Evaluation of ventilation performance and compliance with Belgian covid-19 guidelines in sport infrastructure

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ABSTRACT

During the corona-19 pandemic waves in 2020 and 2021, many cultural and recreational activities inside buildings could no longer take place to prevent virus transmission. In order to allow cultural and recreational sectors to reopen in a safe way by the summer of 2021, a ventilation task force of the corona commissioner's office of the Belgian federal government prepared recommendations for the practical implementation and monitoring of indoor air quality in the context of COVID-19. This implementation plan was conceived as an instrument for building owners or facility managers to evaluate whether existing ventilation facilities, possibly in combination with other technical measures such as opening of windows and doors, or air purification devices, would provide sufficient ventilation to allow a certain number of occupants in a room.

In preparation of the resumption of indoor sports activities, a research consortium investigated the applicability and consequences of the federal guidelines specifically for sports infrastructures in Flanders, Belgium. To this end, various sports federations organized a number of test events in the first half of June 2021. The test events took place in four different indoor sports facilities, including fitness centres, a climbing gym and a sports hall, for varying group sizes of athletes and public. In preparation of the test events, the mechanical ventilation systems were inspected and installed ventilation flow rates measured. During the test events, CO_2 measurements were carried out throughout the sports infrastructures, and the concentrations were permanently logged.

This paper discusses the main results of the ventilation inspections, CO_2 monitoring and subsequent analysis. By applying the recommendations of the implementation plan to the test events in sport, the paper further discusses the feasibility of implementing the plan in practice, what the consequences are for the maximum permissible occupation in sports halls (both for athletes and spectators), and provides guidelines on how the ventilation in existing infrastructure can be improved based on the findings.

KEYWORDS

Ventilation, Corona virus, Inspection, Indoor sports infrastructure, CO_2 monitoring

1 INTRODUCTION

In preparation of the resumption of sports activities in the summer of 2021 in Belgium after more than half a year without activities, various sports federations organized a number of test events to evaluate how activities could be organised in a ‘covid-safe’ way, in consultation with the Belgian Ministry of Health. The Flemish Sports Federation (VSF) investigated the importance of ventilation for good air quality in sports infrastructures. More specifically, during the test events, the recommendations for the practical implementation and monitoring of indoor air quality in the context of COVID-19 of the ventilation task force of the corona commissioner's office of April 2021 were put into practice, the applicability of these guidelines for the sports sector was evaluated, and guidelines developed specifically for sports infrastructures on the basis of the evaluation.

The test events took place between June 1 and 12 2021, in four different indoor sports facilities, for varying group sizes of athletes and public, see Table 1 and Figure 1. Participants to the events were tested with an antigen test. In case of a negative result they were allowed to participate and refrain from wearing mouth caps. Occupancy logbooks were kept for each event.

Table 1: Overview test events in Sports infrastructure

Type of facility	Activity	Number of participants	Length of activity
Fitness centre (FC1)	Individual fitness	50	1.5h
Fitness centre (FC2)	Group classes in 4 rooms	20+16+28+16	4x1h
Indoor climbing hall (CH)	Rope climbing and bouldering	40+40	4x2h
Sports hall (SH)	Basketball match with audience	550	3h

Figure 1: Impressions of sport infrastructure during events, from left to right: individual fitness room in fitness centre 1, group class in fitness centre 2, rope climbing in indoor climbing hall, basketball match in sports hall.

