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EINDHOVEN
UNIVERSITY OF
TECHNOLOGY

AAN:
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SPORTINNOVATOR

17/6/2021

Betreft: Informatie in verband met de inzet van ventilatie en luchtreiniging in het kader van de bestrijding van COVID-19

Geachte heer [redacted]

Bij wijze van deze brief en haar bijlagen zend ik u graag wat informatie in verband met ventilatie en luchtreiniging in het kader van de bestrijding van COVID-19.

Deze informatie wordt aan u verstrekt in wetenschappelijke objectiviteit en integriteit en is gebaseerd op wetenschappelijke studies en de daaruit volgende informatie. Het staat u vrij om, indien gewenst, deze informatie inclusief deze brief te verspreiden.

Ik blijf graag ter beschikking voor verdere verduidelijking.

Met de meeste hoogachting

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INHOUD

1) Korte toelichting: waarom ventilatie en/of luchtreiniging?

1.1. De drie overdrachtsroutes

Kort samengevat zijn er drie overdrachtsroutes van het COVID-19 virus:

(1) Overdracht via grote druppels of kleine druppels (aerosoldeeltjes) tussen twee personen op korte afstand (typisch minder dan 1,5 m)
(2) Overdracht via besmette oppervlakken
(3) Overdracht via hoge aerosolenconcentraties (niet beperkt tot 1,5 m)

Deze overdrachtsroutes moeten geëlimineerd worden om virusverspreiding tegen te gaan. Wat de eerste overdrachtsroute betreft kan dit door het houden van afstand ("social distancing") of door het dragen van mondneusmaskers, of – nog beter – door beiden.
Wat de tweede overdrachtsroute betreft kan dit via het ontsmetten van oppervlakken en het regelmatig en grondig wassen van handen.
Wat de derde overdrachtsroute betreft moet de opbouw van hoge aerosolenconcentraties vermeden worden. Dat kan door ventilatie en/of luchtreiniging.

1.2. De aerosolenroute

Strikt genomen is een aerosol gedefinieerd als de oplossing ("suspensie") van kleine deeltjes (ofwel vast ofwel vloeibaar) in een gas. In het kader van de COVID-19-pandemie wordt met aerosol bedoeld: speeksel- of slijmdeeltjes (of "druppeltjes") in de lucht.
Die speeksel- of slijmaerosolen worden voortdurend gegeneerd door het menselijk ademhalings-systeem. Bij elke gewone uitademing worden door een gemiddelde persoon een 50-tal druppeltjes uitgestoten. Echter, wanneer men dieper en sneller gaat uitademen, kan dit aantal toenemen tot een 900-tal per uitademing (zie bronnen).
Bronnen:

Johnson GR, Morawska L. 2009 The mechanism of breath aerosol formation. J. Aerosol Med. Pulm. Drug Deliv. 22(3): 229-237.
Almstrand AC, Bake B, Ljungstrom EL, et al. 2010. Effect of airway opening on production of exhaled particles. Journal of Applied Physiology 108: 584-588.

1.3. Hoe belangrijk is de aerosolenroute?

Hierover is de voorbije 12 maanden een vurig debat gevoerd tussen wetenschappers uit diverse vakgebieden, en dat debat woedt nog steeds. Maar eigenlijk zijn dit debat en de uitkomst van dit debat in zekere mate irrelevant. Omdat de aerosolenroute de dominante route ***kan*** zijn, zijn we het aan de maatschappij verplicht om de nodige voorzorgen te nemen. Bovendien komt steeds meer wetenschappelijke informatie beschikbaar die aangeeft dat de aerosolenroute mogelijk de meest dominante route is, zeker bij massabesmettingen. Tegelijkertijd komt er ook steeds meer wetenschappelijke informatie beschikbaar die aangeeft dat de route via besmette oppervlakken zeer onwaarschijnlijk is.

Sinds recent (begin mei) onderkent ook de Wereldgezondheidsorganisatie (WHO) het belang van aerosolen als belangrijke besmettingsroute en daarmee ook de rol van ventilatie (en luchtreiniging) in de bestrijding van COVID-19. Later is ook het RIVM gevolgd.

1.4. Waarom ventilatie en/of luchtreiniging

Om te vermijden dat hoge aerosolenconcentraties optreden moet de opbouw van die concentraties in de loop van de tijd vermeden worden. Dat kan door gepaste ventilatie (met buitenlucht) en/of door luchtreiniging.

2) Wetenschappelijk peer-reviewed artikel i.vm. mogelijkheden heropenen sportscholen (Publicatiedatum: 31/05/2020)

Deze publicatie met international co-auteurs benadrukte in dit vroege stadium van de pandemie het belang van ventilatie, luchtreiniging en mondkapjes voor het veilig heropenen van binnenlocaties zoals sportscholen.

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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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ABSTRACT

Within a time span of only a few months, the SARS-CoV-2 virus has managed to spread across the world. This virus can spread by close contact, which includes large droplet spray and inhalation of microscopic droplets, and by indirect contact via contaminated objects. While in most countries, supermarkets have remained open, due to the COVID-19 pandemic, authorities have ordered many other shops, restaurants, bars, music theaters and indoor sports centers to be closed. As part of COVID-19 (semi)lock-down exit strategies, many government authorities are now (May-June 2020) allowing a gradual re-opening, where sometimes indoor sport centers are last in line to be permitted to re-open. This technical note discusses the challenges in safely re-opening these facilities and the measures already suggested by others to partly tackle these challenges. 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. 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. 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.

1. Introduction

Within a time span of only a few months, the SARS-CoV-2 virus has managed to spread to many countries in the world and to generate a world-wide crisis. Many countries have closed their borders and some have imposed long lockdowns or semi-lockdowns on their inhabitants. International, national and local sports and cultural events have been canceled or at least postponed. Restaurants, bars, music and movie theaters and indoor sports centers had to close their doors. In spite of these measures, on 31 May 2020, the European Centre for Disease Prevention and Control reported nearly 5.9 million cases of SARS-CoV-2 including 364,891 deaths world-wide [1]. SARS-CoV-2 is not only a highly transmissible but also a deadly virus. Several sources have suggested that the COVID-19 virus is transmitted by respiratory droplets and by contact routes [2–7]. Direct transmission by droplets can occur between people when infective droplets produced by sneezing, coughing, talking, singing or simply exhaling reach the mucosae (mouth and nose) or conjunctiva (eyes) of another person. That is why during the COVID-19 pandemic, many countries world-wide have declared – sometimes by law – a so-called "social distance" of about 1.5 m, 2 m or 6 ft (actual value dependent on the country) to be kept between individuals. While this is not really a social distance but rather a physical distance, this distance is considered not only feasible but by many also effective because it is sometimes assumed that the largest respiratory droplets will settle by gravity and/or evaporate before having traveled 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].

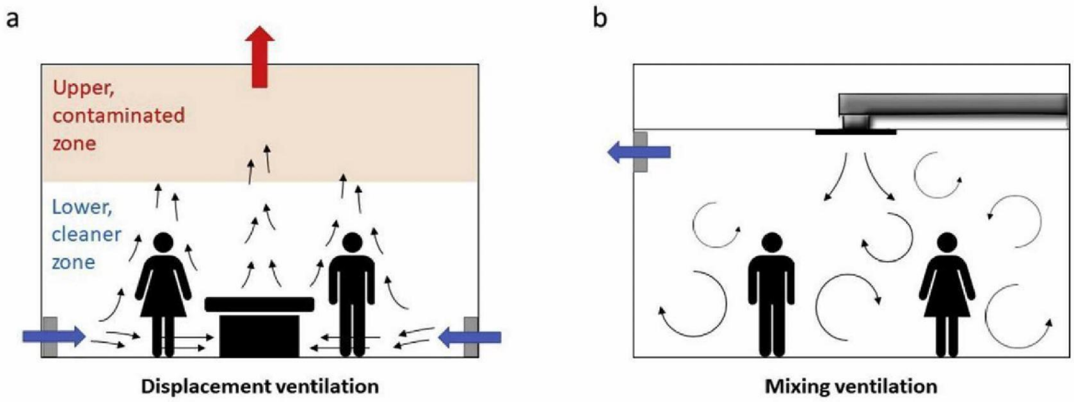

Fig. 2. Concept of (a) displacement ventilation; (b) mixing ventilation.

demonstrated that droplets from coughing and sneezing can sometimes travel 4 m or even 6 m and more, co-propelled by the turbulent air jet by the coughing or sneezing person [8–10]. Indirect or contact route transmission can occur via fomites such as skin cells, hair, clothes, handrails, keyboard buttons and other objects, where virus is deposited after contact with an infected person. There is mounting evidence that the virus can also be transmitted by inhalation of microscopic droplets (i.e. aerosols) at short-to-medium range because the virus has been 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 airborne route.

Respiratory droplets are generated from the fluid lining of the respiratory tract during the expiratory activities breathing, talking, coughing and sneezing [16,17] and the size of these droplets can range from about 0.1 μm to 1 mm [18]. While a sneeze can generate 10,000 droplets or more, a cough can produce about 100–1000 droplets and talking can produce about 50 droplets per second [19,20]. Sneezing and coughing can generate a substantial fraction of larger droplets and breathing mainly generates the smaller range of droplets or aerosols. However, as stated by Mittal et al. [21], previous studies have noted that "even though breathing generates droplets at a much lower rate, it probably accounts for more expired bioaerosols over the course of a day than intermittent events such as coughing and sneezing".

Indoor sports centers are environments that house equipment and services for the purpose of physical exercise. The equipment and services can cover a very wide range of physical activities: (i) cardio equipment with stationary exercise bicycles, treadmills, rowing machines and elliptical trainers, (ii) workout equipment with free weights and weight-based exercise machines, (iii) group exercise services where trainers or instructors provide classes in aerobics, cycling/spinning, step yoga, pilates, stretching, etc. and (iv) additional facilities such as indoor

Table 1
Minimum required ventilation flow rates for different types of utility buildings according to the Dutch Building Code [53].

Function	Requirement in $dm^3/s/person$	
	New buildings	Existing buildings
Childcare	6.5	3.44
Meeting	4	2.12
Healthcare, bed area	12	3.44
Healthcare, other areas	6.5	3.44
Industrial	6.5	3.44
Office	6.5	3.44
Hotel, dormitory	12	6.40
Education	8.5	3.44
Sports	6.5	3.44
Shopping	4	2.12

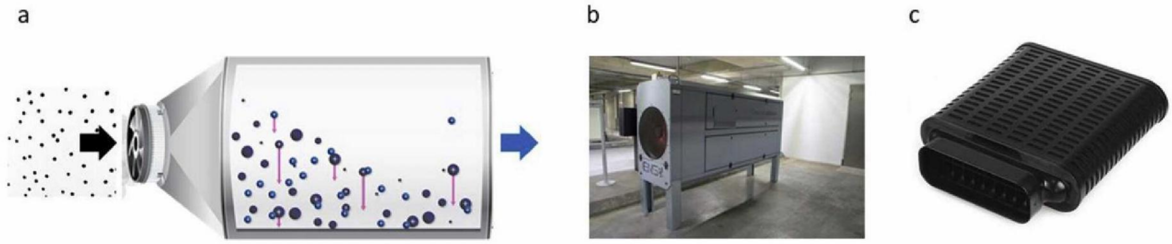

Fig. 3. (a) Concept of ESP with positive ionisation; (b) photo of moderate-size ESP (2.8 × 0.72 × 1.28 m^3) in an indoor environment. (Source: ENS Technology, reproduced with permission); (c) photo of small-size ESP (0.79 x 0.40 x 0.13 m^3) (Source: PlasmaMade, reproduced with permission).

running tracks, basketball courts, squash courts, boxing areas, ice rinks and swimming pools. In the present technical note, we focus on the categories (i), (ii) and (iii), where the people exercising are not moving throughout the room while performing a particular exercise but instead remain confined at a rather fixed position in the room.

