Evaluating the impact of air cleaning on bioaerosols and other IAQ indicators in Belgian daycare facilities

Sarah L. Paralovo*[1], Klaas de Jonge[2], Arnold Janssens[2], Jelle Laverge[2], Reinoud Cartuyvels[3], Koen Van den Driessche[4], Borislav Lazarov[1], Maarten Spruyt[1], and Marianne Stranger[1]

1 VITO
Boeretang 200
Mol, Belgium
**Corresponding author: sarah.limaparalovo@vito.be*

2 UGent
Sint-Pietersnieuwstraat 41
Ghent, Belgium

3 Jessa Hospital Clinical Lab
Stadsomvaart 11
Hasselt, Belgium

4 Antwerp University Hospital
Drie Eikenstraat 655
Antwerp, Belgium

ABSTRACT

The scientific community has been aware of the importance of indoor air quality (IAQ) for many decades, but the COVID-19 pandemic has brought a significantly higher level of attention from the general public and governmental entities to this theme. However, IAQ comprises hundreds of other parameters besides infectious pathogens, many of which can equally impact the health, comfort and well-being of occupants. In this context, an intervention study was conducted in Flanders (Belgium) with the aim of investigating the potential impact of ventilation and air cleaning on the IAQ, comfort and infection risk control in Flemish public spaces. This paper describes part of this study, focusing on the IAQ assessments carried out in four daycare facilities for infants in the province of Antwerp. The two first facilities were assessed simultaneously in March 2022, while the two last ones were assessed simultaneously in September 2022. At each facility, CO_2 concentration, different size fractions of particulate matter (PM_x) concentration, temperature and relative humidity (RH) were continuously monitored in selected indoor spaces and one outdoor site for 2 consecutive weeks. Average ventilation rates were measured in each facility under different airing scenarios. Biological air samples were also collected 2 days per week, in the same spaces at each facility, for in-lab qPCR analysis of over 20 genetic markers of respiratory pathogens. Results generally highlighted the positive impact of efficient ventilation on IAQ, while the effects of air cleaning were not as prominent in each room. CO_2 concentrations up to 4200 ppm were measured in the facilities without mechanical ventilation, while they remained consistently below 800 ppm in the facility with the most effective mechanical ventilation system. SARS-CoV-2 was detected more frequently and in larger quantities in the facilities with lower ventilation rates. The variety of other pathogens was also higher in these less-ventilated facilities. The effectiveness of air cleaners in reducing airborne pathogens could not be clearly established at each location. In the sites where air cleaning clearly affected indoor PM_x, the same effect was also noticeable in the indoor pathogen levels and their variety.

KEYWORDS

Daycare facility, indoor air quality, air cleaning, ventilation, respiratory infection risk

1 INTRODUCTION

The COVID-19 pandemic has considerably increased the public attention to ventilation and CO_2 (as an indicator of ventilation) and aerosol concentrations, since it is now widely known that the SARS-CoV-2 virus spreads mainly through the air in indoor environments (Morawska and Cao, 2020; Randall et al., 2021). However, the quality of the indoor air (IAQ), and by extension of the indoor environment (IEQ), is determined by many different parameters of

varied natures (i.e. physiochemical, biological, thermal, acoustic and lighting). Similarly, the potential impact of inadequate IEQ on the health, behaviour, comfort and well-being of occupants can be very diverse. Thus, IAQ is only one of four main parameters that determine how an indoor space is experienced by its occupants. Consequently, it is perfectly possible to experience discomfort or health complaints in a room with low concentrations of typical IAQ pollutants. When evaluating strategies for improving IAQ, such as air cleaning and ventilation enhancements, it is therefore important to also consider more parameters than exclusively IAQ.

In this context, a large study was conducted in Flanders (Belgium), at the request of the Flemish Government, with the aim of investigating the potential impact of different ventilation and air cleaning strategies on the IEQ and infection risk control in Flemish public spaces, thus enabling an objective evaluation of the effectiveness and impact of such risk reduction methods. Three different types of public spaces were selected for analysis, due to their major potential for spreading infectious diseases among sizeable communities: Schools, daycare for infants and elderly care facilities. The assessments included the continuous monitoring of temperature (T), relative humidity (RH), CO_2 and particulate matter (PM_x) concentrations, the measurement of average ventilation rates (ACHs) and sound pressure levels, the application of occupant comfort surveys and the collection of bioaerosols for analysis of respiratory pathogens. The ultimate goal of this study was to substantiate selection criteria and points of attention for ventilation and air purification with objective data, and to offer actors from the respective settings a workable, low-threshold strategy to select the most suitable risk mitigation technology for a specific context. The present paper describes part of this larger Flemish study, focusing on the measurements of T, RH, ACHs and CO_2, PM_x and pathogens concentrations carried out in four daycare facilities in the province of Antwerp and the effects of air cleaning strategies over infection risk control. The assessments carried out in the other facilities, as well as the acoustic measurements and comfort surveys assessments, are to be reported elsewhere.

