QAI * -Sport project: characterization of Indoor Air Quality in sports facilities

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Abstract. The aim of this study was to characterise the indoor air quality (IAQ) of 10 sports halls of different activities with regard to target pollutants: Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (SVOCs) and micro-organisms. Targeted and non-targeted analytical approaches were applied to provide the broadest possible screening with a focus on emerging pollutants. Two sampling campaigns were performed in unoccupied and occupied rooms to assess the impact of sporting activity on IAQ.

1 Context and objectives

Physical activity is one of the basic functions of human beings and contributes to their health and well-being. The WHO recommends that adults should engage in at least 2.5 hours of moderately intense sporting activity per week [1]. With the growing number of sports enthusiasts, the indoor sports facilities have also been rising sharply over the last few decades. In addition to pollution levels that may be higher indoors than outdoors, the intense physical activity carried out in sports halls may contribute to increasing the risk of exposure to airborne contaminants [2]. Despite this context favoring exposure, indoor air quality in sports facilities is still poorly studied compared to that of housing and other public buildings. In addition, the combination of poor ventilation conditions and a high occupancy rate, encountered in particular in fitness centers or weight rooms, is a cause of deterioration in indoor air quality in sports halls [3].

In this context, one objective of the QAI-Sport project consisted in providing an overview of the organic chemicals and microbiological composition in air of 10 sports halls having different activities: dojos, motricity rooms and weight rooms. To this end, sampling and analysis campaigns were carried out in occupied and unoccupied sports halls in order to assess the influence of sports activities on IAQ. The aim was to screen as exhaustively as possible for chemical (VOCs and SVOCs) and microbiological contaminants. This screening consisted in carrying out targeted and non-targeted analyses of VOCs in air, SVOCs, in air and sedimented dust inside the halls, and microbiological contaminants (bacteria, moulds and SARS-Cov-2) in air.

2 Methodology

2.1 Sports halls studied

Ten sports halls described in table 1 were selected. There were 2 dojos (martial arts rooms), 3 motricity (motor skills) rooms in nursery schools, 3 weight rooms, 1 gym hall in a high school and 1 room dedicated to dance and yoga activities.

Table 1. Sports halls studied (DFV: Dual flow ventilation; CMV: controlled mechanical ventilation)

Name (type)	Mean air exchange rate (h^{-1})	Building date – Miscellaneous information
DOJ1 (dojo)	1.04	2016 - Classic dimensions and equipment, DFV
DOJ2 (dojo)	0.69	1965-1968- Quite small hall, many users, DFV
MOT1 (motricity room)	0.82	1960~1970 – Quite small room natural ventilation
MOT2 (motricity room)	0.39	1950~1960 – natural ventilation

* « QAI »: Qualité de l'Air Intérieur (Indoor Air Quality)

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MOT3 (motricity room)	0.68	2022 – with CMV
MUS1 (weight room)	0.22	1970s renovated in 2021 – wide opening hours, DFV
MUS2 (weight room)	0.44	1950s - Small room with many users, outdated premises, single-flow CMV
MUS3 (weight room)	0.60	2020- Small room, DFV
APS1 (dance, yoga)	1.01	2016- same building than DOJ1, DFV
APS2 (gym)	0.26	for use by high school students only, natural ventilation

2.2 Sampling campaigns

The sampling campaigns were performed between November 2022 and April 2023. Two series of measurements were programmed in each of the halls:

- A series of measurements during an occupied period: normal operation of the halls, in terms of sports activities, user reception and maintenance.
- A series of measurements during a non-occupied period, when the halls were closed (with no activity, human presence or maintenance).

2.3 Sampling and analytical methodologies

Several sampling methods were used to cover all the parameters investigated. These sampling methods were deployed over 4.5 days (from Monday morning to Friday evening), taking care to avoid any interactions between the different methods (Fig.1).