2 RECOMMENDATIONS TASK FORCE VENTILATION

The ventilation task force of the corona commissioner developed recommendations for the practical implementation and monitoring of ventilation and indoor air quality in the context of COVID-19 (Taskforce Ventilatie 2021). The purpose of this implementation plan was to evaluate whether the existing ventilation facilities, possibly in combination with other technical measures such as opening windows and doors, or air purification devices, can provide for sufficient (equivalent) ventilation of the room.
The plan defines a CO_2 concentration lower than 900 ppm, assuming 400 ppm outdoor concentration, as a maximum acceptable value for limiting the spread of the virus via aerosols. This value is in line with the requirements for workspaces in the Belgian Codex Well-being at work, and with recommended concentrations to achieve sufficient ventilation to prevent the spread of the coronavirus (REHVA 2021). For a light activity this concentration corresponds in steady state to an outdoor air flow rate of 40 m^3/h/person. The first version of the implementation plan (April 2021) assumed a light activity for ventilation rate guidelines, but based on the outcome of the test events discussed in this paper, a new version of the plan was published in July 2021, with recommendations as a function of the type of activity.
The plan consists of an assessment scheme to develop mitigation measures based on the presence and performance of ventilation systems, occupancy, openable windows, and/or CO_2-monitoring. Mitigation measures may include in the short term opening windows and reducing occupancy, or in the mid to long term installing air cleaners and improving ventilation provisions. By applying the recommendations of the implementation plan to the test events in sport, the aim is to investigate which are possible problems with ventilation, what are consequences for the maximum permissible occupancy in sports halls (both for athletes and spectators), and how the indoor air quality in existing halls can be improved if necessary.

3 INSPECTION OF MECHANICAL VENTILATION SYSTEMS

Table 2: Characteristics of mechanical ventilation systems present

Facility	Mechanical supply?	Mechanical extraction?	Recirculation of indoor air?	Fraction of indoor air recirculation, before inspection.	Set-point CO_2 in case of demand control, before inspection	Maximum outdoor air flow rate (max. supply or extraction)	Set flow rate during event
Individual fitness room FC1	yes	yes	no	-	900 ppm	9781 m³/h	9781 m³/h
Cycling room FC2	yes	yes	no	-	600 ppm	5795 m³/h	5795$^{(1)}$ m³/h
Cross-fit room FC2	no	no	-	-	-	-	-
Group class FC2	yes	yes	no	-	-	16661 m³/h	9697$^{(3)}$ m³/h
B&M-room FC2$^{(2)}$	-	-	-	-	-	-	-
Rope climbing room CH$^{(4)}$	no	yes	-	-	-	600 m³/h	600 m³/h
Bouldering room CH$^{(4)}$	yes	yes	yes	35% $^{(5)}$	900 $^{(5)}$ ppm	6944 m³/h	6944 m³/h
Sports hall SH$^{(6)}$	yes	yes	yes	0% $^{(6)}$	$^{(6)}$	34503 m³/h	34503 m³/h

(1) Normal flow rate setting 3600 m³/h, but increased to maximum for test event.
(2) Room equipped with mechanical ventilation, but deliberately not used for test event
(3) Normal setting due to noise problems at maximum flow rate.
(4) Ventilation characteristics and flow rates originally unknown to organizers
(5) Outside air fraction increased to 100% and CO_2 set point decreased to 200 ppm for test event to ensure maximum outside air supply.
(6) The operation of ventilation systems was found to be substandard due to incorrectly connected or controlled mixing valves in air groups and dirty extraction grilles. These issues were fixed for the test event. Demand control present but switched off (permanent maximum flow rate).

Knowledge about the presence, performance and operation of ventilation facilities is important for operators in order to obtain an initial indication of the maximum occupancy in the halls in order to meet the requirements of the implementation plan. It requires specific expertise to understand the operation of the often complex systems and to measure the available fresh air flow rates. In the context of the test events, it was evaluated whether it is practically feasible to roll out this type of measurement on a larger scale, and whether the fresh air flows supplied in sports halls meet the recommendations of the ventilation task force. For the inspection of the ventilation systems, the research team was supported by a HVAC engineering office and specialized inspection companies. These companies were chosen on the basis of previous collaborations giving guarantee of the necessary competence. Table 2 summarizes the results.
An analysis of the installed ventilation facilities shows that there is a wide variety of sometimes complex mechanical ventilation systems. In the fitness centres, there was generally a good knowledge of the available systems; the fresh air flow rates estimated by the manager corresponded quite well with the results of the ventilation inspection organized in the context of the study. In the other sport facilities, however, the knowledge of the available systems was incomplete or incorrect, and the ventilation inspection contributed to a more correct determination of the type and operation of the mechanical ventilation facilities, of the fresh air flow rates that the systems could provide, and of deficiencies in the systems. If necessary, the