2 MATERIALS AND METHODS

2.1 Sampling sites

IEQ assessments were carried out during normal working-hours at four different daycare facilities in the province of Antwerp, Belgium, in a few selected locations per facility (playrooms, sleeping rooms and outdoors). The two first facilities (henceforth called C1 and C2) were assessed simultaneously during two consecutive weeks in March 2022, while the two last ones (henceforth called C3 and C4) were assessed simultaneously during two consecutive weeks in September 2022. Mobile air cleaners were placed in selected rooms. Figure 1 shows a sketch of each of the four selected facilities, with the placement of each air cleaner. Table 1 presents the main specifications of the installed air cleaners.

C1 was a naturally ventilated ground-floor space, which had formerly been a retail store, located in a residential area. A total of 13 babies and toddlers were cared for at the time of the experiment. The building featured large front windows of the unopenable shopping window type. Additionally, it had an exterior door that led to an enclosed (fenced) outdoor playground situated on the street side. Behind the indoor playroom of the toddlers (aged > 18 months), there was a kitchen with an openable window. At the back of the daycare center there was a bedroom for the children's naptime. Measurements were performed in the toddler's playroom (C1K1) and bedroom (C1K2).

C2 consisted of a terraced building located in an urban environment and had a mechanical ventilation system (based on mechanical air extraction and natural air supply). The facility provided care for 70 children in total at the time of the experiment, who were divided in groups

by age. Two rooms in the toddlers' building were selected for sampling, one on the ground floor (C2K1) and the other on the first floor (C2K2). In both rooms, there was also a duplex-style sleeping area integrated within the space (playing and sleeping areas could not be closed off from each other). Both rooms shared identical dimensions and spatial arrangements.

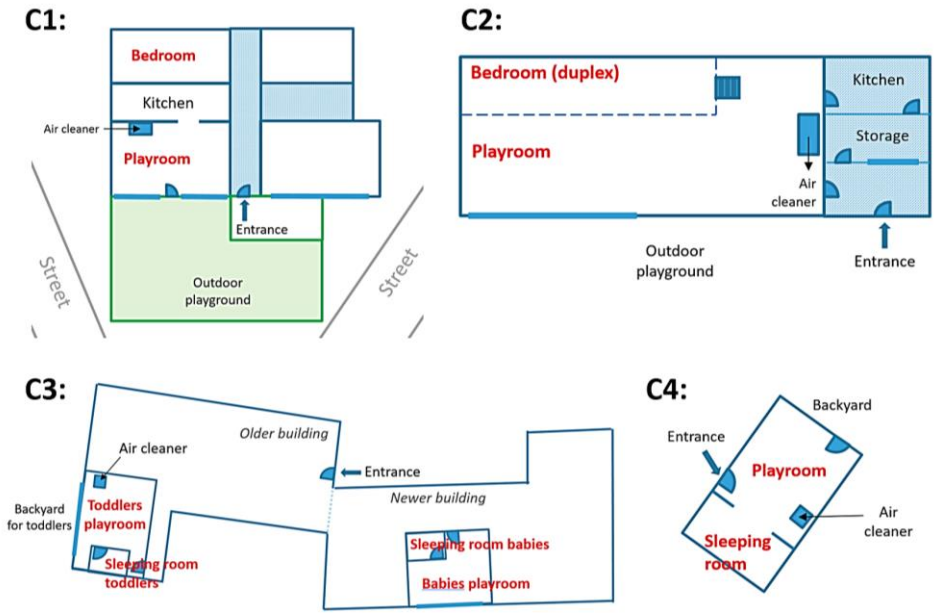

Figure 1: Sketches of each daycare facility assessed in this study (not to scale)

Table 1: Specifications of the air cleaners installed in the daycare facilities.