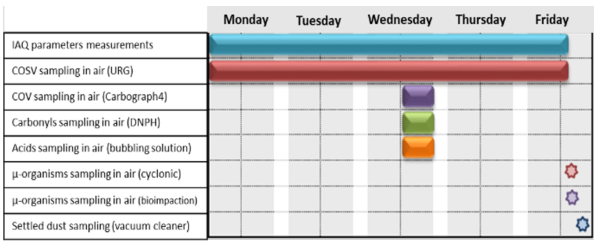

Fig. 1. Diagram of the sampling campaign process

IAQ parameters (temperature, relative humidity and CO_2 concentration) were continuously monitored during the sampling period. The air exchange rate was determined in each room in triplicate from the CO_2 decay kinetics in post occupation periods according to the ASTM standard (E741-00, 2006). The average values are reported in Table 1.

For VOCs, active sampling using various supports was applied: Carbograph4 cartridge, 2,4-dinitrophenylhydrazine cartridge for C1-C3 carbonyls and bubbling solution for C1-C3 carboxylic acids. Each sampling was realized twice. Analyses were carried out by ATD-GC-MS [4], HPLC-UV and IC (ion chromatography)-conductivity, respectively.

The SVOCs in air were sampled on URG cartridge containing polyurethane foam and quartz filter to determine the total concentration (gas + suspended particles) of about forty compounds. Samples were analysed by GC/MS/MS [5] after pressurized solvent extraction (PLE). Settled dust were collected by vacuum cleaner in occupied rooms and sieved to 100 µm before PLE and GC/MS/MS analysis.

54 VOCs and 55 SVOCs were calibrated according to the analytical methods previously described. The limits of quantification in air and dust of the different chemical pollutants are shown in Table 2.

For microbiological contaminants, air was sampled by cyclonic collector in liquid medium and analysed by culture (bacteria and molds identification) and molecular biology (PCR) for viruses, including SARS-Cov-2. The limits of quantification for SARS-Cov-2 is 2.6 10^2 (UG/m^3) and for bacteria and molds, 5 CFU/m^3.

Table 2. Limits of quantification (LOQ) in air and settled dust for the chemical pollutants studied

Chemicals	LOQ in air	LOQ in dust
VOCs	0.05 - 2.76 µg/m^3	/
Carbonyls	0.3 - 1.9 µg/m^3	/
Acids	1.5 µg/m^3	/
Phthalates	2.24 - 18.0 ng/m^3	500 - 4000 ng/g
PAH	0.224 - 0.449 ng/m^3	50 - 250 ng/g
Flame Retardants	0.4 - 89.8 ng/m^3	1 - 200 ng/g
Biocides	0.0045 - 0.9 ng/m^3	5 - 1000 ng/g

3 Results and discussion

3.1 VOCs and SVOCs in air

3.1.1 Nature and sources of main contaminants

About 50 VOCs were identified and quantified in the air of the 10 sports halls studied. Composition and concentrations are globally close to those of other indoor environments, with a predominance of carbonyls, especially hexanal. The cumulative concentrations of the various families of VOCs identified in the occupied and non-occupied rooms are shown in Fig.2. They range from 20 µg/m^3 for non-occupied DOJ1 to 267 µg/m^3 for MUS1 in occupied conditions, 34% of which are carboxylic acids, tracers of physical activity. Other VOCs emitted by the human body have been identified and quantified: these include acetone, emitted by the skin and exhaled air [6], 6-methyl-5-hepten-one (or sulcatone), an oxidation product of squalene emitted by the skin [7].

Measurements also revealed emerging VOCs that are rarely identified in indoor air of buildings, such as methyl methacrylate, and naphthalene identified exclusively in DOJ1 and which are probably originating from the polymeric materials present in this room. The benzothiazole, rubber vulcanising agent [8], is found in weight rooms (MUS1 and MUS2) probably emitted by recycled rubber gymnastic mats. The decamethylcyclopentasiloxane (D5) is specifically identified in APS2, MOT3, MUS1 and MUS2. It is used in cosmetics, which may explain why it is found in higher concentrations in occupied conditions. Glycol ethers, water-based paints components, are only found in motricity room and one of them, 1-(2-methoxy-1-methyl ethoxy)-2-propanol, is specific of MOT2.