company that performed the inspection made adjustments to ensure correct operation and maximum ventilation of the rooms during the test events.
In the sports hall (SH), the functioning of the ventilation system turned out to be substandard due to poor maintenance and installation, and the necessary adjustments had to be made. These problems are not exceptional in mechanical ventilation systems (Janssens et al. 2022). The results of the inspection again emphasize the importance of inspection, adjustment and maintenance of ventilation systems. Many of the inspected systems were equipped with a BEMS system to set flows and controls, but in the event of technical defects in the installations, such as in the sports hall, these do not necessarily correspond to reality, and the operator should therefore not blindly rely on the display on the control panel or in the building management system. However, even when the installations worked properly, the installation quality or control settings were not always optimal for maximum air exchange (eg. FC2, CH).

4 OUTDOOR AIR FLOW RATE PER PERSON

The total available air flow rate in the sports halls consists of the flow rates provided by mechanical ventilation and the natural ventilation flow rate through open windows and exterior doors. The latter flow rate was estimated conservatively on the basis of a rule of thumb described in the implementation plan of the ventilation task force. The rule of thumb of 160 m³/h per m² open window was derived using EN 15242 for single sided ventilation, no wind, and a 3°C inside-outside temperature difference. With this information, the available airflow per person during the test events could be calculated, see Table 3 and Figure 2. The available flow rates per person shown are based on the effective number of participants during these events, which in most cases was significantly lower than the normal room capacity.
These flow rates should be compared with the ventilation flow rate required to keep the CO_2 concentration below 900 ppm. In the first version of the implementation plan of the ventilation task force, this was standard set at 40 m³/h per person. However, the amount of ventilation needed to keep the CO_2 concentration below 900 ppm also depends on the nature of the physical activity being performed in a room. The more strenuous activities people perform in a room, the more CO_2 (and aerosols) they produce through their respiration, so more ventilation is required. Based on the work of Persily and De Jonge (2017) and Ainsworth et al. (2011) ventilation needs for a number of classes of physical activity (characterized by a certain Met value) were estimated to maintain CO_2 concentration difference below 500 ppm in steady state, based on mean CO_2 production rate of 12.3*Met l/h/person:

- Sedentary activity (1.5 Met): 37 m³/h/person
- Light activity (1.8 Met): 44 m³/h/person
- Moderate activity (3.0 Met): 74 m³/h/person
- Heavy activity (4.1 Met): 101 m³/h/person
- Very heavy activity (5.2 Met): 128 m³/h/person
- Intensive activity (7.3 Met): 180 m³/h/person

Many sports activities can be classified as heavy to intensive activities, but the classification depends on the average over a large number of people over a longer period of time, and can therefore only be estimated approximately.
The corresponding ventilation needs for standard, heavy and intensive activities are shown in Figure 2. The comparison shows that the ventilation available at the fitness test events should be sufficient for the effective number of participants, even if all participants were constantly exerting a heavy or even intensive effort. At the rope climbing room, the available means of ventilation during the event may be insufficient if all participants continuously make a heavy effort. At the basketball tournament, the available ventilation is sufficient, since more than 90% of those present are seated audiences who do not have to make efforts. However, the correctness

of these evaluations must be confirmed by the CO_2 monitoring during the events. Also, at a number of events, the supply of sufficient outside air is to a large extent dependent on opening windows and doors (FC2 Crossfit and B&M, Rope Climbing CH).

These conclusions only apply to the effective occupancy during the test events and, for the proportion of natural ventilation, assuming that all available windows and exterior doors are open with sufficiently favourable climate conditions during the test events. If the rooms were used at their normal capacity, the available flow rates per person would be lower. In B&M room FC2, rope climbing room CH and sports hall (SH) the flow rate per person would then probably be too low to keep the CO2 concentration below 900 ppm.