Facility	Basic Technology	Supplement	Airflow rate ($m^3\ h^{-1}$)	CADR* ($m^3\ h^{-1}$)	Noise level (dB)	Energy consumption (W)
C1 / C2	HEPA filter	Pre-filter and charcoal filter	736	-	28 - 58 dB	4-90 W
C3 / C4			-	735 (pollen, smoke) >675 (dust)	27 - 55 dB	9-72 W

*CADR = Clean air delivery rate

C3 was a mechanically ventilated (with a controlled air intake and exhaust), ground-floor detached building in a residential area. A total of 101 children were cared for in the facility as a whole (considering all the available rooms), divided into 2 age groups: babies (≤ 18 months old) and toddlers (>18 months and < 3 years old). The facility consisted of a less recent building (completed in 2017, vent. sys. with heat recovery with a supply of 100% fresh air per room at design flow rate = 8.35 $m^3\ h^{-1}$ per person supply air purified with an F7 panel filter) and a more recent extension (completed in 2021, vent. sys. with heating coil, design supply air at flow rate = 30.2 $m^3\ h^{-1}\ person^{-1}$ filtered with an F7 bag filter). In both older and newer constructions, every room had glass doors that can be slide opened. Two rooms were selected for air sampling in each part of the facility: Playroom for toddlers in older building (C3K1) and its adjacent sleeping room (C3K3) and playroom for babies in the newer building (C3K2) and its adjacent sleeping room (C3K4). One air cleaner was installed in C3K1.

Lastly, C4 consisted of a previously terraced house located in an urban environment and counted only on natural ventilation (door opening and infiltration). It provided care for 20 children in total (15 children > 18 months and 5 children < 18 months old), not separated by age since the facility only counts with one large playroom (C4K1) and bedroom (C4K2). Measurements were performed in both spaces, which were on ground floor and could not be

closed off from each other (the facility is one large open space, acting as a single-zone). There was a kitchen/service area in between C4K1 and C4K2, where the air cleaner was placed.

2.2 Measurement methods

In each sampling location, monitoring of T, RH, CO_2 and PM_x was carried out by stationary equipment, while the measurements of ACHs and bioaerosols were performed at specific moments according to the specific air cleaning schedules. Installations of the stationary equipment were done following the ISO 16000-1 recommendations (height of 1 to 1.5 m in the room, away from openable doors and windows or heating) as well as possible, since all areas selected for the measurements were in use and thus the devices' location should be safe for the occupants and avoid hindering daily activities. For outdoor measurements, all stationary devices were placed in a cage so that they could not be reached by the children.

The concentrations of PM_1, $PM_{2.5}$, PM_{10} and TSP fractions of PM_x were measured at a 1min frequency via optical detection using GRIMM 1.108 Dust Monitors placed inside weatherproof housing. Measurements of CO_2, T and RH were performed with HUMILOG20 devices (E+E Elektronik, Austria), also at a 1min frequency, via optical detection, negative temperature coefficient and capacitive principle, respectively. Average ACHs were inferred in each assessed room via a tracer gas decay test, using CO_2 artificially injected from a pressurized cylinder as a tracer gas and several automatic CO_2 loggers scattered around the assessed room to check for air mixing (Paralovo et al., 2021). Each decay test was performed during several hours either before or after the other IEQ assessments, preferably during unoccupied hours. In each test, a few different scenarios leading from lowest to highest ventilation rates were tested (e.g. all doors and windows closed vs. all doors and windows opened), depending on the room, to provide a more comprehensive overview of the ventilation potential in each space. Air tightness of the assessed rooms was measured via standard pressurization tests (blower door test). Where available, inlet and outlet airflows from mechanical ventilation systems were measured with a FlowFinder-mk2® device (ACIN instruments, The Netherlands).

Bioaerosols were sampled using a Coriolis µ device (Bertin Technologies, St-Berthely, France), which collects aerosols with aerodynamic diameters between 0.5 and 20 µm via cyclonic liquid impingement (Bertin, 2012). Biological samples were collected twice per week in each daycare facility (on the same days for C1/C2 and C3/C4), aiming at collecting one sample per bedroom and two samples per playroom (one with the air cleaner active, and another with it inactive) during each sampling day (specific sampling schedules were adapted onsite depending on the facility's practicalities). Each sample was collected for 30min into 3ml of lysis buffer, at an air flow rate of 100 l min^{-1}. After sampling, the biological samples were sent to the Jessa Hospital lab (Hasselt, Belgium) for qPCR analysis. In this analysis, the following genetic markers for infectious agents were included as targets: SARS-CoV-2 RNA, Adenovirus DNA, Bocavirus DNA, Coronavirus 229E, NL63, OC43 and HKU1 RNA, Enterovirus RNA, hMPV RNA, Influenza A and B RNA, Parainfluenza 1-4 RNA, Rhinovirus RNA, RSV-A and B RNA, Herpes simplex and Varicella-zoster virus DNA, *Bordetella pertussis* DNA, *Bordetella parapertussis* DNA, *Bordetella holmesii* DNA, *Chlamydophila pneumoniae* DNA, *Legionella pneumophila* DNA, *Mycoplasma pneumoniae* DNA and *streptococcus pneumoniae* DNA.