Sports have an important role in the society. They contribute to several of the United Nations Sustainable Development Goals [22] (Fig. 1). For centuries, sports have succeeded in bringing people together. Even in the darkest of times, sports have been practiced to maintain at least a semblance of normality and to build and sustain morale. During war, soldiers would exercise some sports in the trenches to pass time and enjoy themselves [23,24]. Also during the COVID-19 pandemic, sports have been and still are undoubtedly important [25, 26]. However, the fact that in many countries indoor sports centers have been closed has equally undoubtedly made it more difficult for people to cope with this pandemic and the associated (semi-)lockdown [27]. A long closure of indoor sports centers could also lead to detrimental economic consequences, with bankruptcies and the associated negative consequences throughout the whole supply chain.

During the COVID-19 pandemic, in most countries, supermarkets have remained open, but many other shops, restaurants, bars, music theaters and indoor sports centers have been closed. As part of a COVID-19 (semi)lock-down exit strategy, many government authorities are allowing a gradual re-opening, where sometimes indoor sport centers are last in line to be permitted to re-open. This technical note discusses the challenges in re-opening these facilities and the measures already suggested by others to partly tackle these challenges. It also elaborates three additional measures and based on the implementation of some of 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. It also attempts to stimulate increased preparedness of indoor sports centers that should allow them to remain open safely during potential next waves of this virus as well as future pandemics. As an example, the situation of the Netherlands is taken, but similar situations are undoubtedly present in many countries around the world.

This document does not attempt to be complete. Given the urgency of the situation and the historical lack of research on infectious diseases and sports, it attempts to provide a first overview of challenges, current measures and additional measures supplemented with a potential practical framework.

Table 2
Minimum required ventilation flow rates (Q) in dm^3/s and air change rates per hour (n) for an indoor sports center and a shop of 1000 m^2 floor area, 5 m height and 100 persons present, according to Ref. [49,[54,55]].

Function	Indoor sports center		Shop	
	Q (dm^3/s)	n (h^{-1})	Q (dm^3/s)	n (h^{-1})
Building Code (new buildings) [49]	650	0.47	400	0.29
Building Code (existing buildings) [49]	344	0.25	212	0.15
Sports Guidelines [54,55]				
General (11.11 dm^3/s/person)	1111	0.80		
Fitness area	8333	6		
Aerobics and martial sports area	11111	8		
Indoor cycling area	13889	10		

2. Challenges and current measures for indoor sports centers

In indoor sports centers, typically the facilities such as exercise equipment, lockers, showers and all means to access them such as keyboard buttons, handlebars, railings and doorknobs are used by many visitors, which could result in many opportunities of infection transmission, either directly (by expired droplets at short range) or indirectly (by fomites). Therefore, a wide range of precautionary measures can and should be taken. The NOC*NSF (Dutch Olympic Committee * Dutch Sports Federation) is the overarching organization for all sports activities, professional and recreational, in the Netherlands. This organization has issued a "Protocol for Responsible Physical Exercise" [28]. Based on this document, the Dutch organization "NL Actief" has published a similar document but especially focused on indoor sports centers: "Protocol for Responsible Physical Exercise – Branche: Fitness" [29]. This protocol contains a comprehensive list of precautionary measures and is intended to supplement the already imposed measures by the Dutch National Institute of Public Health and the Environment (RIVM) and the protocol by the NOC*NSF. It explicitly focuses on those physical activities that do not involve physical contact between persons. The precautionary measures are provided in four categories: for (i) operators, (ii) visitors, (iii) employees and (iv) suppliers. The measures should be applied on top of the basic measures that hold for all people in the Netherlands such as keeping the 1.5 m physical distance at all times, sneezing and coughing in one's elbow cavity and using paper towels, staying at home after you have tested positive for the virus, staying at home when showing at least one of the typical symptoms, staying at 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]:

- For operators: controlling the maximum number of visitors and routing inside the buildings, providing masks, gloves, glasses and regular disinfection of payment terminal keyboards, door handles and other surfaces, appointing a COVID-19 supervisor and instructions for employees including pointing visitors to unsafe behavior;
- For visitors: required reservation of a time slot, only visiting with members from the same household, avoiding public transport, using the sanitary facilities at home instead of in the center, only starting exercise after having washed the hands and leaving the center immediately after having finalized your physical activity;
- For employees: working at home as much as possible, regular washing of the hands before every meal, after use of the sanitary

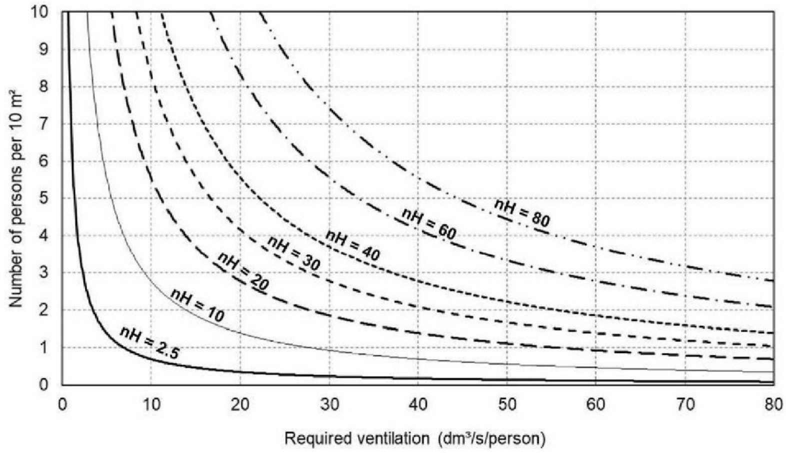

Fig. 4. Nomogram of number of persons per 10 m^2 as a function of required ventilation rate per person, with the product of air change rate per hour (n) and room height (H) as a parameter (nH with unit m/h).

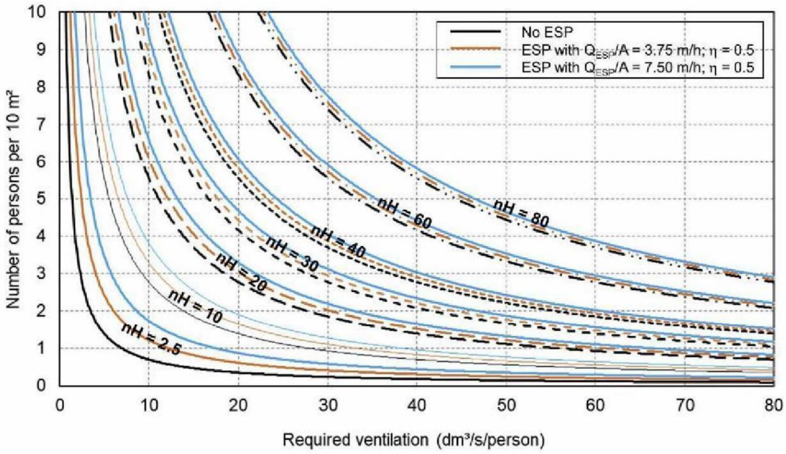

Fig. 5. Nomogram of number of persons per 10 m^2 as a function of required ventilation rate per person, with the product of air change rate per hour (n) and room height (H) and the ESP characteristics as parameters (unit of nH is m/h).

facilities, after having traveled with public transport, and after cleaning, not sharing tools with other employees, keeping personal tools clean and disinfected;

- For suppliers: announcing arrival 15 min in advance, wearing gloves, announcing where the goods will be placed, giving preference to delivery at the doorstep.

The protocol also advises a gradual re-opening in three phases, from a first and limited opening that should have started on 15 March 2020 to a full regular opening including catering facilities afterwards.

In spite of this document, the Dutch government decided on 6 May 2020 that indoor sports centers would have to remain closed until 1 September 2020. The main argument provided for this decision by the Ministry of Health, Welfare and Sports pointed to the issue that was not addressed in the Protocol document: concern about the increased amount of aerosols expired during physical exercise that can remain in the air for a long duration [30]. They also raised the concern that it was yet insufficiently clear whether asymptomatic SARS-CoV-2 carriers also expire such aerosols. Given the current status of knowledge on aerosol expiration and on SARS-CoV-2, both concerns seem justified. Indeed, there is evidence that deep exhalation (as with physical exercise) produces more aerosols [17,31], there are indications of SARS-CoV-2 infection in 12 fitness dance classes in South Korea [32] and recent studies do suggest that asymptomatic carriers can transfer the SARS-CoV-2 virus [33,34].

To the best of our knowledge, there are only a few studies that provide some indirect indication of how physical exercise influences the emission of respiratory droplets. Johnson and Morawska [17] found that deep exhalation resulted in a 4- to 6-fold increase in aerosol concentration and rapid inhalation produced a further 2- to 3-fold increase in concentration. In contrast, rapid exhalation had little effect on the measured concentration. Almstrand et al. [31] analyzed the effect of airway opening on the production of exhaled particles. Ten healthy test subjects were asked to perform different breathing maneuvers in which the initial lung volume preceding an inhalation to total lung capacity was varied between functional residual capacity (FRC – the volume of air in the lungs at the end of passive expiration) and residual volume (RV – the volume of air in the lungs after full exhalation). They measured exhaled particles in the size range 0.30–2.0 μm. The number of exhaled particles demonstrated a 2- to 18-fold increase after exhalations to RV compared with exhalations where no airway closure was shown [31]. However, both studies were performed with persons not conducting physical exercise, therefore more research is needed on whether and to what extent physical exercise can further increase the generation of aerosols.

Considering the contents of the protocol [29], the aforementioned studies on increased aerosol production by deep exhalation and rapid inhalation [17,31], the indication of infection in the fitness dance classes [32] and the aforementioned studies on virus viability in small aerosols that can remain in the air for hours [11–15], it would be judicious to apply additional precautionary measures to handle the potential surplus of aerosols produced by breathing during physical exercise in indoor sports centers. While the study [32] suggested that vigorous exercise in confined spaces should be minimized during outbreaks, the present authors do not necessarily share that opinion, because many other parameters are involved, including those mentioned in the next section, that have received relatively little attention in most SARS-CoV-2 publications so far.

3. Towards a certificate of equivalence with additional measures

3.1. High-intensity building ventilation

Building or room ventilation can be defined as "the process by which 'clean' air (normally outdoor air) is intentionally provided to a space and stale air is removed" [35]. Several authoritative books and extensive reviews have been provided on the topic in the past decades (e.g. Refs. [36–39]). Ventilation can be driven by mechanical systems (mechanical ventilation) or by natural forces such as wind and buoyancy (natural ventilation) or a combination of both. Some mechanical systems employ recirculation of heated or cooled air for the purpose of energy conservation. Strictly, according to the above-mentioned AIVC definition, recirculated air cannot be labeled as ventilation. In this technical note, we strictly follow the definition that ventilation air is outdoor clean air free of infectious aerosols. In its simplest case, high-intensity natural ventilation consists of opening windows and doors in opposite facades (if weather allows). Two main categories of building ventilation are displacement ventilation and mixing ventilation. In displacement ventilation, the outdoor air is generally supplied at a low velocity from diffusers near the floor level and extracted above the occupied zone, near or at the ceiling (Fig. 2a). In mixing ventilation, the outdoor air is supplied at a high velocity outside the occupied zone, such as near or at the ceiling, and is mixed with the stale indoor air (Fig. 2b), with the intention to dilute the concentrations of e.g. aerosols, after which part of this mixed air is extracted out of the room. Displacement ventilation generally leads to lower aerosol concentrations in the occupied zone and an overall better ventilation efficiency than mixing ventilation, but locating diffusors and ducts near the floor is not always feasible. Mixing ventilation is easier to implement with diffusors and ducts near the ceiling but generally leads to more evenly distributed and overall higher aerosol concentrations in the enclosure. To our knowledge, the vast majority of indoor sports centers are equipped with mixing ventilation systems, but in view of reducing infection risk, the future design of such centers could benefit from displacement ventilation systems if sufficient buoyancy forces will act to generate upward movement of the air.