Table 3: Outdoor air flow rate per occupant as a result of mechanical and natural ventilation

Facility	Normal capacity (maximum occupancy)	Effective number of participants event (1)	Surface area opening windows and doors	Estimated flow rate by natural ventilation	Mechanical flow rate of outdoor air per person	Natural flow rate of outdoor air per person
Individual fitness room FC1	70	61	-	-	160 m³/h	-
Cycling room FC2	45	22	-	-	263 m³/h	-
Cross-fit room FC2	30	18	22.5 m²	5855 m³/h	-	325 m³/h
Group class FC2	50	29	-	-	334 m³/h	-
B&M-room FC2	30	18	8.8 m²	2290 m³/h	-	127 m³/h
Rope climbing room CH	60	35	9.6 m²	2485 m³/h	17 m³/h	71 m³/h
Bouldering room CH	60	35	10.0 m²	2602 m³/h	198 m³/h	74 m³/h
Sports hall SH	2400	572 (2)	57.6 m²	16419 m³/h	60 m³/h	29 m³/h

(1) At some events these numbers are higher than in Table 1 because of presence of teachers, technicians and/or press.
(2) 453 public + 45 basketball teams and staff + 74 logistics and press.

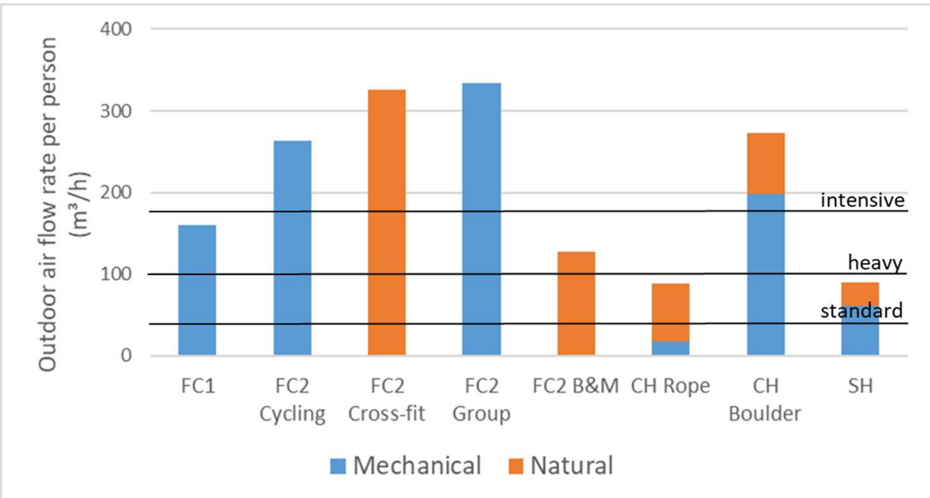

Figure 2: Available outdoor air flow rate per person by mechanical and/or natural ventilation provisions for the effective occupancy during the different test events, with indication of minimum flow rates necessary to ensure that the CO_2 concentration remains below 900 ppm.

5 MEASURED CO_2 CONCENTRATIONS COMPARED TO TARGETS

During the test events, CO_2 measurements were carried out throughout the sports facilities, and the concentrations were permanently logged. To this end, the following measuring equipment was used:

- 15 Indoor@Box sensor units from Environment and Health, calibrated annually by VITO, and recalibrated after the test events. The reported values are based on the recalibration.
- 16 Netatmo modules from BBRI, calibrated at the end of May before the start of test events on fresh outside air (400 ppm). A number of these were also installed in secondary usage areas (changing rooms, sanitary facilities).

Figure 3 summarizes the results based on the sensor units of the Environment and Health Department. BBRI's modules have similar results. The figures show resp. the average and maximum measured CO_2 concentrations over the duration of the events, compared to the target value of 900 ppm (red line). The value shown by the bar is the average value over the different sensor locations in a room, the error flags show the spread over the different locations. The number of sensor units differed from room to room, ranging from 3 units (FC2 Cycling, B&M), 4 units (FC2 Cross-fit, Group class), 6 units (FC1), 7 units (CH) to 15 units (SH).
The results show that the CO_2 concentrations in only 4 of the 8 rooms studied remained below the target value of 900 ppm for the entire duration of the event and at all sensor locations. These are FC2 Cross-fit, FC2 Group class, FC2 B&M and SH. In FC1, the CO_2 concentration of a single sensor exceeded the target value of 900 ppm, but the exceedance was minimal and limited in time, and remained within the typical measurement uncertainty of 50 ppm. These results thus confirm the previous comparison between the available ventilation per person and the ventilation needs of the participants. In FC2's Cross-fit and Group class, the air flow rate per person was the highest of all rooms (> 300 m³/h/person). In FC1 and FC2 B&M, the flow rate was sufficient for activities involving very heavy activity (≥ 128 m³/h). In the Sports Hall SH, the available flow rate per person was the lowest of all rooms (~90 m³/h/person), but sufficient for the predominantly seated participants. The monitored CO2-concentrations didn't show a significant difference between facilities with mechanical ventilation and facilities which had to rely on opening of windows and natural driving forces to achieve ventilation (FC2 B&M, FC2 Cross-fit, CH Rope climbing).

