reducing the perception of thermo-hygrometric comfort. High humidity values also increase the risk of **formation of condensation** on cold surfaces, a problem which is particularly present in all buildings that are poorly thermally insulated and in the presence of thermal bridges, where condensation favours the formation of moulds that can also evaporate into the ambient air. The use of aeraulic systems therefore becomes fundamental as the introduction of external air with a low vapour content (especially in winter conditions), making it possible to reduce and control the value of relative humidity in the environment, **thus improving health and comfort**, and preserving the condition of the building structures.

There are different types of aeraulic and Controlled Mechanical Ventilation (CMV) systems. One possible distinction is between centralised and punctual systems.

→ **Centralised VMC systems**: these systems are serving several rooms and are characterised by a large central machine, ducts for transporting air to individual rooms/offices (generally distributed in false ceilings) and diffusers and extraction grilles placed on the wall or false ceiling. Among these systems, a distinction must be made between those dedicated exclusively to air exchange (primary air systems) in which the room temperature control is entrusted to hydronic systems (radiators, fan coils, radiant panels) and those dedicated also to air conditioning (all-air systems) in which the air injected into the room allows the room temperature and humidity to be controlled.

→ **Punctual VMC systems**: these are small machines serving individual rooms, normally housed on the external wall or integrated in the frame or box system. These machines normally perform the air exchange service only (possibly integrated with a heat recovery unit). Due to their small size, they have limitations on the air flow rate so that in the case of large rooms, several installations in the same room are required.

Several aspects must be taken into account when making the most appropriate choice of aeraulic or VMC system, including:

- required air flow rates depending on the pollutants produced;
- type of filtration system;
- Energy-saving systems
- possibility of ensuring heating,
- cooling and relative humidity control;
- internal architectural constraints
- (availability of space for installations) and any pre-existing installations;
- choice and positioning of air diffusers and extraction points, as factors affecting ventilation efficiency and the ability of such systems to ensure consistent air quality throughout the room;
- control logics (on air flow rates, inlet temperature, timings, etc.) that optimise IAQ and energy savings;
- plant noise;
- maintenance and sanitisation aspects;
- possibility of monitoring microclimate parameters and IAQ;
- costs (installation + management).

Particular attention must be paid during the design stage to the following aspects:

4.a Ventilation air flow rates

The current regulatory framework is quite complex, as there are several regulatory references that start from a prescriptive approach. As far as school buildings are concerned, we cite the Ministerial **Decree of 18/12/1975** "Updated Technical Standards for School Buildings" which provides for specific hourly air exchange rates and the **UNI 10339 (1995)** standard on aeraulic systems which, in the specific case of schools, establishes the minimum air exchange values per pupil present inside the classroom. A recent normative reference is **EN 16798-1**, which defines both the reference values of CO_2 levels inside rooms and the values of air changes according to different performance classes. These last two regulations are also explicitly stated in the **CAM Decree** (DM 23 June 2022) which reiterates the need to ensure adequate indoor air quality in all habitable rooms by means of mechanical ventilation systems, with reference to the standards in force. A summary of the air exchange values proposed by the aforementioned standards is given in 👉Annex 4.

Therefore, the appropriate design should be based on a performance approach, defining the necessary air exchange rates according to the real need for dilution of pollutants.

Moreover, the possibility of being able to monitor certain pollutants in real time and, at the same time, the use of systems with different flow rates, allows air flow rates to be modulated under different operating conditions, maintaining adequate IAQ values, while minimising energy consumption.

4.b Filtration

Aeraulic systems are equipped with appropriate filtration systems to to retain pollutants present in the external environment, so as to guarantee the incoming of 'clean' air from outside. The choice of the filtration system and the features and efficiency of the filters is very important and must be made according to the conditions of the outside air and the room functions. The recent EN ISO 16890-1 standard allows a more conscious choice of the type of filter to be adopted, as it introduces a performance approach to the problem in which filters are classified according to their capacity to abate concentrations of PM (in the fractions PM10, PM2.5 and PM1). For more detail, see 👉Annex 5.

Other types of filters include activated carbon filters, which are used to deodorise and remove gaseous and treated chemical pollutants depending on the pollutant they must intercept (NOx - SOx - CO - VOC - benzene - etc.). Other types of filtration are also available on the market, such as biocide filters and UV-C2 lamps, capable of eliminating mould, bacteria, viruses and fungi from sources such as human beings, animals and plants.

4.c Energy-related aspects

The entry of outside air at a different temperature from the inside air causes a thermal load for the air-conditioning system, which must heat (in winter) or cool (in summer) the air with a consequent increase in energy consumption. This is particularly the case in the winter period, when the temperature differences between indoor and outdoor air are particularly high.

