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Can indoor sports centers be allowed to re-open during the COVID-19

pandemic based on a certificate of equivalence?

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A R T I C L E I N F O

A B S T R A C T

Keywords:

Within a time span of only a few months, the SARS-CoV-2 virus has managed to spread across the world. This Corona virus

virus can spread by close contact, which includes large droplet spray and inhalation of microscopic droplets, and Sports club

by indirect contact via contaminated objects. While in most countries, supermarkets have remained open, due to Gym

the COVID-19 pandemic, authorities have ordered many other shops, restaurants, bars, music theaters and in-Fitness

Aerodynamics

door sports centers to be closed *[Code a1]*. As part of COVID-19 (semi)lockdown exit strategies, many government au-Building ventilation

thorities are now (May-June 2020) allowing a gradual re-opening, where sometimes indoor sport centers are last Filters

in line to be permitted to re-open. This technical note discusses the challenges in safely re-opening these facilities *[Code a2]* Face masks

and the measures already suggested by others to partly tackle these challenges *[Code a1]*. It also elaborates three potential additional measures and based on these additional measures, it suggests the concept of a certificate of equivalence that could allow indoor sports centers with such a certificate to re-open safely and more rapidly. *[Code a3]* It also attempts to stimulate increased preparedness of indoor sports centers that should allow them to remain open safely during potential next waves of SARS-CoV-2 as well as future pandemics. *[Code a3]* It is concluded that fighting situations such as the COVID-19 pandemic and limiting economic damage requires increased collaboration and research by virologists, epidemiologists, microbiologists, aerosol scientists, building physicists, building services engineers and sports scientists *[Code a5]*.

1. Introduction

suggested that the COVID-19 virus is transmitted by respiratory droplets and by contact routes [2–7]. Direct transmission by droplets can occur Within a time span of only a few months, the SARS-CoV-2 virus has between people when infective droplets produced by sneezing, cough- managed to spread to many countries in the world and to generate a ing, talking, singing or simply exhaling reach the mucosae (mouth and world- wide crisis. Many countries have closed their borders and some nose) or conjunctiva (eyes) of another person. That is why during the have imposed long lockdowns or semi-lockdowns on their inhabitants.

COVID-19 pandemic, many countries world-wide have declared –

International, national and local sports and cultural events have been sometimes by law – a so-called “social distance” of about 1.5 m, 2 m or 6

canceled or at least postponed. Restaurants, bars, music and movie ft (actual value dependent on the country) to be kept between in-theaters and indoor sports centers had to close their doors. In spite of dividuals. While this is not really a social distance but rather a physical these measures, on 31 May 2020, the European Centre for Disease Pre-distance, this distance is considered not only feasible but by many also vention and Control reported nearly 5.9 million cases of SARS-CoV-2

effective because it is sometimes assumed that the largest respiratory including 364,891 deaths world-wide [1]. SARS-CoV-2 is not only a droplets will settle by gravity and/or evaporate before having traveled highly transmissible but also a deadly virus. Several sources have this distance to impact the other person. However, recent studies have

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Fig. 1. Sports contributes to several of the Sustainable Development Goals of the United Nations [22].

Fig. 2. Concept of (a) displacement ventilation; (b) mixing ventilation.

demonstrated that droplets from coughing and sneezing can sometimes Indoor sports centers are environments that house equipment and travel 4 m or even 6 m and more, co-propelled by the turbulent air jet by services for the purpose of physical exercise. The equipment and services the coughing or sneezing person [8–10]. Indirect or contact route can cover a very wide range of physical activities: (i) cardio equipment transmission can occur via fomites such as skin cells, hair, clothes, with stationary exercise bicycles, treadmills, rowing machines and handrails, keyboard buttons and other objects, where virus is deposited elliptical trainers, (ii) workout equipment with free weights and weight-after contact with an infected person. There is mounting evidence that based exercise machines, (iii) group exercise services where trainers or the virus can also be transmitted by inhalation of microscopic droplets instructors provide classes in aerobics, cycling/spinning, step yoga, (i.e. aerosols) at short-to-medium range because the virus has been pilates, stretching, etc. and (iv) additional facilities such as indoor found in small aerosols that can remain in the air for hours, and it has been shown to maintain viability in such aerosols [11–15]. Thus, it would be judicious to apply precautionary measures also for the **Table 1**

airborne route.

