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Assessment of Indoor Air Quality in School Facilities: An Educational Experience of Pathways for Transversal Skills and Orientation (PCTO)

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Abstract: Italy's education landscape witnessed a significant reform with the introduction of alternating school–work programs known as the School–Work Alternating System (PTCO). This innovative approach aims to enhance students' transversal skills and career orientation while addressing crucial health concerns, including indoor air and environmental quality within school environments. This study, conducted at an Italian high school in collaboration with a university as part of a PTCO initiative, engaged eight students in environmental monitoring data collection. The students focused on thermal comfort, CO_2 levels, and microbiological pollutants, collecting data in 19 classrooms and other school areas using professional instruments during February 2019. The results revealed varying thermal comfort levels and acceptable room temperatures, but inadequate ventilation and elevated CO_2 concentrations, particularly in crowded areas like the cafeteria. Microbial analysis identified potential health hazards, underscoring the need for proactive indoor air and environmental quality measures. Post-intervention data showed improved CO_2 levels, suggesting increased student awareness about the importance of air circulation. Engaging students in indoor air and environmental quality research through PTCO fosters critical thinking and civic engagement, which are crucial for sustainable development. Advocating for improved ventilation and periodic indoor air and environmental quality assessments aligns with the United Nations' 2030 Agenda for Sustainable Development, particularly Goal 3 (Good Health and Well-being) and Goal 4 (Quality Education). The PTCO initiative empowers students to tackle real-world challenges like indoor air and environmental quality, developing essential skills and promoting positive change. Further research and policy efforts are needed to ensure equitable access to healthy learning environments, contributing to both educational success and long-term environmental sustainability.

Keywords: environmental education; schools; indoor air; ventilation; thermal comfort

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1. Introduction

Many countries in Europe, including Italy, are currently developing and implementing policies that facilitate the school-to-work transition. In Italy, the school reform introduced with the law called "La Buona Scuola" [1] established a compulsory alternating school–work programme as an innovative education method, named School–Work Alternating System, mandatory for all learners in the last three years of upper secondary school [1,2].

The school–work alternating system has recently been renamed Pathways for transversal skills and orientation (PTCO) [3]. Students alternate between periods of traditional classroom-based learning in school and periods of practical work experience in a professional setting, often involving specific initiatives to strengthen laboratory methodologies and activities. Universities regularly offer transversal skills pathways to high school students at their departments and laboratories, considering the students' aptitude and educational background to create a unique educational and professional experience. The definition of the project is established in collaboration between university tutors and schoolteachers, and the activities can involve different areas.

In this context, the PTCO could also be considered an opportunity to increase students' interest in health and provide tools to gain awareness of responsible healthy behaviours.

An activity that is very useful and appreciated by the students during their traineeships at the universities is the involvement in the data collection of real research projects, especially those that collect data on variables that affect their health or the assessment of the quality of the school environment.

School buildings represent for students the indoor environment where they spend most of their time, after their homes, and according to relevant national and international research, indoor air quality environments influence their health [4–9].

The data published by the Italian Ministry of Education, Universities, and Research in the school year 2023/2024 showed that the Italian school system was composed of 40,321 schools, more than 7 million students, and a population of more than 800 thousand school teachers, without counting the educational services employees, the cleaning staff, and the parents who frequently go to these institutions [10]. Many people study, teach, or work in Italian schools, and their well-being, concentration, satisfaction, performance, and absenteeism could depend on indoor air and environmental quality in the schools they attend or work in; thus, monitoring the air quality in these buildings represents an important area of research [5,11–13].

Indoor air quality is considered to be a basic requirement for human health and well-being, and school facilities are recognised as one of the most influencing concerns in terms of health effects; non-specific symptoms such as coughing, headache, eye irritation, and fatigue are all connected to poor indoor air quality in non-industrial buildings like offices and schools [14]. All this can be associated with physical stress and can also be responsible for low profit, reduced occupant productivity, reduced attendance, and reduced satisfaction [15–22].

Those distresses often depend on thermal discomfort [23–25], which is perceived in too-cold or overheated classrooms, and the humidity factor, which can both directly and indirectly influence the health. In fact, a relatively low relative humidity (RH) can cause eye irritation, while a relatively high RH prevents proper evaporative cooling of the human body, which usually results in remarkable discomfort or exhaustion.

One of the effects of a high RH is the more elevated presence of moulds and bacteria that proliferate better in these conditions. They are mainly transmitted by air, and the main health effects associated with their exposure are hypersensitivity reactions (allergy), infections, and irritation [4,26,27].

Indoor carbon dioxide concentration (CO_2) is another important aspect to consider, and the air exhaled by humans is usually the main source of CO_2 in schools [28,29]. An elevated carbon dioxide concentration has several health effects, including irritation and discomfort for the occupants [30–32]. CO_2 is rarely found at levels that pose a health risk in buildings. However, it is frequently used as a surrogate measure of ventilation effectiveness. The ventilation rate is essential as it affects the dilution of indoor-generated pollutants, removes unpleasant smells, introduces outdoor air, keeps indoor air circulating, and prevents stagnation of the indoor air. Inadequate ventilation is a common problem in many school facilities worldwide [25,33].

Compared to other indoor environments, schools are characterized by their high level of occupancy, and human occupants represent the main source of bioaerosol at school that can be generated through talking, coughing, and sneezing microorganisms of which man is a carrier that can be scattered in the ambient, and their proliferation can result in many diseases [34–36].

As previously mentioned, the well-being, concentration, satisfaction, performance, and absenteeism of many individuals studying, teaching, or working in schools may be influenced by the indoor air and environmental quality in these environments. Thus, monitoring the air quality in these buildings represents an important area of research.

Although the assessment of schools' indoor air and environmental quality has been previously investigated [14,37], there are no studies based on analysis derived from data collected during school educational interventions using professional instruments and university tutors' supervision. Therefore, we decided to promote a traineeship for data collection to assess indoor air quality in school facilities.

Integrating this type of experience into ordinary school activities helps students develop transversal skills such as critical thinking, problem solving, and interdisciplinary collaboration. It provides students with a real-world context, allowing them to apply theoretical knowledge to practical situations, fostering a holistic educational experience.

