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Monitoring and analysis of environmental and IAQ conditions in classrooms with controlled mechanical ventilation

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Abstract. Following the health emergency from COVID-19, indoor air quality control has become of paramount importance, especially inside school buildings. For this reason, in 2021, the Marche region proposed and implemented an extraordinary intervention for the safe conduct of educational activities through the installation in classrooms of controlled mechanical ventilation systems aimed at air exchange. This type of system has been installed in more than 1,200 classrooms belonging to about 130 schools throughout the Marche region. This intervention made it possible to carry out a robust experimental measurement campaign on a significant number of classrooms where controlled mechanical ventilation systems were installed. Specifically, the work proposes a replicable measurement and analysis methodology for classrooms, with the aim of monitoring thermo-hygrometric and air quality conditions for environmental comfort. Thus, the research aims to implement knowledge on environmental comfort in classrooms equipped with controlled mechanical ventilation systems. The proposed measurements and analyses cover the most important environmental variables, i.e., air temperature, relative humidity, and CO_2 concentration. In addition, measurements regarding system ventilation flow rates, smoke tests and evaluations of the permeability of classrooms.

1. Introduction

As a consequence of the pandemic due to the SARS-CoV2 virus, it has been necessary to study and apply new strategies to prevent virus transmission and improve indoor air quality. It is known in the literature that the risk of contagion increases within confined environments as the number of users and the time they spend inside increase [1]. In particular, buildings such as schools are particularly vulnerable, being highly crowded environments and used by the most fragile individuals (children). Ensuring adequate indoor air quality is crucial, in addition to limiting the risk of contagion, in order to provide students with an optimal learning environment. Several studies [2][3] have found greater learning difficulties for students when the CO_2 level of the environment is high. The main possible strategies to be adopted within classrooms to improve IAQ are natural ventilation and mechanical ventilation using appropriate systems. Natural ventilation alone, however, cannot ensure adequate IAQ [4][5], so it is essential to use controlled mechanical ventilation systems. The Marche region, a government institution in central Italy, in order to improve air quality conditions inside schools, carried out a series of installations of controlled mechanical ventilation systems. These systems had to comply the minimum airflow requirements specified in the Italian regulations [6] and UNI 10339 [7]. The systems were installed on more than 1200 classrooms located in the Marche region. Since the number of educational buildings provided with ventilation systems is very small, this intervention allowed the realization of an extensive experimental measurement campaign concerning several classrooms with mechanical ventilation systems. The measurement activity started and developed during the years 2022/2023, involved 6 schools located in 6 different locations in central Italy. The application of the procedure studied allowed to improve and define the most important aspects to be taken into account for the collection of results as complete and reliable as possible. The measurement methodology applied is set out in the following section (Section 2), while Section 3 shows the results obtained, using the studied procedure, concerning a selected sample classroom.

2. Methods

Following the intervention carried out by the Marche Region (Central Italy), a series of mechanical ventilation systems were installed inside classrooms. These numerous installations have allowed the realization of an experimental campaign of measurements on classrooms provided with mechanical ventilation systems. The main purpose of this experimental campaign is not only to implement knowledge regarding IAQ inside classrooms, but also to establish a measurement methodology aimed at collecting data inside educational buildings and replicable in the future by other institutions interested in the subject. The measurements were divided into two categories: thermal-IAQ and fluid dynamics. Thermal-IAQ measurements consist of monitoring air temperature, relative humidity and CO_2 concentration. The fluid-dynamic measurements include measurement of the air flow rate provided by the installed mechanical ventilation system, the "blower door test" to assess the permeability of the classroom, and a smoke test to evaluate the decay time of the generated particles. This measurement methodology has been applied to date to 6 schools in the Marche region, involving more than 50 classrooms.