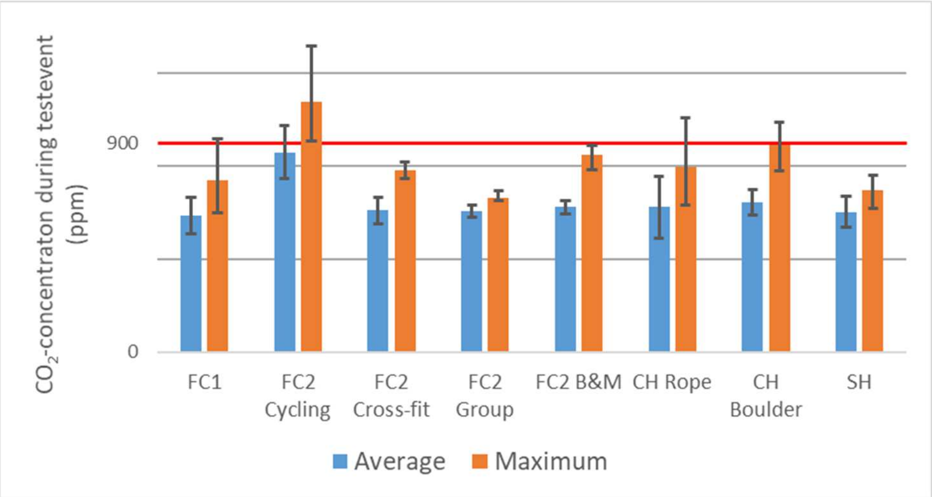

Figure 3: Average and maximum CO_2 concentration over the duration of the test events; the error flags represent the spread across the different sensor locations in each room. Scale of grey grid lines is 400-800-1200 ppm.

The average CO_2 concentrations in 7 of the 8 rooms examined remained well below the target value at all sensor locations. This indicates that in rooms where the maximum concentrations were higher than the guideline value in some places, the exceedance was limited in time.
In one room, FC2 cycling, the target value of 900 ppm was exceeded at all sensor locations, and in one location even the alarm level of 1200 ppm. At this location, the average value is also higher than the target value. This is surprising, as this room is equipped with mechanical ventilation with a more than sufficient flow rate per person. However, the poor CO_2 values are the result of a misunderstanding in the setup of the installation. The research team had asked the organizer to ensure that the ventilation would operate at maximum flow without CO_2 based demand control. In response to this question, the set point of the CO_2 based control was raised to 1400 ppm by the operator. As a result, the ventilation never reached the maximum flow rate during the event. This incident illustrates how sensitive the indoor air quality is to the correct operation and setting of the mechanical ventilation system, and how important it is for the manager to have good knowledge of this.
In demand-driven ventilation systems where the ventilation flow rate is adjusted on the basis of the CO_2 concentration measured in the extraction duct, such as in FC2 cycling and FC1, it is important to set the setpoint for regulation significantly lower than the target value of 900 ppm, preferably lower than 400 ppm to always have the maximum possible fresh air flow. This is necessary to avoid excessive concentrations due to a delayed reaction of the system. This probably explains why even in FC1, despite the generously dimensioned ventilation system, the CO_2 concentration in one place in the fitness room slightly exceeded 900 ppm; the demand control was set to this value.
With regard to the climbing rooms: for the rope climbing room it was expected that it would be difficult to limit the CO_2 concentration sufficiently due to the limited available flow per person (~90 m^3/h/person, mainly by opening the room doors) . Here, the target value of 900 ppm was exceeded in a few locations, especially higher in the room. For the bouldering room, where a large flow rate per person was available, the exceedances of 900 ppm are probably the result of an insufficient distribution and mixing of the supplied outside air. As a result, it is possible that despite the presence of a mechanical ventilation system with sufficient capacity, the pollutants in the zone where the participants were active were insufficiently diluted.
Finally, the test events showed that problems can arise due to inadequate ventilation of secondary areas, such as sanitary facilities and changing rooms, especially when large groups of people gather. The highest CO_2 concentrations were not measured in the sports halls, where the organizers took measures when they observed that the concentrations rose too high, but in the sanitary areas and changing rooms, more specifically those of the Sports Hall SH. Concentrations up to 1500 ppm were measured here by the BBRI. Despite the generally short residence time in these types of rooms, these high concentrations could have entailed risks, also depending on the use of mouth masks.