Given the low inertia of the aerosols, after expiration, their movement in the enclosure will rapidly be determined by the indoor airflow patterns. These patterns can be very complex as demonstrated by many earlier studies [40–48]. Persons are sources of heat, vapor and CO_2. Not only the expired air and aerosols will therefore be exposed to the resulting upward buoyancy forces, but also a – mainly – thermal convective plume is present around people that causes a clear upward airflow near their body [49]. The movement of people, and finally the ventilation system itself, also contribute to the complexity of the airflow patterns in enclosures.

Li et al. [50] extensively reviewed studies on the role of ventilation in the airborne transmission of infectious agents in buildings. They concluded that there is clear evidence of an association between ventilation, air movement in buildings and the transmission/spread of infectious diseases such as influenza and SARS. However, they also indicated that there was insufficient data to specify and quantify the minimum ventilation requirements in hospitals, schools, offices and other buildings to avoid the spread of these and other infectious diseases via the airborne route. Indeed, ventilation implies air movement and also aerosol movement inside the building, and in some cases the ventilation system uses recirculation of part of the exhausted air back to the inside, which, in case of infectious diseases, is undesirable [51]. Therefore, only high-intensity ventilation without recirculation should be applied in this type of pandemic in order to effectively and quickly remove aerosols and keep indoor aerosol concentrations as low as possible. If recirculation is applied, the recirculated air should be treated so that infectious aerosols are physically removed and/or pathogens are inactivated, for example by UV germicidal irradiation.

Ai and Melikov [52] reviewed studies on the airborne spread of expiratory droplet nuclei between the occupants of indoor environments, with specific focus on the spread of droplet nuclei from mouth/nose to mouth/nose for non-specific diseases. They stressed the importance of indoor airflow patterns and indicated that future research is needed in three specific areas: the importance of the direction of indoor airflow patterns, the dynamics of airborne transmission and the application of CFD simulations.

In most countries world-wide, building ventilation is mandatory by law, as an essential requirement for health and comfort in buildings. In the Netherlands, the minimum requirements for the ventilation of buildings are prescribed by the Building Code ("Bouwbesluit") published in 2012, and last amended in 2020 [53]. The minimum ventilation flow rates in terms of provision of fresh air for different types of utility buildings are given in Table 1. A distinction is made between new buildings and existing buildings. In 2008, the Dutch Guidebook for Sports Accommodations was published [54] and in 2014 specific guidelines for sports facilities for people with disabilities were provided [55]. These guidelines stipulate a minimum ventilation flow rate of 11.1 dm^3/s per exercising person for sports halls, which is 70% above the minimum required value in the Dutch Building Code for new buildings and even 3.2 times higher for existing buildings. These higher values are probably intended to try to take into account the higher heat, vapor, CO_2 and aerosol emission by people during physical exercise. In addition, these specific guidelines for indoor sports accommodations [54,55] suggest a total of 6 air changes per hour (ACH) for fitness spaces (i.e. the volume of air in the room is replaced by clean air 6 times per hour), while the ACH for aerobics and martial arts spaces should be 8 h^{-1} and for indoor cycling 10 h^{-1}. In view of the COVID-19 pandemic, ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, has acknowledged the potential for aerosol transmission of SARS-CoV-2 and states that facilities of all types should follow, as a minimum, the latest published standards and guidelines and good engineering practice [56]. ASHRAE Standard 62.1 specifies ventilation rates for acceptable indoor air quality [57]. For gyms, health clubs, aerobics rooms, and weight rooms, the minimum outdoor airflow rate is 10 dm^3/s/person. This is higher than specified for most retail (3.8 dm^3/s/person, except for beauty and nail salons where 10 dm^3/s/person is required) and educational buildings (3.8–5 dm^3/s/person). Note that the ASRHAE value for gyms aligns well with the 11.1 dm^3/s from the Dutch guidelines [55].

3.2. Filtering

Technological solutions exist for removing moderate to large fractions of aerosols from airstreams inside buildings. These systems can be installed either in the ducts of the HVAC (Heating, Ventilation and Air-Conditioning) system or freely inside the room itself. In both cases, they will need to provide sufficiently high clean air delivery rates. In the former case, they should be able to handle the high volume flow rates through the ducts, while in the latter, they should be able to handle high enough flow rates in balance with the room ventilation flow rates. A first option are HEPA filters (high-efficiency particulate absorbing or high-efficiency particulate arrestance). HEPA filtering can be very effective because these filters remove at least 99.95% of the particles with diameter 0.3 μm and larger fractions of the other sizes. The initial cost is relatively low but the operational costs are high, as the flow resistance of these filters is very high and therefore a lot of energy is required to overcome the large pressure drop over these filters that is unavoidably associated with the large flow rates. HEPA filters are used in clean rooms and some hospital operating theaters, but their future large-scale application for indoor sports centers might be hampered by the associated energy costs. As an alternative, electrostatic precipitators (ESPs) or similar devices can be considered. An ESP is a filtration device where the air is forced to flow through a largely open box by a small industrial fan and where the solid or liquid particles are electrically charged and collected on a generally grounded plate inside the device [58] (Fig. 3). The initial cost of an ESP can be relatively high but the operational cost is low due to low energy consumption. However, the efficiency is generally also lower than that of HEPA filters. On-site measurements on a particular commercially available moderate-size ESP (Fig. 3b) have indicated an efficiency of 70% for PM10 and about 45% for PM2.5 [59], which is nevertheless still considerable given that when the ESP is mounted inside the room itself and – depending on the ventilation rate – the same air could be handled this way multiple times yielding higher efficiencies.

3.3. Masks

A distinction is made between surgical masks and respirator masks. A surgical mask or face mask is a loose-fitting, disposable device intended to block splashes and large droplets, and it can also filter out some aerosols. A respirator on the other hand should provide a close facial fit and a very efficient filtration of also the aerosols.

Chen and [redacted] [60] tested the collection efficiency of surgical masks and respirators with aerosol-size spectrometers. They found that surgical masks with only a shell with a coarse pore structure passed 80% of the aerosols below 1 μm with almost no dependency on the flow. On the other hand, surgical masks including specific filter material allowed only 25% passage at 5 L/min to 70% at 100 L/min [60]. He et al. [61] found that surgical masks sealed to a manikin passed less than 20% of aerosols below 1 μm at flow rates of 15–85 L/min; without sealing, the penetration was higher, up to 45%. Van der Sande et al. [62] analyzed the transmission reduction potential provided by personal respirators, surgical masks and home-made masks when worn during a variety of activities by a small number of healthy volunteers and a simulated patient. They found that all types of masks did reduce aerosol exposure relatively stably over time and unaffected by duration of wear and type of activity, but with a high degree of variation by type of mask [62]. Unsurprisingly, personal respirators were most efficient, followed by surgical masks, followed by home-made masks.

The use of masks is fairly well accepted in many countries in Asia, where often wearing a surgical mask when you are ill is considered as a token of respect towards others. However, in many other countries, the use of masks has been an issue of debate, although currently governments are implementing the mandatory use of surgical or home-made masks at an increasing pace [63–70]. Indeed, while initially in several countries, scientists, political advisors and politicians have made some radical statements pro and con the usefulness of wearing of masks by the public in various situations, an overview of the recent peer-reviewed scientific literature provides a more moderate image (e.g. Ref. [60–62]). There are indeed clear pros and cons concerning masks for the public. First, many will agree that the best quality masks should be provided to our healthcare facilities and only after abundant stock there, could one consider distribution among the public The FDA [69] explicitly states that the Centers for Disease Control and Prevention (CDC) do not recommend the general public to wear N95 respirators to protect themselves from respiratory diseases such as COVID-19. Instead, these are considered critical supplies that must continue to be reserved for health care workers and other medical first responders. Second, facial masks could provide a false sense of security, as people could put them on leaving leakages, touching the outside of the masks, etc., but there is no evidence that this could be detrimental for the general public [70]. The masks also do not cover the eyes that could also be receptors of the virus. Third, wearing masks can have a negative psychological impact on people by reducing the level of human interaction [71]. Conversely, it has been demonstrated that facial masks, even of the most primitive type, can provide some protection (e.g. Ref. [62]). Using such masks in turn can allow people to exercise more freedom in the society, including the use of public transportation and gathering in public places, and could assist in restarting economic activity. In terms of indoor sports centers, the future development of sports face masks is not unlikely. These should provide a compromise between droplet and aerosol collection efficiency, large respiration flow rates and resistance to sweat.

3.4. Certificate

Ideally, one would want to know the specific infection risk for a given activity in a given building as a function of occupation, ventilation settings and other relevant parameters, and decide on re-opening based on risk assessment. However, many aspects of SARS-CoV-2 are still unknown and might remain unknown for a considerable time to come. It could take years before knowledge will be available on which viral dose during which time is an infection risk for a given person performing a given activity. Nevertheless, governments are under pressure from the economy and the public to resume – at least gradually – economic and leisure activity. This should be done as safely as possible. Therefore, in spite of the many unknowns and in view of safely re-opening indoor sports centers, government authorities could consider the implementation of a certificate of equivalence in terms of aerosol exposure. This certificate would be obtained if, apart from the measures outlined in documents such as [28,29], a combination of some of the three above-mentioned measures (high-intensity ventilation, filtering, facial masks) can demonstrably and quantifiably lead to a concentration of aerosols that is equivalent in terms of exposure (including concentration and inhalation) to the exposure occurring in other facilities that are allowed to re-open earlier, such as shops, restaurants and bars, taking into account the maximum allowed number of people per floor area.

A first substantial step towards equivalence could be high-intensity ventilation in order to compensate for the increased aerosol generation and the increased aerosol inhalation by physical exercise. A small calculation example is presented, in which we do not consider specific government-imposed limits in terms of maximum number of persons per floor area per type of building – as some of these numbers are being adjusted frequently. Consider an indoor sports center with a total rectangular floor area of $50 \times 20\ m^2 = 1000\ m^2$. Physical distancing of 1.5 m will generally not be an issue as many of the exercise machines already consume considerable space. We assume that the center, in setting up the machines, very strictly adheres to the required physical distancing between exercising visitors of 1.5 m. This implies that around every machine a $3 \times 3\ m^2$ perimeter is indicated that is a "no go" zone for visitors using other machines. In this situation, a maximum of 96 visitors (assuming no corridor space) can be present at the same time. This corresponds to about 1 person per $10\ m^2$. Table 2 provides the resulting minimum ventilation flow rates for this center and for a shop of the same floor area as provided by the Dutch Building Code. For the sports center, also the larger ventilation flow rates recommended by the Dutch Sports Guidelines [54,55] are listed. Table 2 shows that for the most critical situation of new buildings, the ACH of a fitness area as recommended by Ref. [54,55] is about 20 times larger than the minimum for a shop of equal floor area and the same maximum number of 100 persons present as required by the Dutch Building Code. Note however that the ventilation rates from the building code are minimum requirements and that actual ventilation rates in e.g. supermarkets are probably designed and set to be higher than those in the Building Code.

Equivalence in terms of aerosol exposure between the indoor sports center and the shop could be achieved by balancing a number of factors. Some main factors that can be controlled and engaged to reduce aerosol concentrations are the higher ventilation rates, limiting the number of persons in the indoor sports center well below the maximum occupation and limiting the intensity of the exercise. On the other hand, factors contributing to aerosol exposure are the higher aerosol production by exercising people and the possibility that aerosols can be inhaled deeper into the respiratory system by exercising persons. The studies by Johnson and Morawska [17] and Almstrand et al. [31] provide a first indication of the aerosol production during deep inhalation and exhalation, where an increase up to a factor 18 has been found between functional residual capacity and residual volume. However, at present there is insufficient information in the scientific literature to argue that this 18-fold increase in aerosol production could be balanced by a 20-fold increase in ventilation flow rates. Indeed, both studies [17,31] were performed with persons not performing physical exercise and it is possible that physical exercise increases the aerosol production even further. Note also that even the best mixing ventilation systems will not provide perfect mixing and therefore provide non-uniform aerosol concentrations will occur in the room. Much more research is needed on each of these topics. But if this extra information would be available, it seems plausible that the ventilation flow rates could be augmented and the maximum allowed number of people and the intensity of the physical exercise could be reduced in such a way that they balance the higher aerosol exposure (production and inhalation) leading to a quantifiably equivalent situation between indoor sports centers and other spaces such as shops, restaurants and bars.