In addition, understanding and addressing indoor air and environmental quality align with broader sustainability and health goals, particularly in the context of ensuring healthy living environments and promoting quality education. The United Nations' 2030 Agenda for Sustainable Development underscores the importance of providing safe and inclusive learning environments as part of its Goal 4 (Quality Education) and highlights the need for good health and well-being (Goal 3). By integrating indoor air and environmental quality monitoring into the School–Work Alternating System, this research not only addresses immediate health concerns but also contributes to the development of sustainable practices in educational institutions.

Therefore, the scope of the present paper is to illustrate an experience of PTCO involving students from an Italian high school in February 2019. The first aim was to investigate the air quality of school buildings and its implication on health by providing a field research experience based on the active participation of the students through the deepening of theoretical knowledge and practical experience. A second and more specific aim of our research was to assess the thermal comfort, carbon dioxide level, and microbiological air quality in an Italian high school with data collected by the students under the supervision of the university tutors.

2. Materials and Methods

2.1. Participants and Procedure

The research was conducted in a high school in central Italy and was part of a PCTO project with the University of Cassino and Southern Lazio (Italy).

The first phase of the project consisted of two meetings conducted by university tutors with students of two classes of the school, selected from the classes with biomedical curriculum, to illustrate indoor environmental quality as a determinant of health: its characteristics, physical, chemical, and microbial contamination, and the influence of the occupants on indoor air and environmental quality.

For the second phase of the project, eight students were chosen (20% of the total students in two classes), according to their interest and availability to participate, to learn more about the study's conceptual framework and its implications for the research that would be conducted inside the school. The selected students visited the Hygiene Laboratory at the University of Cassino and Southern Lazio to learn more about the instruments, laboratory management, and opportunities in academia in general. During this stage, eight students received intensive training from university professors and staff on how to use the equipment required for research. The intervention for the eight students included theoretical seminars on air quality, literature research, preparation of culture media, air sampling, and learning how to use the relevant instruments. Along with explaining how to perform a scientific literature search, the researchers assisted the students in creating the study's research procedure.

In the third phase of the project, before sampling, the students actively participated in the search, illustrated the purpose and the modalities of the research to the other students in their classrooms, and teachers were asked to keep the windows closed.

The fourth phase of the project consisted of data collection in the classrooms of the school.

The fifth phase consisted of data analysis carried out exclusively by the University tutors and staff.

The sixth phase consisted of presenting the results to the other students during a dedicated event.

The seventh and last phase consisted of a second data collection of the CO_2 in the classrooms.

A graphic representation of the methodology is shown in Figure 1.

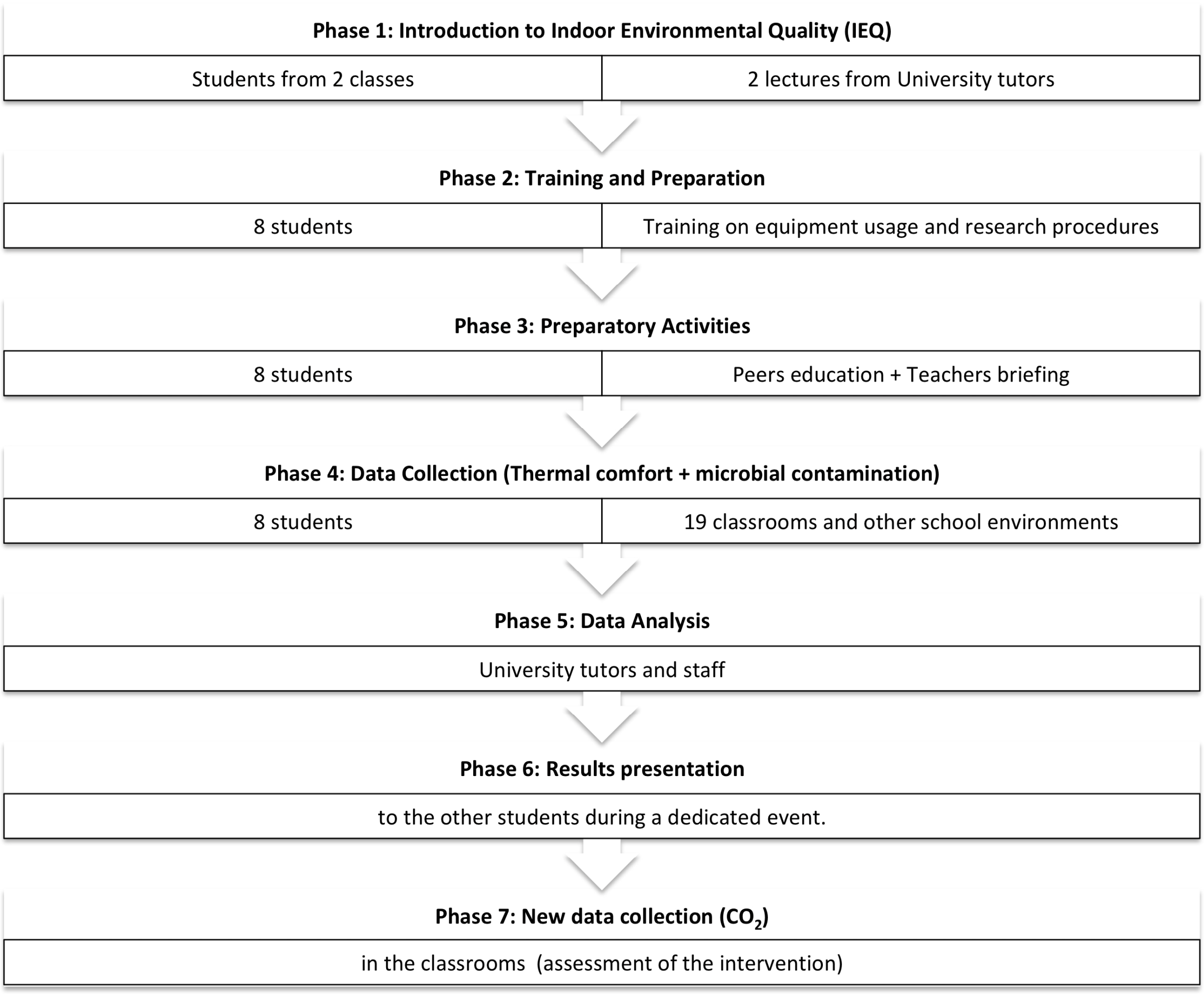

Figure 1. Methodology overview.