Natural ventilation (through window openings) often uncontrolled results in high energy consumption. It can be estimated that the incidence of energy consumption due to natural ventilation in a school environment is in the order of 20-50% compared to the envelope losses.

Conversely, the use of aeraulic systems equipped with a heat recovery unit reduces heat loss while providing the air required for IAQ control. In this way, ventilation losses can be reduced to 5-10%.

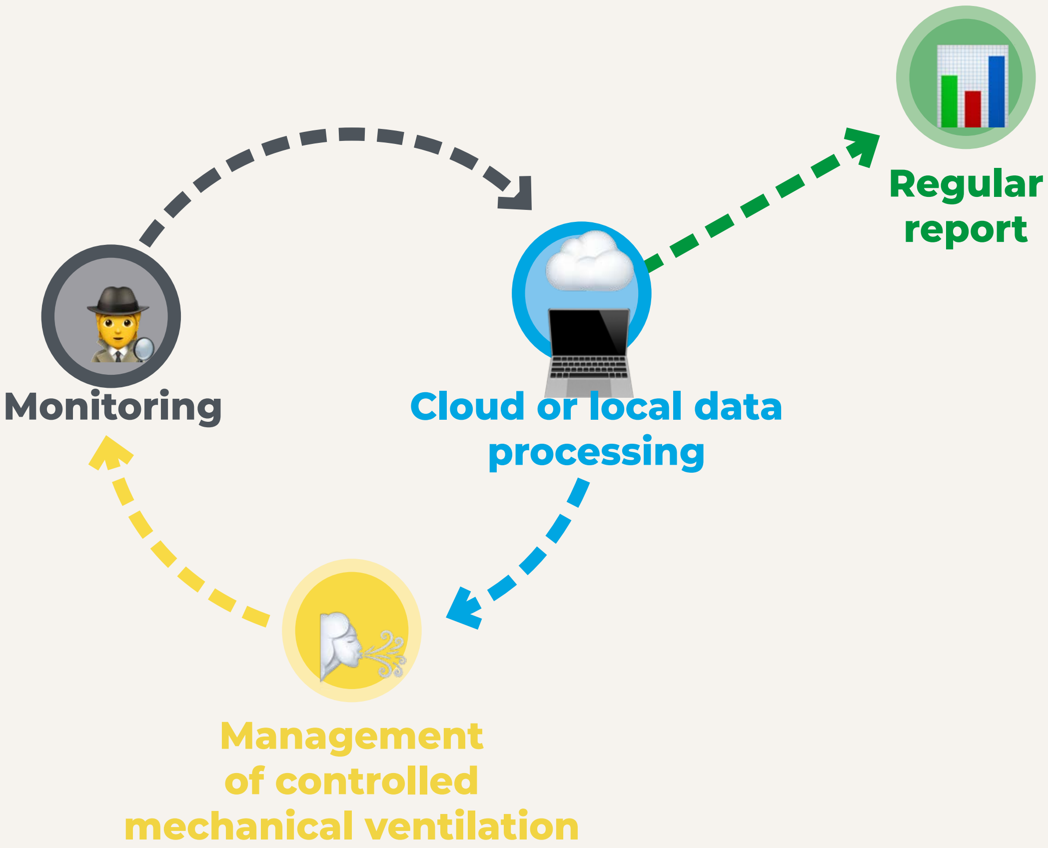
The **cross-flow heat recuperator** determines a heat exchange between the incoming and outgoing air, without any mixing between the two flows. The indoor air, before being expelled, releases its heat to the incoming outdoor air, which, instead of entering cold (e.g. in winter), is heated, thus determining an advantage both in terms of reducing energy costs and because it avoids incoming cold airflows. The thermal energy recovery that can be achieved depends on the type of recuperator and the temperature difference between indoor and outdoor air and can be as high as 90%. When there are space problems and the dimensions of the equipment must be smaller, the **rotary heat recuperator** can be installed: in this case, the heat exchange between the two air flows takes place through the material with which the rotary wheel is made.

4.d The importance of the implementation phases of the aeraulic system

In order to achieve high standards of comfort and air quality in rooms, particularly in schools, it is necessary to adopt a process for the realisation of aeraulic systems that goes from **design** to **implementation** up to **operation and maintenance**, which must comply with specific regulatory standards and be followed at each stage by experienced professionals in the sector, in order to guarantee the quality results required and foreseen in the project over time.