Key parameters in terms of ventilation are the floor area A, the room height H, the required ventilation flow rate per person (Q/N) with N the number of persons, the maximum allowed number of persons per unit floor area (N/A) and the air change rate per hour n. Eq. (1) represents the simplified mass balance in the room assuming a uniform concentration c in the room with volume V, a total aerosol production rate G and a clean air ventilation flow rate Q. Under steady-state conditions, it yields Q = G/c which can be rewritten as Eq. (2), where g is the aerosol production rate per person. Eq. (2) can be expanded into Eq. (3) that relates N/A to Q/N or to g/c.

$$V\frac{dc}{dt} = G - Qc \quad (1)$$

$$Q = nAH = \frac{G}{c} = \frac{Ng}{c} \quad (2)$$

$$\frac{N}{A} = nH\left(\frac{Q}{N}\right)^{-1} = nH\left(\frac{g}{c}\right)^{-1} \quad (3)$$

Based on Eq. (3), Fig. 4 presents a simple nomogram that provides N/A per 10 m^2 as a function of Q/N with the product of n and room height H as a parameter, with nH in unit m/h. Given the required N/A, the air change ratio per hour n and the room height H, the maximum number of persons per 10 m^2 can easily be determined.

A second step towards equivalence, possibly in combination with high-intensity ventilation, is the use of filters, which can be HEPA filters of ESPs. When part of the air exhausted from the room is handled (heated, cooled, dehumidified, filtered) and recirculated back into the room after handling, filtering will be necessary in the return duct and should have been completed before the air is re-injected into the room. Whether a filter system with HEPA filters or an ESP is installed inside the room itself and should work in addition to the clean air ventilation, its effect will depend on the efficiency and the capacity (m^3/h) of the filter system and the degree to which high-intensity ventilation is possible. At very high ventilation rates, the effect of the filter system might be limited. But if required, it could assist a less powerful ventilation system towards equivalence. This is shown in Fig. 5, which is an extension of Fig. 4 in which – as an example – an ESP with a capacity of 3750 m^3/h or 7500 m^3/h and an efficiency of 50% is installed in the room, assuming perfect mixing, i.e. a uniform aerosol concentration in the room. Fig. 5 is based on the mass balance in the room:

$$V\frac{dc}{dt} = G - Qc - Q_{ESP}\eta c \quad (4)$$

Where Q_{ESP} is the ESP flow rate and η the ESP efficiency. Under steady-state conditions, Eq. (4) can be used to extend Eq. (3) as follows:

$$\frac{N}{A} = nH\left(\frac{Q}{N}\right)^{-1}\left(1 + \frac{\eta}{nH}\frac{Q_{ESP}}{A}\right) \quad (5)$$

Fig. 5 suggests that for N/A of about 10 dm^3/s/person, installing an ESP with Q_{ESP} = 7500 m^3/h (Q_{ESP}/A = 7.5 m/h) would allow doubling the occupancy from 1 to 2 person per 10 m^2 while keeping the ventilation flow rate per person and thus the aerosol concentration constant. Note that Eq. (5) and Fig. 5 assume that the 50% ESP efficiency effectively applies to the potentially infectious aerosols generated inside the room, while also (non-infectious) aerosols can be brought from outside to inside by the ventilation system.

A third step towards equivalence could be the use of masks, although especially here more research and development is needed in view of masks that are both efficient and suitable for indoor physical exercise.

4. Discussion

An additional question in indoor sports centers is whether or not sweat can contribute to the transmission of infection. Ding et al. [72] found that SARS-CoV is present in sweat gland. There is potential for aerosolization of sweat, but the measures suggested to mitigate transmission from respiratory droplets and aerosols also apply to aerosolized sweat. If the virus is shed in sweat, probably the bigger concern is the contact route: people leaving behind sweat on machines, either high-touch areas of cardio machines or the seats and handles of weight machines and free weights/benches. This could be tackled by the guidelines in Ref. [29].

Mixing ventilation will not provide uniform aerosol concentrations in the entire volume of the room. This should be taken into account when implementing the certificate of equivalence. In view of this limitation, one could consider real-time monitoring of some environmental parameters at a few strategic locations in the sports center. These parameters could be aerosol concentrations or parameters that can be measured with less costly equipment and that could be used as indicators for aerosol concentrations, such as relative humidity and CO_2 concentration. This real-time monitoring could also be used to control both the settings of the ventilation and the potentially present ESPs.

More research is needed on the production of respiratory droplets and aerosols during physical exercise but also concerning the increased and deeper inhalation of aerosols during such exercise. The latter could be studied with advanced computational fluid dynamics (CFD) models [73–76].

For the three indoor sports categories covered in this technical note (cardio training; workout training with weights; non-contact group exercises in classes), if the outdoor space is available and if weather allows, these could partially be restarted outside. In such cases, it is advised to position the equipment and the participants as much as possible in rows perpendicular to the wind direction, so that they are not downwind and directly exposed to exhaled droplets and aerosols of other participants.

This technical note did not address contact sports. Physical distancing is clearly not an option here so the only viable route remaining might be testing and contact tracing followed by quarantining if necessary, as done in the German football competition that restarted on 16 May 2020.

5. Closing

COVID-19 is not the first and likely also not the last pandemic to rage around the globe and to disturb human life and activity world-wide. While in most countries, supermarkets have remained open, due to the COVID-19 situation, authorities have ordered many other shops, restaurants, bars, music theaters and indoor sports centers to be closed. As part of COVID-19 (semi)lock-down exit strategies, many government authorities are now (May-June 2020) allowing a gradual re-opening, where sometimes indoor sport centers are last in line to be permitted to re-open. This technical note discusses the challenges in safely re-opening these facilities and the measures already suggested by others to partly tackle these challenges. It also elaborates three potential additional measures: high-intensity building ventilation, filtering and face masks. These measures should be applied on top of the existing basic measures imposed by the government and the indoor sports school branche organizations. Of the additional measures, high-intensity building ventilation is considered as the most straightforward measure. However, large ventilation flow rates also require large energy consumption for heating, cooling and/or (de)humidifying of the clean intake air, which in turn might necessitate heat exchangers to be installed. Certainly if the capacity of the existing ventilation system is limited, direct filtering of the indoor air could be attempted by HEPA filters or electrostatic precipitators (ESPs). Finally, facial masks could be an option. Although in many countries the use of masks has been an issue of debate, governments are now implementing the mandatory use of surgical or home-made masks at an increasing pace. However, masks that are both efficient and suitable for physical exercise might require considerable additional research and development. Based on the adoption of some of these three additional measures, this technical note suggests the concept of a quantifiable certificate of equivalence that could allow indoor sports centers with such a certificate to re-open more safely and more rapidly. This technical note is also an attempt 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. The complexity of SARS-CoV-2 and its behavior in the indoor environment indicates that fighting crises such as the COVID-19 situation and limiting economic damage requires increased collaboration and research by virologists, epidemiologists, microbiologists, aerosol scientists, building physicists, building services engineers and sports scientists.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] European Centre for Disease Prevention and Control, COVID-19 Situation update 19 May 2020, dataset collected 6:00-10:00 CET, Retrieved on, https://www.ecdc.europa.eu/en/covid-19-pandemic, 2020. (Accessed 31 May 2020).

[2] J. Chan, S. Yuan, K. Kok, et al., A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster, Lancet 395 (2020) 514–523.

[3] Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N. Engl. J. Med. 382: 1199-1207.

[4] C. Huang, Y. Wang, X. Li, et al., Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China, Lancet 395 (2020) 497–506.

[5] R.M. Burke, C.M. Midgley, A. Dratch, et al., Active monitoring of persons exposed to patients with confirmed COVID-19 — United States, January–February 2020, MMWR (Morb. Mortal. Wkly. Rep.) 69 (9) (2020) 245–246.

[6] World Health Organization, Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19) 16-24 February 2020 [Internet], World Health Organization, Geneva, 2020. Available from: https://www.who.int/docs/default- source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf.

[7] World Health Organization, Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendations, Sci. Brief 29 (2020). March 2020. [Internet]. Geneva: World Health Organization; 2020 Available from: www.who.int/news-room/commentaries/detail/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations.

[8] X. Xie, Y. Li, A.T.Y. Chwang, et al., How far droplets can move in indoor environments - revisiting the Wells evaporation falling curve, Indoor Air 17 (3) (2007) 211–225.

[9] L. Bourouiba, E. Dehandschoewercker, J.W.M. Bush, Violent expiratory events: on coughing and sneezing, J. Fluid Mech. 745 (2014) 537–563.

[10] J. Wie, Y. Li, Enhanced spread of expiratory droplets by turbulence in a cough jet, Build. Environ. 93 (2015) 86–96.

[11] Y. Liu, Z. Ning, Yu Chen, et al., Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals, Nature (2020) in press, https://www.nature.com/articles/s41586-020-2271-3. (Accessed 13 May 2020).

[12] N. van Doremalen, D.H. Morris, M.G. Holbrook, et al., Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1, New Engl. J. Med. 382 (2020) 1564–1567.

[13] L. Morawska, J. Cao, Airborne transmission of SARS-CoV-2: the world should face the reality, Environ. Int. 139 (2020) 105730, https://doi.org/10.1016/j.envint.2020.105730.

[14] M. Hadei, P.K. Hopke, A. Jonidi, A. Shahsavani, A letter about the airborne transmission of SARS-CoV-2 based on the current evidence, Aerosol Air Qual. Res. 20 (2020) 991, https://doi.org/10.4209/aaqr.2020.04.0158, 914.

[15] S. Asadi, N. Bouvier, A.S. Wexler, W.D. Ristenpart, The coronavirus pandemic and aerosols: does COVID-19 transmit via expiratory particles? Aerosol. Sci. Technol. 54 (6) (2020) 635–638.

[16] L. Morawska, G.R. Johnson, Z.D. Ristovski, et al., Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities, J. Aerosol Sci. 40 (3) (2009) 256–269.

[17] G.R. Johnson, L. Morawska, The mechanism of breath aerosol formation, J. Aerosol Med. Pulm. Drug Deliv. 22 (3) (2009) 229–237.

[18] G.R. Johnson, L. Morawska, Z.D. Ristovski, et al., Modality of human expired aerosol size distributions, J. Aerosol Sci. 42 (12) (2011) 839–851.

[19] Z.Y. Han, W.G. Weng, Q.Y. Huang, Characterizations of particle size distribution of the droplets exhaled by sneeze, J. R. Soc. Interface 10 (88) (2013) 20130560.

[20] S. Asadi, A.S. Wexler, C.D. Cappa, et al., Aerosol emission and superemission during human speech increase with voice loudness, Sci. Rep. 9 (1) (2019) 2348.

[21] R. Mitttal, R. Ni, J.H. Seo, The flow physics of COVID-19, J. Fluid Mech. 894 (2020). Article nr. F2.

[22] United Nations, United Nations sustainable development Goals. https://www.un.org/sustainabledevelopment/sustainable-development-goals/. (Accessed 10 May 2020).

[23] F.J.G. Van Der Merwe, British and South African soccer on the western front during World War I, South Afr. J. Res. Sport, Phys. Educ. Recreat. 35 (2) (2013) 197–209.

[24] A. Waquet, Sport in the trenches: the new deal for masculinity in France, Int. J. Hist. Sport 28 (3–4) (2011) 331–350.