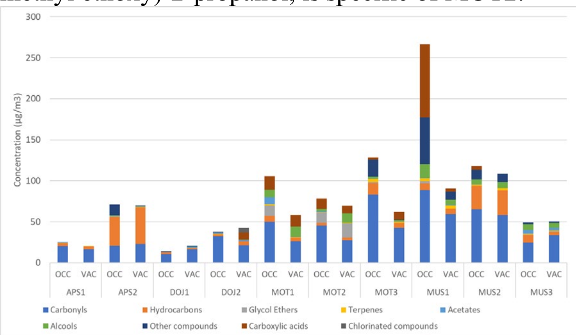

Fig. 2. Chemical families of VOCs identified and quantified in air of occupied (occ) and non-occupied (vac) sports halls.

SVOCs determined by targeted analysis in air are presented by chemical families in Fig. 3.

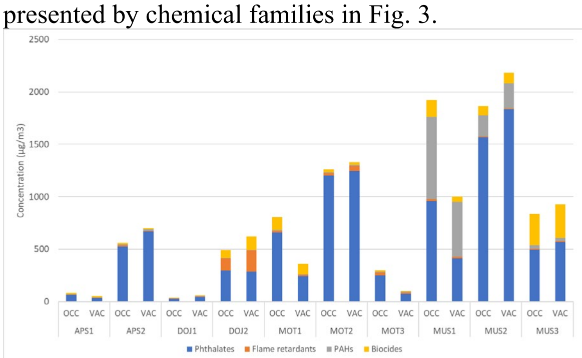

Fig.3 . Chemical families of SVOCs identified and quantified in the air of occupied (occ) and non-occupied (vac) sports halls.

The cumulated concentrations range from 50 ng/m^3 for non-occupied APS1 to 2183 ng/m^3 for non-occupied MUS2. A majority of phthalates, used as plasticizers in polymeric materials, is observed in all the rooms. The proportion of their concentrations varying from 41.0% (unoccupied MUS1) to 95.6% (occupied MOT2). The main compounds are di-isobutyl phthalate (DiBP), which concentration reaches 1608 ng/m^3 in occupied MUS2, and di-butyl phthalate (DBP). Organophosphate flame retardants (OPFRs) are mainly identified in DOJ2 with cumulated concentrations of 113 and 200 ng/m^3 in occupied and non-occupied conditions respectively. The major compound is ethyl hexyl diphenyl phosphate (EHDPP) mainly used as a flame-retardant plasticizer in the production of flexible polyvinyl chloride. The high concentration of EHDPP in this dojo is probably due to large areas of protective wall foam which are not present in DOJ1.

PAHs (fluorene, phenanthrene) were also identified, especially in MUS1 and MUS2. They probably issued from recycled rubber mats.

3.1.2 Influence of ventilation on VOCs and SVOCs concentrations in air

The less contaminated sports halls are DOJ1 and APS1, which are located in the same recent building (2016) designed with low emission materials and equipped with a dual flow ventilation leading to the highest air exchange rate of the studied rooms (1 h^{-1}). The highest VOCs and SVOCs concentrations in air are globally found in weight rooms and motricity rooms having the lowest air exchange rates, e.g. 0.22 h^{-1} for MUS1, 0.44 h^{-1} for MUS2 and 0.39 h^{-1} for MOT2.

Fig. 4 presents the VOCs and SVOCs cumulated concentrations in air in occupied and unoccupied rooms *vs* air exchange rates (considered the same for occupied and unoccupied conditions, see § 2.3).

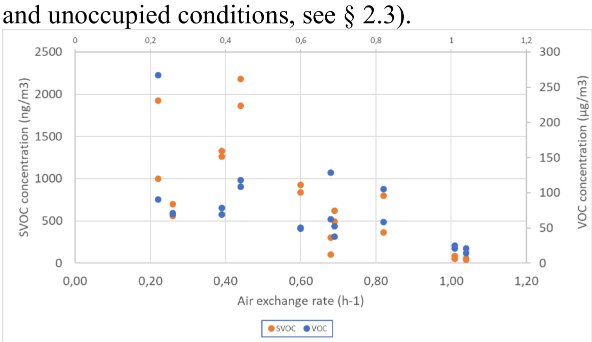

Fig.4 . Cumulated concentrations of VOCs and SVOCs in occupied and unoccupied sports halls *vs* air exchange rates

An overall trend of decreasing concentrations with increasing air exchange rate can be seen from these results, despite the differences between the rooms in terms of activities, equipment (ventilation and materials), type and age of the buildings. That confirms the importance of ventilation in indoor air quality management.