Minimum required ventilation flow rates for different types of utility buildings Respiratory droplets are generated from the fluid lining of the res- according to the Dutch Building Code [53].

piratory tract during the expiratory activities breathing, talking, Function

Requirement in dm3/s/person

coughing and sneezing [16,17] and the size of these droplets can range New buildings

Existing buildings

from about 0.1 μm to 1 mm [18]. While a sneeze can generate 10,000

droplets or more, a cough can produce about 100

Childcare

6.5

3.44

–1000 droplets and

Meeting

4

2.12

talking can produce about 50 droplets per second [19,20]. Sneezing and Healthcare, bed area

12

3.44

coughing can generate a substantial fraction of larger droplets and Healthcare, other areas

6.5

3.44

breathing mainly generates the smaller range of droplets or aerosols.

Industrial

6.5

3.44

However, as stated by Mittal et al. [21], previous studies have noted that Office

6.5

3.44

“even though breathing generates droplets at a much lower rate, it Hotel, dormitory

12

6.40

Education

8.5

3.44

probably accounts for more expired bioaerosols over the course of a day Sports

6.5

3.44

than intermittent events such as coughing and sneezing”.

Shopping

4

2.12

2

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Fig. 3. (a) Concept of ESP with positive ionisation; (b) photo of moderate-size ESP (2.8 ⁄ 0.72 ⁄ 1.28 m3) in an indoor environment. (Source: ENS Technology, reproduced with permission); (c) photo of small-size ESP (0.79 x 0.40 x 0.13 m3) (Source: PlasmaMade, reproduced with permission).

running tracks, basketball courts, squash courts, boxing areas, ice rinks around the world.

and swimming pools. In the present technical note, we focus on the This document does not attempt to be complete. Given the urgency of categories (i), (ii) and (iii), where the people exercising are not moving the situation and the historical lack of research on infectious diseases throughout the room while performing a particular exercise but instead and sports, it attempts to provide a first overview of challenges, current remain confined at a rather fixed position in the room.

measures and additional measures supplemented with a potential Sports have an important role in the society. They contribute to practical framework.

several of the United Nations Sustainable Development Goals [22]

(Fig. 1). For centuries, sports have succeeded in bringing people **2. Challenges and current measures for indoor sports centers** together. Even in the darkest of times, sports have been practiced to maintain at least a semblance of normality and to build and sustain In indoor sports centers, typically the facilities such as exercise morale. During war, soldiers would exercise some sports in the trenches equipment, lockers, showers and all means to access them such as to pass time and enjoy themselves [23,24]. Also during the COVID-19

keyboard buttons, handlebars, railings and doorknobs are used by many pandemic, sports have been and still are undoubtedly important [25,

visitors, which could result in many opportunities of infection trans-

26]. However, the fact that in many countries indoor sports centers have mission, either directly (by expired droplets at short range) or indirectly been closed has equally undoubtedly made it more difficult for people to (by fomites). Therefore, a wide range of precautionary measures can and cope with this pandemic and the associated (semi-)lockdown [27]. A should be taken. The NOC*NSF (Dutch Olympic Committee * Dutch long closure of indoor sports centers could also lead to detrimental Sports Federation) is the overarching organization for all sports activ-economic consequences, with bankruptcies and the associated negative ities, professional and recreational, in the Netherlands. This organiza-consequences throughout the whole supply chain.

tion has issued a “Protocol for Responsible Physical Exercise” [28].

During the COVID-19 pandemic, in most countries, supermarkets Based on this document, the Dutch organization “NL Actief” has pub-have remained open, but many other shops, restaurants, bars, music lished a similar document but especially focused on indoor sports cen-theaters and indoor sports centers have been closed. As part of a COVID-ters: “Protocol for Responsible Physical Exercise – Branche: Fitness”

19 (semi)lockdown exit strategy, many government authorities are

[29]. This protocol contains a comprehensive list of precautionary allowing a gradual re-opening, where sometimes indoor sport centers measures and is intended to supplement the already imposed measures are last in line to be permitted to re-open. This technical note discusses by the Dutch National Institute of Public Health and the Environment the challenges in re-opening these facilities and the measures already (RIVM) and the protocol by the NOC*NSF. It explicitly focuses on those suggested by others to partly tackle these challenges. It also elaborates physical activities that do not involve physical contact between persons.

