Evaluating the Impact of Air Cleaning and Ventilation of Airborne Pathogens and Human Bio-effluents at Two Primary Schools in Belgium

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ABSTRACT

The COVID-19 pandemic increased the awareness and importance of infectious pathogens as contaminant in the indoor air, especially for non-residential buildings with a high occupational density like schools. During the COVID-19 pandemic air cleaning is often proposed as mitigation strategy for infectious risk in these types of buildings. However, indoor air quality (IAQ) in general comprises of a large range of possible contaminants and factors that can equally impact the health, comfort and well-being of occupants. In this context, a study was conducted in Flanders (Belgium) with the aim of investigating the potential impact of ventilation and air cleaning on the IAQ and infection risk control in Flemish public spaces. This paper describes part of this larger study, focusing on the assessments carried out in two primary schools.

In the first school, which did not have a mechanical ventilation system, 4 classrooms were assessed for three weeks. In the second school, 4 classrooms connected to a centralized mechanical ventilation system were assessed in two separate measurement campaigns of 3 weeks. Between the two measurement campaigns in school 2, the defects in the mechanical ventilation system which were observed during the first campaign were corrected.

In each school, in three of the four classrooms, specific interventions were done after the first week of monitoring, among which the introduction of air cleaners. The fourth class was monitored without intervention. In each classroom, CO_2 concentrations and biological air samples were collected 2 days per week for in-lab qPCR analysis of over 20 genetic markers of respiratory pathogens. The results for SARS-CoV-2 are presented.

Unfortunately, in both schools, the effectiveness of the interventions on airborne pathogens (incl. SARS-CoV-2) could not be quantified due to the lack of infected schoolchildren and other measures like the wearing of face masks at that time resulting in mostly negative or borderline results. In general, the results indicate the importance of proper commissioning and maintenance to mechanical ventilation systems and show an overall better expected perceived indoor air quality when the ventilation system works properly. In the school without mechanical ventilation system, manual airing through the opening of windows can achieve the same level of expected perceived indoor air quality if operated correctly.

KEYWORDS

Primary school, Indoor Air Quality, Ventilation, Airing, CO_2, COVID-19

1 INTRODUCTION

The COVID-19 pandemic increased the awareness and importance of infectious pathogens as contaminants in the indoor air in the general public and governmental agencies. In this context, the Flemish department of care (“*Departement Zorg*”) has ordered a pilot study to investigate the effectiveness of two possible IAQ management strategies namely, ventilation/airing and stand-alone air cleaning devices based on filtration. Although the main goal is to better understand the effectiveness of the two IAQ management strategies to decrease the spread of airborne pathogens, the study allowed a wider range of investigation to investigate the overall feasibility of the IAQ management strategies. A multidisciplinary consortium was assigned to investigate the IAQ (human bio-effluents(~CO_2), airborne pathogens, PM_x, RH), other parameters related to indoor health and sensation of comfort (e.g., temperature, acoustics) and record building related parameters (e.g., air change rates – ACH for different airing scenario’s)(Stranger et al. 2022).

The multidisciplinary nature of the consortium made it possible to measure and record a wide range of parameters related to the indoor air, the building and the building ventilation. The study focused on public buildings with a high occupational density and/or buildings primarily occupied by the most sensitive parts of the population (elderly and infants).

Three types of public spaces were selected: Elderly care homes, Daycares for infants and schools. This paper in particular focusses on the measurement of CO_2 and airborne pathogens carried out in two Flemish schools and their relation to the two tested IAQ management strategies. The measurements in the first school were done in February 2022, during this time the Belgian COVID-19 incidence showed a downward trend. In the second school, two measurement campaigns were done, the first one in March 2022, the second in May-June 2022. The Belgian COVID-19 incidence had an upward trend in March 2022 while it was much lower during the second round of measurements in May-June 2022 (Sciensano 2023).

The assessments carried out in the other types of buildings and other data are to be reported elsewhere (Lima Paralovo et al. 2023).