3 RESULTS AND DISCUSSION

3.1 Ventilation characterization

In C1 and C4, no ventilation system was present. In C2, a mechanical ventilation system was present but after assessing its vent holes, it was learnt that this system provided no measurable airflow, which was confirmed by the tracer gas decay test. C2 should thus be regarded as

without ventilation system. C3 was equipped with two separate mechanical balanced ventilation systems. All facilities enabled incrementing the ACHs by opening windows and/or doors. The average ventilation rates measured in the four daycare facilities are summarized in Table 2.

Table 2: Average ventilation rates measured in the four assessed daycare facilities under different scenarios.

C1	**Air tightness**	**'Normal' scenario** (window tilted in room next to the assessed room)		**'Summer' scenario** ('Normal' + door to outdoor playground open)	
	n50	ACH	Vol. flow	ACH	Vol. flow
	(h^{-1} 50Pa)	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*
K1	8.7	1.10	75.6	5.40	372

C2	**Air tightness**	**All doors and windows closed**		**'Winter'** (Front door open, door to playground slightly open, storage room door closed)		**'Enhanced winter'** ('Winter' + storage room door open with window tilted)		**'Summer'** (Sliding windows to playground open)	
	n50	ACH	Vol. flow	ACH	Vol. flow	ACH	Vol. flow	ACH	Vol. flow
	(h^{-1} 50Pa)	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*
K1/K2	3.1	0.18	38.0	0.82	174	3.61	768	13.2	2807

C3	**Air tightness**	**All doors and windows closed**		**Door to corridor open**		**Sliding window open** (to width of mosquito screen)		**Door + sliding window open** (to width of mosquito screen)	
	n50	ACH	Vol. flow	ACH	Vol. flow	ACH	Vol. flow	ACH	Vol. flow
	(h^{-1} 50Pa)	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*
K1	-	0.67	167	1.20	299	2.01	501	1.80	449
K2		1.82	363	2.93	585	2.30	458	4.44	886
K3	-	1.23	50.0	2.57	104	-	-	-	-
K4	-	5.34	138	12.0	310	-	-	-	-

C4	**Air tightness**	**All doors and windows closed**		**Door to backyard open**		**Window to the street side open**		**Door to backyard + window to street side open**	
	n50	ACH	Vol. flow	ACH	Vol. flow	ACH	Vol. flow	ACH	Vol. flow
	(h^{-1} 50Pa)	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*	*(h^{-1})*	*(m^3 h^{-1})*
K1	-	<1	<140	3.33	465	1.11	155	12.0	1669

In C1, the 'normal' scenario led to an ACH of 1.1, which corresponds to an air supply of approx. 5 m^3 h^{-1} per person (average occupancy of 15 persons: children + staff). By warmer weather, the door to the playground is kept open and approx. 25 m^3 h^{-1} per person can be achieved. However, both scenarios are well below the guideline formulated by the Belgian Task Force Ventilation of the Corona Commissioner's Office, which recommends an air supply rate of 40 m^3 h^{-1} per person in any indoor environment (Flemish Government, 2022). In C2, the 'winter' scenario led to a ventilation rate of 8.3 m^3 h^{-1} per person (average occupancy of 21 persons in C2K1). In the 'enhanced winter' scenario, some cross-ventilation is created through the room, increasing the flow rate to 36 m^3 h^{-1} per person. But only in the 'summer' scenario the ventilation rate is above the recommended guideline (approx. 134 m^3 h^{-1} per person).

In C4, it was not possible to perform measurements during unoccupied hours. An exact ventilation rate for the scenario with all doors and windows closed could not be determined, but approximate values were theoretically calculated, resulting in a value of approx. 6.1 m^3 h^{-1} per person (average of 23 occupants: children + staff). Both scenarios with one-sided ventilation were also insufficient to achieve the recommended 40 m^3 h^{-1} per person. Opening windows on both sides (i.e. providing cross-ventilation) resulted in a flow rate of 72.5 m^3 h^{-1} per person.

In C3, a better situation was expected due to the functional mechanical ventilation system. However, the mechanical system alone was not enough to provide the minimum recommended guideline of 40 m^3 h^{-1} per person in neither of the playrooms (in the first scenario C3K1 reaches 8.4 m^3 h^{-1} per person for 20 occupants, and C3K2 reaches 30 m^3 h^{-1} per person for 12 occupants). In C3K2, opening the door to the corridor is sufficient to reach the recommended guideline, but

in C3K1 the guideline is not reached even with both sliding door and door to the corridor simultaneously open. Although this difference is mostly due to the lower occupancy in C3K2, there was also an imbalance in the airflows provided by the mechanical ventilation system (the newer part of the building received more airflow than the design airflow, while the older received less). This issue affected the ventilation in both bedrooms (C3K3 and K4) similarly, with the aggravation that no immediate measures can be taken to supplement the airflows (i.e. there are no windows and the doors must remain closed for the children's sleep quality).