2.1. Thermal and IAQ measurements

During the tests, the main parameters for comfort and air quality were measured, namely indoor air temperature, relative humidity, and CO_2 concentration. Indoor air quality in a confined environment depends on various types of indicators and pollutants. The main indicator used to determine air quality is carbon dioxide because it is easy to measure compared to other pollutants. CO_2 is a gas produced by combustion processes but also by humans through respiration, which is why within school premises the main source of CO_2 emission is the users. A high CO_2 level can compromise the attention of the occupants in the classroom [3], causing headaches, drowsiness and difficulty in concentration. The technical reference standard used for the measurement of air temperature and relative humidity is EN ISO 7726:2002 [8], while EN ISO 16000-26:2012 [9] was used for the measurement of CO_2. The reference limit values considered for the measured parameters, in the case of educational buildings, are those given in the Italian regulations DM 18/12/75 [6] and technical standard EN 16798-1:2019 [10], summarized in table 1.

Table 1. Normative references measurement and limits of indoor variables studied.

Measure	Normative reference (measure)	Normative reference (limit)	Limit value
Air temperature	EN ISO 7726:2002	DM 18/12/75 (5.3.11.)	20 ± 2°C
		EN 16798-1:2019 (Table A.2)	$T_{op,min}$= 19°C $T_{op,max}$=27°C
Relative Humidity	EN ISO 7726:2002	DM 18/12/75 (5.3.11.)	45-55%
		EN 16798-1:2019 (Table A.13)	35-65%
CO_2	EN ISO 16000-26:2012	EN 16798-1:2019 (Table A.9)	1350 ppm

The measurement of the listed variables was carried out using a data logger provided with non-dispersive infrared (NDIR) self-calibrating CO_2 sensor, integrated with temperature and relative humidity sensors, the main characteristics of which are shown in table 2.

Table 2. Model and characteristics of the data logger used to monitor the indoor variables studied.

Sensor type	Model	Acquisition system	Measure	Range	Accuracy
Data logger	HOBO MX1102A	Internal Logger	Air temperature	0°C ÷ + 50°C	± 0.21°C
			Relative Humidity	1% ÷ 90%	± 2-6%
			CO_2	0 ÷ 5000 ppm	± 50 ppm

The literature recommends a sampling height of 1.50 m, but such an installation is not always possible due to the lack of proper supports or possible sensor tampering by students. The sensor can also be installed at a height of around 2.00 m, Muelas et al. [11] reports that 2.20 m turns out to be a good sampling location because the measured values are closer to the average values measured in the classroom. It is recommended, whenever possible, to avoid the installation of sensors on the wall, since the real values of the variables measured in the classroom would be underestimated [11]. Monitoring should provide a continuous data set; a sampling interval of at least 1 minute and a monitoring period of at least two weeks is recommended. Remember that indoor air temperature, relative humidity, and CO_2 concentration are affected by many parameters, including: the number of people present in the classroom and the activity carried out by them, the ignition profile of the ventilation and heating system, the possible opening and closing of windows. For a correct evaluation of the measured parameters, these aspects must be known. The ignition profile of the facilities shall be required, such as the number of users in the classrooms. For the opening/closing of windows, the installation of appropriate sensors that report their use profile is recommended. By superimposing these data it will be possible to obtain an accurate assessment of the variables studied.

2.2. Fluid dynamic measurements

2.2.1. Ventilation system flow rate measurement. Measurement of the air flow rate supplied by the ventilation system is essential to verify compliance with the minimum flow rate limits imposed by current regulations and to assess the effective hourly changes (n) in the room. The reference standards for determining the air flow rate are the Ministerial Decree 18/12/75 [6] and UNI 10339 [7]. Ministerial Decree 18/12/75 [6] establishes, depending on the type of school and classroom, the value of the air change coefficient n, expressed in 1/h, for calculating the air flow rate to be supplied to the environment concerned. This coefficient should be multiplied by the internal volume of the room to determine the flow rate to be supplied according to regulations (Equation 1). The values of the coefficient n are given in Section 5.3.12. of DM 18/12/75 [6].

$$Q_{(DM\ 18/12/75)}=V_{classroom}*n_{(DM\ 18/12/75\ (5.3.12.)}\quad (1)$$

The calculation of the air flow rate according to UNI 10339 [7] varies according to the crowding index ns, the area of the room and the outdoor air flow rate per person Qop (Equation 2). The crowding index and airflow rate per person depend on the intended use of the room under consideration and are listed in Schedule VIII and Schedule III of UNI 10339 [7], respectively.

$$Q_{(UNI\ 10339)}=A_{classroom}*n_{s(Schedule\ VIII)}*Q_{op(Schedule\ III)}\quad (2)$$

The reference technical standard used for measurements is EN 12599:2012 [12]. Measurements should be made for each available speed setting of the system and should affect both the supply and extract air flow rates. The main characteristics and models of the instruments used are given in table 3.