Therefore, the main phases of the life cycle of an aeraulic system are:

- **Design**: suitable to the building and to its purposes, aimed at **air quality, comfort and energy saving**.
- **Installation**: carried out according to plan made by **experienced companies**.
- **Management**: the use of the system must be shared with the user. **Automatic management is better**, based on pollutants and room use, outdoor and indoor temperatures and energy-saving.
- **Monitoring**: through **sensors in the plant and in the environment** allowing to monitor the various Key Performance Indicators (KPIs) identified, which are related to both the design and the plant operating parameters.
- **Periodic maintenance**: **calibration-cleaning-sanitisation** of the system, periodically performed by professionals.



Monitoring:

- Outdoor air quality
- Energy consumption
- Environmental sensors

Management of controlled mechanical ventilation:

- On-site air quality reporting
- Management of filtration systems
- Plant maintenance management
- Proactive signalling of abnormal situations

Cloud or local data processing:

- Risk assessment
- Development of remedial scenarios
- Data storage
- Big Data Analysis
- Predictive analysis
- Energy analysis

Regular reporting on the state of air quality:

- Indications for improvement strategies
- Regular communications for stakeholders (parents, teachers, workers)
- Verification of the investment payback

Figure 4.1: The smart model for Indoor Air Quality.

The aeraulic system, as any other equipment, **needs periodic mechanical and hygienic maintenance** so as not to alter, over time, the indoor air quality results guaranteed by the new system. It is necessary to periodically check the air treatment unit in order to remove oxidation and fouling, carry out internal mechanical cleaning of the air distribution ducts, wash the terminal units and replace the flexible hoses, as well as replace worn and dirty filters with new and efficient ones. Finally, the system, once it has been cleaned, is treated with a bactericidal disinfectant. The frequency of interventions must be assessed on a case-by-case basis, according to the technical-functional state of the system and the actual operating conditions of the system.

4.e Data Interoperability and Integration Systems

With a view to making full use of the IAQ data collected by the on-site sensors, and transforming them into useful information for the building management in order to achieve higher levels of comfort, healthiness and efficiency, the following features are required:

→ **Data must be channelled and collected in a single IT platform**, where analyses can be carried out, KPIs assessed, static and dynamic alarms created in relation to the monitored data and any deviations, and automations created with a view to efficiency and healthiness, allowing for proper and timely maintenance of the building and the installed equipments;

→ Together with the IAQ data, in view of sustainability, **it is useful to collect data on the consumption of interconnected machines** that are used for heating, cooling, ventilation and air conditioning, to create algorithms with a view to comfort, healthiness and efficiency to improve both the quality of life inside the building, but also to make efficient use of energy to achieve this comfort;

→ In light of the fact that HVAC[6] consumption in many types of buildings where IAQ needs to be assessed is one of the largest consumptions (in the order of 30-50% of the total), **it is recommended to perform in-depth assessment of the installation of systems powered by renewable energy** to reduce the burden of energy costs and increase the sustainability of the building itself; evaluation to be implemented in advance with an energy management system that evaluates the various load and consumption curves;

→ with the use of data from on site IAQ sensors, one could see an increase in the costs of protecting the health of the people in the building itself. These **costs come from stricter and more careful maintenance of the machines, by increased utilisation of the machines themselves**, more frequent changes of certain 'parts' of field equipments. From a cost recovery perspective, we recommend a more efficient use of the technologies themselves, integrating IAQ data with consumption data, with the aim of achieving a higher degree of energy efficiency and predictive plant maintenance in both detail and as a whole.

[6] HVAC stands for Heating, Ventilation and Air Conditioning.

In order to achieve all these objectives, we recommend:

→ **The use of market protocols for data communication from IAQ sensors to the data collection and analysis platform.** Protocols could be, for instance, ModBus (in its various declinations) MQTT, IFTTT;

→ **The use of hardware gateways and data loggers**, for the communication (and 'storage') of the data collected in the field to the cloud platform, which are adapted to the various types of building in which IAQ sensors are installed. Communication can take place from time to time via Ethernet, Wi-Fi, LoRa, etc., choices that also depend on the type of building (square footage, walls). The objective remains non-invasiveness, or the least degree of invasiveness, and a solution that works especially in the case of retrofits, implementing installations that are almost always in the "already built" and very often in the "very old" situations;

→ **A platform, installable both in the cloud and on site** (in school servers, buildings, etc.) capable of conveying data from various sources (IAQ, energy, machines, PLCs, SCADA, building management system if required, excel files, meters, etc.), and from various communication protocols (modbus, OCPP, Bacnet, etc.) to enable accurate data analysis, use in any type of situation, and transformation of data into useful information as accurately as possible;

→ **A suitable but not oversized hardware-software endowment**, with a view to sustainability and comfort, but also sustainability in terms of payback time of the technology itself, to be achieved through energy efficiency (consumption data monitoring, KPIs, analysis, setting and automation for energy efficiency and IAQ improvement).