3.2 Measurements of T and RH

According to the advice of the Flemish Indoor Environment Decree, the temperature should stay between 20-24°C during the cold season and between 22 and 26°C in the warm season. In C2, C3 and C4, the P75-values were in accordance with these recommendations, while C1 presented P-75 values < 20°C in both assessed rooms. C1 and C2 were assessed simultaneously during the cold season, but the median temperatures of both facilities differed by up to 6 degrees. C1's bedroom was significantly cooler than the playroom, while C2's bedroom was significantly warmer than the playroom. In C3 and C4, assessed during the warm season, temperatures only occasionally exceeded the maximum recommendation of 26°C.

In C3 and C4 the RH values were at least 75% of the time (i.e. P75-value) measured at acceptable levels according to the Flemish Indoor Environment Decree (40% < RH < 60% in cold season, 30% < RH < 70% in warm seasons). In C1 and C4, RH was higher in the bedrooms than in the playrooms. On the other hand, in C1's playroom the median RH was below the recommended level for the cold season (when the assessment took place). In C2 the air was remarkably dry, with RH medians < 25% in all assessed rooms, and no clear reason could be found. RH is an important comfort parameter, but more importantly a point of attention to limit the transmission of viruses indoors. Evidence shows that RH influences both evaporation kinematics and particle growth, thus in dry indoor spaces (< 40% RH) the risk of airborne transmission of SARS-CoV-2 is higher than that of humid spaces (Ahlawat et al., 2020). Recent research points to a strong negative relationship between relative humidity and the transmission of both SARS-CoV-2 and influenza (Keetels et al., 2022), partly due to the greater sensitivity of airways at lower humidity levels.

3.3 Measurements of CO_2

Figure 2 summarizes the CO_2 measurements during occupied hours at each of the assessed rooms in all 4 daycare facilities. Although C1 had the smallest group (13 children + 2 supervisors) of all facilities, the highest CO_2 concentrations were consistently measured in there, both in the playroom and bedroom, with an average peak concentration in the bedroom over the entire 2-week period of 3740 ± 360 ppm (highest peak 4250 ppm). The playroom was ventilated through a tilt window in the kitchen which remains open 90% of the day. Another possibility to boost ventilation in this room is opening the door to the playground, which is usually done for 20 minutes in the morning and in the afternoon (longer in good weather). The openable window in the bedroom is usually closed for more than half of the day. In C2, the CO_2 concentrations were generally lower than in C1, but the recommended value of 900 ppm was exceeded daily. Both C2K1 and C2K2 showed similar CO_2 profiles during the experiment. Although the ventilation characterization pointed to a non-functioning ventilation system, the concentrations also did not exceed 1500 ppm, indicating that aeration through opening windows and/or doors was reasonably effective.

C3 had generally the lowest CO_2 concentrations. However, a clear difference was noticed between the two parts of the facility. In C3K1 (18 children + 2 supervisors), the recommended value of 900 ppm CO_2 is (slightly) exceeded every day. The exceedances are more frequent and

larger in the bedroom (C3K3), where the highest measured concentration was 1150 ppm, and the ventilation rate is entirely dependent on the ventilation system. In C3K2, with 10 children + 2 supervisors and located in the newest part of the facility, with a different ventilation system, the CO_2 concentration never surpassed 800 ppm (neither in the playroom nor bedroom).