Table 3. Models and characteristics of instruments used to measure the flow rate of ventilation systems.

Instrument type	Model	Measure	Range	Resolution
Anemometer	TESTO 417	Air flow	0 m^3/h ÷ 99999 m^3/h	1 m^3/h
Balometer	EBT721 Balometer Capture Hood (ALNOR)	Air flow	42 m^3/h ÷ 4250 m^3/h	1 m^3/h

Depending on the type of system, two different instruments were used to measure the flow rate: for ventilation units installed directly inside the classrooms, an anemometer was used, while in the case of the presence of supply/return grilles, a balometer was used. The use of the balometer in the case of ventilation units installed in the classroom was never possible because the supply and return air grilles always had larger or different dimensions than the measurement area of the balometer. When using the balometer, it should be placed perpendicular to the vent, making sure to cover it entirely. The balometer should be positioned so that it adheres perfectly to the surface that houses the nozzle and should be kept still during the measurement. Regarding the use of the anemometer, several points on the grilles on which to make the measurement should be considered. After measuring the flow rate at the relevant points, it will be necessary to calculate the average. Measuring the flow rate at different points on the grid also allows one to check how the airflow is supplied by the ventilation machine, whether homogeneously (regardless of the point considered) or heterogeneously (e.g., side points might supply a lower flow rate than central points or vice versa).

2.2.2. Smoke test. A smoke generator and particle counter were used in this test to evaluate the decay time, associated with the installed ventilation system, of particles generated inside the classrooms. The main characteristics and models of the instruments used are shown in table 4.

Table 4. Models and characteristics of instruments used for particle measurement/generation.

Instrument type	Model	Measure	Particle size
Particle counter	FLUKE 983	Number of particles	0.3, 0.5, 1.0, 2.0, 5.0, 10.0 μm (measurable)
Smoke generator	Colt 4 Basic	-	0.2-0.3 μm (produced)

During the first phase of the test, the particle counter must be placed outside, in order to assess the conditions of the environment outside the classrooms. A data acquisition interval of at least 1 minute is recommended, with an air sample taken for measurement equal to 1 liter. The measurement should continue until a stationary condition of the measured particles is reached. Once the first phase is completed, the particle counter should be placed inside the classroom, in a central position, and started to obtain the stationary condition of the classroom before the smoke generator is used (second phase). To assess the efficiency of the ventilation system, windows, doors and any screens (shutters) must be closed before starting the smoke generator. The test can be repeated for all the speeds with which the ventilation system is provided; if there is insufficient time, use the speed normally set during school hours. When all classroom openings are closed, the particle counter is positioned, and the desired speed of the ventilation system is set, the smoke generator can be started (third step). The generator should be turned on until the room is completely saturated; once its use is over, it should be turned off so that it does not continue to generate excess smoke. The measurement should continue until the same conditions obtained before the start of the smoke generator are reached. At the end of the test, the data collected should be analyzed by evaluating the decay time of the particles from the maximum peak concentration until the steady-state condition is reached before the smoke generator is started.

2.2.3. Bloower door test. The blower door test is carried out for the purpose of assessing the air permeability of the classroom envelope being evaluated. The test consists of generating a pressure difference between the interior and exterior equal to 50 Pascal by means of a fan temporarily mounted on the door through an adaptable frame and a sheet sealing the door. The air flow generated by the set pressure difference defines the infiltration air flow rate at 50 Pa (q50). By making the ratio between the q50 value and the internal volume of the classroom, the number of air changes at 50 Pa (n50) is obtained. The reference technical standard used for conducting the blower door test is EN ISO 9972:2015 [13]. To carry out the test, it is also necessary to measure the temperature and relative humidity inside and outside the classroom, wind speed and atmospheric pressure. The main characteristics and models of the instruments used for the test are shown in table 5.