three additional measures and based on the implementation of some of The precautionary measures are provided in four categories: for (i) op-these additional measures, it suggests the concept of a certificate of erators, (ii) visitors, (iii) employees and (iv) suppliers. The measures equivalence that could allow indoor sports centers with such a certifi-should be applied on top of the basic measures that hold for all people in cate to re-open safely and more rapidly. It also attempts to stimulate the Netherlands such as keeping the 1.5 m physical distance at all times, increased preparedness of indoor sports centers that should allow them sneezing and coughing in one’s elbow cavity and using paper towels, to remain open safely during potential next waves of this virus as well as staying at home after you have tested positive for the virus, staying at future pandemics. As an example, the situation of the Netherlands is home when showing at least one of the typical symptoms, staying at taken, but similar situations are undoubtedly present in many countries home when one of your housemates has tested positive for the virus and staying at home when one of your housemates has a fever (38 C and above) or a tightness feeling. The additional measures include [28, 29]: **Table 2**

Minimum required ventilation flow rates (Q) in dm3/s and air change rates per

 For operators: controlling the maximum number of visitors and hour (n) for an indoor sports center and a shop of 1000 m2 floor area, 5 m height routing inside the buildings, providing masks, gloves, glasses and and 100 persons present, according to Ref. [49,[54,55]].

regular disinfection of payment terminal keyboards, door handles Function

Indoor sports center

Shop

and other surfaces, appointing a COVID-19 supervisor and instructions for employees including pointing visitors to unsafe Q (dm3/

n

Q (dm3/

n

s)

(h 1)

s)

(h 1)

behavior;

 For visitors: required reservation of a time slot, only visiting with Building Code (new buildings) [49]

650

0.47

400

0.29

Building Code (existing buildings)

344

0.25

212

0.15

members from the same household, avoiding public transport, using

[49]

the sanitary facilities at home instead of in the center, only starting Sports Guidelines [54,55]

exercise after having washed the hands and leaving the center General (11.11 dm3/s/person)

1111

0.80

immediately after having finalized your physical activity; Fitness area

8333

6

 For employees: working at home as much as possible, regular Aerobics and martial sports area

11111

8

Indoor cycling area

13889

10

washing of the hands before every meal, after use of the sanitary 3

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Fig. 4. Nomogram of number of persons per 10 m2 as a function of required ventilation rate per person, with the product of air change rate per hour (n) and room height (H) as a parameter (nH with unit m/h).

Fig. 5. Nomogram of number of persons per 10 m2 as a function of required ventilation rate per person, with the product of air change rate per hour (n) and room height (H) and the ESP characteristics as parameters (unit of nH is m/h).

facilities, after having traveled with public transport, and after yet insufficiently clear whether asymptomatic SARS-CoV-2 carriers also cleaning, not sharing tools with other employees, keeping personal expire such aerosols. Given the current status of knowledge on aerosol tools clean and disinfected;

expiration and on SARS-CoV-2, both concerns seem justified. Indeed,

- For suppliers: announcing arrival 15 min in advance, wearing gloves, there is evidence that deep exhalation (as with physical exercise) pro- announcing where the goods will be placed, giving preference to duces more aerosols [17,31], there are indications of SARS-CoV-2

delivery at the doorstep.

infection in 12 fitness dance classes in South Korea [32] and recent studies do suggest that asymptomatic carriers can transfer the The protocol also advises a gradual re-opening in three phases, from SARS-CoV-2 virus [33, 34].

a first and limited opening that should have started on 15 March 2020 to To the best of our knowledge, there are only a few studies that a full regular opening including catering facilities afterwards.