Everything can be measured in KPIs, including:

→ **Improvement of IAQ from initial measurements at regular intervals set by the operators;**

→ **Improvement of energy saving** in terms of kWh saved per consumption type;

→ **Improvement of predictive maintenance** in terms of saved maintenance costs;

→ **Payback of adopted solutions** in terms of total kWh savings when using an energy management solution together with the IAQ solution.

5. Greentech and Build Clust-ERs recommendations for indoor well-being in schools

With this document, the Greentech and Build Clust-ERs intend to raise awareness among Facility Managers, HSE Managers, school managers and other potentially interested parties on the **relevance of careful indoor air quality management in schools**, describing the latest available technologies and methodologies.

It is believed that future school building interventions cannot disregard a careful assessment of the aspects of healthiness and comfort in school environments, which nowadays can be guaranteed by the integrated use of sensors, aeraulic systems and system management methodologies. The use of **pre-set values of air changes**, regardless of the real-time assessment of room occupancy and actual air quality is **not efficient and often results in wasted energy** for the treatment and heating/cooling of the incoming air.

Within the Greentech and Build Clust-ERs of the Emilia-Romagna Region, both academic and entrepreneurial skills, needed to support the authorities in the planning of school building upgrading interventions are available.

The shared objective of the authors of this paper is to propose, on the basis of their own knowledge and experience, the best available practices and technologies to build, in the coming years, the **healthy, sustainable and energy efficient school environments of the future**.

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Clust-ER Greentech members, who developed the Air Path, and Clust-ER Build members made available their technologies and skills. Here is an overview of contacts to foster new initiatives and collaborations:

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Attached documents

Annex 1. Flow chart for IAQ assessment

Numerous scientific studies have verified the positive effects of good indoor air on overall performance during human activities such as learning and daily work. Every indoor scenario is different (e.g. building design, furnishings, categories and habits of people, activities performed). Many substances with different effects on human health can be introduced into the indoor air from the most diverse sources of pollution.

It is not possible to adopt a one-size-fits-all technique, in compliance with all contexts, when it comes to assess long-term exposure to known and emerging chemical, physical and biological pollutants; just as it is important to assess the context in order to understand the real contribution of outdoor air. **This annex describes an integrated approach to the assessment of indoor air quality management systems.**

Figure 1.1: The flow diagram of the methodology described below is shown here. The same scheme and technical approach underlies the `ISO 16000` standard on IAQ management.