[25] S.M. Nyenhuis, J. Greiwe, J.S. Zeiger, et al., Exercise and Fitness in the age of social distancing during the COVID-19 Pandemic, J. Allergy Clin. Immunol.: In Pract. (2020), https://doi.org/10.1016/j.jaip.2020.04.039. Epub ahead of print.

[26] P. Chen, L. Mao, G.P. Nassis, et al., Coronavirus disease (COVID-19): the need to maintain regular physical activity while taking precautions, J. Sport Health Sci. 9 (2) (2020) 103–104.

[27] G.J. Rubin, S. Wessely, The psychological effects of quarantining a city, Br. Med. J. 368 (2020) m313.

[28] NOC*NSF, Protocol responsible physical exercise (in Dutch), Retrieved on, https://nocnsf.nl/media/2669/nocnsf_protocol_verantwoord-sporten-v3.pdf, 2020. (Accessed 10 May 2020).

[29] NL Actief, Protocol responsible physical exercise – Branche: fitness (in Dutch). Concept version, Retrieved on, www.nlactief.nl, 2020. (Accessed 8 May 2020).

[30] D. Metselaar, Indoor sports centers surprised by longer closure (in Dutch), 7 May 2020, https://www.nrc.nl/nieuws/2020/05/07/we-staan-in-hetzelfde-rijtje-als-de-seksclubs-a3999041, 2020. (Accessed 13 May 2020).

[31] A.C. Almstrand, B. Bake, E.L. Ljungström, et al., Effect of airway opening on production of exhaled particles, J. Appl. Physiol. 108 (2010) 584–588.

[32] S. Jang, S.H. Han, J.Y. Rhee, Cluster of coronavirus disease associated with fitness dance classes, South Korea, Emerg. Infect. Dis. 268 (2020), https://doi.org/10.3201/eid2608.200633. Research Letter.
[33] F. Ye, S. Xu, Z. Rong, et al., Delivery of infection from asymptomatic carriers of COVID-19 in a familial cluster, Int. J. Infect. Dis. 94 (2020) 133–138.
[34] C. Rothe, M. Schunk, P. Sothmann, et al., Transmission of 2019-ncov infection from an asymptomatic contact in Germany, N. Engl. J. Med. 382 (10) (2020) 970–971.
[35] AIVC, Air Infiltration and Ventilation Centre, International Energy Agency, 2020. Retrieved on 11 May 2020: https://www.aivc.org/resources/faqs/what-ventilation.
[36] D. Etheridge, M. Sandberg, Building Ventilation: Theory and Measurements, Wiley, 1996. -13: 978-0471960874.
[37] H. Awbi, Ventilation of Buildings, Spon Press, 2003.
[38] Q. Chen, Ventilation performance prediction for buildings: a method overview and recent applications, Build. Environ. 44 (4) (2009) 848–858.
[39] B. Blocken, 50 years of computational wind engineering: past, present and future, J. Wind Eng. Ind. Aerod. 129 (2014) 69–102.
[40] P.V. Nielsen, Flow in Air Conditioned Rooms. English Translation and Revision of PhD Thesis, Technical University of Denmark, Copenhagen, 1976.
[41] P.V. Nielsen, Computational fluid dynamics and room air movement, Indoor Air 14 (Suppl. 7) (2004) 134–143.
[42] Q. Chen, Prediction of room air motion by Reynolds-stress models, Build. Environ. 31 (1996) 233–244.
[43] Q. Chen, N.T. Chao, Comparing turbulence models for buoyant plume and displacement ventilation simulation, Indoor Built Environ. 6 (1997) 140–149.
[44] P. Karava, T. Stathopoulos, A.K. Athienitis, Airflow assessment in cross-ventilated buildings with operable facade elements, Build. Environ. 46 (2011) 266–279.
[45] S. Kato, S. Murakami, A. Mochida, S. Akabayashi, Y. Tominaga, Velocity-pressure field of cross ventilation with open windows analyzed by wind tunnel and numerical simulation, J. Wind Eng. Ind. Aerod. 44 (1992) 2575–2586.
[46] T. van Hooff, B. Blocken, Coupled urban wind flow and indoor natural ventilation modelling on a high resolution grid: a case study for the Amsterdam ArenA stadium, Environ. Model. Software 25 (1) (2010) 51–65.
[47] R. Ramponi, B. Blocken, CFD simulation of cross-ventilation for a generic isolated building: impact of computational parameters, Build. Environ. 53 (2012) 34–48.
[48] B. Blocken, Computational Fluid Dynamics for Urban Physics: importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations, Build. Environ. 91 (2015) 219–245.
[49] B.A. Craven, G.S. Settles, A computational and experimental investigation of the human thermal plume, J. Fluids Eng. Trans. ASME 128 (6) (2006) 1251–1258.
[50] Y. Li, G.M. Leung, J.W. Tang, et al., Role of ventilation in airborne transmission of infectious agents in the built environment – a multidisciplinary systematic review, Indoor Air 17 (2007) 2–18.
[51] REHVA, How to operate and use building services in order to prevent the spread of the coronavirus disease (COVID-19) virus (SARS-CoV-2) in workplaces. COVID-19 Guidance Document, 3 April 2020aa. https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_ver2_20200403_1.pdf, 2020. (Accessed 19 May 2020).
[52] Z.T. Ai, A.K. Melikov, Airborne spread of expiratory droplet nuclei between the occupants of indoor environments: a review, Indoor Air 28 (2018) 500–524.
[53] Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, Building code. Bouwbesluit online (in Dutch), Retrieved on 11 May 2020, https://rijksoverheid.bouwbesluit.com/Inhoud/docs/wet/bb2012/hfd3, 2012.
[54] J.P.E. Ariëns, T.A. Joosten, W. Schriemer, et al., Guidebook Sports Accommodations (In Dutch). Handboek Sportaccommodaties. ISA Sport, NOC*NSF, Arko Sports Media BV, 2008.
[55] Stichting Onbeperkt Sportief, Guidelines for Access Indoor Sports Accommodations (In Dutch), Richtlijnen Toegankelijkheid Indoor Sportaccommodaties, 2014.
[56] ASHRAE, Pandemic COVID-19 and airborne transmission. Environmental health committee (EHC) emerging issue brief, Retrieved on, https://www.ashrae.org/file%20library/technical%20resources/covid-19/eiband-airbornetransmission.pdf, 2020. (Accessed 13 May 2020).
[57] ASHRAE, Ventilation for acceptable indoor air quality, ANSI/ASHRAE Standard 62 (2019) 1, 2019.
[58] IUPAC, Compendium of chemical terminology, in: (the "Gold Book") (1997). Online Corrected Version: (2006–) "electrostatic Precipitator", second ed., 2006, https://doi.org/10.1351/goldbook.E02028.
[59] R.P.M. Vervoort, T. van Hooff, B. Blocken, Reduction of particulate matter concentrations by local removal in a building courtyard: case study for the Delhi American Embassy School, Sci. Total Environ. 686 (2019) 657–680.
[60] C.C. Chen, K. [redacted], Aerosol penetration through surgical masks, Am. J. Infect. Contr. 20 (1992) 177–184.
[61] X. He, T. Reponen, R.T. McKay, et al., Effect of particle size on the performance of an N95 filtering facepiece respirator and a surgical mask at various breathing conditions, Aerosol. Sci. Technol. 47 (11) (2013) 1180–1187.
[62] M. Van der Sande, P. Teunis, R. Sabel, Professional and home-made face masks reduce exposure to respiratory infections among the general population, PloS One 3 (7) (2008), e2618.
[63] J. Zhai, Facial mask: a necessity to beat COVID-19: the review of an air quality and ventilation expert, Build. Environ. 175 (2020) 106827.
[64] C. Dwyer, A. Aubrey, CDC now recommends Americans consider wearing cloth face coverings in public, Available at: https://www.npr.org/sections/coronavirus-live-updates/2020/04/03/826219824/president-trump-says-cdc-now-recommends-americans-wear-cloth-masksin- public, 2020.
[65] N.X. Elegant, Coronavirus outbreak changes US's mind on everyone wearing face masks, Fortune (2020). Available at: https://fortune.com/2020/04/03/coronavirus-face-mask-cdc/.
[66] Feng S, Shen C, Xia N, et al Rational use of face masks in the covid-19 pandemic. Lancet Respir. Med. Available at: https://www.thelancet.com/journals/lanres/article/PIIS2213-2600(20)30134-X/fulltext.
[67] The Bulletin, Coronavirus in Belgium: what are the rules on wearing masks? 9 May 2020. https://www.thebulletin.be/coronavirus-belgium-should-we-be-wearing-masks-0, 2020.
[68] DutchNews nl, Dutch start easing coronavirus restrictions, face masks a must on public transport. 6 May 2020. https://www.dutchnews.nl/news/2020/05/dutch-start-easing-coronavirus-restrictions-face-masks-a-must-on-public-transport/, 2020.
[69] FDA, Personal protective equipment for infection control, N95 respirators and surgical masks (face masks), Retreived on 12 May 2020, www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-and-surgical-masks-face-masks, 2020.
[70] J. Howard, A. Huang, Z. Li, et al., Face masks against COVID-19: an evidence review, Preprints 2020 (2020) 2020040203, https://doi.org/10.20944/preprints202004.0203.v1.
[71] C.K.M. Wong, B.H.K. Yip, S. Mercer, et al., Effect of facemasks on empathy and relational continuity: a randomised controlled trial in primary care, BCM Family Pract. 14 (2013) 200. PMID: 24364989.
[72] Y. Ding, L. He, Q. Zhang, et al., Organ distribution of severe acute respiratory syndrome (SARS) associated coronavirus (SARS-CoV) in SARS patients: implications for pathogenesis and virus transmission pathways, J. Pathol. 203 (2) (2004) 622–630.
[73] M.H. Tawhai, P.J. Hunter, J. Tschirren, et al., CT-based geometry analysis and finite element models of the human and ovine bronchial tree, J. Appl. Physiol. 97 (6) (2004) 2310–2321.
[74] Y. Yin, J. Choi, E.A. Hoffman, et al., A multiscale MDCT image-based breathing lung model with time-varying regional ventilation, J. Comput. Phys. 244 (2013) 168–192.
[75] Y. Yin, J. Choi, E.A. Hoffman, et al., Simulation of pulmonary air flow with a subject-specific boundary condition, J. Biomech. 43 (11) (2010) 2159–2163.
[76] K.S. Burrowes, T. Doel, C. Brightling, Computational modeling of the obstructive lung diseases asthma and COPD, J. Transl. Med. 12 (2014) S5.

3) Wetenschappelijk artikel over ventilatie en luchtreiniging in een fitnesscentrum (Publicatiedatum: 04/02/2021)

Deze publicatie toont aan, met behulp van metingen en berekeningen, hoezeer ventilatie en luchtreiniging de aerosolenconcentraties in een sportschool kunnen reduceren. Dat een deel van dit werk met berekeningen is uitgevoerd i.p.v. met metingen en daarom minder betrouwbaar zou zijn, **is geen valabel punt van kritiek**. Als dat wel zo was, dan was deze publicatie niet door de peer review geraakt in het Tijdschrift Building & Environment, wat een toptijdschrift is (Tier 1, gerangschikt als nr. 4 op 134 tijdschriften in "Civil Engineering"). Deze berekeningen zijn een klein deel van de publicatie, het zijn elementaire berekeningen in het vakgebied ventilatie van gebouwen die al vele decennia worden toegepast. Bovendien zijn de berekeningen geijkt op basis van de metingen.

De publicatie toont aan dat ventilatie en luchtreiniging samen, met een totaal van ongeveer 6 luchtwisselingscycli per uur, de aerosolenconcentraties met 90 tot 95% kunnen reduceren.

De publicatie toont aan dat luchtreiniging, zoals toegepast in deze studie met deze sportschoolgeometrie, 50% efficiënter is dan het ventilatiesysteem.