The school building where the research took place includes the ground floor and the first and second floors. It is equipped with water-filled radiators that operate only during the season (November–March). It is naturally ventilated, and air changes occur only through manually operable doors and windows. A detailed description of classroom characteristics is shown in Table 1.

Of 41 classrooms, 19 were sampled, and measurements were performed in the classrooms during February between 10:00 a.m. and 01:30 p.m. in occupied classes or those that were just left unoccupied by the students (17 occupied, two not occupied due to physical education lessons). The classrooms were chosen according to the floor and sun exposure, ensuring representativeness. The cafeteria, gym, computer and science laboratories (two rooms), teachers' room, and corridors (two for each floor, a total of six) were also considered in our investigation. Outdoor control sampling was performed for comparison. The second data collection was performed in March of the same year in the same classrooms and consisted of the CO_2 assessment that we used as an indirect measure of the success of the intervention.

Table 1. Characteristics of the school and the 19 classrooms analysed in an Italian high school (measured in February 2019).

	Classrooms (N.19)	
	N.	**%**
Nr of students in classroom (mean)	22	/
Grade		
1 (14 years old)	4	21.05
2 (15 years old)	5	26.32
3 (16 years old)	4	21.05
4(17 years old)	3	15.79
5 (18–19 years old)	3	15.79
Classrooms levels		
Ground floor	4	21.05
First floor	8	42.11
Second floor	7	36.84
m^2 classroom (mean)	49.6	/
Classroom volume (m^3) (mean)	142.7	/
m^3/person (mean)	6.5	/
Flooring		
Ceramic tiles	19/19	100%
Wall covering		
Painted	19/19	100%
Type of windows		
Aluminum	19/19	100%
Type of ventilation		
Natural	19/19	100%
Classroom orientation		
South-east	9	47.37%
South-west	10	52.63/%
Sun exposure		
Direct	8	42.11
Indirect	11	57.89
Type of heating		
Gas	19/19	100%

2.2. Instrumentation

To evaluate indoor environmental quality, measurements of thermal comfort, CO_2 levels, and microbial air sampling were performed by the students, assisted by the university tutors. Environmental samples were collected during two periods: February and March 2019. Sampling sessions were conducted within a time frame from 10:00 a.m. to 1:30 p.m. each day, during which we collected data from multiple areas of the school. For each area, data collection occurred only once and lasted for 30–40 min. The total data collection process took 5 days to complete.

Thermal comfort was evaluated by assessing air temperature, globe temperature, relative humidity (RH), air speed, and Fanger's Indices, Predicted Mean Vote (PMV), and

Predicted Percentage of Dissatisfied (PPD), according to ISO 7730 [38]. For the measurements, the thermal microclimate HD32.3 delta OHM was used and placed in the central area of each classroom at the height of approximately 1.5 m from the ground.

The data analysis was carried out in reference to the limits indicated by Italian legislative decree 81/2008 for the values of air temperature (20 ± 2 °C) and relative humidity during the winter (45–55%) [39].

The standard UNI EN ISO 7730 (PMV−0.5/+0.5, PPD < 10%) was used to assess thermal comfort about air speed (0.05–0.15 m/s) [38].

The concentration of carbon dioxide (CO_2) was assessed using Q-trak (trust science innovation) type 7565 certified ISO 9001 [40].

For the assessment of the concentration of CO_2, in terms of air quality, we considered the recommended limit for school classrooms of 1000 ppm [31,34,36,41].

Microbiological air sampling was performed using the Surface Air System DUO SAS 360 (PBI International), a plate impact active sampler, and using 90-mm Petri dishes.

The instrument was placed centrally in classrooms at students' breathing heights (1.5 m) with a sampled air volume of 200 L [4,19,32]. Samples were transported refrigerated to the lab within four hours. Various culture media were used for different microbes, and Petri dishes were incubated at specified temperatures. Colony concentrations were expressed as colony-forming units (CFU) per cubic meter of air [42]. Microbial contamination was evaluated using bacterial and fungal counts, with the global index of microbial contamination (GIMC) calculated [43–46], categorizing levels from very low (<500) to very high (>10,000) [43,44].

For the identification of bacteria, the BD BBL crystal system has been used. This is a miniaturized identification method employing modified conventional, fluorogenic, and chromogenic substrates.

2.3. Data Analysis

An observational study was carried out. From a statistical standpoint, the study focused on the descriptive analysis of collected data concerning indoor air quality in school facilities. Mean values and standard deviations were calculated for the key parameters outlined in the methodology.

Statistical analyses were performed using the EpiInfo 7.2 statistical package, and the level of statistical significance was set at $p < 0.05$.

3. Results

This section reveals insightful findings regarding indoor air and environmental quality in school facilities, a crucial aspect of students' health and well-being. Through the collaborative efforts of students and university tutors within the PTCO programme, comprehensive assessments were conducted to evaluate thermal comfort, carbon dioxide levels, and microbiological contamination across various school environments. The results are summarised in Table 2.

Room temperatures in the classrooms exhibited a mean value of 23.2 °C (±1.4). These data results were slightly higher than the reference range (20 °C ± 2 °C) and in no case was the temperature lower, except for in the gym, which had a room temperature of 15.1 °C. Humidity values (classes' range 43.4–60.5%) were found to comply with the norm, except for the teachers' room and the cafeteria, where RH values were below the reference range [39]. Airspeed measurements were generally low, averaging 0.02 m/s in both classrooms and hallways. The values relating to the air speed in some classes were below the norm indicated as 0.04–0.15, and in six classes, they were equal to 0.00 m/s. Notably, carbon dioxide concentrations exceeded the recommended levels in several areas, particularly in the cafeteria and IT laboratory, with mean values ranging from 458 ppm to 2701 ppm. In the classrooms, the mean CO_2 level was 2555.5. In almost all classes, the PMV index indicated acceptable thermal comfort levels in most locations, with minor deviations observed in the gym. It was optimal in 89.5% of the classes, only exceeding the suggested value (±0.05) in the remaining ones, where PPD also showed values higher than only 2–3%. However, the PPD index suggested discomfort in the gym (93%), which was likely attributed to the lower temperature. A second data collection for CO_2 was performed at the end of March 2019, one month after the presentation of the analysis of the results to the classes. Data analysis showed better values of CO_2 in the classrooms with a mean ppm of 912.75.