provide some indirect indication of how physical exercise influences the In spite of this document, the Dutch government decided on 6 May emission of respiratory droplets. Johnson and Morawska [17] found that 2020 that indoor sports centers would have to remain closed until 1

deep exhalation resulted in a 4-to 6-fold increase in aerosol concen- September 2020. The main argument provided for this decision by the tration and rapid inhalation produced a further 2-to 3-fold increase in Ministry of Health, Welfare and Sports pointed to the issue that was not concentration. In contrast, rapid exhalation had little effect on the addressed in the Protocol document: concern about the increased measured concentration. Almstrand et al. [31] analyzed the effect of amount of aerosols expired during physical exercise that can remain in airway opening on the production of exhaled particles. Ten healthy test the air for a long duration [30]. They also raised the concern that it was subjects were asked to perform different breathing maneuvers in which 4

the initial lung volume preceding an inhalation to total lung capacity only the expired air and aerosols will therefore be exposed to the was varied between functional residual capacity (FRC – the volume of resulting upward buoyancy forces, but also a – mainly – thermal air in the lungs at the end of passive expiration) and residual volume (RV

convective plume is present around people that causes a clear upward

– the volume of air in the lungs after full exhalation). They measured airflow near their body [49]. The movement of people, and finally the exhaled particles in the size range 0.30–2.0 μm. The number of exhaled ventilation system itself, also contribute to the complexity of the airflow particles demonstrated a 2-to 18-fold increase after exhalations to RV

patterns in enclosures.

compared with exhalations where no airway closure was shown [31].

Li et al. [50] extensively reviewed studies on the role of ventilation in However, both studies were performed with persons not conducting the airborne transmission of infectious agents in buildings. They physical exercise, therefore more research is needed on whether and to concluded that there is clear evidence of an association between venti-what extent physical exercise can further increase the generation of lation, air movement in buildings and the transmission/spread of in-aerosols.

fectious diseases such as influenza and SARS. However, they also Considering the contents of the protocol [29], the aforementioned indicated that there was insufficient data to specify and quantify the studies on increased aerosol production by deep exhalation and rapid minimum ventilation requirements in hospitals, schools, offices and inhalation [17, 31], the indication of infection in the fitness dance classes other buildings to avoid the spread of these and other infectious diseases

[32] and the aforementioned studies on virus viability in small aerosols via the airborne route. Indeed, ventilation implies air movement and that can remain in the air for hours [11–15], it would be judicious to also aerosol movement inside the building, and in some cases the apply additional precautionary measures to handle the potential surplus ventilation system uses recirculation of part of the exhausted air back to of aerosols produced by breathing during physical exercise in indoor the inside, which, in case of infectious diseases, is undesirable [51].

sports centers. While the study [32] suggested that vigorous exercise in Therefore, only high-intensity ventilation without recirculation should confined spaces should be minimized during outbreaks, the present be applied in this type of pandemic in order to effectively and quickly authors do not necessarily share that opinion, because many other pa-remove aerosols and keep indoor aerosol concentrations as low as rameters are involved, including those mentioned in the next section, possible. If recirculation is applied, the recirculated air should be treated that have received relatively little attention in most SARS-CoV-2 pub-so that infectious aerosols are physically removed and/or pathogens are lications so far.

inactivated, for example by UV germicidal irradiation.

Ai and Melikov [52] reviewed studies on the airborne spread of **3. Towards a certificate of equivalence with additional** expiratory droplet nuclei between the occupants of indoor environ-measures

ments, with specific focus on the spread of droplet nuclei from mouth/nose to mouth/nose for non-specific diseases. They stressed the 3.1. High-intensity building ventilation

importance of indoor airflow patterns and indicated that future research is needed in three specific areas: the importance of the direction of in-Building or room ventilation can be defined as “the process by which door airflow patterns, the dynamics of airborne transmission and the

‘clean’ air (normally outdoor air) is intentionally provided to a space application of CFD simulations.

and stale air is removed” [35]. Several authoritative books and extensive In most countries world-wide, building ventilation is mandatory by reviews have been provided on the topic in the past decades (e.g. Refs.

law, as an essential requirement for health and comfort in buildings. In

[36–39]). Ventilation can be driven by mechanical systems (mechanical the Netherlands, the minimum requirements for the ventilation of ventilation) or by natural forces such as wind and buoyancy (natural buildings are prescribed by the Building Code (“Bouwbesluit”) pub-ventilation) or a combination of both. Some mechanical systems employ lished in 2012, and last amended in 2020 [53]. The minimum ventila-recirculation of heated or cooled air for the purpose of energy conser-tion flow rates in terms of provision of fresh air for different types of vation. Strictly, according to the above-mentioned AIVC definition, utility buildings are given in Table 1. A distinction is made between new recirculated air cannot be labeled as ventilation. In this technical note, buildings and existing buildings. In 2008, the Dutch Guidebook for we strictly follow the definition that ventilation air is outdoor clean air Sports Accommodations was published [54] and in 2014 specific free of infectious aerosols. In its simplest case, high-intensity

natural guidelines for sports facilities for people with disabilities were provided ventilation consists of opening windows and doors in opposite facades