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Ventilation and air cleaning to limit aerosol particle concentrations in a gym during the COVID-19 pandemic

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ABSTRACT

SARS-CoV-2 can spread by close contact through large droplet spray and indirect contact via contaminated objects. There is mounting evidence that it can also be transmitted by inhalation of infected saliva aerosol particles. These particles are generated when breathing, talking, laughing, coughing or sneezing. It can be assumed that aerosol particle concentrations should be kept low in order to minimize the potential risk of airborne virus transmission. This paper presents measurements of aerosol particle concentrations in a gym, where saliva aerosol production is pronounced. 35 test persons performed physical exercise and aerosol particle concentrations, CO_2 concentrations, air temperature and relative humidity were obtained in the room of 886 m^3. A separate test was used to discriminate between human endogenous and exogenous aerosol particles. Aerosol particle removal by mechanical ventilation and mobile air cleaning units was measured. The gym test showed that ventilation with air-change rate ACH = 2.2 h^{-1}, i.e. 4.5 times the minimum of the Dutch Building Code, was insufficient to stop the significant aerosol concentration rise over 30 min. Air cleaning alone with ACH = 1.39 h^{-1} had a similar effect as ventilation alone. Simplified mathematical models were engaged to provide further insight into ventilation, air cleaning and deposition. It was shown that combining the above-mentioned ventilation and air cleaning can reduce aerosol particle concentrations with 80 to 90% , depending on aerosol size. This combination of existing ventilation supplemented with air cleaning is energy efficient and can also be applied for other indoor environments.

1. Introduction

In the second week of 2021, the European Centre for Disease Prevention and Control reported 94,582,873 cases of SARS-CoV-2 including 2,036,713 deaths, world-wide [1]. It has been suggested that this virus can be transmitted by respiratory droplets and by contact routes [2–7]. Direct transmission can occur when infective droplets produced by activities such as talking, laughing, coughing or sneezing reach the mucosae (mouth and nose) or conjunctiva (eyes) of another person. Indirect or contact route transmission can occur via handrails, keyboard buttons and other objects, where virus is deposited after contact with an infected person. There is mounting evidence that the virus can also be transmitted by inhalation of saliva aerosol particles because the virus has been found in small aerosol particles that can remain in the air for hours, and it has been shown to maintain viability in such aerosols [8–12]. Therefore, precautionary measures should not only be applied for the direct transmission route and the contact route, but also for the airborne route.

Respiratory droplets are generated from the fluid lining of the respiratory tract during expiratory activities such as breathing, talking, laughing, coughing and sneezing [13–16]. A single sneeze can produce 10,000 droplets or more [17]. A cough can produce from 100 up to 1000

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droplets or more. Talking can produce about 50 droplets per second [18]. On an hourly or daily basis however, normal mouth breathing is assumed to generate more aerosol particles than coughing or sneezing because the latter are intermittent events [13,19–22].

Expired droplet sizes can range from about 0.1 μm to 1 mm [16]. Large droplets will generally settle rather quickly due to gravity and therefore can only contribute to virus transmission between individuals in close proximity. This is why "social distancing" has been introduced in countries around the world, although there is no strict consensus on the distance to be kept and the currently used 1.5 m, 1.8 m or 2 m distance is actually a compromise between avoiding large droplet spray and practical feasibility in keeping this distance in daily life. Small droplets however, and their residues or droplet nuclei after evaporation, can remain suspended in the air for a much longer time and could transfer SARS-CoV-2 over larger distances [16,23–25].

There is no clear consensus in the scientific literature on the diameter separating large droplets from small droplets or aerosol particles. Large droplets were initially defined as those with diameter larger than 100 μm by Wells [23]. In line with this definition, Hinds [26] defines aerosols as a suspension of solid or liquid particles in a gas with particle size from 0.001 to over 100 μm. Others however have labeled droplets larger than 5 μm [27,28] or 10 μm [29] as large droplets. Nicas et al. [30] suggested a particle with a diameter of a few tens of μm or larger to be a droplet. Xie et al. [25] revisited the Wells evaporation-falling curve and defined the critical droplet size as the diameter of a droplet that has completed evaporated at the time it hits the ground, falling from 2 m height. They found that a saline water droplet can have a critical diameter of about 30 μm to nearly 100 μm, depending on the drop ejection speed and the ambient temperature and relative humidity (RH). It is assumed that the consideration of different RH led to the different critical diameters from different studies [16,22,25].

Small droplets evaporate quickly to the size of droplet nuclei, which settle very slowly and can remain suspended in the air for a long time [30]. Nicas et al. [30] estimated that expired aerosol particles rapidly evaporate to a diameter slightly below half of the initial diameter if the concentration of non-volatile components is assumed to be 88 g/L. For a particle of 20 μm at RH = 30 and 70%, it would take only 0.17 s and 0.4 s, respectively, to evaporate to an equilibrium diameter of 10 μm [30]. Morawska et al. [31] stated that a 5 μm droplet of pure water evaporates in 0.8 s at 97% RH and a 3 μm droplet in less than 0.33 s. Holmgren et al. [32] found that the droplet diameter reduced by a factor 0.42 in 75% ambient RH and that evaporation is a very fast process, in line with Nicas et al. [30].

After expiration, the movement of the aerosol particles in the enclosure is initially influenced by the expiratory jet, which is a moist and turbulent buoyant gas cloud [25,33,34]. Evidently this jet is much less pronounced for breathing than for coughing and sneezing. After the influence of the expiratory jet, the indoor airflow patterns take over. Indoor airflow patterns can be very complex [35–43]. A person is also a source of heat and vapor and a – mainly thermal – convective plume is present around each person that yields a clear upward airflow near their body [22,44]. The movement of the aerosol particles is therefore determined by the interaction between the expiratory jet, the human thermal plume and other sources that affect the indoor airflow pattern, such as the ventilation system, thermal plumes from appliances and other heat sources, and the movement of people in the enclosure.

The droplet nuclei are submicrometer to approximately 10 μm in size and can remain suspended in the air for hours while each carrying multiple virions [16], and van Doremalen et al. [9] demonstrated an approximately 1-h viability half-life of the SARS-CoV-2 virus. Therefore, precautions against COVID-19 transmission should also address the potential aerosol or airborne transmission route. It can be assumed that aerosol particle concentrations in indoor environments should be kept low in order to minimize the potential risk of virus transmission. Respiratory aerosol particle concentration build-up in indoor environments can be pronounced, certainly when ventilation is insufficient.

The role of building ventilation in the airborne transmission of infectious agents was reviewed by Li et al. [45]. They concluded on the existence of an association between ventilation, air movement in buildings and the spread of infectious diseases such as influenza and SARS. However, they also indicated the lack of data to specify the minimum ventilation requirements in buildings such as hospitals, schools and offices to avoid the airborne spread of infectious diseases. Ai and Melikov [22] reviewed the airborne spread of expiratory droplet nuclei between the occupants of indoor environments. They highlighted the importance of indoor airflow patterns and stated the need for future research in three specific areas: the importance of the direction of indoor airflow patterns, the dynamics of airborne transmission and the application of computational fluid dynamics (CFD) simulations to obtain more detailed insights.

In the second half of the year 2020 during the COVID-19 pandemic, an increasingly large number of international organizations and national government authorities have stressed that "sufficient ventilation" should be ensured [46–49]. However, to the best of our knowledge, there are three main questions for which, to date, no clear quantitative answer has been provided. First, it is not clear how much ventilation is required to keep aerosol concentrations limited. Clearly, this will depend on the number of persons per unit surface area, on the physical and respiratory activity of these persons, on their physiological characteristics in terms of aerosol particle emission and on the ventilation efficiency. Especially concerning human aerosol particle emission during various types of activities, the information available in the scientific literature is rather scarce. Second, in terms of exposure, it is not yet known which limit of aerosol concentrations can be considered safe. In other words, it is not yet known which level of potentially infected aerosol particle concentrations for which duration can be a risk for which people with which type of immune system. Third, in case ventilation is insufficient, it is not clear to what extent air cleaning can be engaged to bring the aerosol particle concentrations below a certain threshold value. The present study attempts to provide information that can help in answering the first and third question. The study does not explicitly focus on infection risk but on ventilation and air cleaning as measures to limit the build-up of aerosol concentrations in the indoor environment of a gym.

The paper is structured as follows. In section 2, some more information about the state-of-the-art in aerosol particle production during physical exercise and about the state-of-the-art in ventilation and in air cleaning is provided. Section 3 contains a short study to discriminate between human endogenous and exogenous aerosol particles. Section 4 presents the measurement set-up and associated measurement results in the gym under study. In sections 5 and 6, simplified mathematical modeling is applied to provide insight into the effective ventilation, air cleaning and deposition fluxes, and to extrapolate the findings to scenarios with longer exercise sessions and more air cleaning units. Sections 7 (discussion) and 8 (conclusions) conclude the paper.

2. Aerosol production, ventilation and air cleaning in gyms

2.1. Gyms and aerosol particle production during physical exercise

A gym is an environment that houses equipment and services for the purpose of physical exercise. A gym was selected as a case study for several reasons. First, respiratory aerosol particle production and aerosol particle inhalation in gyms is expected to be more pronounced than in many other indoor environments. Although there are only a few studies that provide some indirect indication of how physical exercise influences the emission of respiratory droplets, these studies are consistent in indicating an overall substantial increase in aerosol expiration due to more intensive breathing compared to tidal breathing. Johnson and Morawska [13] found that deep exhalation resulted in a 4 to 6-fold increase in aerosol particle concentration. Rapid inhalation produced a further 2- to 3-fold increase in concentration, while rapid exhalation had little effect on the measured concentration. Almstrand et al. [14] studied the effect of airway opening on aerosol particle production. Test subjects performed different breathing maneuvers in which the initial lung volume preceding an inhalation to total lung capacity was varied between functional residual capacity (FRC; the volume of air in the lungs at the end of passive expiration) and residual volume (RV; the volume of air in the lungs after full exhalation). The number of expired aerosol particles showed a 2 to 18-fold increase after exhalations to RV compared with exhalations without airway closure. Concerning inhalation during physical exercise, at least three aggravating factors are discerned: (i) the quantity of inhaled pollutants increases proportionally with the minute ventilation; (ii) most of the air is inhaled through the mouth and therefore by-passes the normal nasal mechanisms for filtration of large particles; and (iii) the increased airflow velocity carries pollutants deeper into the respiratory tract [50]. A second reason for selecting a gym as case study is that gyms have been identified as key locations for possible infection transmission and even potential 'superspreading' events [51–53]. For example, COVID-19 outbreaks have been reported in 12 fitness dance classes in South Korea [53] and in a fitness center in Belgium [54] where aerosol transmission could have been a factor. Together with recent studies suggesting that asymptomatic carriers can transfer SARS-CoV-2 [55,56], these studies have fueled concerns on SARS-CoV-2 spreading in fitness centers. A third reason is public health and economy. Sports have an important role in society in view of the health and well-being of the population and reducing the burden on healthcare services. Certainly during the COVID-19 pandemic, sports have been and still are undoubtedly important [57–59]. However, due to the pandemic, authorities in many countries have ordered fitness centers and gyms to be closed and over the past months they have only gradually and partially reopened, and eventually in many countries closed again near the end of 2020. A long closure or a long reduced occupation density can negatively affect the health and well-being of the population. It can also have detrimental economic consequences, with bankruptcies and the associated negative consequences throughout the whole supply chain. As an example, in the Netherlands, fitness is the most practiced sport [60] with a total of 3,900 fitness centers that are registered at the main national branch organization and with an associated total revenue of 1.9 billion Euro in 2019 [61].