The concentration of CO_2 inside school classrooms is a crucial indicator of indoor air quality and ventilation efficiency. Typically, CO_2 levels in indoor environments are higher than those outdoors due to human respiration, especially in densely populated settings like classrooms and in naturally ventilated schools where the only possible air exchange occurs due to the opening of doors and windows. In our study, we observed that the CO_2 levels inside the classrooms were significantly higher, indicating inadequate ventilation within the school. Outdoor CO_2 levels were not assessed in this study because the school is located on the outskirts of the city, away from the central urban area and sources of pollution.

Table 2. Thermal comfort parameters in the 19 classrooms and other school environments in an Italian high school (measured in February 2019).

	Classrooms n.19 (Mean)		Hallways n.6 (Mean)		Gym	Cafeteria	Teachers Room	Lab IT	Lab Science	Outdoor
		SD		SD						
Room temperature (°C)	23.2	±1.4	23.2	±1.4	15.1	25.8	22	23.7	21.9	12.6
Floor temperature (°C)	21.5	±1.3	NA	NA	NA	NA	NA	NA	NA	NA
Relative Humidity (%)	52.9	±5.7	52.9	±5.7	53.8	35	37.1	50.4	48	NA
Air speed (m/s)	0.02	±0.02	0.02	±0.02	NA	NA	NA	NA	NA	NA
CO_2 (ppm)	2555.6	±1073.7	2382.6	±1073.7	638	1224	702	2701	458	NA
PMV	−0.07	±0.29	0.23	±1.38	−2.5	0.4	−0.7	−0.1	−0.4	NA
PPD (%)	6.7	±2.3	6.7	±2.3	93	7.5	14.7	5.1	7.8	NA

NA: not assessed.

The microbial contamination levels in various areas of the school premises are summarised in Table 3. The mean levels of mesophilic bacteria in classrooms were 334.55 cfu/m^3 (±334.4), and the Global Index of Microbial Contamination (GIMC) averaged 729.95 (±464.5), categorizing them as low-contamination areas.

The cafeteria showed notably higher mesophilic bacteria (622 cfu/m^3) and a GIMC of 797, indicating slightly elevated contamination compared to classrooms. The teachers' room had the lowest contamination levels, with mesophilic bacteria at 67 cfu/m^3 and a GIMC of 144. The gym had moderate contamination, with a GIMC of 732, and the computer lab had low microbial levels, with a GIMC of 160. The science lab exhibited high levels of fungi/moulds (320 cfu/m^3), leading to a GIMC of 646. Hallways displayed variable contamination, with mesophilic bacteria at 269 cfu/m^3 (±158) and a GIMC of 729.7 (±128.6). The outdoor area had the highest psychrotrophic bacteria (1100 cfu/m^3) and a GIMC of 1237, indicating a higher microbial presence due to environmental factors. Staphylococci bacteria were predominantly found in the hallways and in the cafeteria. Gram-negative bacteria were generally absent. Fungal and mould concentrations varied, with the highest levels observed in the hallways and outdoors. Overall, 47% of classrooms had very low microbial air contamination, with only 15.8% exhibiting intermediate contamination levels. The teacher's room and computer labs had low contamination, while the gym and cafeteria showed intermediate levels.

The specific results of the microbiological analysis across the 19 classrooms investigated and the outdoor area are presented in Table 4 and revealed significant variability in microbial contamination. The highest levels of mesophilic bacteria recorded were 1355 cfu/m^3, and the highest Global Index of Microbial Contamination (GIMC) was 1945. In contrast, the lowest mesophilic bacteria level found was 47 cfu/m^3, and the lowest GIMC was 209. The outdoor area had high levels of psychrotrophic bacteria (1100 cfu/m^3), but lower mesophilic bacteria (27 cfu/m^3) compared to indoors. Classrooms 7 and 6 showed high GIMC values, highlighting areas with significant microbial activity. Fungi and moulds varied, with Classroom 7 having the highest concentration (290 cfu/m^3). Most classrooms had no gram-negative bacteria, except for a few with a minimal presence.

Table 3. Results of microbiological analysis in classrooms (mean) and other rooms in an Italian high school (measured in February 2019).

	Mesophilic Bacteria (cfu m^3)	**Psycotrophilic Bacteria (cfu m^3)**	**Staphyococci (cfu m^3)**	**Gram-Bacteria (cfu m^3)**	**Fungi/Moulds (cfu m^3)**	**GIMC ***
Classrooms (mean ± SD)	334.55; ±334.4	307.65; ±128.4	0	1.5; ±3.3	87.75; ±86	729.95; ±464.5
Cafeteria	622	130	75	0	45	797
Teachers' room	67	47	25	0	30	144
Gym	375	292	35	5	65	732
Computer lab	100	60	25	0	0	160
Science lab	34	292	4	0	320	646
Hallways (mean ± SD)	269; ±158	198; ±59.6	167.3; ±128.2	0	250.7; ±59.3	729.7; ±128.6
Outdoor	27	1100	20	0	95	1237

* Global Index of Microbial Contamination (GIMC) assessment: very low category: <500; low if <1000; intermediate >1000; high if >5000; and very high if >10,000.

Table 4. Results of microbiological analysis inside the 19 classrooms investigated and in the outdoor area of an Italian high school (measured in February 2019).

	Mesophilic Bacteria (cfu m^3)	**Psycotrophilic Bacteria (cfu m^3)**	**Staphylococci (cfu m^3)**	**Gram-Bacteria (cfu m^3)**	**Fungi/Moulds (cfu m^3)**	**GIMC ***
classroom 1	402	330	35	0	135	867
classroom 2	630	400	45	5	75	1105
classroom 3	600	370	160	0	10	980
classroom 4	670	70	70	0	65	805
classroom 5	265	225	75	10	60	550
classroom 6	1355	495	190	10	95	1945
classroom 7	922	530	135	0	290	1742
classroom 8	92	162	0	0	175	429
classroom 9	75	220	50	0	70	365
classroom 10	320	320	90	0	140	780
classroom 11	197	167	75	5	65	429
classroom 12	75	290	15	0	60	425
classroom 13	75	170	30	0	0	245
classroom 14	47	132	65	0	30	209
classroom 15	137	117	40	0	60	314
classroom 16	267	290	5	0	60	617
classroom 17	350	380	55	0	140	870
classroom 18	95	300	55	0	55	450
classroom 19	90	85	85	0	60	235
Outdoor	27	1100	20	0	110	1237

* GIMC is the acronyms for Global Index of Microbial Contamination.