[55]. These guidelines stipulate a minimum ventilation flow rate of 11.1

(if weather allows). Two main categories of building ventilation are dm3/s per exercising person for sports halls, which is 70% above the displacement ventilation and mixing ventilation. In displacement minimum required value in the Dutch Building Code for new buildings ventilation, the outdoor air is generally supplied at a low velocity from and even 3.2 times higher for existing buildings. These higher values are diffusers near the floor level and extracted above the occupied zone, probably intended to try to take into account the higher heat, vapor, CO_2

near or at the ceiling (Fig. 2a). In mixing ventilation, the outdoor air is and aerosol emission by people during physical exercise. In addition, supplied at a high velocity outside the occupied zone, such as near or at these specific guidelines for indoor sports accommodations [54,55]

the ceiling, and is mixed with the stale indoor air (Fig. 2b), with the suggest a total of 6 air changes per hour (ACH) for fitness spaces (i.e. the intention to dilute the concentrations of e.g. aerosols, after which part of volume of air in the room is replaced by clean air 6 times per hour), this mixed air is extracted out of the room. Displacement ventilation while the ACH for aerobics and martial arts spaces should be 8 h 1 and generally leads to lower aerosol concentrations in the occupied zone and for indoor cycling 10 h 1. In view of the COVID-19 pandemic, ASHRAE, an overall better ventilation efficiency than mixing ventilation, but the American Society of Heating, Refrigerating and Air-Conditioning locating diffusors and ducts near the floor is not always feasible. Mixing Engineers, has acknowledged the potential for aerosol transmission of ventilation is easier to implement with diffusors and ducts near the SARS-CoV-2 and states that facilities of all types should follow, as a ceiling but generally leads to more evenly distributed and overall higher minimum, the latest published standards and guidelines and good en-aerosol concentrations in the enclosure. To our knowledge, the vast gineering practice [56]. ASHRAE Standard 62.1 specifies ventilation majority of indoor sports centers are equipped with

mixing ventilation rates for acceptable indoor air quality [57]. For gyms, health clubs, systems, but in view of reducing infection risk, the future design of such aerobics rooms, and weight rooms, the minimum outdoor airflow rate is centers could benefit from displacement ventilation systems if sufficient 10 dm3/s/person. This is higher than specified for most retail (3.8

buoyancy forces will act to generate upward movement of the air.

dm3/s/person, except for beauty and nail salons where 10 dm3/s/person Given the low inertia of the aerosols, after expiration, their move-is required) and educational buildings (3.8–5 dm3/s/person). Note that ment in the enclosure will rapidly be determined by the indoor airflow the ASRHAE value for gyms aligns well with the 11.1 dm3/s from the patterns. These patterns can be very complex as demonstrated by many Dutch guidelines [55].

earlier studies [40–48]. Persons are sources of heat, vapor and CO2. Not 5

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3.2. Filtering

radical statements pro and con the usefulness of wearing of masks by the public in various situations, an overview of the recent peer-reviewed Technological solutions exist for removing moderate to large frac-scientific literature provides a more moderate image (e.g.

tions of aerosols from airstreams inside buildings. These systems can be Ref. [60–62]). There are indeed clear pros and cons concerning masks installed either in the ducts of the HVAC (Heating, Ventilation and Air-for the public. First, many will agree that the best quality masks should Conditioning) system or freely inside the room itself. In both cases, they be provided to our healthcare facilities and only after abundant stock will need

to provide sufficiently high clean air delivery rates. In the there, could one consider distribution among the public The FDA [69]