2 MATERIALS AND METHODS

2.1 Experiment design

The study was conducted in 2 primary schools, with parallel measurements in 4 classrooms of similar building typology (elementary schools, 2nd or 3rd grade):

- control class
- ventilation intervention class
- air purification intervention class

- combination ventilation and air purification intervention class.

Each measurement campaign went on for 3 weeks. On Tuesday and Thursday of each week, virus samples were taken using the Coriolis µ device (Bertin Technologies 2012). In the morning a sample was taken in each class with the intervention on. In the afternoon, in two of the classes, a second sample was taken with the intervention off. CO_2 measurements were performed with HUMLOG20-M12 devices (E+E Elektronics n.d.)

2.2 School 1

The first school is situated in a suburban, residential neighborhood close to the city of Antwerp. The 4 measured classrooms are part of the same building which was constructed around the year 2000 and is not equipped with a mechanical ventilation system. The classrooms are accessed through the gymnasium of the school and (acoustically) separated from the gymnasium by means of an intermediate space. Figure 1 shows a schematic plan of the building and the position of the different classrooms.

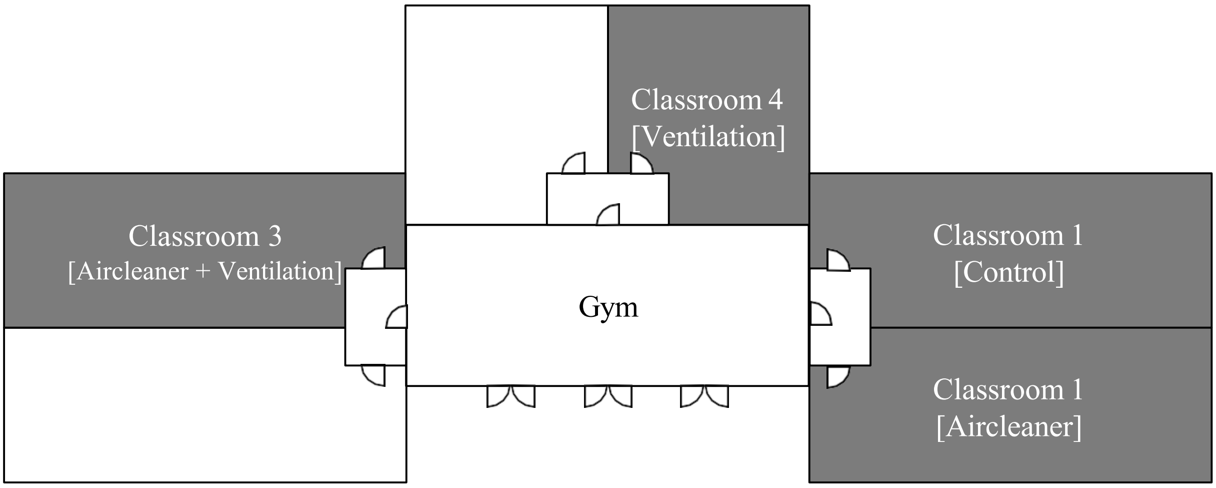

Figure 1 Plan of school 1

The 4 different classrooms are very similar in terms of occupancy density [0.31-0.41 children/m²].

The following steps were followed:

Week 0 - preparation: determination of ventilation characteristics of each classroom (ACH measured on 26/01/2022), determination of (required and effective) airflows following the guidelines published by the Belgian government (<900ppm or 40 m³/h/person) (FOD Economie 2022) ‚selection of the desired the air cleaning systems, determination of a plausible ventilation optimization strategy to be used as ‘ventilation intervention’.

Weeks 1-3: Continuous monitoring of CO_2. Collection of air samples for virus detection during 2 school days per week (to allow for (1) comparison of 4 classes within the same time span during the day and (2) evaluation of the impact of air purification intervention, ventilation intervention, and combined air purification and ventilation within the same population on the same day).