4. Discussion

The implementation of PTCO provided a unique opportunity to integrate practical experiences into the educational curriculum, developing students' transversal skills essential for their personal and professional growth and success in the modern workforce [47]. Students actively participated in discussing and interpreting the findings of the indoor air and environmental quality study, which enhanced their critical thinking and problem-solving abilities. This peer-led dialogue not only enriched the educational experience but also highlighted the importance of student engagement in promoting healthier school environments.

Beyond the educational objective, this study focused on investigating indoor air and environmental quality in school buildings, recognising its crucial role in student health and well-being. In addressing the need for improved indoor environmental quality in schools, Shendell et al. (2004) provide practical, science-based recommendations aimed at reducing exposure to biological, chemical, and physical hazards, emphasizing the importance of effective ventilation, moisture control, and the use of non-toxic materials [48].

Our study's findings offer a thorough examination of the school environment's microbiological contamination, air quality, and thermal comfort. Although slightly higher than the reference norms, the room and floor temperatures were generally within acceptable ranges for thermal comfort. A notable exception was the gym, where the temperature dropped to as low as 15.1 °C. Except for a few places, such as the teachers' room and the cafeteria, humidity levels were generally within acceptable ranges. Air speed measurements frequently showed numbers that fell outside the advised range, and several classes showed no air movement. Fanger's indices revealed that most classrooms had the ideal level of thermal comfort, with a few minor exceptions. The findings regarding thermal comfort parameters in our study suggest generally acceptable conditions in many classrooms, with the predicted percentage of dissatisfied students never exceeding 13%. In fact, we noticed that classes with the best PPD and PMV levels have the best temperatures, but also show the lowest air speeds and highest levels of CO_2.

Nearly all classrooms exhibited elevated carbon dioxide concentrations, suggesting inadequate ventilation, which could be influenced by the winter season (February–March) when natural ventilation through windows and doors is limited. Furthermore, we recorded high levels of CO_2 in hallways, where windows are also rarely opened during the winter, in the cafeteria, probably the most crowded environment of our school, and in the computer laboratory, where we registered high levels as well. Critical issues concerning low air velocities, often reaching 0 m/s, indicate insufficient air movement due to infrequent window openings. This stagnant air contributes to elevated carbon dioxide (CO_2) levels, which exceed the recommended standards in most classrooms, reaching almost 5000 ppm in one instance. As proved by previous studies, longer airing periods produce lower indoor CO_2 concentrations and other gaseous indoor-generated pollutants [49]. High CO_2 concentrations pose health risks, including headaches, dizziness, and nausea, highlighting the importance of effective ventilation strategies [21,29,31]. The installation of mechanical ventilation systems could mitigate these issues, as demonstrated in studies showing improved air exchange rates and decreased CO_2 concentrations following ventilation system upgrades [27]. In their study, Smedje and Norbäck [27] studied the change in indoor air quality in schools that renewed their ventilation systems. They observed that air exchange rates improved and associated CO_2 concentrations decreased on average by 270 ppm because of the new ventilation system. Furthermore, they also reported a significant decrease in relative humidity in schools with a new ventilation system (−10%) compared with schools that did not change their ventilation system (−2%). However, it is essential to acknowledge the challenges associated with mechanical ventilation systems. They entail considerable costs for acquisition, installation, and maintenance. In addition, regular cleaning and frequent replacement of philtres are necessary to prevent contamination and the spread of microbes and pathogens within the building [29].

Microbial analysis revealed Staphylococcus spp. and other bacteria, indicative of potential health hazards. Comparison with previous studies suggests some improvement in air quality parameters over time but highlights the need for ongoing efforts to enhance indoor environmental quality for the well-being of students and staff [32].

Despite these challenges, the data did not reveal immediate health risks, emphasising the opportunity for proactive measures to improve indoor air quality and ensure a favourable learning environment [26,50–52].

The results of the second data collection, which took place only in the classrooms and included only CO_2, suggest that the intervention had a positive impact on reducing CO_2 levels. The mean CO_2 concentration decreased significantly from the initial 2555.5 ppm to 912.75 ppm, indicating improved ventilation practices and possibly more frequent airing of classrooms. This notable reduction highlights the efficacy of the implemented measures and underscores the potential for continuous improvement in indoor air and environmental quality through targeted interventions. Further monitoring and sustained efforts are essential to maintain these improved conditions and to extend similar interventions to other areas within the school premises.

Strengths and Limitations

This study employed a practical approach in which students actively participated in environmental monitoring within their school, offering a unique educational experience. The results were presented as a peer education intervention that potentially contributed to enhancing knowledge, attitudes, and beliefs regarding indoor air and environmental quality among students, empowering them to make informed decisions. Furthermore, this study tried to bridge the gap between theoretical knowledge and practical application by integrating real-world research experiences into the educational curriculum.

In our study, the experiential learning approach has shown the potential to deepen students' understanding of the relationship between human activities and environmental outcomes, fostering a sense of responsibility and stewardship [53]. By involving students in identifying and addressing indoor air and environmental quality challenges within their school, and presenting the results to their peers, the PTCO initiative has promoted civic engagement and community empowerment, positioning students as agents of positive change within their local communities [54]. According to previous studies, this approach nurtures a growth mindset, encouraging a passion for inquiry and discovery [55,56], and enhances interpersonal skills, empathy, and social and emotional intelligence as students work together to tackle complex problems and navigate diverse perspectives [57], preparing them for success in an increasingly interconnected and globalized world [58–60].

However, this study has several limitations.