3.1.3 Effect of occupancy on air pollution of rooms

The sums of VOC concentrations obtained for occupied and unoccupied rooms are shown in Fig. 5. Dojos are the only type of room for which higher concentrations (around 30%) are observed in unoccupied rooms than in occupied rooms. This can be explained by the large volume of dojos compared with the other rooms studied and by the presence of large surfaces of VOC-emitting materials (protective foam walls, tatami mats). The greatest differences between occupied and unoccupied rooms are observed in MOT1, MOT3 and MUS1, with an increase in overall VOC concentrations of 81%, 106% and 194% respectively. This can be explained by the high occupancy rate of these rooms in relation to their volumes (in comparison, occupancy of dojos was low and combined with high room volumes), but also by the type and intensity of the sports activities: weight training for MUS1 and motor skills exercises for young children for MOT1 and MOT3. For the other rooms, there was no significant difference between occupancy and non-occupancy.

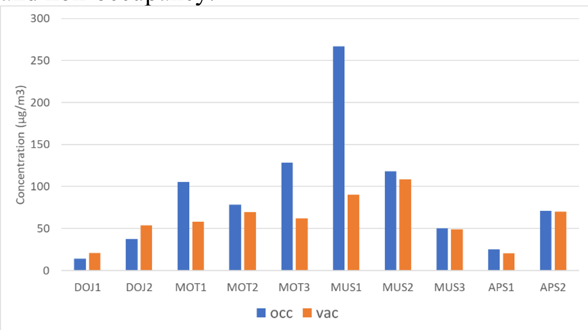

Fig.5 . Cumulated concentrations of VOCs in occupied (occ) and unoccupied (vac) sports halls.

A similar trend is observed for SVOCs (Fig.6). As most of the compounds quantified are originating from building materials and equipment, occupancy has little impact on SVOCs in indoor air of the rooms, excepted for MUS1, probably due to intensive activity.

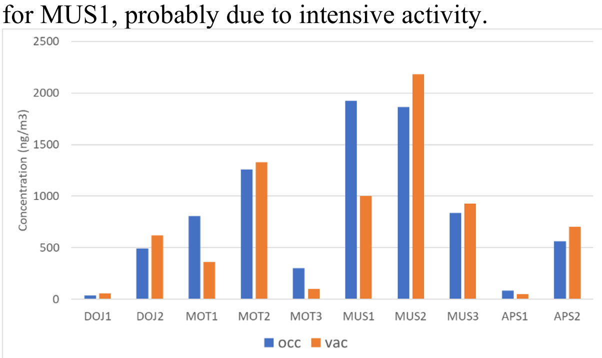

Fig.6 . Cumulated concentrations of SVOCs in occupied (occ) and unoccupied (vac) sports halls.

3.2 SVOCs in settled dust

In order to collect a sufficient quantity of dust, sampling was carried out at the end of the occupied period. The cumulated concentrations (ng/g) of SVOCs in the occupied rooms are presented in Fig.7. They range from 158.5 µg/g (DOJ1) to 9 260 µg/g (MOT2).

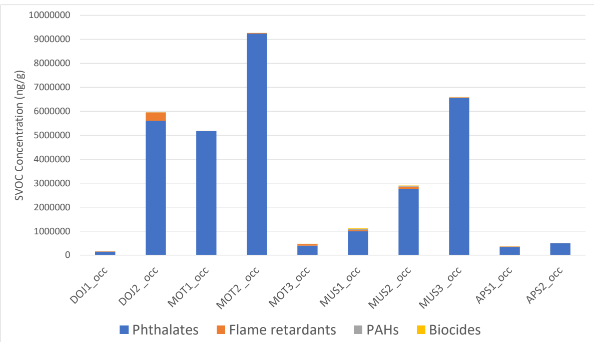

Fig.7 . Chemical families of SVOCs identified in the dust of occupied sports halls.

While Figures 5 and 6 show that the same hierarchy of contamination exists for VOCs and SVOCs in air, the hierarchy is different for dust.