Table 5. Models and characteristics of the instruments used to conduct the blower door test.

Instrument type	Model	Measure	Range	Accuracy	Resolution
Blower door test system	Infiltec E3 Blower Door	n_{50}	-	-	-
Temperature and relative humidity meter	Vaisala HM 70	Air temperature	-70°C ÷ + 180°C	± 0.20°C	-
		Relative Humidity	0% ÷ 100%	± 1.50%	
Anemometer	TESTO 417	Air velocity	0.30 m/s ÷ 20 m/s	-	0.10 m/s

To carry out the test, a frame must be placed and secured in the doorway that will allow the placement of a sheet (to make the opening airtight) and the fan necessary to generate the desired pressure difference. Any points of seepage should be sealed by plastic parts or some adhesive tape. The test can be carried out under pressure or vacuum, defining the direction of the airflow generated by the fan. For classrooms where there is a false ceiling, conducting the test under vacuum is recommended to prevent the ceiling panels from moving relative to their housing.

3. Results (sample classroom)

The monitoring techniques described in the previous sections were applied and improved over time on 6 different schools, involving more than 50 classrooms. As an example, the results obtained through the illustrated methodology on a sample classroom are shown below. The chosen classroom belongs to a secondary school and is provided with a ducted ventilation system with return air vents. The classroom, with an area of 50 m^2 and volume of 179 m^3, is located on the first floor and is used by one teacher and 23 students, for a total of 24 occupants. Monitoring of indoor environmental variables (temperature, relative humidity, CO_2) was carried out for two weeks in April 2022, Figure 1 shows the measurements taken during the week of 21/04-28/04. It can be seen that the presence of the ventilation system ensures that the CO_2 concentration is always below the EN 16798-1:2019 [10] recommended limit of 1350 ppm referred to comfort category III. In addition, the maximum allowable CO_2 limit reported by WHO [14] of 1000 ppm also appears to be always respected except for a few minutes during the day of 23/04. The ventilation system present in the classroom is only used for air renewal, but it is still possible to note that the action of the latter combined with the heating system (hybrid generation system with radiant floor panels) ensures an acceptable temperature and relative humidity trend inside the classroom.

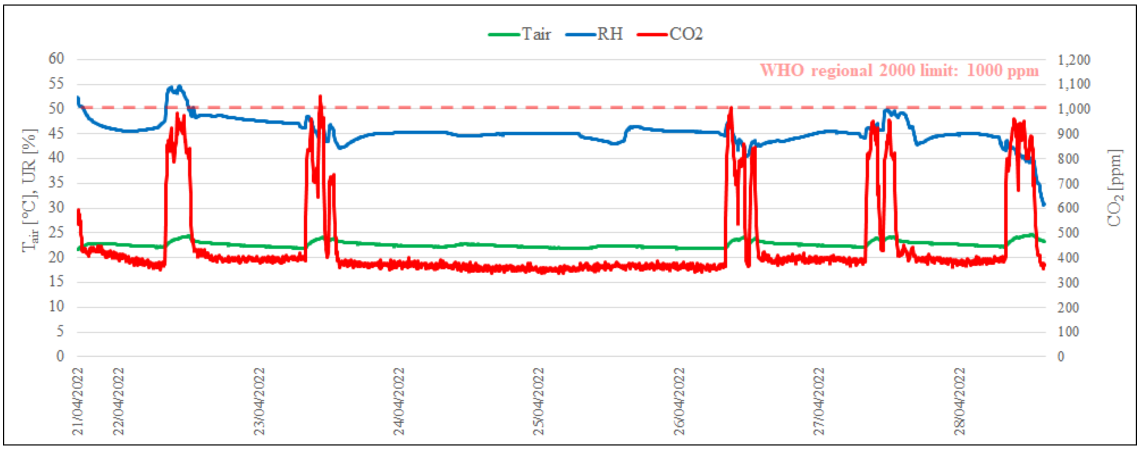

Figure 1. Trends of internal variables measured during the week of 21/04/2022-28/04/2022.