To the best of our knowledge, there is no study in the scientific literature that specifically focuses on respiratory aerosol production in fitness centers or gyms. There is even relatively little published research about air quality in fitness centers in general, as opposed to residential buildings and other types of public spaces such as schools and offices [62–64]. The few studies that are available in the scientific literature have measured particulate matter (PM) concentrations in fitness centers as part of indoor air quality studies, without focus on saliva aerosol particles. Indeed, PM concentrations in fitness centers can not only originate from respiratory activity (endogenous particles) but also from injection by the ventilation system, resuspension from room and equipment surfaces after earlier deposition, resuspension from clothing, skin and hair, friction between fitness machine components, friction between clothing, etc. The latter are termed exogenous particles. Salonen et al. [64] provided a review of studies on contaminants in indoor sports facilities including fitness centers. The PM concentration levels in fitness centers were found to be highly influenced by the occupancy level, the type or intensity of the indoor activity and the ventilation type. Ramos et al. [65] measured higher PM concentrations for aerobic than for holistic classes. Aerobic included all the classes that involved power, strength, vigorous and fast movements, however excluding cycling. Holistic included all classes that involved meditation, stability and flexibility movements. The higher concentrations during aerobic classes were attributed to the activity patterns that promoted resuspension of particles [66–68]. PM_{10} concentrations measured in the same classroom and on the same day were also higher during the aerobic class (average 45 $\mu g/m^3$) than in the holistic class (average 33 $\mu g/m^3$), which was again attributed to the greater resuspension caused by the aerobic activities. The relation between PM concentration and resuspension was also indicated by Ramos et al. [69] who found higher PM concentrations coinciding with the period of fitness classes. Concentrations were much lower in fitness centers with mechanical ventilation including filtration of outdoor air than in centers with natural ventilation with open windows [70]. Maximum PM concentrations were typically higher in rooms for group classes than in large workout areas such as those with cardiovascular equipment and free weights. The maxima occurred during high-intensity cardio group classes, with the highest PM_{10} concentration observed for a cycling class.

2.2. Ventilation in gyms

Ventilation can be defined as "the process of introducing and distributing outdoor and/or properly treated recycled air into a building or a room" [71] or "the process by which 'clean' air (normally outdoor air) is intentionally provided to a space and stale air is removed" [72]. Authoritative books and extensive reviews have been dedicated to this the topic over the past decades (e.g. Refs. [71,73–75]). A distinction is made between two main ventilation categories: displacement ventilation and mixing ventilation. To the best of our knowledge, the vast majority of gyms apply mixing ventilation. This can be either mechanical ventilation, natural ventilation or hybrid mechanical/natural ventilation. The indoor air flow patterns in mixing ventilation in general and around persons in particular can be very complex [35–44]. These air flow patterns also govern the motion of the expired aerosol particles due to their low inertia. The intention of mixing ventilation is to dilute the concentrations of e.g. aerosol particles, after which part of this mixed air is expelled to the outside. In some cases ventilation includes recirculation of part of the heated or cooled exhausted air back to the inside, for the purpose of energy conservation. In case of infectious diseases, if recirculation is applied, which is not recommended (e.g. Refs. [48,49]), the recirculated air should be treated so that infectious aerosols are annihilated.

In the Netherlands, the minimum requirements for the ventilation of buildings are prescribed by the Building Code ("Bouwbesluit") published in 2012 and last amended in 2020 [76]. The Building Code applies a person-based approach in which the minimum fresh air ventilation rates in dm^3/s per person are stipulated. The minimum values for different types of buildings are given in Table 1, where a distinction is made between new and existing buildings. Table 1 shows that the required flow rates for indoor sports centers are higher than for shops but – for new buildings – lower than for educational buildings and identical to those of industrial and office buildings. This does not seem to be aligned with the expected higher aerosol particle production during physical exercise [13,14].

In 2008, the Dutch "Guidebook for Sports Accommodations" was published by the NOC*NSF [77]. The NOC*NSF (Dutch Olympic Committee * Dutch Sports Federation) is the overarching organization for all

Table 1
Minimum required ventilation flow rates for different building usage types in the Dutch Building Code [76].

Function	Requirement in dm^3/s/person	
	New buildings	Existing buildings
Childcare	6.5	3.44
Meeting	4	2.12
Healthcare, bed area	12	3.44
Healthcare, other areas	6.5	3.44
Industrial	6.5	3.44
Office	6.5	3.44
Hotel, dormitory	12	6.40
Education	8.5	3.44
Sports	6.5	3.44
Shopping	4	2.12

sports activities, professional and recreational, in the Netherlands. In 2014, specific guidelines for sports facilities for people with disabilities were published by a consortium of organizations including the NOC*NSF [78]. These guidelines stipulate a minimum ventilation flow rate of 11.1 dm^3/s per exercising person for sports halls, which is 70% above the minimum required value in the Dutch Building Code for new buildings and even 3.2 times higher for existing buildings (see Table 1). The Guidebook [77] even suggests a total of 6 air change rates per hour (ACH) for fitness spaces, which implies that the volume of air in the room is replaced by fresh air 6 times per hour. For aerobics and martial arts spaces, it advices ACH = 8 h^{-1} and for indoor cycling ACH = 10 h^{-1}. These higher values seem better aligned with the expected higher production of heat, vapor, CO_2 and aerosol particles by people during physical exercise.

In view of the COVID-19 pandemic, ASHRAE, the American Society of Heating, Refrigerating and Airconditioning Engineers, has acknowledged the potential for aerosol transmission of SARS-CoV-2 and states that facilities of all types should follow, as a minimum, the latest published standards and guidelines and good engineering practice [79]. ASHRAE Standard 62.1 specifies ventilation rates for acceptable indoor air quality [80]. For gyms, health clubs, aerobics rooms and weight rooms, the minimum outdoor airflow rate is 10 dm^3/s/person. This is higher than specified for most retail buildings (3.8 dm^3/s/person, except for beauty and nail salons where 10 dm^3/s/person is required) and educational buildings (3.8–5 dm^3/s/person). Note that the ASRHAE value for gyms aligns well with the 11.1 dm^3/s from the Dutch guidelines [77,78].

2.3. Air cleaning in gyms

Air cleaning can be defined as the removal of potentially harmful airborne contaminants, usually aerosol particles but sometimes also gases, from the air [81]. Air cleaners (ACs) can be installed in indoor environments as small stand-alone mobile units or inside HVAC (heating, ventilation, airconditioning) units or air handler units in buildings. A wide range of technologies for ACs exist, such as filtration, activated carbon, ultraviolet germicidal irradiation, electrostatic precipitators, photocatalytic oxidation and plasma. Large ACs are also referred to as professional ACs. ACs should have a sufficiently high aerosol particle removal efficiency and a sufficiently high volume flow rate, in comparison to the room volume to be treated. Fisk et al. [82] stated that filter efficiencies above 85% provide only modest gains in performance. Several authors mentioned that the air flow rates must be at least several ACH to obtain substantial particle reductions [82–85]. The Association of Home Appliance Manufacturers (AHAM) Air Cleaner Council defines the steady state for air cleaning as at least an 80% continuous removal of smoke particles [86]. Asbach et al. [87] mention that ACs should yield 3 to 6 air changes per hour, with the higher value preferred in the context of the COVID-19 pandemic [88]. The US ANSI/AHAM AC-1:2015 standard [86] evaluates ACs based on their clean air delivery rate (CADR), which is defined as the measure of the delivery of contaminant free air, within the defined particle size range, by an AC, expressed in cubic feet per minute (cfm) or m^3/h. The CADR is the rate of contaminant reduction in a test chamber when the AC is turned on, minus the rate of natural decay when the AC is not running, multiplied by the volume of the test chamber as measured in ft^3 or m^3 [86]. Assuming a room 8 ft high (= 2.44 m) and to achieve a 80% steady state removal, the floor area is related to the CADR by Ref. [86]:

$$A = 1.55\ CADR \quad (1)$$

with A in ft^2 and CADR in cfm. In SI units with A in m^2 and the CADR in m^3/h, this is:

$$A = 0.0852\ CADR \quad (2)$$

To the best of our knowledge, at the moment of writing this paper, the application of air cleaning in public spaces in the Netherlands and many other European countries is rather rare, even though AC technology is not new and the COVID-19 pandemic is already more than a year old. This is partly attributed to the sometimes less good reputation of commercially available ACs and the inferior performance of some of these ACs. First, while several high-quality ACs are available on the market, others have very low efficiencies and some even generate harmful by-products such as O_3 and NO_x [89–92]. Asbach et al. [87] stated that evidence provided by manufacturers on the effectiveness of their ACs should always be critically reviewed. There is a lack of proper testing standards and certification. There is currently no European testing standard for ACs and an international IEC standard to replace the national standards is currently in preparation [87]. Second, mobile ACs are easy to install (plug and play) and it is tempting for uneducated individuals to perform the selection, purchase, installation and operation themselves. However, ACs will only provide good results if the efficiency is high enough, if the installed capacity is in line with the room air volume to be handled and if proper maintenance procedures and frequencies are applied.

3. Endogenously versus exogenously generated aerosol particles

3.1. Measurement set-up and protocol

Measurements were conducted to provide a first indication on the amount of endogenously (i.e. saliva) versus exogenously generated aerosol particles during physical exercise. It is known that the amount of endogenously generated saliva aerosols is small compared to the particle concentrations typically found in outdoor and indoor environments [92, 93]. So breathing only provides small additions to PM concentrations although it is these small amounts of saliva aerosol particles that are of concern in view of the spread of infectious diseases. Tests were performed in a 3.9 x 2.7 × 2.3 m^3 = 24.2 m^3 airtight stainless steel test room (Fig. 1). The room was equipped with a stationary bicycle in the center, an AC, a fan for generating well-mixed indoor conditions and three Grimm 11D aerosol particle sizers (APS) with a measurement range from about 0.25 to about 30 μm [94]. There was no supply or exhaust of air from the room. Three healthy human volunteers, aged 20–22 years and accustomed to regular physical exercise, participated in this study. Approval for use of human subjects was obtained from the Ethical Review Board of Eindhoven University of Technology with file number ERB2020BE58. The subjects signed an informed consent form prior to participating in the study. Every subject performed two times a session of 30 min exercise on the stationary bicycle in heart rate zones 3 and 4. In the first session, the subject released its breath freely into the room and the APS measured the aerosol particles from the different sources. In the second session, the subject released its breath via a mask into a tube that was connected to the outside environment. The mixing fan was operated during the two sessions. Prior to every session, the mask and tube were disinfected and air cleaning was performed while operating an additional fan inside during at least 30 min to reduce the aerosol particle concentration. Assuming that the amount of endogenously and exogenously generated particles was similar in both sets by the same individual, the difference between both sessions provided an indication of the amount of endogenous aerosol particles. The subjects were given at least 30 min rest between the two exercise sessions and were provided with a bottle of drinking water to be consumed in the rest period. The temperature was 21 °C and the RH ranged between 55 and 65%. Subject 1 had short hair, a short beard, wore a short-sleeved shirt and short trousers and applied a pedaling frequency of about 90 rpm. Subject 2 had medium long hair, no beard, wore a short-sleeved shirt and short trousers and applied a pedaling frequency of about 70 rpm. Subject 3 had short hair, a short beard, wore a short-sleeved shirt and long trousers and applied a pedaling frequency of about 80 rpm.

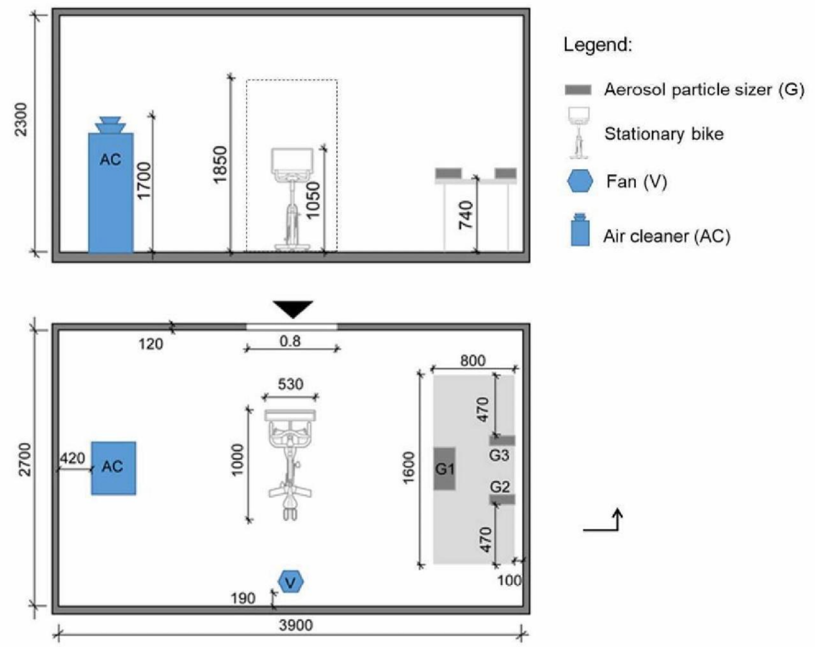

Fig. 1. Measurement set-up in stainless steel test room. Dimensions in mm.