Classroom 1 served as control class and the teachers were asked to not change the window/door opening behavior during the measurements. We did not ask to ventilate less as it would be unethical to increase the risk on COVID-19 transmission intentionally.

Classroom 4, served as "ventilation-intervention" class. Because the building is not equipped with a mechanical ventilation system the intervention actually classifies better as "increased airing". In this classroom, the windows that could not be opened anymore were fixed so the teacher had more opportunity for airing and was instructed to make use of this opportunity as much as (comfortably) possible. In this room, an additional CO_2 sensor was installed that could inform the teacher about the CO_2 levels in the room.

Classroom 2, served as "Air Cleaner intervention" class. In this classroom, a stand-alone air cleaner device with a maximum airflow rate of 800m³/h was installed. However, due to noise complaints, the air cleaner was never operated at this maximum setting.

Classroom 3 served as the room with both increased outdoor air airflow rates and air cleaning. In this room, two air cleaners witch each 400m³/h maximum airflow rate were installed.

2.3 School 2

The second school is situated in a suburban, residential neighborhood close to the city of Ghent. On the campus of this school, with buildings dating mainly from the 1960-1970, one newly constructed (2018) can be found. This newer building is equipped with a balanced mechanical supply and extraction ventilation system.

Three of the measured classrooms are situated on the first level in this newer building while the control class was situated on the first level of one of the older buildings to make sure that no mechanical airflow rates were affecting the measurements in the control class. It should be noted here that the older building was less airtight than the classes in the newer building so a higher infiltration airflow rate can be expected. Figure 2 shows schematic plans of the buildings and the position of the different classrooms.

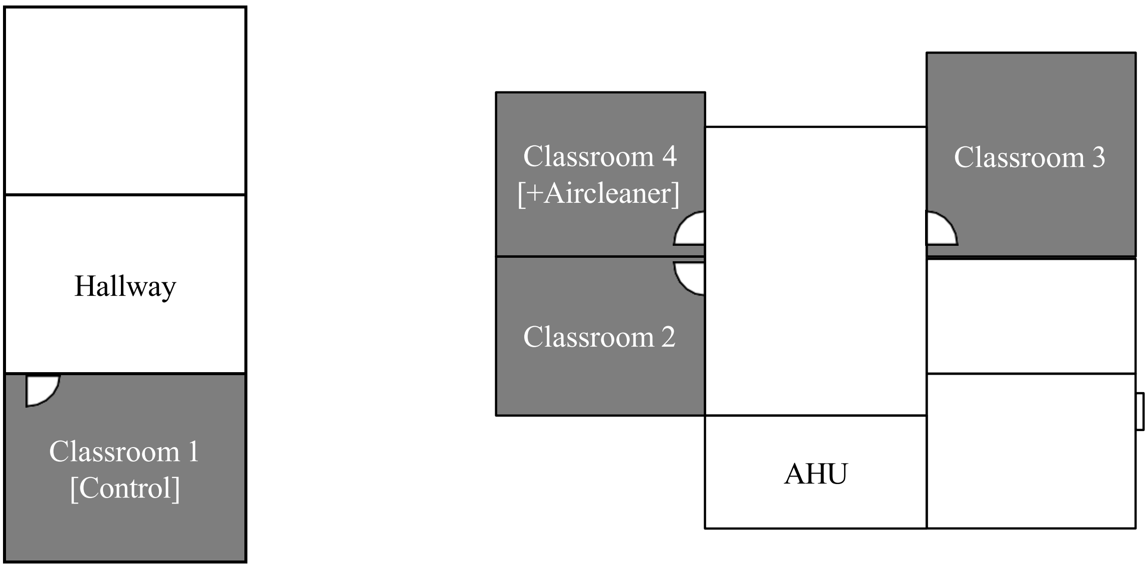

Figure 2 Plan of school 2

The 4 different classrooms are very similar in terms of occupancy density [0.33-0.36 children/m²].