6 ESTIMATION OF FLOW RATES BASED ON CO_2 MEASUREMENTS

The implementation plan of the ventilation task force provides a method for estimating the mechanical ventilation flow rate based on the measured CO_2 concentrations. One of the objectives of the test events was to test this procedure. An important condition for the application of this procedure is that the CO_2 concentration has reached a steady state, a value that remains more or less constant. During the test events, this was only the case in 4 facilities: FC1, FC2 Cycling, FC2 Group class and SH. In the other rooms, the opening of external doors was used to limit the CO_2 concentration, so that the concentrations in those rooms continued to vary greatly and no stationary regime occurred.
The first-mentioned rooms all have a short time constant (ratio between volume and ventilation flow) in relation to the duration of the event, which makes it logical that a stationary regime

was reached during the event. This requires a time of 3 times the time constant. The time constants were resp. 7, 4, 8 and 45 minutes for FC1, FC2 Cycling, FC2 Group class and SH.

The following formula allows to derive the flow rate from the measured concentration:

$$Q_{vent} = \frac{12300 \cdot Met}{C_{i,stat} - C_e} \text{ (m}^3\text{/h/person)} \quad (1)$$

With Q_{vent} the ventilation flow rate per person, M the average metabolism of the participants, $C_{i,stat}$ the stationary CO_2 concentration inside (ppm) and C_e the CO_2 concentration outside (ppm).

The maximum measured concentration averaged over all sensor locations was considered as the stationary CO_2 concentration indoors. The CO_2 concentration outside is typically taken as 400 ppm, but the measurements during the test events showed it to be generally higher. Therefore a value of 450 ppm was assumed, and the sensitivity of this assumption was checked. A determining parameter in the formula is the value of the participants' average metabolism. For this the activity classes and corresponding metabolisms listed in §4 were used:

- FC1, average of 82% participants with very heavy activity and 18% participants light activity (press): 4.6 Met
- FC2 cycling, intensive activity: 7.3 Met
- FC2 Group class, very heavy activity: 5.2 Met
- SH, average of 98% sedentary participants and 2% intensive activity: 1.6 Met

Figure 4 shows the result of the calculation, and compares the mechanical ventilation flow rates measured during the inspection with the ventilation flow rates derived from the CO_2 measurements. In the latter, the error flags indicate how the calculated flow rate varies with the assumed CO_2 concentration outside (lower error flag 400 ppm, upper error flag 500 ppm).
Except for FC2 Cycling, for which it has already been shown that the system has not worked at full capacity, the estimated flow rates appear to correspond reasonably well with the values measured during the inspection, albeit with a large margin of uncertainty. Even though the procedure can only be applied to a limited extent in practice due to the condition of a stationary regime, if the conditions are met, the method does allow the determination of incorrect functioning of ventilation systems, cf. the result for FC2 cycling.
The comparison also shows that the estimation of the metabolism based on activity classes leads to a fairly reliable estimate of the CO_2 emissions and ventilation needs in sports facilities.