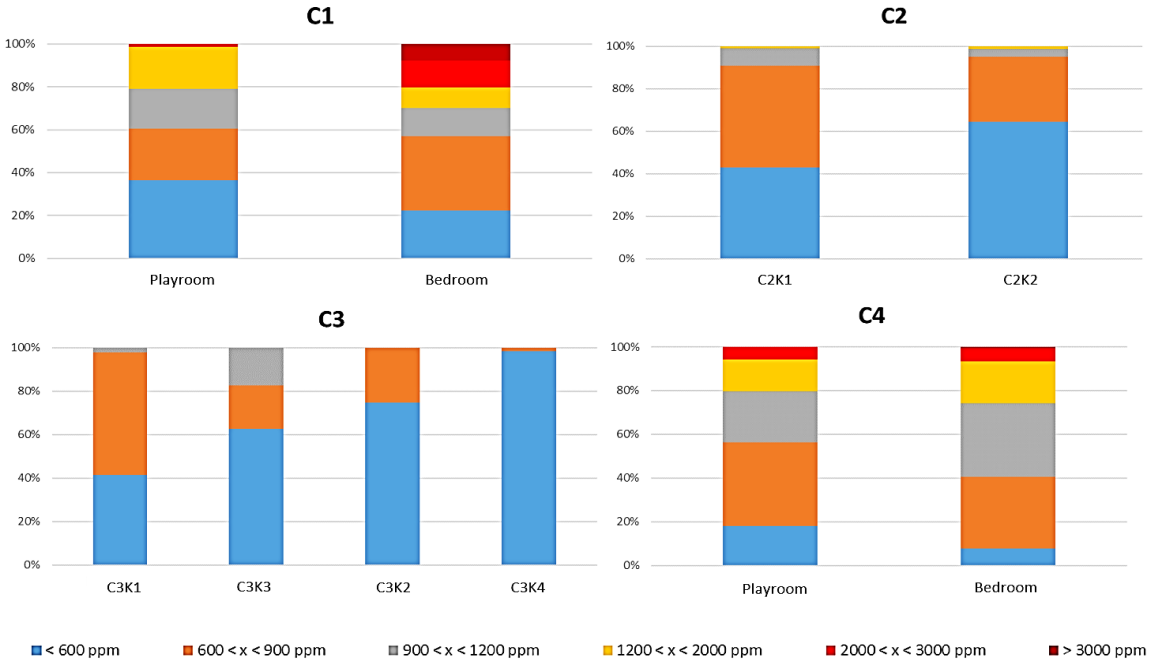

Figure 2: CO_2 measurements per concentration range during occupied hours at each assessed room.

In C4, the single-zone aspect was clearly reflected in the almost parallel CO_2 profiles in the bedroom and playroom during the measurement period (the only difference were the consistently higher peaks in the bedroom when the children were asleep). Although C1 presented the highest CO_2 peaks of all the facilities, in C4 the CO_2 concentrations were the most frequently above the 900ppm recommendation (>60% of the time in C4K2 and >45% of the time in C4K1). The 900ppm limit was exceeded daily, with greater exceedances in the second sampling week. During the first week, the good weather allowed to ventilate by opening windows and backyard door (highest concentration = 1300 ppm), but in the second week the temperature dropped, and the space was less aerated (highest concentration = 2390 ppm). On the last sampling day, the heating was switched on and all the windows/doors remained closed, and then the CO_2 concentrations rose to almost 3200 ppm. Although the construction of C4 allowed a high ACH to be achieved thanks to the possibility of cross ventilation, these measurements show that this is usually not applied in this facility.

3.4 Measurements of PM_x

The concentration of PM_x is one of the parameters by which the efficiency of air cleaning can be evaluated, since most air cleaners focus primarily on the removal of PM_x from the indoor air. In this study, the concentration of PM_x is presented in the form of indoor/outdoor ratios (I/O), which "normalize" the absolute concentrations and already account for potential outdoor environment influence indoors. I/O ratios >1 can indicate either indoor sources of PM or an accumulation of outdoor PM in the indoor environment. Table 3 summarizes the median and P-75 I/O ratios for different fractions of the PM_x calculated for each of the four facilities, considering only the rooms with air cleaners installed and only data from the days when the air cleaners were operated by the research team (i.e. intervention days, which happened 2x/week in each facility: air cleaners were switched off in the mornings and back on in the afternoons).

A consistent reduction of the different PM_x fractions due to switching on the air cleaners cannot be established in every facility. In C1, although a slightly lower I/O ratio is observed for PM_1 with the air cleaner switched on compared to the situation with air cleaner off, the I/O ratios for the larger particle fractions (TSP, PM_{10} and $PM_{2.5}$) are either the same or higher with the air cleaner switched on. Similarly, in C2 the I/O ratios for all PM_x fractions in the playroom are slightly higher with the air cleaner switched on.

Table 3: Overview of the median and P-75 I/O ratios of different PM_x fractions in the four daycare facilities, with air cleaning on and off.