former case, they should be able to handle the high volume flow rates explicitly states that the Centers for Disease Control and Prevention through the ducts, while in the latter, they should be able to handle high (CDC) do not recommend the general public to wear N95 respirators to enough flow rates in balance with the room ventilation flow rates. A first protect themselves from respiratory diseases such as COVID-19. Instead, option are HEPA filters (high-efficiency particulate absorbing or high-these are considered critical supplies that must continue to be reserved efficiency particulate arrestance). HEPA filtering can be very effective for health care workers and other medical first responders. Second, because these filters remove at least 99.95% of the particles with facial masks could provide a false sense of security, as people could put diameter 0.3 μm and larger fractions of the other sizes. The initial cost is them on leaving leakages, touching the outside of the masks, etc., but relatively low but the operational costs are high, as the flow resistance of there is no evidence that this could be detrimental for the general public these filters is very high and therefore a lot of energy is required to

[70]. The masks also do not cover the eyes that could also be receptors of overcome the large pressure drop over these filters that is unavoidably the virus. Third, wearing masks can have a negative psychological associated with the large flow rates. HEPA filters are used in clean rooms impact on people by reducing the level of human interaction [71].

and some hospital operating theaters, but their future large-scale Conversely, it has been demonstrated that facial masks, even of the most application for indoor sports centers might be hampered by the associ- primitive type, can provide some protection (e.g. Ref. [62]). Using such ated energy costs. As an alternative, electrostatic precipitators (ESPs) or masks in turn can allow people to exercise more freedom in the society, similar devices can be considered. An ESP is a filtration device where the including the use of public transportation and gathering in public places, air is forced to flow through a largely open box by a small industrial fan and could assist in restarting economic activity. In terms of indoor sports and

where the solid or liquid particles are electrically charged and centers, the future development of sports face masks is not unlikely.

collected on a generally grounded plate inside the device [58] (Fig. 3).

These should provide a compromise between droplet and aerosol The initial cost of an ESP can be relatively high but the operational cost collection efficiency, large respiration flow rates and resistance to sweat.

is low due to low energy consumption. However, the efficiency is generally also lower than that of HEPA filters. On-site measurements on 3.4. Certificate

a particular commercially available moderate-size ESP (Fig. 3b) have indicated an efficiency of 70% for PM10 and about 45% for PM2.5 [59],

Ideally, one would want to know the specific infection risk for a given which is nevertheless still considerable given that when the ESP is activity in a given building as a function of occupation, ventilation mounted inside the room itself and – depending on the ventilation rate –

settings and other relevant parameters, and decide on re-opening based the same air could be handled this way multiple times yielding higher on risk assessment. However, many aspects of SARS-CoV-2 are still un-efficiencies.

known and might remain unknown for a considerable time to come. It could take years before knowledge will be available on which viral dose 3.3. Masks

during which time is an infection risk for a given person performing a given activity. Nevertheless, governments are under pressure from the A distinction is made between surgical masks and respirator masks. A economy and the public to resume – at least gradually – economic and surgical mask or face mask is a loose-fitting, disposable device intended leisure activity. This should be done as safely as possible. Therefore, in to block splashes and large droplets, and it can also filter out some spite of the many unknowns and in view of safely re-opening indoor aerosols. A

respirator on the other hand should provide a close facial fit sports centers, government authorities could consider the implementa-and a very efficient filtration of also the aerosols.

tion of a certificate of equivalence in terms of aerosol exposure. This Chen and Willeke [60] tested the collection efficiency of surgical certificate would be obtained if, apart from the measures outlined in masks and respirators with aerosol-size spectrometers. They found that documents such as [28, 29], a combination of some of the three surgical masks with only a shell with a coarse pore structure passed 80%

above-mentioned measures (high-intensity ventilation, filtering, facial of the aerosols below 1 μm with almost no dependency on the flow. On masks) can demonstrably and quantifiably lead to a concentration of the other hand, surgical masks including specific filter material allowed aerosols that is equivalent in terms of exposure (including concentration only 25% passage at 5 L/min to 70% at 100 L/min [60]. He et al. [61]

and inhalation) to the exposure occurring in other facilities that are found that surgical masks sealed to a manikin passed less than 20% of allowed to re-open earlier, such as shops, restaurants and bars, taking aerosols below 1 μm at flow rates of 15–85 L/min; without sealing, the into account the maximum allowed number of people per floor area.