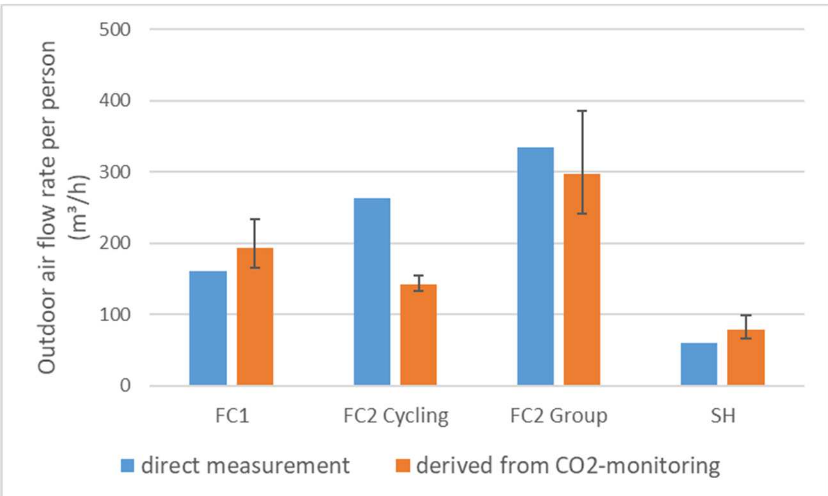

Figure 4: Comparison between mechanical flow rates measured during the inspections, and estimated from CO_2 measurements and estimated average Met value; the error flags show the sensitivity of the estimated flow rate to the assumed outdoor CO_2 concentration (bar 450 ppm, lower error flag 400 ppm, upper error flag 500 ppm).

7 CONCLUSIONS

This paper presented the results of ventilation inspections, CO_2 monitoring and subsequent analysis during a series of test events organised in sports facilities in June 2021, with the objective to evaluate the feasibility of recommendations for the practical implementation and monitoring of indoor air quality in the context of COVID-19, developed by the Belgian task force ventilation.

At two sports facilities, there was good knowledge about the available systems, and the fresh air flow rates estimated by the manager corresponded with the results of the ventilation inspection organized in the context of the study. At two other facilities however, knowledge of the available systems was incomplete, and the ventilation inspection revealed problems with the installation, maintenance or operation. Remedial measures needed to be taken to maximize the fresh air flow rates that the systems could provide.

In sports facilities ventilation flow rates need to be increased compared to standard design flow rates to take account of higher effort during exercise, with a larger CO_2 (and aerosol) production rate by athletes. Ventilation rates for a range of classes of physical activity were proposed. The comparison between directly measured ventilation flow rates, and flow rates estimated from measured CO_2 concentrations during the events showed that the estimation of the metabolism based on activity classes leads to a fairly reliable estimate of the CO_2 emissions and ventilation needs in sports facilities.

Based on the above findings, the following recommendations for sports infrastructure managers were formulated to ensure good ventilation:

- Invest in a ventilation inspection that calls on an expert to inspect the operation and flow rates of mechanical ventilation systems, to detect and repair problems, to maintain and adjust systems.
- When designing ventilation for a given occupancy, take into account the activity level of the athletes in order to safely estimate the necessary fresh airflow rate per person. In some sport halls it turned out that the maximum occupancy had to be kept considerably lower compared to the normal hall capacity in order to keep the CO_2 concentrations under control.
- Because of uncertainties in CO_2 production and good mixing of fresh air in sports halls, it remains important to monitor the concentrations at representative locations, even when ventilation systems are present, so that timely action can be taken, for example by improving the functioning of the system or by opening windows and doors.
- In rooms without a mechanical ventilation system, the flow rates provided by opening windows and doors can be estimated based on rules of thumb from the recommendations of the ventilation task force. The test events showed that these rules of thumb are on the safe side.
- In rooms with a small time constant in relation to the duration of occupancy, monitoring the CO_2 concentration makes it possible to derive the effective fresh air flow rate per person, and to estimate the maximum occupancy that can be allowed.
- Also pay attention to the good ventilation of secondary areas (sanitary, changing rooms), where the highest CO_2 concentrations were measured during the test events in one of the locations. Despite the generally short residence time in these types of rooms, these high concentrations can pose risks.

8 ACKNOWLEDGEMENTS

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