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Multidisciplinary Study of Air Quality in Schools: multiple approaches to a single problem

Introduction:
In recent years, the scientific community has shown growing concern regarding the effects of indoor air quality on health. The COVID-19 pandemic has also highlighted the importance and necessity of addressing these issues through interdisciplinary approaches. In this context, we formed a team of engineers, architects, microbiologists, and physicians to study air quality in educational settings in Uruguay, where no similar analyses have been conducted at the national level.
Aim:
This initiative aims to develop diagnostic tools and generate knowledge about the relationship between air quality, ventilation, thermal comfort, and health in elementary schools in Uruguay.
Methodology:
The study, conducted from 2023 to 2024, involved two naturally ventilated school buildings with two shifts each, encompassing four elementary schools. Continuous monitoring of carbon dioxide (CO_2) concentration, air temperature, and relative humidity was performed in all classrooms over two years. Five classrooms in each building were selected for microbiological air sampling; two classrooms for particulate matter ($PM_{2.5}$ and PM_{10}) and nitrogen dioxide measurements; and three classrooms for thermal comfort assessments. Outdoor particulate pollution was also monitored.
Microbiological sampling was conducted biannually using air filtration and sedimentation plates, followed by colony-forming unit (CFU) counts at 48 hours for bacteria and 168 hours for fungi. Hygrothermal comfort was evaluated through surveys and thermal condition assessments. Additionally, interviews with families captured data on children's health. Computational fluid dynamics (CFD) simulations were used to model airflow patterns and pathogen dispersion indoors.
Results:
Each classroom housed an average of 23 children (range: 0–31) and 3 adults (range: 2–6). The average classroom conditions were 20℃ (18–22℃), 68% humidity (51–86%), and 1079 ppm CO_2 (530–2019 ppm), with only 13% of samples using air conditioning.
The children surveyed were between 5 and 12 years old. The average bacterial counts in Trypticase soy agar were 1324.3 CFU/m^3 (range: 0–5040), and the average fungal count in Malta chloramphenicol medium was 98.0 CFU/m^3 (range: 0–909). We found a positive correlation between CO2 levels and bacterial counts.
Surveys indicated low comfort levels, likely due to poor ventilation, high temperatures, and odors. In spring of 2024, 50% of the families reported infectious symptoms the week before the microbiological monitoring (mainly respiratory symptoms) with a school absenteeism rate of 20%.
Regarding criteria for atmospheric pollutants monitoring, it is suggested that indoor particle concentrations result from the influence of outdoor air entering the classrooms and indoor particle emission processes, such as the resuspension of particles deposited on the floor.
Based on the CFD simulations, the airflow pattern is influenced by two main factors: the ventilation configuration and the thermal plumes generated by the presence of occupants. Certain inhomogeneities, represented as passive tracers, appear in the concentration field when simulating pathogen dispersion. Nevertheless, calculating the infection risk using the well-mixed hypothesis provides a conservative yet cost-effective initial approach compared to the infection risk estimated directly from the CFD simulations.
Conclusions:
This pioneering study offers critical insights into the interplay between indoor air quality, ventilation, and

health in elementary schools in Uruguay. By combining environmental monitoring, microbiological assessments, and computational simulations, we have developed a robust framework for diagnosing and addressing air quality issues in educational settings. The observed correlations between CO_2 levels, microbial load, and health outcomes underline the importance of adequate ventilation to mitigate pathogen transmission and improve thermal comfort. Additionally, the integration of CFD simulations provides a valuable tool for designing ventilation strategies tailored to reduce infection risk. Notably, this work is pioneering in our country, as it addresses air quality through an interdisciplinary approach.

Primary authors: ARREDONDO, Daniela (Department of Microbiology, Instituto de Investigaciones Biológicas Clemente Estable, MEC, Montevideo, Uruguay); CAPDEHOURAT, Germán (Ceibal - Ministerio de Educación y Cultura - Uruguay); PÉREZ, Germán (Laboratory of Microbiology, Department of General Biology, Faculty of Agronomy, UDELAR, Montevideo, Uruguay); FRANCHI, Ignacio (Facultad de Ingeniería - Universidad de la República - Uruguay); VILLARREAL, Joaquin (Department of Microbiology, Instituto de Investigaciones Biológicas Clemente Estable, MEC, Montevideo, Uruguay); FLOREZ, Jonathan (Universidad de la República); OLIVER, Juan Pablo (Facultad de Ingeniería - Universidad de la República - Uruguay); AZZIZ, Julia (Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República, Uruguay.); DÍAZ, Leandro (Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República, Uruguay.); PARDO, Lorena (Facultad de Medicina, Universidad de la República); ROBINO, Luciana (Academic Unit of Bacteriology and Virology, Faculty of Medicine, UDELAR, Montevideo, Uruguay); Ms GUTIERREZ, Lucía (Área de Clima y Confort, instituto de Tecnologías, Facultad de arquitectura Diseño y Urbanismo, UDELAR); Ms PEREIRA, Lucía (Área de Clima y Confort, instituto de Tecnologías, Facultad de arquitectura Diseño y Urbanismo, UDELAR); Ms CAMACHO, Magdalena (Área de Clima y Confort, instituto de Tecnologías, Facultad de arquitectura Diseño y Urbanismo, UDELAR); MENDINA, Mariana (Facultad de Ingeniería - Universidad de la República - Uruguay); DRAPER, Martín (Facultad de Ingeniería - Universidad de la República - Uruguay); GONZALEZ, María José (Department of Microbiology, Instituto de Investigaciones Biológicas Clemente Estable, MEC, Montevideo, Uruguay); Ms LÓPEZ, María Noel (Área de Clima y Confort, instituto de Tecnologías, Facultad de arquitectura Diseño y Urbanismo, UDELAR); D'ANGELO, Mauro; SCAVONE, Paola (Department of Microbiology, Instituto de Investigaciones Biológicas Clemente Estable, MEC, Montevideo, Uruguay); GÓMEZ, Paula (Institute of Fluid Mechanics and Environmental Engineering, Faculty of Engineering, UDELAR, Montevideo, Uruguay)

Presenter: DRAPER, Martín (Facultad de Ingeniería - Universidad de la República - Uruguay)