In this school, 1 week of preparation (ACH measured on 1/04/2022 and 23/05/2022) was followed by 2 times, 3 weeks of measurements. In the preparation phase, technical issues were uncovered with the AHU of the building. These technical issues led to high noise complaints which made the teaching staff decide to shut off the AHU while teaching. Before the first round of measurements, some small issues were resolved. Other technical issues related to the AHU were resolved between the first 3 weeks of measurements and the second 3 weeks of measurements. This led to 3 settings in the measurements:

- No mechanical ventilation
- Better mechanical ventilation (after cleaning the filters and installing silencers)
- Optimized ventilation (after maintenance and fixes to AHU) – increased airflow rates 2-3 times.

In all cases, the teachers could also open an additional window for airing.

Classroom 1, in the older building, was selected as the control because of the absence of a mechanical ventilation system in this building. The classroom was operated using normal airing habits: windows tilted most of the time and opening the door leading to the staircase. This room is not affected by the changes to the AHU.

As classroom 2, 3 and 4 are all connected to the same AHU, the impact of the mechanical ventilation system was the same in all rooms. Therefore, the settings of the ventilation systems were varied each week:

- Week 1 No mechanical ventilation
- Week 2,3 Better ventilation
- Week 4,5,6 Optimized ventilation

In classroom 4, in addition to the variations in the ventilation, a stand-alone air cleaner was installed with a maximum airflow rate of 720 m^3/h. This device was always switched on.

3 RESULTS

3.1 School 1

The continuous CO_2 measurements in all classrooms during the occupied periods are summarized as box and whiskers in Figure 3. It shows that the ventilation intervention class (classroom 4) can successfully limit the occurrence of higher CO_2 levels and that we expect the perceived air quality to be good. The box, which represents 50% of the time, is noticeably smaller for classroom 4. None of the air cleaners can have any impact on the CO_2 levels, so these measurements are a good indicator of the airing behavior in the different classes.

In all other classes, the spread in measured CO_2 concentrations is larger. Remarkably, the classrooms where an air cleaner is installed show higher levels of CO_2 than the control class indicating that the presence of the device changed the airing behavior for the worse.