penetration was higher, up to 45%. Van der Sande et al. [62] analyzed A first substantial step towards equivalence could be high-intensity the transmission reduction potential provided by personal respirators, ventilation in order to compensate for the increased aerosol genera-surgical masks and home-made masks when worn during a variety of tion and the increased aerosol inhalation by physical exercise. A small activities by a small number of healthy volunteers and a simulated pa-calculation example is presented, in which we do not consider specific tient. They found that all types of masks did reduce aerosol exposure government-imposed limits in terms of maximum number of persons per relatively stably over time and unaffected by duration of wear and type floor area per type of building – as some of these numbers are being of activity, but with a high degree of variation by type of mask [62].

adjusted frequently. Consider an indoor sports center with a total rect- Unsurprisingly, personal respirators were most efficient, followed by angular floor area of 50 ﬀ 20 m2 ¼ 1000 m2. Physical distancing of 1.5 m surgical masks, followed by home-made masks.

will generally not be an issue as many of the exercise machines already The use of masks is fairly well accepted in many countries in Asia, consume considerable space. We assume that the center, in setting up where often wearing a surgical mask when you are ill is considered as a the machines, very strictly adheres to the required physical distancing token of respect towards others. However, in many other countries, the between exercising visitors of 1.5 m. This implies that around every use of masks has been an issue of debate, although currently govern-machine a 3 ﬀ 3 m2 perimeter is indicated that is a “no go” zone for ments are implementing the mandatory use of surgical or home-made visitors using other machines. In this situation, a maximum of 96 visitors masks at an increasing pace [63–70]. Indeed, while initially in several (assuming no corridor space) can be present at the same time. This countries, scientists, political advisors and politicians have made some corresponds to about 1 person per 10 m2. Table 2 provides the resulting 6

minimum ventilation flow rates for this center and for a shop of the same (heated, cooled, dehumidified, filtered) and recirculated back into the floor area as provided by the Dutch Building Code. For the sports center, room after handling, filtering will be necessary in the return duct and also the larger ventilation flow rates recommended by the Dutch Sports should have been completed before the air is re-injected into the room.

Guidelines [54, 55] are listed. Table 2 shows that for the most critical Whether a filter system with HEPA filters or an ESP is installed inside the situation of new buildings, the ACH of a fitness area as recommended by room itself and should work in addition to the clean air ventilation, its Ref.

[54,55] is about 20 times larger than the minimum for a shop of effect will depend on the efficiency and the capacity (m3/h) of the filter equal floor area and the same maximum number of 100 persons present system and the degree to which high-intensity ventilation is possible. At as required by the Dutch Building Code. Note however that the venti-very high ventilation rates, the effect of the filter system might be lation rates from the building code are minimum requirements and that limited. But if required, it could assist a less powerful ventilation system actual ventilation rates in e.g. supermarkets are probably designed and towards equivalence. This is shown in Fig. 5, which is an extension of set to be higher than those in the Building Code.

Fig. 4 in which – as an example – an ESP with a capacity of 3750 m3/h or Equivalence in terms of aerosol exposure between the indoor sports 7500 m3/h and an efficiency of 50% is installed in the room, assuming center and the shop could be achieved by balancing a number of factors.

perfect mixing, i.e. a uniform aerosol concentration in the room. Fig. 5 is Some main factors that can be controlled and engaged to reduce aerosol based on the mass balance in the room:

concentrations are the higher ventilation rates, limiting the number of persons in the indoor sports center well below the maximum occupation dc

V

¼ G

Qc

QESPηc

(4)

and limiting the intensity of the exercise. On the other hand, factors dt

contributing to aerosol exposure are the higher aerosol production by Where QESP is the ESP flow rate and η the ESP efficiency. Under steady-

exercising people and the possibility that aerosols can be inhaled deeper state conditions, Eq. (4) can be used to extend Eq. (3) as follows: into the respiratory system by exercising persons. The studies by John-

son and Morawska [17] and Almstrand et al. [31] provide a first indi-N

Q

1

η Q

¼ nH

1 þ

ESP

(5)

cation of the aerosol production during deep inhalation and exhalation, A

N

nH

A

where an increase up to a factor 18 has been found between functional

Fig. 5 suggests that for N/A of about 10 dm3/s/person, installing an residual capacity and residual volume. However, at present there is ESP with Q

insufficient information in the scientific literature to argue that this ESP ¼ 7500 m3/h (QESP/A ¼ 7.5 m/h) would allow doubling the occupancy from