📝 Inventory

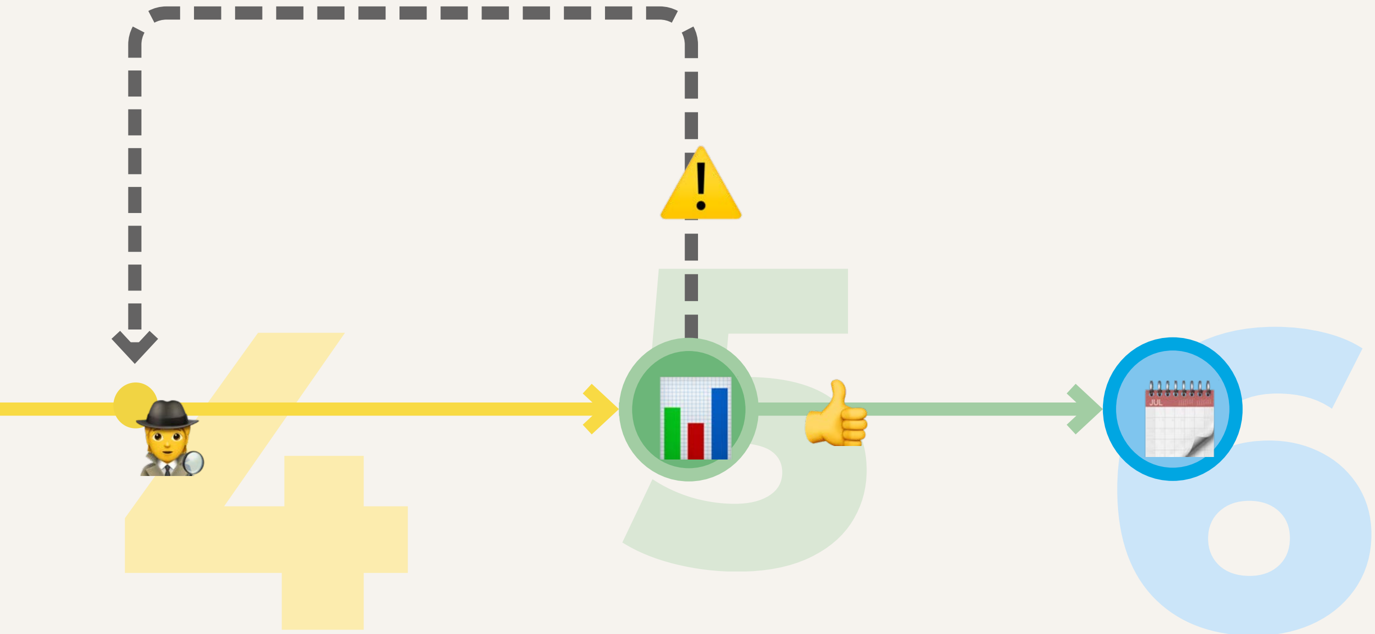
List of air quality-related aspects

⚖️ Risk level

Deciding the relevance of indoor air quality-related aspects on the basis of a probability/impact risk matrix

🤔 Preliminary assessment

Deciding the environments and the parameters to be monitored, the document to be reviewed and visual inspections or other analyses to be carried out



Analytical evaluation

Assess the status of relevant aspects of indoor air quality.
Typical actions:
→ Measurement of pollutants
→ Document review
→ Visual inspections
→ Analysis of complaints and epidemiological data

Outcome of the assessment

→ Are pollutants below the level of concern?
→ Are control programs implemented and registered?
→ No visual evidence of potential problems?
→ No significant complaints?

Periodic audits

Establish a protocol for the reassessment of relevant aspects of indoor air quality.

Integrated approach to the evaluation of Indoor Air Quality management systems

The methodology for identifying and assessing the elements characterising IAQ and ensuring continuous improvement of air hygiene and human well-being is summarised here, taking inspiration from part 40 of **ISO 16000**, the technical reference standard. The process management to ensure IAQ is based on the following pillars: (i) building construction and installation data; (ii) continuous measurement of IAQ through reportable devices; (iii) collection of individual subjective perceptions and complaints about IAQ from residents.

A list of each point to be observed and implemented is given and described below.

1.a Identification of risk level and assessment of indoor air quality-related aspects in a building

This action could be performed in the following steps:

→ **Drawing up an inventory** of the aspects that may have an impact on indoor air quality for each building. Typical aspects are:

- The building location;
- Uses, activities and building layout;
- Building materials; furniture, consumer goods and electrical equipment;
- Building installations;
- Parking spaces;
- Premises with special purpose (storage, mechanics, refreshment areas, canteens, etc.);
- Building maintenance, including cleaning and maintenance products;
- Possible features of building renovation.

→ **Determine the risk level** by assessing whether the specific features of each building have a relevant influence on indoor air quality;

→ **Carry out an assessment** of all indoor air quality using the following steps.

1.b Measurement of pollutants

The main parameters to be considered are the following:

→ Carbon dioxide (CO_2)
→ Volatile Organic Compounds (VOCs)
→ Formaldehyde (FA)
→ Particle Material (PM1, PM2.5, PM10)
→ Airborne microorganisms (moulds and bacteria)
→ Odours
→ Radon

Within the integrated approach to the evaluation of IAQ management systems, it is up to the expert to choose which of these main parameters need to be assessed, depending on the characteristics of the indoor environment. Two clarifications in this regard:

- **The appearance of mould** is usually associated with the presence of filamentous fungi and yeasts. Bacteria are also often present. In the case of air measurements, it is usually mainly the concentration of moulds and bacteria that is recorded[7].
- **The physical parameters "temperature of ambient air" and "relative humidity"** must be recorded separately in the representation of measurement results, as they influence pollutant concentrations in ambient air and are often associated by users with inadequate indoor air quality.

In the case of wanting to implement an approach that proves practical and easy to implement, it is now possible to install (even temporarily) air quality monitoring networks (see measurement techniques and recent developments in the CEN-ISO technical tables) performing continuous measurements.

In addition and as a complement to the above, it is suggested to:

- **Carry out investigations or planned sampling** in the most representative indoor environments, especially if the monitoring campaign is being undertaken in a multi-level building or with separate activities.
- **Document** the measurement method, the methodology being used, the measurement results and the framework conditions of the investigation.