While the transformative potential of experiential learning is well-supported by studies on internships and cooperative education programs [61,62], we acknowledge that a formal evaluation of the educational interventions, including a follow-up data collection, was planned but could not be completed due to the COVID-19 pandemic. The effectiveness of the educational intervention and student satisfaction were not directly measured, although the successful execution of the data collection process and the improved CO_2 values recorded after the intervention can be considered positive indicators.

Another limitation is that the sample was not fully representative of the entire high school population because the selection of the school was based on participation in the PCTO project, potentially introducing bias. From a structural and environmental point of view, data analysis excluded cross-referencing with structural characteristics of the school and classrooms, limiting the depth of insights into potential correlations between environmental factors and school infrastructure.

Moreover, the indoor environmental monitoring was conducted over a relatively short period (30–40 min), which may not capture fluctuations in air quality throughout the day or across seasons. In addition, the study primarily focused on the winter period, and the influence of seasonal variations on indoor air and environmental quality was not explored. Future research covering different seasons is required.

Overall, while the study offers valuable insights into student-led environmental monitoring and peer education initiatives, addressing these limitations could further enhance the robustness and applicability of future research in this area.

5. Conclusions

Ensuring adequate ventilation and addressing indoor air and environmental quality issues are essential steps towards fostering a healthy and conducive learning environment. This research demonstrates that involving students in environmental monitoring through programs like School–Work Alternating System can significantly enhance their understanding of sustainability challenges and equip them with the skills necessary to address these issues. By promoting experiential learning and civic engagement, the PTCO initiative supports the broader goals of sustainable development, contributing to both educational and environmental sustainability. With the identification of important elements, including thermal comfort, indoor carbon dioxide, as an indicator of ventilation, and indoor air microbiological pollutants to which students are exposed, this study offers insightful information on the school environment. The findings highlight the critical need for on-going monitoring and improvement of indoor air and environmental quality in schools, underscoring the importance of more frequent ventilation practices by airing out classrooms during breaks and between lessons, especially if there is no mechanical ventilation system that can regulate the temperature, humidity, and air speed. By encouraging students to actively participate in discussions and propose solutions based on scientific evidence, our intervention promoted a sense of ownership and responsibility towards improving indoor air and environmental quality and overall well-being within the school community.

Future research should focus on expanding such initiatives to maximize the impact of experiential learning on student development and well-being, and to integrate comprehensive indoor air and environmental quality management strategies in schools, ensuring long-term benefits for students' health and well-being in line with the 2030 Agenda for Sustainable Development.

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References

1. Law No. 107 of 13 July 2015. Riforma del Sistema Nazionale di Istruzione e Formazione e Delega per il Riordino Delle Disposizioni Legislative Vigenti. (15G00122) (GU Serie Generale n. 162 del 15/07/2015). Available online: https://www.gazzettaufficiale.it/eli/id/2015/07/15/15G00122/sg (accessed on 24 April 2024).
2. Legislative Decree No. 77 of 15 April 2005. Definizione delle Norme Generali Relative All'alternanza Scuola-Lavoro, a Norma Dell'articolo 4 della Legge 28 Marzo 2003, n. 53. Available online: https://www.istruzione.it/alternanza/allegati/NORMATIVA%20ASL/D.L.77%20DEL%202005.pdf (accessed on 23 April 2024).