The measurement of the ventilation flow rate was carried out, given the presence of the supply and exhaust vents, by using the balometer. It can be seen from Figure 2 that the supply flow rate is higher than the extract flow rate, bringing the room under pressure. The use of the ventilation system amply guarantees compliance with the minimum hourly changes defined by DM 18/12/75 [6] and UNI 10339 [7].

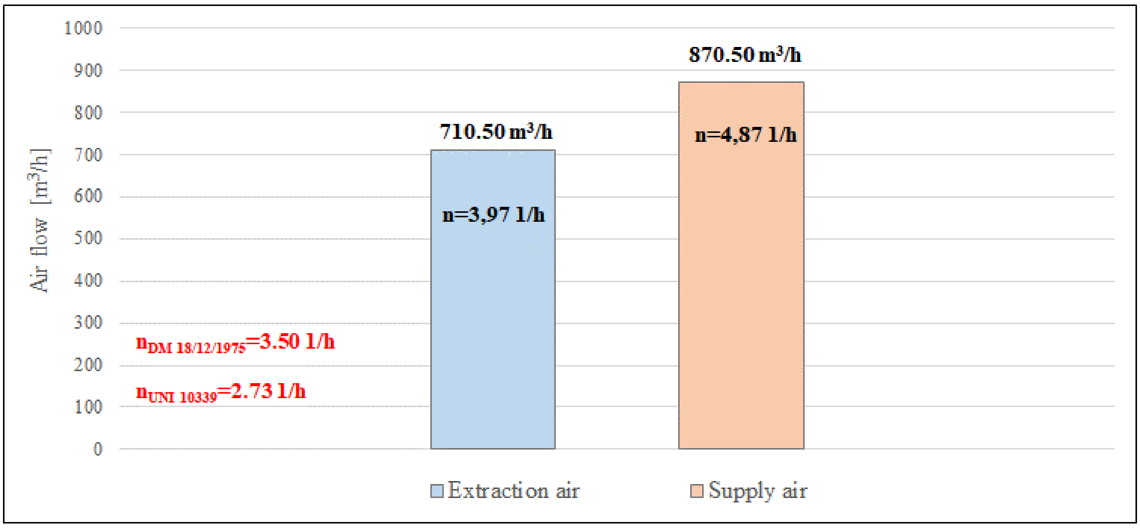

Figure 2. Ventilation flow rate measured at the supply and return vents showing the minimum hourly changes required by the standards and the actual ones.

Figure 3 illustrates the decay over time of the particles generated inside the classroom by the smoke generator. It can be seen that the peak of particles is reached around 3:45 p.m., just after the smoke generator was started. After 15 minutes, the condition before the start of the test was reached. The measurement decay time is in line with the calculated air changes.

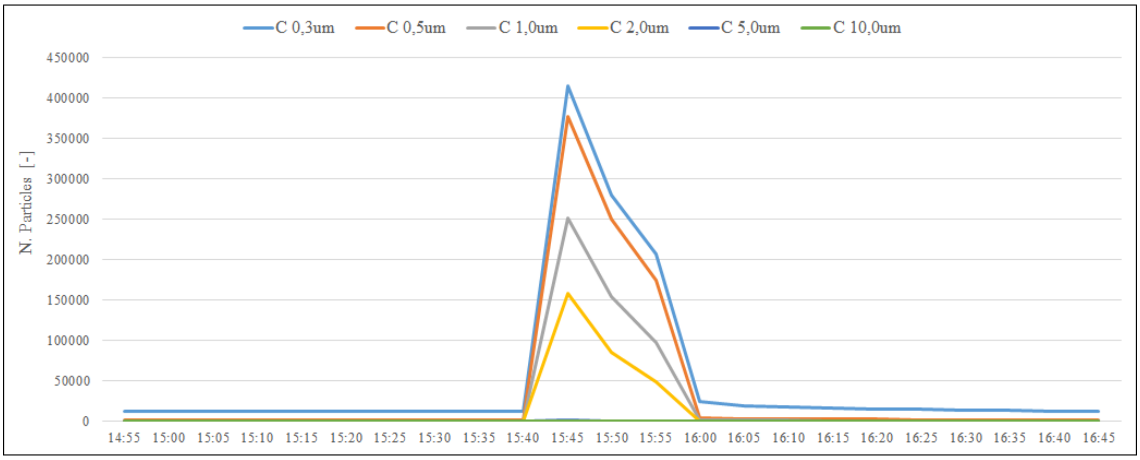

Figure 3. Decay over time of particles generated within the classroom under evaluation.