1.c Gathering people perceptions and complaints about IAQ

The periodic collection of perceptions of the state of comfort and well-being of people living in or visiting the indoor premises under investigation is essential, especially in contexts where people are to be proactively involved and/or it is required to implement a system fostering the adoption of behavioural changes. These feedbacks, if collected, should be systematically analysed and compared with data on the building, on IAQ-related risks and monitored air quality, in order to verify its reliability and identify possible corrective actions.

1.d Periodic review and data management

Periodic review of benchmarks based on a **Planned maintenance plan**, people's perceptions and changes in activities and/or behaviours is recommended.

[7] For further details on other macro-categories, please refer to the INAIL provisions https://www.inail.it/cs/Satellite?c=Page&cid=2443085354483&d=68&pagename=Internet%2FPage%2FpaginaFoglia%2Flayout

Annex 2. Tables of VOC emission limits established by the CAM decree

Substances	Emission limit (µg/m³) at 28 days
Benzene Trichloroethylene (trichloroethylene) di-2-ethylhexylphthalate (DEHP) Dibutyl phthalate (DBP)	1 for each substance
Total VOCs*	1500
Formaldehyde	<60
Acetaldehyde	<300
Toluene	<450
Tetrachloroethylene	<350
Xylene	<300
1,2,4-Trimethylbenzen	<1500
1,4-dichlorobenzene	<90
Ethylbenzene	<1000
2-Butoxyethanol	<1500
Styrene	<350

Table 2.1: Emission limits (µg/m³) at 28 days prescribed by the CAM decree and determined in accordance with UNI-EN ISO 16000 or UNI-EN ISO 16516

Substances	Class C	Class B	Class A	Class A+
Formaldehyde	>120	<120	<60	<10
Acetaldehyde	>400	<400	<300	<200
Toluene	>600	<600	<450	<300
Tetrachloroethylene	>500	<500	<350	<250
Xylene	>400	<400	<300	<200
1,2,4 -Trimethylbenzene	>2000	<2000	<1500	<1000
1,4 Dichlorobenzene	>120	<120	<90	<60
Ethylbenzene	>1500	<1500	<1000	<750
2Butoxyethanol	>2000	<2000	<1500	<1000
Styrene	>500	<500	<350	<250
TCOV	>2000	<2000	<1500	<1000

Table 2.2: emission limits (µg/m³) at 28 days prescribed by the French decree and determined in accordance with ISO 16000

Annex 3. Parameters to be considered for the choice of the instrumental method used to determine airborne chemicals

Concept of calibration and recalibration. By definition, calibration refers to the process of correcting systematic errors in sensor readings, often by comparing a known measurement from a first device (Level II/III) with an unknown measurement from a second device in order to calibrate the parameters governing this second device to provide an accurate measurement. The term has also often been used to refer to the process of adjusting the raw sensor readings to obtain correct values by mapping them into standardised units (e.g. the sensor may provide a variable electrical voltage based on the concentration of a specific pollutant in the surrounding environment, in which case the signal in volts is converted to pollutant concentration through the application of algorithms or calibration curves).

Calibration is often based on providing a specific input with a known result, thus creating a direct mapping (calibration curves) between sensor outputs and expected values. Consequently, such a calibration for a sensor is often subject to specific intervals and restrictions of operating conditions, which are stated in the sensor manufacturer's specifications. This type of calibration can be performed in the factory with a controlled test environment, during production, manually in the field, or both.

Recalibration, on the other hand, is usually necessary to ensure the correct operation of a measuring device, as ageing and other factors affect sensors and other measuring hardware over time. It is assumed that sensors remain active for long periods of time after deployment; therefore, they should be checked regularly against standard instruments to ensure the quality of measurements and to allow for periodic recalibration as necessary due to loss of accuracy caused by environmental conditions or internal defects. **Sensor sensitivity** may change when the device is subjected to large variations in temperature or humidity. However, low-cost sensors may provide more reliable indoor data, where temperature and relative humidity vary less than outdoor and where indoor sources may possibly raise concentrations of monitored species above outdoor levels.

→ **Selectivity of the method**: Selectivity refers to the ability of an analytical method to uniquely determine the analyte of interest. A measurement can be influenced by several variables, including the other chemical species that make up the matrix. A high selectivity therefore ensures that the measurement is indeed reportable only to the analyte being analysed. Interference can lead to under- or over-estimation of the final result, impairing its accuracy. To remedy this, whenever possible and when no other methods are available, procedures are carried out to eliminate such interference before the analyte is measured. It is therefore obvious that, in addition to reliable results, high selectivity also provides advantages such as shorter analysis times and lower costs, no additional pre-treatment being required. One way of assessing selectivity is to check how the measurement varies by adding species potentially present in the samples, in the same way one can vary operating conditions (e.g. in chromatography, the effect of the change in stationary phase, of the eluent or of the temperature at which separation is carried out).