3. Law No.145 of December 2018. Ripubblicazione del Testo della Legge 30 Dicembre 2018, n. 145, Recante: «Bilancio di Previsione dello Stato per L'anno Finanziario 2019 e Bilancio Pluriennale per il Triennio 2019–2021», Corredato delle Relative Note. (Legge Pubblicata nel Supplemento Ordinario n. 62/L alla Gazzetta Ufficiale—Serie Generale—n. 302 del 31 Dicembre 2018). (19A00318). Available online: https://www.edscuola.eu/wordpress/wp-content/uploads/2019/01/20190118_015_SO_003.pdf (accessed on 23 April 2024).
4. Bragoszewska, E.; Mainka, A.; Pastuszka, J.S.; Lizończyk, K.; Desta, Y.G. Assessment of Bacterial Aerosol in a Preschool, Primary School and High School in Poland. *Atmosphere* **2018**, *9*, 87. [CrossRef]
5. Chithra, V.S.; Shiva Nagendra, S.M. A review of scientific evidence on indoor Air of school building: Pollutants, sources, health effects and management. *Asian J. Atmos. Environ.* **2018**, *12*, 87–108. [CrossRef]
6. Cincinelli, A.; Martellini, T. Indoor Air Quality and Health. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1286. [CrossRef] [PubMed]
7. Ferreira, A.M.; Cardoso, M. Indoor air quality and health in schools. *J. Bras. Pneumol.* **2014**, *40*, 259–268. [CrossRef] [PubMed]
8. Fsadni, P.; Frank, B.; Fsadni, C. The Impact of Microbiological Pollutants on School Indoor Air Quality. *J. Geosci. Environ. Prot.* **2017**, *5*, 54–65. [CrossRef]
9. Kalimeri, K.K.; Saraga, D.E.; Lazaridis, V.D. Indoor air quality investigation of the school environment and estimated health risks: Two-season measurements in primary schools in Kozani, Greece. *Atmos. Pollut. Res.* **2016**, *7*, 1128–1142. [CrossRef]
10. Ministero dell'Istruzione e del Merito. Direzione Generale per i Sistemi Informativi e la Statistica—Ufficio di Statistica. Fonte: Elaborazione su Dati del Ministero Dell'istruzione e del Merito—Direzione Generale per i Sistemi Informativi e la Statistica—Ufficio di Statistica. 2023. Available online: https://www.miur.gov.it/documents/20182/0/Principali+dati+della+scuola+-+Focus+avvio+anno+scolastico+2023-2024.pdf/8ba0c506-a14f-9071-fbb7-e0aede0a5ebb?t=1695388882235 (accessed on 23 April 2024).
11. Madureira, J.; Alvim-Ferraz, M.C.M.; Rodrigues, S.; Gonçalves, C.; Azevedo, M.C.; Pinto, E.; Mayan, O. Indoor Air Quality in Schools and Health Symptoms among Portuguese Teachers. *Hum. Ecol. Risk Assess.* **2009**, *15*, 159–169. [CrossRef]
12. Singh, P. Indoor environmental quality & student health and performance: A conceptual review. *IJPSS* **2013**, *3*, 96–107.
13. Bluyssen, P.M. Health, comfort and performance of children in classrooms—New directions for research. *Indoor Built Environ.* **2017**, *26*, 1040–1050. [CrossRef]
14. Daisey, J.M.; Angell, W.J.; Apte, M.G. Indoor air quality, ventilation and health symptoms in schools: An analysis of existing information. *Indoor Air* **2003**, *13*, 53–64. [CrossRef]
15. Bluyssen, P.M.; Zhang, D.; Kurvers, S.; Overtoom, M.; Ortiz-Sanchez, M. Self-reported health and comfort of school children in 54 classrooms of 21 Dutch school buildings. *Build. Environ.* **2018**, *138*, 106–123. [CrossRef]
16. Gaihre, S.; Semple, S.; Miller, J. Classroom carbon dioxide concentration, school attendance, and educational attainment. *J. Sch. Health* **2014**, *84*, 569–574. [CrossRef] [PubMed]
17. Ervasti, J.; Kivimäki, M.; Kawachi, I.; Subramanian, S.V.; Pentti, J.; Oksanen, T.; Puusniekka, R.; Pohjonen, T.; Vahtera, J.; Virtanen, M. School environment as predictor of teacher sick leave: Data-linked prospective cohort study. *BMC Public Health* **2012**, *12*, 770. [CrossRef] [PubMed]
18. Karapetsis, A.; Alexandri, E. Indoor environmental quality and its impacts on health–case study: School buildings. In Proceedings of the EinB2016—5th International Conference Energy in Buildings, Botanique, Greece, 12 November 2016.
19. Langiano, E.; Lanni, L.; Atrei, P.; Ferrara, M.; La Torre, G.; Capelli, G.; De Vito, E. La qualità dell'aria negli edifici scolastici progettati ad hoc e in edifici abitativi riadattati. *Ig. Sanità Pubblica* **2008**, *64*, 53–66.
20. Mendell, M.J.; Heath, G.A. Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air* **2005**, *15*, 27–52. [CrossRef] [PubMed]
21. Teli, D.; Dalenbäck, J.; Ekberg, L. Winter thermal comfort and indoor air quality in Swedish grade school classrooms, as assessed by the children. In Proceedings of the 14th International Conference of Indoor Air Quality and Climate, Ghent, Belgium, 3–8 July 2016.
22. Zhang, D.; Ortiz, M.A.; Bluyssen, P.M. Clustering of Dutch school children based on their preferences and needs of the IEQ in classrooms. *Build. Environ.* **2019**, *147*, 258–266. [CrossRef]
23. Stazi, F.; Naspi, F.; Ulpiani, G.; Di Perna, C. Indoor air quality and thermal comfort optimization in classrooms developing an automatic system for windows opening and closing. *Energy Build.* **2017**, *139*, 732–746. [CrossRef]
24. Najafi, N.; Movahed, K.; Barzegar, Z.; Samani, S. The effect of thermal comfort in female high school students. *Int. J. Sch. Health* **2018**, *5*, e67539.
25. Najafi, N.; Movahed, K.; Barzegar, Z.; Samani, S. The effect of ventilation by window opening on stress, anxiety, and depression of female high school students. *Int. J. Sch. Health* **2019**, *6*, e87038. [CrossRef]
26. Madesn, A.M.; Moslehi-Jenabian, S.; Islamb, Z.; Frankel, M.; Spilak, M.; Frederiksen, M.W. Concentrations of Staphylococcus species in indoor air as associated with other bacteria, season, relative humidity, air change rate, and S. aureus-positive occupants. *Environ. Res.* **2018**, *160*, 282–291. [CrossRef]
27. Smedje, G.; Norback, D. Irritants and Allergens at School in Relation to Furnishings and Cleaning. *Indoor Air* **2001**, *11*, 127–133. [CrossRef]
28. Batterman, S. Review and extension of CO_2-based methods to determine ventilation rates with application to school classrooms. *Int. J. Environ. Res. Public Health* **2017**, *14*, 145. [CrossRef] [PubMed]