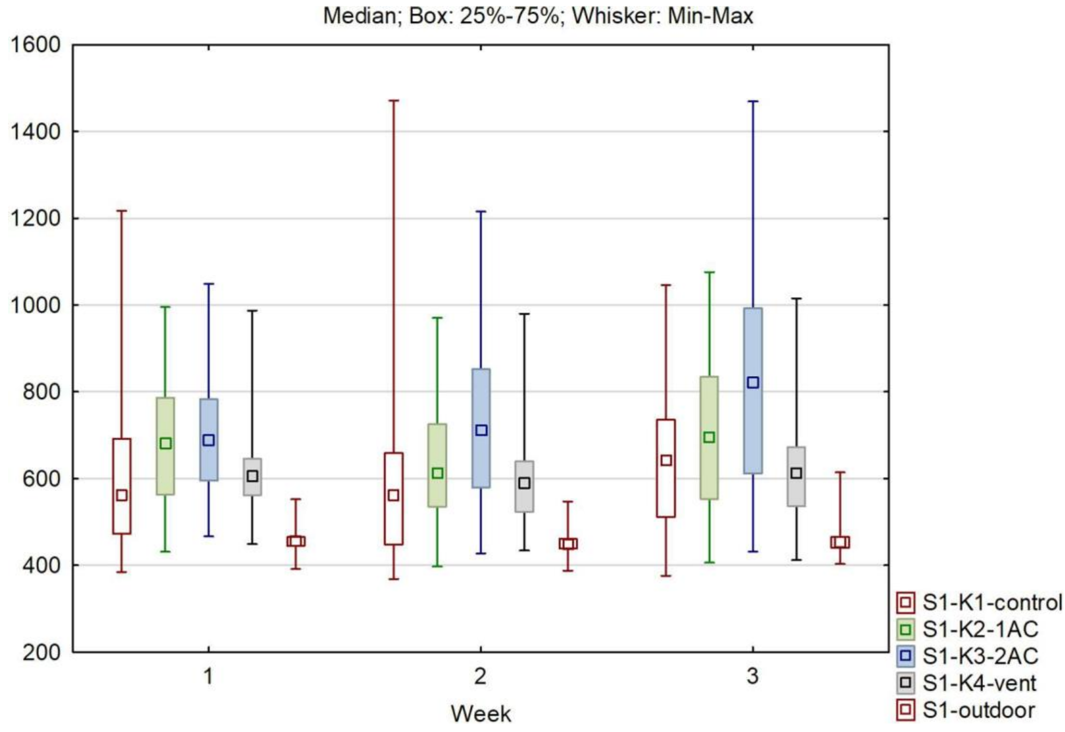

Figure 3 Box en Whiskers plot of the CO_2-concentrations [ppm] in the four classrooms and ambient air during the occupied hours from school 1

The results from the virus sampling are summarized in Table 1 showed that for most of the samples no virus was detected and for the others, virus was detected but with large uncertainties.

Although the air measurements clearly showed lower CO2 levels in K4, the class with additional ventilation, the impact of this on virus circulation in the classroom environment cannot be determined from these measurements: no virus was detected in any sample from this class, so we assume that none of those present were infected with the virus.

With regards to air cleaning:

- During week 1 in K3, no effect of air purifier detected: both with and without air purifier, SARS-CoV-2 is detected in the air.
- During week 2 and week 3, 2 interventions found that no virus is detected with air purifier turned on, while it is detected with air purifier turned off.
- The reverse finding during week 3 (virus is detected with air purifier turned on, while it is not with air purifier turned off) may have something to do with the location of the infected person relative to the air purifier or due to a group of students that left the classroom during the second measurement of the day.

Table 1 Overview of virus sample results for school 1

SARS-CoV-2		**Tuesday**		**Thursday**	
		Intervention ON	Intervention OFF	Intervention ON	Intervention OFF
Week 1	Class. 1 - Control			Limit (ct 39.3)	
	Class 2 - Air cleaner			Neg.	Neg.
	Class 3 - Air clean + Vent.			Limit (ct 36.9)	Limit (ct 37.0)
	Class. 4 - Vent.			Neg.	
Week 2	Class. 1 - Control	Neg.		Neg.	

	Class 2 - Air cleaner	Neg.		Neg.	Neg.
	Class 3 – Air clean + Vent.	Neg.	Limit (ct 38.7)	Neg.	
	Class. 4 - Vent.	Neg.	Neg.	Neg.	
Week 3	Class. 1 - Control	Neg.		Neg.	
	Class 2 – Air cleaner	Neg.		Neg.	Neg.
	Class 3 – Air clean + Vent.	Limit (ct 39.4)	Neg.	Neg.	Limit (ct 38.3)
	Class. 4 - Vent.	Neg.	Neg.	Neg.	

3.2 School 2

All CO_2 measurements are analyzed and grouped per classroom, per setting in Figure 4. Although the control class is unaffected by the different settings, due to meteorological or behavioral differences in the measured weeks, the control can change. A first observation is that when the mechanical ventilation system is OFF (setting 1), the median CO2 levels in the different classes are lower than the control. This is probably due to a higher sense of responsibility with regards to the IAQ when the mechanical ventilation system is OFF. Secondly, setting 2 does not seem to have a noticeable impact in comparison with no ventilation. This is due to the still relatively low airflow rates of the ventilation system in this setting. Lastly, when the full maintenance of the system was done (setting 3), the median concentration in all classrooms is 600ppm and the 75th percentile is below 1000ppm. However, higher peak concentrations up to 2500ppm did still occur.