Almost all the SVOCs identified and quantified are phthalates. The major compounds are di-isononyl phthalate (DiNP), and di-ethylhexyl phthalate (DEHP) particularly predominant in MOT2 with a concentration of around 8 mg/g. OPFRs are also present in dust with EHDPP and TPP (triphenyl phosphate) with concentrations reaching respectively 103.9 µg/g and 154.5 µg/g in DOJ2 probably due to the important surface of protective wall foam covered by PVC coating.

As already observed in air, PAHs are also specifically identified in the settled dust of weight rooms, especially in MUS1 and MUS2 where the concentrations levels of phenanthrene and pyrene exceed 10 µg/g. Biocides are also significantly detected, such as benzophenone in MUS1 (14 µg/g) and 2-Benzisothiazol-3(2H)-one (BIT) in MOT3 (2 µg/g).

3.3 Microbiological contaminants

The total bacteria and total mold concentrations are presented in Fig.8 for occupied and unoccupied rooms.

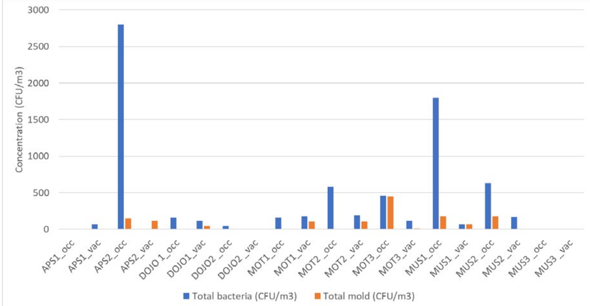

Fig. 8 . Total bacteria and mold concentration (CFU/m^3) for occupied (occ) and unoccupied (vac) sports halls.

Overall, the microbiological contamination (mold and bacteria) of the sports halls studied is in the range of that of dwellings. The concentration of Sars-Cov-2 was below the limit of quantification for all the rooms studied.

The concentrations of bacteria and molds in the Dojos were abnormally low and can be explained by a change in the collection medium used to collect viruses, which proved unsuitable for bacteria and moulds.

Bacterial contamination in the motricity rooms is higher during the occupancy phase, which is quite logical, as the bacteria in the indoor air are largely brought in by the occupants. This is confirmed by the identification of the genera *Micrococcus* and *Staphylococcus*. The genera *Pseudomonas*, *Bacillus* and *Kocuria*, identified in unoccupied rooms, are environmental bacteria that can be brought in from outside. The motricity rooms contain very little mold contamination.

In the weight rooms, bacterial concentrations are much higher during the occupancy phase. This difference is less significant for molds, and concentrations are fairly low.

In APS2, a significant presence of bacteria was observed during the occupancy phase. Mold is not very present.

4 Conclusion

This study assessed the indoor air quality of 10 sports halls of different activities (dojos, motricity rooms for young children, weight rooms and gyms).

Targeted and non-targeted analysis allowed to identify and quantify more than a hundred VOCs and SVOCs and several microbiological contaminants in indoor air and dust in occupied and unoccupied conditions. VOCs pollution is globally similar to those of other indoor environments, with a predominance of carbonyl compounds. Some specific and emerging compounds (like benzothiazole, decamethylcyclopentasiloxane and 1-(2-methoxy-1-methyl ethoxy)-2-propanol)) were also highlighted. Acetone and 6-methyl-5-hepten-one, emitted by human body, were identified as occupancy tracers. SVOCs are mainly phthalates (DiBP, DBP in air, DEHP, DiNP in dust), organophosphate flame retardants (EHDPP in air and dust, TPP in dust) and PAHs (Fluorene, phenanthrene in air, pyrene in dust) with high concentrations in one weight room's dust, probably issued from a recycled rubber flooring. Microbiological contamination is similar to residential ones and SARS-Cov-2 was not detected.

The positive impact of the ventilation on the gaseous concentrations of VOCs and SVOCs was also highlighted, confirming the key role of air exchange rate in building to improve and manage indoor air quality. Appropriate strategies, such as by increasing the ventilation rate, controlling occupancy rate, or the removal of contaminant sources could be envisaged.

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