29. Hänninen, O.; Canha, N.; Kulinkina, A.H.; Dume, I.; Deliu, A.; Mataj, E.; Lusati, A.; Krzyzanowski, M.; Egorov, A.I. Analysis of CO_2 monitoring data demonstrates poor ventilation rates in Albanian schools during the cold season. *Air Qual. Atmos. Health* **2017**, *10*, 773–782. [CrossRef]
30. Madureira, J.; Paciência, I.; Pereira, C.; Teixeira, J.P.; Fernandes, E.D.O. Indoor air quality in Portuguese schools: Levels and sources of pollutants. *Indoor Air* **2015**, *26*, 526–537. [CrossRef] [PubMed]
31. Persily, A.K. Evaluating building IAQ and ventilation with indoor carbon dioxide. In Proceedings of the Ashrae Summer Meeting, Boston, MA, USA, 29 June–2 July 1997.
32. Rosbach, J.T.; Vonk, M.; Dujim, F.; Rosbach, J.T.; Vonk, M.; Duijm, F.; Van Ginkel, J.T.; Gehring, U.; Brunekreef, B. A ventilation intervention study in classroom to improve indoor air quality: The FRESH study. *Environ. Health* **2013**, *12*, 110–120. [CrossRef]
33. Golshan, M.; Thoen, H.; Zeiler, W. Dutch sustainable schools towards energy positive. *J. Build. Eng.* **2018**, *19*, 161–171. [CrossRef]
34. Norbäck, D.; Wieslander, G.; Zhang, X.; Zhao, Z. Respiratory symptoms, perceived air quality and physiological signs in elementary school pupils in relation to displacement and mixing ventilation system: An intervention study. *Indoor Air* **2011**, *21*, 427–437. [CrossRef]
35. Qian, J.; Hospodsky, D.; Yamamoto, N.; Nazaroff, W.W.; Peccia, J. Size-resolved emission rates of airborne bacteria and fungi in an occupied classroom. *Indoor Air* **2012**, *22*, 339–351. [CrossRef]
36. Täubel, M.; Leppänen, H.K. Microbial Exposures in Schools and Daycare Centers. *Environments* **2017**, *14*, 253–287.
37. De Gennaro, G.; Dambruoso, P.R.; Loiotile, A.D.; Di Gilio, A.; Giungato, P.; Tutino, M.; Marzocca, A.; Mazzone, A.; Palmisani, J.; Porcelli, F. Indoor air quality in schools. *Environ. Chem. Lett.* **2014**, *12*, 467–482. [CrossRef]
38. *ISO 7730 EN*; Ergonomics of the Thermal Environment. Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. International Standardisation Organisation: Geneva, Switzerland, 2005.
39. Legislative Decree No. 81 of 9 April 2008. Implementation of Article 1 of Law 3 August 2007, No. 123, concerning the protection of health and safety in the workplace (Official Gazette No. 101 of 30 April 2008). Available online: https://www.gazzettaufficiale.it/eli/id/2008/04/30/008G0104/sg (accessed on 30 July 2024).
40. *ISO 9001*; Quality Management Systems. Requirements. International Standardisation Organisation: Geneva, Switzerland, 2015.
41. *ASHRAE 62–2001*; Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.: Atlanta, GA, USA, 2001.
42. Bonadonna, L.; Briancesco, R.; Brunetto, B.; Coccia, A.M.; De Gironimo, V.; Della Libera, S.; Fuselli, S.; Gucci, P.M.B.; Iacovacci, P.; Lacchetti, I.; et al. *Strategie di Monitoraggio Dell'inquinamento di Origine Biologica Dell'aria in Ambiente Indoor*; Istituto Superiore di Sanità: Roma, Italy, 2013; Rapporti ISTISAN 13/37.
43. Dacarro, C.; Grignani, E.; Lodola, L.; Grisoli, P.; Cottica, D. Proposta di indici microbiologici per la valutazione della qualità dell'aria degli edifici. *G. Ital. Med. Lav. Ergon.* **2000**, *22*, 229–235. [PubMed]
44. Dacarro, C.; Picco, A.M.; Grisoli, P.; Rodolfi, M. Determination of aerial microbiological contamination in scholastic sports environments. *J. Appl. Microbiol.* **2003**, *95*, 904–912. [CrossRef] [PubMed]
45. INAIL. *CONTARP—Guidelines-Microbiological Monitoring in Work Environments. Sampling and Analysis*; Edizioni INAIL: Milano, Italy, November 2005; ISBN 978-88-7484-162-2. (In Italian)
46. INAIL. *CONTARP—Safety and Well-Being in Schools: Survey on Air Quality and Ergonomics*; Piccioni, R., Giovinazzo, E., Incocciati, F., Nappi, D., Rughi, Eds.; Edizioni INAIL: Milano, Italy, 2015; ISBN 978-88-7484-449-4. (In Italian)
47. European Commission. *DigComp 2.1: The Digital Competence Framework for Citizens*; Publications Office of the European Union: Luxembourg, 2018.
48. Shendell, D.G.; Barnett, C.; Boese, S. Science-based recommendations to prevent or reduce potential exposure to biological, chemical, and physical agents in schools. *J. Sch. Health* **2004**, *74*, 390–396. [CrossRef] [PubMed]
49. Stabile, L.; Dell'Isola, M.; Russi, A.; Massimo, A.; Buonanno, G. The effect of natural ventilation strategy on indoor air quality in schools. *Sci. Total Environ.* **2017**, *595*, 894–902. [CrossRef] [PubMed]
50. Assafi, M.S.; Polse, R.F.; Hussein, N.R.; Assafi, M.S.; Polse, R.F.; Hussein, N.R.; Haji, A.H.; Issa, A.R. The Prevalence of S. aureus nasal colonisation and its antibiotic sensitivity pattern amongst primary school pupils. *Sci. J. Univ. Zakho* **2017**, *5*, 7–10. [CrossRef]
51. Decker, C.F. Flavimonas oryzihabitans (*Pseudomonas oryzihabitans*; CDC Group Ve-2) Bacteremia in the Immunocompromised Host. *Arch. Intern. Med.* **1991**, *151*, 603. [CrossRef]
52. Lalucat, J.; Bennasar, A.; Bosch, R.; García-Valdés, E.; Palleroni, N.J. Biology of *Pseudomonas stutzeri*. *Microbiol. Mol. Biol. Rev.* **2006**, *70*, 510–547. [CrossRef] [PubMed]
53. Brundiers, K.; Wiek, A. Beyond interpersonal competencies: Teaching and learning professional skills in sustainability. *High. Educ.* **2017**, *73*, 407–422.
54. Hart, P.S.; Nolan, J.M. The role of the internet in raising environmental awareness: Media priming, behavior change, and support for climate policies. *J. Comput. -Mediat. Commun.* **2018**, *23*, 328–343.
55. Dweck, C.S. *Mindset: The New Psychology of Success*; Ballantine Books: New York, NY, USA, 2006.
56. Bluyssen, P.M.; Kim, D.H.; Eijkelenboom, A.; Ortiz-Sanchez, M. Workshop with 335 primary school children in The Netherlands: What is needed to improve the IEQ in their classrooms? *Build. Environ.* **2020**, *168*, 106486. [CrossRef]
57. Mizell, H. Empathy in the Classroom: A Conceptual Model and its Practical Implications. *J. Teach. Educ.* **2010**, *61*, 165–174.

58. Darling-Hammond, L.; Flook, L.; Cook-Harvey, C.; Barron, B.; Osher, D. Implications for educational practice of the science of learning and development. *Appl. Dev. Sci.* **2019**, *24*, 97–140. [CrossRef]
59. Billett, S. Integrating Practice-Based Experiences with Higher Education. In *Integrating Practice-Based Experiences into Higher Education. Professional and Practice-Based Learning*; Springer: Dordrecht, The Netherlands, 2015; pp. 1–26.
60. Johnson, D.W.; Johnson, R.T.; Smith, K.A. Cooperative learning and individual student achievement in secondary schools. In *Secondary Schools and Cooperative Learning*; Routledge: London, UK, 2014; pp. 3–54.
61. Kolbe, L.J. School Health as a Strategy to Improve Both Public Health and Education. *Annu. Rev. Public Health* **2019**, *40*, 443–463. [CrossRef]
62. Liem, G.A.D.; Chong, W.H. Fostering student engagement in schools: International best practices. *Sch. Psychol. Int.* **2017**, *38*, 121–130. [CrossRef]