As for the blower door test, since it is a classroom provided with a false ceiling, only the vacuum test was carried out. Flow rate and pressure data were collected for six points (Figure 4) with the purpose of defining the straight line to determine the value of n50. In this case, the n50 value is very high, amounting to 10.64 1/h, due to the presence of the false ceiling that was impossible to seal during the test.

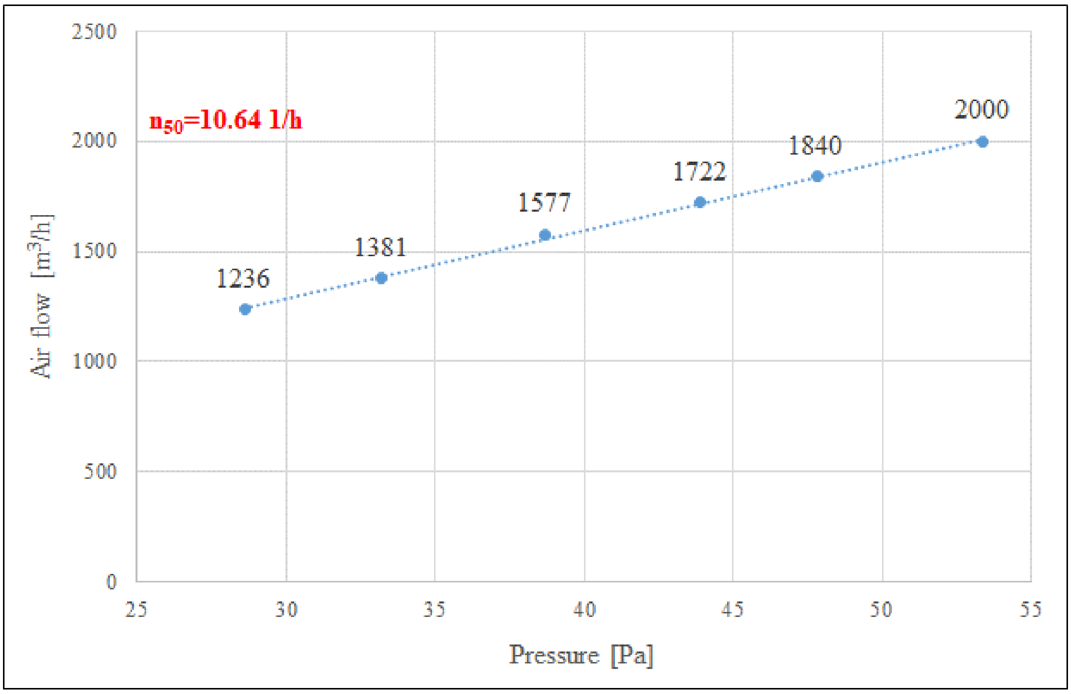

Figure 4. Construction of the straight line by the values of air pressure and air flow rate measured during the blower door test with an indication of the value of n50 obtained.