→ **Range of obtainable values**: define a concentration range (minimum - maximum) within which instrumental performances and the method need to be verified

→ **Limit of Detection (LOD)**: It defines the smallest amount of analyte that can be detected, but not exactly quantified. The detection limit is the lowest analyte concentration produced by a signal other than the blank, i.e. the concentration corresponding to the lowest significant signal. It is commonly referred to as DL and LOD (Detection Limit and Limit Of Detection respectively).

→ **Limit of Quantification (LOQ)**: It expresses the smallest amount of analyte that can be quantified with adequate precision and accuracy. It is proportional to the limit of detection (in many cases it is considered to be 3 times the LOD). Typically, the LOQ value is evaluated as 10 times the standard deviation of the measurement made on the blank, but there are other methods to evaluate it.

→ **Linearity**: Linearity of response is the ability of a method to determine in a directly proportional manner the presence of an analyte, in relation to its quantity in the sample. To do this, one verifies at different concentration ranges including the theoretical value (in the case of quantitative content determinations) or the maximum acceptable quantity (in the case of impurities), that the response values obtained for the analyte are not too far from the most appropriate line drawn using all concentration levels. This interval is defined as the "range of linearity" and the linearity of the response is guaranteed only within the minimum and maximum concentration values.

→ **Selectivity**: Selectivity is the ability of a method to determine the analyte uniquely, without interference from other components present in the sample, whether they are excipients forming part of the matrix, secondary synthesis or degradation products etc., or of other compounds with similar chemical characteristics.

→ **Repeatability**: estimation of the variability of results obtained by the same operator using the same instrument analysing the same sample in the shortest period of time.

→ **Intermediate precision (Reproducibility)**: estimation of the variability of results obtained using the environmental conditions and execution, over an extended period of time.

→ **Accuracy**: refers to the method: the difference between the result and the true value only due to systematic error (*Bias*).

→ **Robustness**: the robustness of an analytical procedure is its ability to remain unaffected by small but deliberate variations in method parameters, and provides an indication of its reliability during normal use. The evaluation of robustness should be considered at the development stage and depends on the type of method under study. It should demonstrate the reliability of results against deliberate variations in method parameters. If results are susceptible to variations in analytical conditions, these should be appropriately controlled.

→ **Calibration**: calibration consists of measuring the instrumental signal of solutions of known titre (or solutions to which known quantities have been added) of analyte. Usually, it is sufficient to measure the instrumental signal at 4-5 concentration values. From these experimental points, we derive (normally by the method of Ordinary Least Squares) the expression of the algebraic function that best correlates signal and concentration.

→ **Measurement uncertainty**: Estimating measurement uncertainty is one of the most important operations in performing a measurement, as the uncertainty, which must always be communicated, expresses the indeterminacy in the knowledge of the measured parameter. A default estimate of uncertainty leads to assign a greater significance to a measure than it actually is, leading to technical and/or legal problems. On the other hand, an overestimation decreases the quality of the measurement same method and the same laboratory but different operators and/or instruments and/or achieved through the use of expensive equipment and complex methods. Determining the measurement uncertainty is a complex process that takes into account the contribution of the various systematic and random errors associated with the measurement.

Annex 4. Tables of air change rates for mechanical ventilation systems

The **1995 UNI 10339 standard** for buildings used for school and similar activities requires an external air intake equal to or greater than the minimum values given in Table 4.1. Tables 4.2 and 4.3 below show the values of specific air flow rates, generally valid for non-residential buildings.

Type of room	Outside air flow rates **per person** l/s (m^3/h)	Extraction capacities (vol/s)
Kindergartens and nursery schools	4 (14,4)	
Primary school classrooms	5 (18,0)	
Junior high school classrooms	6 (21,6)	
Secondary school classrooms	7 (25,2)	
University classrooms	7 (25,2)	
Libraries, Reading Rooms, Teachers' rooms	6 (21,6)	
Music Classrooms, Language Classrooms, Laboratories	7 (25,2)	
Transits, Corridors, Services		8

Table 4.1: Outdoor air renewal flow rates for school buildings, according to UNI 10339 (1995)

Building category	Air flow rate **Per qualified person** (l/s person)	
	Not suitable	Suitable
I	10	3,5
II	7 *	2,5
III	4	1,5
IV	2,5	1