1 to 2 person per 10 m2 while keeping the venti-18-fold increase in aerosol production could be balanced by a 20-fold lation flow rate per person and thus the aerosol concentration constant.

increase in ventilation flow rates. Indeed, both studies [17,31] were Note that Eq. (5) and Fig. 5 assume that the 50% ESP efficiency effec-performed with persons not performing physical exercise and it is tively applies to the potentially infectious aerosols generated inside the possible that physical exercise increases the aerosol production even room, while also (non-infectious) aerosols can be brought from outside further. Note also that even the best mixing ventilation systems will not to inside by the ventilation system.

provide perfect mixing and therefore provide non-uniform aerosol A third step towards equivalence could be the use of masks, although concentrations will occur in the room. Much more research is needed on especially here more research and development is needed in view of each of these topics. But if this extra information would be available, it masks that are both efficient and suitable for indoor physical exercise.

seems plausible that the ventilation flow rates could be augmented and the maximum allowed number of people and the intensity of the phys-4. Discussion

ical exercise could be reduced in such a way that they balance the higher aerosol exposure (production and inhalation) leading to a quantifiably An additional question in indoor sports centers is whether or not equivalent situation between indoor sports centers and other spaces sweat can contribute to the transmission of infection. Ding et al. [72]

such as shops, restaurants and bars.

found that SARS-CoV is present in sweat gland. There is potential for Key parameters in terms of ventilation are the floor area A, the room aerosolization of sweat, but the measures suggested to mitigate trans-height H, the required ventilation flow rate per person (Q/N) with N the mission from respiratory droplets and aerosols also apply to aerosolized number of persons, the maximum allowed number of persons per unit sweat. If the

virus is shed in sweat, probably the bigger concern is the floor area (N/A) and the air change rate per hour n. Eq. (1) represents contact route: people leaving behind sweat on machines, either the simplified mass balance in the room assuming a uniform concen-high-touch areas of cardio machines or the seats and handles of weight tration c in the room with volume V, a total aerosol production rate G

machines and free weights/benches. This could be tackled by the and a clean air ventilation flow rate Q. Under steady-state conditions, it guidelines in Ref. [29].

yields Q ¼ G/c which can be rewritten as Eq. (2), where g is the aerosol Mixing ventilation will not provide uniform aerosol concentrations production rate per person. Eq. (2) can be expanded into Eq. (3) that in the entire volume of the room. This should be taken into account relates N/A to Q/N or to g/c.

when implementing the certificate of equivalence. In view of this limi-dc

tation, one could consider real-time monitoring of some environmental V

¼ G

Qc

(1)

dt

parameters at a few strategic locations in the sports center. These parameters could be aerosol concentrations or parameters that can be G

Ng

Q ¼ nAH ¼

¼

(2)

measured with less costly equipment and that could be used as in-c

c

dicators for aerosol concentrations, such as relative humidity and CO2

concentration. This real-time monitoring could also be used to control N

Q

1

¼ nH

¼ nH

(3)

both the settings of the ventilation and the potentially present ESPs.

A

N

c

More research is needed on the production of respiratory droplets Based on Eq. (3), Fig. 4 presents a simple nomogram that provides N/

and aerosols during physical exercise but also concerning the increased A per 10 m2 as a function of Q/N with the product of n and room height and deeper inhalation of aerosols during such exercise. The latter could H as a parameter, with nH in unit m/h. Given the required N/A, the air be studied with advanced computational fluid dynamics (CFD) models change ratio per hour n and the room height H, the maximum number of

[73–76].

persons per 10 m2 can easily be determined.

For the three indoor sports categories covered in this technical note A second step towards equivalence, possibly in combination with (cardio training; workout training with weights; non-contact group ex-high-intensity ventilation, is the use of filters, which can be HEPA filters ercises in classes), if the outdoor space is available and if weather allows, of ESPs. When part of the air exhausted from the room is handled these could partially be restarted outside. In such cases, it is advised to 7

position the equipment and the participants as much as possible in rows

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