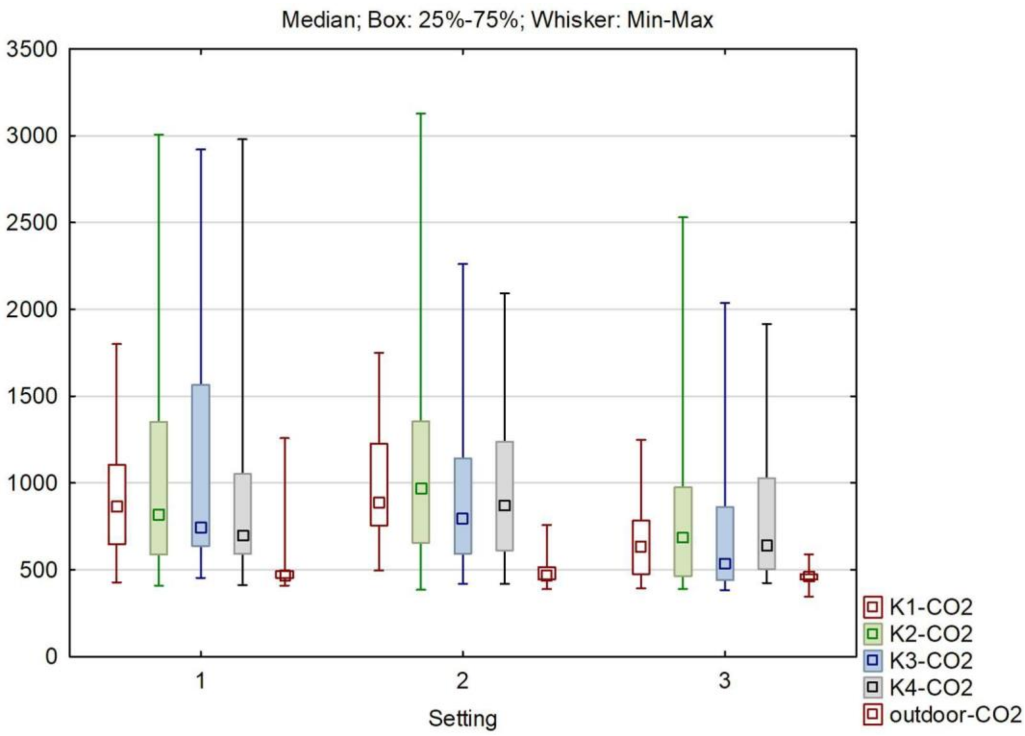

Figure 4 Box en whiskers plot of the CO_2 concentrations [ppm] recorded during the occupied hours for the 4 classrooms in school 2 for the different ventilation settings. Setting 1 = no ventilation, 2= better ventilation and 3= optimized ventilation.

Table 2 summarizes the results from the virus samples in school 2 which shows that SARS-CoV-2 was detected in most samples based on this 30-minute sampling, albeit in low concentrations. Thus, the virus circulated in classrooms mainly during the initial 3-week measurement period, reflecting the situation in Belgium at that time (Sciensano 2023).

The lower incidence in Belgium at the time of second campaign in this school can also be noticed in the lower number of samples in which SARS-CoV-2 was detected during weeks 4, 5 and 6 (although during this period the school had "optimized ventilation" which may also have contributed to a lower incidence of SARS-CoV-2 during the second measurement period).

With regards to extra ventilation as intervention, no measurable reduction of virus particles in air because of extra ventilation can be confirmed in this dataset:

- 4x no effect was detected (low viral loads detected)
- 3x there was indication of a positive effect with ventilation system turned off.
- 4x a reversed effect was observed, (higher viral load after increasing ventilation)

With regards to air cleaning, no measurable effect could be determined, and rather effect opposite to what would be expected was detected: with air purification turned on, SARS-CoV-2 was detected, while nothing was detected with air purification turned off.

Because of the low concentrations with relatively high measurement uncertainty during the second measurement period in school 2, no statement about the effect of the interventions can be formulated. Also, regarding the other pathogens measured, no effect of ventilation or air purification can be determined in school 2.