Table 4.2: Fresh air flow rates per person according to EN 16798-1

Building category	Air flow rates **per surface area qB** (l/s m^2)		
	VLPB	LPB	NLPB
I	0,5	1	2,0
II	0,35 **	0,7 ***	1,4
III	0,2	0,4	0,8
IV	0,15	0,3	0,6

Table 4.3: Outside air renewal rates per unit area according to EN 16798-1

FOCUS
UNI EN 16798-1

UNI EN 16798-1 provides design values for the ventilation flow rate based on perceived air quality. The design flow rate value is obtained by adding an air flow rate (qp) required to dilute/remove bioeffluents from the occupants and an air flow rate (qB) required to dilute/remove pollutants generated by the building and the systems therein. The sum of these values must be multiplied by the ventilation efficiency in the case the air distribution deviates from complete mixing.

GLOSSARIO
The flow rate values qp are given for 4 different building "quality" categories, as defined by the same standard. Instead, **the qB flow rate values** are defined as a function of the levels of pollutants produced by the materials according to the following definitions:

VLPB
(Very Low Polluting Buildings)

LPB
(Low Polluting Buildings)

NLPB
(Non Low Polluting Buildings)

* To be used according to CAM decree
** To be used according to CAM decree for new construction, demolition and reconstruction, extension and superelevation
*** To be used according to CAM decree for major renovations of Level I

Annex 5. Outdoor and indoor air classification tables according to UNI- EN 16798

The filtration system suitable for IAQ takes into account the **type of pollutant** to be treated, the **outdoor air quality** and the **intended use of the building**.

Outside air is classified by the UNI-EN 16798-3 standard according to 3 categories (👉Table 5.1). Whereas indoor air is classified according to its intended use (👉Table 5.2).

🔍 GLOSSARY

ODA
(Outdoor Air, category indicating outdoor air quality)

SUP
(Supply, classification system of the supply air input based on the concentration of pollutants)

Pollution	Category	Typical Environment	Particulate concentration and/or gaseous pollutants	μg/m³ (annual average)	
Low level	ODA 1	Rural areas	Low	PM2,5 PM10	< 10 μg/m³ < 20 μg/m³
	ODA 2	Small towns	High	PM2,5 PM10	< 15 μg/m³ < 30 μg/m³
High level	ODA 3	Polluted city centres	Very High	PM2,5 PM10	< 15 μg/m³ > 30 μg/m³

Table 5.1: Indicative air quality values according to UNI- EN 16798

Pollution	Category	Typical Environment	Particulate concentration and/or gaseous pollutants	μg/m³ (annual average)	
Low level	SUP 1	Hospitals, pharmaceutical industries	Very low	PM2,5 PM10	< 2,5 μg/m³ < 5 μg/m³
	SUP 2	Places with people, offices, hotels, residential buildings, schools, theatres, cinemas	Low	PM2,5 PM10	< 5 μg/m³ < 10 μg/m³
	SUP 3	Premises with a temporary presence of people, shops, restaurants	Medium	PM2,5 PM10	< 7,5 μg/m³ < 15 μg/m³
	SUP 4	Short-stay or transit rooms, toilets, stairs, storage rooms	High	PM2,5 PM10	< 10 μg/m³ < 20 μg/m³
High level	SUP 5	Unoccupied rooms, rubbish rooms, garages, heavy industry	Very high	PM2,5 PM10	< 15 μg/m³ < 30 μg/m³

Table 5.2: Indicative air quality values according to UNI- EN 16798-3

☝ **Schools fall under SUP 2, so the choice of filters to be placed in the aeraulic systems to adjust the air quality inside the classrooms depends on the air quality outside the school (ODA).**

In order to achieve a level of indoor air quality in the classrooms (**SUP 2** compliant), suitable filters must be chosen and be integrated within the aeraulic system with specific performance, as per the table below.

Outside air (ODA)	Air intake (SUP)				
	SUP 1	**SUP 2**	**SUP 3**	**SUP 4**	**SUP 5**
ODA 1	ePM10 50% + ePM1 60%	ePM1 50%	ePM10 50%	ePM10 50%	-
ODA 2	ePM2,5 50% + ePM1 60%	ePM10 50% + ePM1 60%	ePM1 50%	ePM2,5 50%	ePM10 50%
ODA 3	ePM2,5 50% + ePM1 80%	ePM2,5 50% + ePM1 60%	ePM2,5 80%	ePM10 90%	ePM10 80%

Table 5.3: Filter selection based on outside air (ODA) and indoor air quality given in `UNI16798-3` for the intended use of the premises to be treated (SUP)

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