	C1		**C2**		**C3**		**C4**	
	Air cleaner status		Air cleaner status		Air cleaner status		Air cleaner status	
	OFF	ON	OFF	ON	OFF	ON	OFF	ON
	Median (P-75)							
I/O TSP	0,6 (1,2)	1,0 (2,0)	0,3 (0,6)	0,4 (1,0)	2,8 (5,5)	2,7 (5,8)	2,9 (5,1)	2,6 (4,8)
I/O PM_{10}	0,8 (1,1)	1,2 (1,9)	0,9 (1,6)	1,3 (1,8)	1,5 (2,3)	1,4 (1,9)	1,5 (2,0)	1,1 (1,5)
I/O $PM_{2.5}$	0,8 (1,0)	0,9 (1,1)	0,8 (1,1)	0,9 (1,0)	0,6 (0,8)	0,6 (0,8)	1,5 (1,8)	0,9 (1,1)
I/O PM_1	0,7 (0,9)	0,6 (0,8)	0,7 (0,8)	0,8 (0,9)	0,5 (0,6)	0,5 (0,6)	1,9 (2,4)	1,1 (1,5)

Potential reasons for this could be: inadequate configuration or location of the air cleaner in the room (in relation to PM_x sources), different activities in the facility in the morning and in the afternoon that generate different levels of particles resuspension and possibly different ventilation/airing during morning and afternoon. The latter seems to have been particularly the case for C2, which was assessed in early spring (colder mornings and warmer afternoons). Thus, the playroom door was closed in the morning with the air purifier switched on, while it was open in the afternoon with the air purifier switched off. This provided extra airing during the afternoon, possibly resulting in a reduction of the indoor PM_x concentrations unrelated to air cleaning itself.

In C3, air cleaning seems to have had virtually no effect over the I/O ratios of the measured PM_x in the playroom during the intervention days. On the other hand, in C4 a consistent decrease is observed in the I/O ratios of all PM_x fractions when the air cleaner is on, especially for PM_{10}, $PM_{2.5}$ and PM_1. The I/O ratios of $PM_{2.5}$ and PM_1 were reduced by 40% when air cleaning was active.

3.5 Measurements of pathogens in air

Figure 3 summarizes the results obtained after qPCR analysis of the biological air samples collected at the four daycare facilities. Cells are coloured according to the detection of SARS-CoV-2 in each sample. For the non-negative samples, the cycle threshold value (CT) is indicated. Results with a CT-value > 35.0 were considered as “limit-value”, indicating a very low viral load. For these samples, there is a higher chance of configuring a false positive result due to analytical issues or contamination during the preanalytical or analytical phase.

C1 and C2 were assessed simultaneously in March 2022, when the official daily COVID-19 incidence in Belgium was about 60/100k inhabitants, while C3 and C4 were assessed simultaneously in September 2022, when the incidence was about 15/100k inhabitants (Sciensano, 2023). Although the groups of children were different in each of the assessed rooms of each facility, it was assumed that the incidence of respiratory infections among sizeable groups of children in the same age group would be comparable in the same neighbourhood in each period, following the regional COVID-19 incidence pattern. Therefore, it was assumed that the pairs C1/C2 and C3/C4 would be comparable between themselves in terms of average emission of SARS-CoV-2, so the difference in analytical results between C1 and C2 could be attributed to the removal strategies. Moreover, it was expected that such emission would be

higher in C1/C2 than in C3/C4 due to the difference in national incidence. However, as shown in Figure 3, the facility with the most positive samples was C4, suggesting that the influence of the national incidence over the presence of pathogen (potentially infective) genetic material in the bioaerosol was smaller than initially thought.

			Week 1		Week 2	
			Day 1	Day 2	Day 3	Day 4
C1	K1	AC ON	LV* (CT 36,6)[1]	Negative	LV* (CT 37,0)	Positive (*vl* *<1000, CT 33,9)[1,3,4,5]
		AC OFF	-	Negative	LV* (CT 34,7)	Negative
	K2	-	Negative[1,2]	-	LV* (CT 35,3)[1]	-
C2	K1	AC ON	Negative	Negative	LV* (CT 36,2)	LV* (CT 39,8)
		AC OFF	-	Negative	Negative[5]	Negative
	K2	-	Negative	Negative	Negative	LV* (CT 36,8)
		-	-	Negative	-	Negative
C3	K1	AC ON	Negative[6,7]	LV* (CT 39,9)[1,7]	Negative[1]	LV* (CT 40,9)[1,3]
		AC OFF	Negative	Negative[1,7]	LV* (CT 38,4)[1]	Negative[3]
	K2	-	Negative[1]	Negative	Negative	Negative
	K3	-	Negative[6]	-	-	Negative[1,3]
	K4	-	-	-	LV* (CT 37,5)[1,6]	-
C4	K1	AC ON	Positive (*vl* * <1000, CT 30,7)[6]	Positive (*vl* * < 1000, CT 32,2)[1,3]	Positive (*vl* * < 1000, CT 29,8)[1,3]	Positive (*vl* * < 1000, CT 29,6)[1,3,8,9]
		AC OFF	Positive (*vl* * >1000, CT 27,0)[3]	Positive (*vl* * > 1000, CT 29,0)[1,3,7]	Positive (*vl* * < 1000, CT 30,3)[1,3]	Positive (*vl* * > 1000, CT 28,1)[1,3,10,11]
	K2	-	-	Positive (*vl* * > 1000, CT 27,6)[1,3,9]	-	-