Table 2 Overview of virus sample results for school 2

SARS-CoV-2		**Tuesday**		**Thursday**	
		Intervention ON	Intervention OFF	Intervention ON	Intervention OFF
Week 1	Class. 1 - Control		Limit (ct 36.0)		Limit (ct 36.7)
	Class 2 - Mech. Vent.	Limit (ct 36.7)	Limit (ct 38.3)	Neg.	Limit (ct 38.9)
	Class 3 - Mech. Vent.		Neg.	Neg.	Limit (ct 38.5)
	Class 4 - Vent.+Air cleaner				Limit (ct 35.4)
Week 2	Class. 1 - Control	Limit (ct 38.9)		Limit (ct 39.7)	
	Class 2 - Mech. Vent.	Neg.	Limit (ct 38.7)	POS. (ct 33.0)	
	Class 3 - Mech. Vent.	Limit (ct 40.5)		Limit (ct 37.9)	Limit (ct 36.5)
	Class 4 - Vent.+Air cleaner	Limit (ct 40.7)	Neg.	Limit (ct 38.9)	Neg.
Week 3	Class. 1 - Control	Neg.		Limit (ct 40.4)	
	Class 2 - Mech. Vent.	Limit (ct 39.3)	Limit (ct 39.2)	Limit (ct 38.3)	Neg.
	Class 3 - Mech. Vent.	Limit (ct 38.5)		Limit (ct 37.4)	Limit (ct 38.2)
	Class 4 - Vent.+Air cleaner	Limit (ct 38.2)	Neg.	Limit (ct 40.0)	
Maintenance and commissioning to AHU					
Week 4	Class. 1 - Control	Limit (ct 39.1)			
	Class 2 - Mech. Vent.	Neg.		School closed	
	Class 3 - Mech. Vent.	Neg.	Neg.		
	Class 4 - Vent.+Air cleaner	Limit (ct 41.1)	Neg.		
Week 5	Class. 1 - Control	Neg.		Limit (ct 37.0)	
	Class 2 - Mech. Vent.	Neg.		Limit (ct 40.0)	
	Class 3 - Mech. Vent.	Limit (ct 38.9)	Neg.	Limit (ct 38.2)	
	Class 4 - Vent.+Air cleaner	Limit (ct 39.0)	Limit (ct 37.6)	Neg.	Neg.
Week 6	Class. 1 - Control			Limit (ct 39.5)	
	Class 2 - Mech. Vent.	Limit (ct 37.3)		Limit (ct 40.2)	Neg.
	Class 3 - Mech. Vent.	Neg.	Limit (ct 40.1)	Neg.	Limit (ct 40.0)
	Class 4 - Vent.+Air cleaner				

4 CONCLUSIONS

The virus was clearly more prevalent in the classrooms of school 2 than in school at time of measurement, although according to the Sciensano SARS-CoV-2 dashboard, virus circulation in the society was similar during the measurements in school 1 and the first measurement period in school 2 (Sciensano 2023). The more effective ventilation and aeration in school 1, combined with the wearing of mouth masks in the first school, probably also contributed to the overall lower detection of SARS-CoV-2 and other viruses in the indoor air of school 1.

A relevant note to this table is that almost all the samples with detection of SARS-CoV-2 were in fact borderline, meaning that the CT values were rather high and thus the concentration in air was reasonably low (the detection limit for this qPCR analysis is CT value ≈ 40). The closer the CT value of a PCR analysis is to 39-40, the higher the measurement uncertainty of this method (e.g., CT 39.04).

For both schools, no measurable effect of increased ventilation or air cleaning on the occurrence of SARS-CoV-2 could be objectively observed for these in-situ and in-use situations. Most virus concentration in the samples were low, which can be explained by the trends in national COVID-19 disease incidence and the fact that students were wearing facemasks.

In general, the results indicate the importance of proper commissioning and maintenance to mechanical ventilation systems and show an overall better expected perceived indoor air quality when the ventilation system works properly. In the school without a mechanical ventilation system, manual airing through the opening of windows can achieve the same level of expected perceived indoor air quality if operated correctly.

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