4. Conclusions

The topic of indoor air quality in educational buildings has become increasingly relevant over time, especially following the health emergency due to the SARS-CoV2 virus. There is a need to define a replicable measurement methodology inside classrooms with the aim of assessing indoor air quality and thermo-hygrometric comfort. Since there are still few contributions in the literature on IAQ assessment in the presence of ventilation systems, the measurement procedure must necessarily also assess the efficiency of the latter. For these reasons, an experimental measurement campaign was carried out inside educational buildings provided with controlled mechanical ventilation systems. The experimental campaign involved 6 schools in central Italy during the years 2022/2023. The measurement procedures were developed according to two categories: thermal-IAQ and fluid dynamic. Thermal-IAQ measurements consisted of monitoring the most important environmental variables for the evaluation of thermo-hygrometric comfort and air quality (T_{air}, RH, CO_2). Fluid dynamic measurements, on the other hand, aim to assess the efficiency of the ventilation system, through flow rate measurement and smoke tests, and the permeability of the classrooms being ventilated (blower door test). In general, from the results collected and specifically analyzing a sample classroom, the presence of a ventilation system that complies with the minimum flow rate limits imposed by the regulations guarantees an acceptable condition both from a thermal and air quality point of view. By extending the measurements carried out on an increasing number of schools and classrooms, it will be possible to evaluate the best operating configurations of the ventilation systems. The future development of this work is to extend the monitoring to other educational buildings provided with different ventilation systems and to evaluate other types of tests to be included in the measurement procedure.

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References

[1] H. Qian, T. Miao, L. Liu, X. Zheng, D. Luo, and Y. Li, "Indoor transmission of SARS-CoV-2," *Indoor Air*, vol. 31, no. 3, pp. 639–645, 2021, doi: https://doi.org/10.1111/ina.12766.

[2] P. Barrett, F. Davies, Y. Zhang, and L. Barrett, "The impact of classroom design on pupils' learning: Final results of a holistic, multi-level analysis," *Build. Environ.*, vol. 89, pp. 118–133, 2015, doi: https://doi.org/10.1016/j.buildenv.2015.02.013.

[3] S. Petersen, K. L. Jensen, A. L. S. Pedersen, and H. S. Rasmussen, "The effect of increased classroom ventilation rate indicated by reduced CO2 concentration on the performance of schoolwork by children," *Indoor Air*, vol. 26, no. 3, pp. 366–379, 2016, doi: https://doi.org/10.1111/ina.12210.

[4] A. Di Gilio *et al.*, "CO2 concentration monitoring inside educational buildings as a strategic tool to reduce the risk of Sars-CoV-2 airborne transmission," *Environ. Res.*, vol. 202, p. 111560, 2021, doi: https://doi.org/10.1016/j.envres.2021.111560.

[5] A. Zivelonghi and M. Lai, "Mitigating aerosol infection risk in school buildings: the role of natural ventilation, volume, occupancy and CO2 monitoring," *Build. Environ.*, vol. 204, p. 108139, 2021, doi: https://doi.org/10.1016/j.buildenv.2021.108139.

[6] Ministri per i lavori pubblici e per la pubblica istruzione, *Italian Ministerial Decree 18/12/75, Upgraded technical standards relating to school construction, including minimum indices of educational, building and urban functionality, to be observed in the execution of school construction works*. 1975.

[7] UNI Italian Organisation for Stardardization, *UNI 10339:1995 Air-conditioning systems for thermal comfort in buildings. General, classification and requirements. Offer, order and supply specifications*. 1995.

[8] CEN European Commitee for Standardization, *EN ISO 7726:2002 Ergonomics of the thermal environment - Instruments for measuring physical quantities.* 2002.

[9] CEN European Commitee for Standardization, *EN ISO 16000-26:2012 Indoor air - Part 26: Sampling strategy for carbon dioxide (CO2)*. 2012.

[10] CEN European Commitee for Standardization, *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 acous*. 2019.
[11] Á. Muelas *et al.*, “Analysis of different ventilation strategies and CO2 distribution in a naturally ventilated classroom,” *Atmos. Environ.*, vol. 283, p. 119176, 2022, doi: https://doi.org/10.1016/j.atmosenv.2022.119176.
[12] CEN European Commitee for Standardization, *EN 12599:2012 Ventilation for buildings - Test procedures and measurement methods to hand over air conditioning and ventilation systems*. 2012.
[13] CEN European Commitee for Standardization, *EN ISO 9972:2015 Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method*. 2015.
[14] W. Regional and P. E. Ser, “WHO Air Quality Guidelines for Europe,” *Reg. Off. Eur. Denmark*, no. 91, 2000.