*LV = limit value
vl = viral load

1. Streptococcus pneumoniae DNA positive
2. Corona virus OC43 RNA at LV
3. Rhinovirus positive
4. Enterovirus RNA at LV
5. Influenza A virus RNA at LV
6. Rhinovirus LV
7. Bordetella parapertussis DNA positive
8. Bordetella parapertussis DNA LV
9. Bocavirus DNA LV
10. Bocavirus DNA positive
11. Adenovirus DNA LV

Figure 3: Results of qPCR analysis from the biological air samples collected at the four daycare facilities.

First comparing C1 and C2, in 37% of samples in C2 at least one pathogen was detected, while in C1 this rate was 67%, suggesting that the air in C2 had an overall lower infective potential than C1. While it is possible that this is due to the presence of more numerous infectious children in C1 than in C2, it is also expected to be a reflection of the better ventilation in C2 (see Table 2). Also, air cleaning did not seem to influence the presence of pathogens in the bioaerosol in either facility. In the second week, SARS-CoV-2 was detected in C1K1, C2K2 and twice in C2K1 when the air cleaner was switched on, but the subsequent samples collected in the same spaces but with the air cleaners off were negative. In all these cases, the first sample was collected earlier in the morning, when doors and windows were kept closed for thermal comfort, and the second one later in the afternoon, after the children had their outdoor playing time, during which the doors remained open, a common practice in both facilities when the weather is sunny. These results seem to suggest that a better ventilation, especially when combined with lengthier periods of airing, could be efficient in diminishing the presence of different airborne pathogens in daycare facilities, and consequently in reducing the risk of airborne pathogens transmission in these spaces.

Comparison between C3 and C4 provide a stronger indication that, in this study, a better ventilation was possibly more efficient in reducing the presence of airborne pathogens than the use of air cleaning. All samples collected at C4, arguably the less ventilated facility (according to the CO_2 measurements), were highly positive for SARS-CoV-2 (plus several other target pathogens, especially in the last week). In C3, the best ventilated of all four facilities, only 27% of the samples were non-negative for SARS-CoV-2, the lowest rate of all facilities. The presence of other targeted pathogens was also generally lower in C3 when compared to C4.

On the other hand, air cleaning did seem to have an impact, albeit less prominent, in the presence of pathogenic aerosols in the indoor air at C4. In this facility, except for day 3, the samples collected when the air cleaner was off had a higher viral load and lower CT-values than the samples collected in the same day/location when the air cleaner was on. Unlike what

happened in C1 and C2, during the C4 assessment the weather was warmer all throughout the day, and therefore there were no big changes in airing from morning to afternoon. This indicates that the different qPCR results in C4 were due to air cleaning, suggesting thus that air cleaning may be an appropriate alternative strategy when proper ventilation levels cannot be achieved. However, this alternate solution should be well-researched and adapted to the intended location, in order to provide a sufficient CADR. Moreover, attention should also be paid to the practical aspects of the installation and use of such air cleaners. Especially in C3K1, the research team had difficulties in finding an adequate location for the device, and the children interfered with it on a few occasions (i.e. shutting it on or off when not supposed to).

4 CONCLUSIONS

This paper focused on part of a larger Flemish study on IEQ in public spaces. Four daycare facilities were assessed via measurements of T, RH, ACH and CO_2 and PM_x concentrations and collection of biological air samples for in-lab qPCR analysis of over 20 respiratory pathogens. Ventilation measurements showed that most of the time the airflow rates per person were below the recommended in Belgium regarding COVID-19 spread prevention, but could generally be improved by airing. Higher CO_2 concentrations were measured in the facilities without mechanical ventilation, while they remained consistently below 800 ppm in C3, the facility with the most effective mechanical ventilation system. SARS-CoV-2 and other pathogens were detected more frequently and in larger quantities in the bioaerosol of C4, arguably the less ventilated facility (according to the CO_2 measurements). In the rooms where indoor PM_x concentrations correlated well with the air cleaning schedules, the same effect was also noticeable in the pathogen concentrations and variety. These results seem to corroborate the expected positive impact of ventilation over IAQ, while the impact of air cleaning was not as consistent in all facilities.

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