3.2. Results

Because only two measurements sessions were performed for only three persons, the results only provide a first indication on the proportion of exogenous versus endogenous particle concentrations. Table 2 lists the resulting aerosol particle concentrations in five size fractions: 10 to 2.5 μm, 2.5 to 1 μm, 1 to 0.5 μm, 0.5 to 0.25 μm and below 0.25 μm, averaged over the three measurement locations (Fig. 1). The following observations are made:

- For every subject, rather similar concentrations of exogenously generated particles are found, except for the largest size range of 10-2.5 μm. This is attributed to the fact that only relatively few particles in this size range were present and therefore only few could be detected, giving rise to large uncertainties. Note that, assuming a density of 1004 kg/m^3, 0.5 μg/m^3 PM_{10} corresponds to about 951 particles of 10 μm diameter per m^3. For 0.5 μg/m^3 $PM_{2.5}$ this is about 60,872 particles of 2.5 μm diameter per m^3. For 0.1 μg/m^3 PM_1 this is about 190,225 particles of 1 μm diameter per m^3. For 0.01 μg/m^3 $PM_{0.5}$ this is about 152,180 particles of 0.5 μm diameter per m^3. Finally, for 0.01 μg/m^3 $PM_{0.25}$ this is about 1,217,440 particles of 0.25 μm diameter per m^3. Additional variations in the exogenous particle emission among the subjects could be attributed to the different pedalling frequencies, clothing and hair style.
- The results indicate a very high inter-subject variability for the endogenous particle emission. This is in line with previous studies that also showed very large variability [13,14,20,31]. The first subject yielded only very low concentrations of saliva aerosol

Table 2
Aerosol particle concentrations (μg/m^3) in five size fractions measured in test room during physical exercise on stationary bicycle in 5-min intervals during 30 min. Exo = exogeneous aerosol particles; Endo = endogenous (i.e. saliva) aerosol particles.

Subject	t (min)	PM_{10}-$PM_{2.5}$ (μg/m^3)		$PM_{2.5}$-PM_1 (μg/m^3)		PM_1-$PM_{0.5}$ (μg/m^3)		$PM_{0.5}$-$PM_{0.25}$ (μg/m^3)		$PM_{0.25}$ (μg/m^3)	
		exo	endo	Exo	endo	exo	endo	exo	endo	exo	endo
1	5	0.63	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	0.08	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	0.00	0.00	0.11	0.00	0.01	0.01	0.01	0.00	0.00	0.00
	20	0.06	0.00	0.21	0.00	0.06	0.00	0.02	0.01	0.00	0.00
	25	0.49	0.00	0.31	0.00	0.10	0.01	0.03	0.01	0.01	0.00
	30	0.20	0.00	0.45	0.00	0.18	0.03	0.06	0.02	0.01	0.01
2	5	1.04	0.00	0.22	0.03	0.03	0.00	0.01	0.00	0.00	0.00
	10	0.74	0.37	0.31	0.01	0.04	0.00	0.01	0.00	0.00	0.00
	15	0.50	0.18	0.30	0.06	0.05	0.00	0.01	0.00	0.00	0.00
	20	0.59	0.00	0.36	0.06	0.06	0.00	0.02	0.00	0.00	0.00
	25	0.52	0.54	0.38	0.06	0.09	0.00	0.02	0.00	0.01	0.00
	30	0.40	0.67	0.39	0.07	0.11	0.00	0.03	0.00	0.01	0.00
3	5	0.52	0.91	0.10	0.24	0.02	0.05	0.01	0.01	0.00	0.01
	10	1.35	0.21	0.29	0.11	0.03	0.05	0.01	0.01	0.00	0.01
	15	1.04	1.72	0.36	0.24	0.05	0.05	0.01	0.01	0.00	0.00
	20	1.33	0.89	0.47	0.24	0.07	0.08	0.02	0.01	0.00	0.01
	25	1.16	1.15	0.43	0.34	0.09	0.06	0.02	0.01	0.01	0.01
	30	0.98	0.81	0.47	0.27	0.10	0.08	0.03	0.01	0.00	0.01

particles, only significant in the size ranges below 1 μm. The second subject yielded higher concentrations of saliva aerosol particles, only detectable in the size range above 1 μm. For the largest particles (>2.5 μm), the concentration of endogenous particles was in the order of magnitude of that of the exogenous particles. Finally, the third subject emitted saliva aerosol particles in all size ranges, with the same order of magnitude as the exogenous particles, for all size ranges.
- Apart from the largest size range, both the exogenously and endogenously generated particle concentrations showed an increasing trend over time in the 30-min sessions.

Note that the APS itself did not allow to discriminate between solid and liquid particles and that all concentrations were obtained by assuming the particles had a density similar to that of saliva (1002–1006 kg/m^3), as the density of the actual solid particles was unknown. Therefore, it could be assumed that solid (exogenous) particle concentrations as mentioned in Table 2 are underestimated due to their actual higher densities.

4. Measurements in the gym

4.1. Measurement set-up

The measurements were performed in the fitness 3 room of the Student Sports Center at Eindhoven University of Technology in the Netherlands. Fig. 2 shows the plan view. The room was split in two parts by a vertical screen and only the south part was used for this study. The floor area of this part is 173.7 m^2 and the height was about 5.1 m, yielding a room volume of about 886 m^3. The ventilation system in the fitness room was a mechanical mixing ventilation system by which fresh air was supplied into the room by openings with swirl diffusors in the ceiling (indicated with p1-p10 in Fig. 3). The openings p4 to p8 were situated in the half of the room used in the present study. The exhaust openings were present on the west side of the room, near the ceiling (Fig. 3). The ventilation flow rate per opening was measured with a FlowFinder device to which a flow straightener was added to remove the swirl and allow an accurate measurement. Every measurement was performed five times and the resulting average measured volume flow rates were 377.6, 365.8, 375.3, 418.6 and 411.3 m^3/h for positions p4, p5, p6, p7 and p8, respectively, yielding a total volume flow rate of 1948.6 m^3/h. This implies ACH = 2.20 h^{-1}, which is 4.5 times higher than the minimum requirement in the Dutch Building Code for existing buildings, assuming a near-full occupancy with 35 persons (see Table 1). However, note that this ACH is considerably lower than the recommended value of ACH = 6 h^{-1} in Ref. [77].

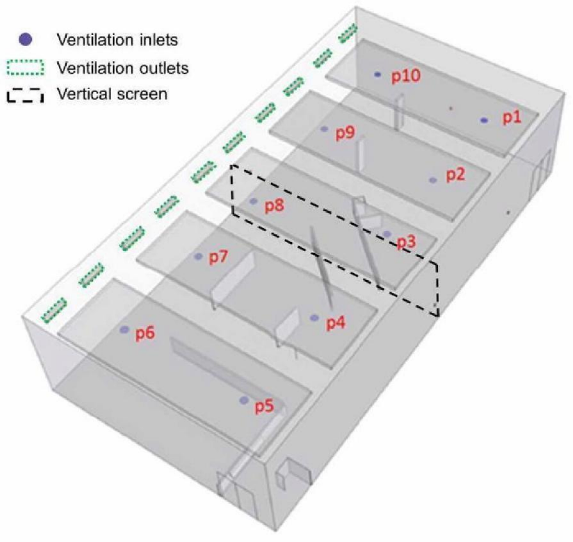

Fig. 3. Position of ventilation inlets and outlets near the ceiling. Openings p4 to p8 apply for the half of the room used in this study.

Fig. 4 shows a perspective view of the measurement set-up in the gym with the cardio and weight machines. We focused on a gym with cardio equipment consisting of stationary exercise bicycles and treadmills and with workout equipment consisting of weight-based exercise machines. When using this equipment, the people exercising are not moving throughout the room but instead remain confined at a rather fixed position in the room, which was aimed at limiting resuspension of particles. Two AC units [95], two Grimm APS [94] and 110 AQS2020PRO APS [96] were installed (Fig. 4). The two AC units each consisted of a combination of four cleaning components: a dielectric barrier discharge plasma component, an electrostatic exterior component, an electrostatic with glass fiber component and a carbon filter

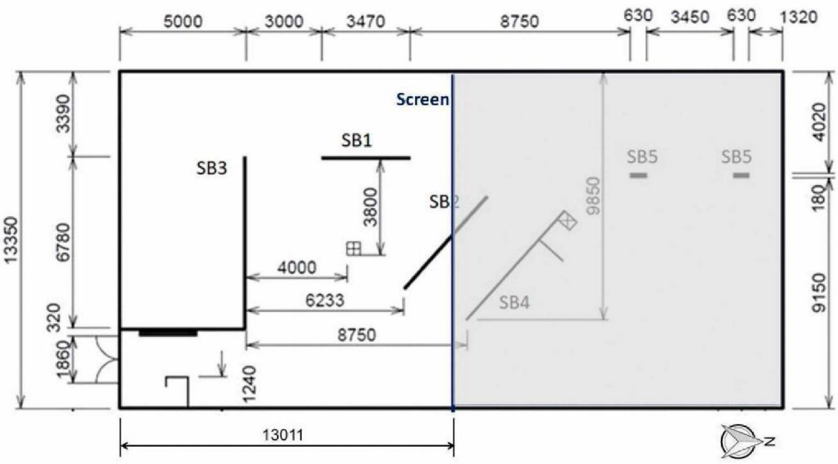

Fig. 2. Plan view of fitness room 3 of Student Sports Center with indication of vertical screen that divides the room in two spaces of about equal volume. Left part is considered in this study. SB refers to vertical shield boards, also visible in Figs. 4 and 5. Dimensions in mm.

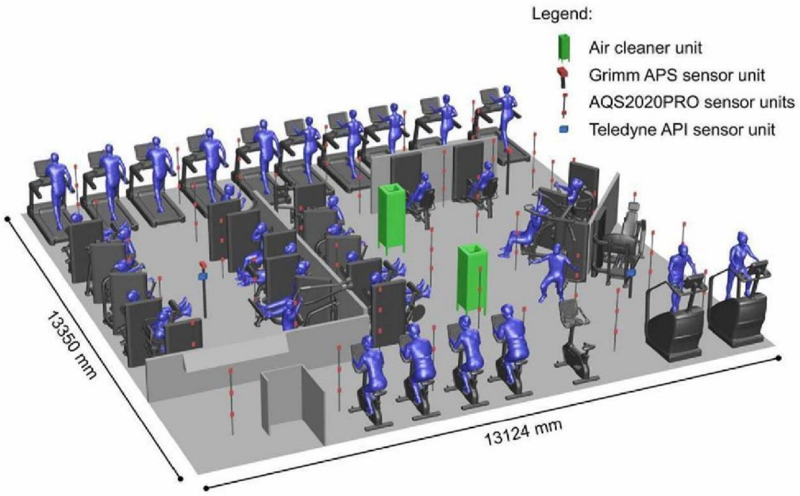

Fig. 4. Measurement set-up in gym.

component. The units ingested the airflow at their bottom opening and exhausted the cleaned air at the top at 1.6 m height at an angle of 45° to the vertical. Every unit had an air flow rate of 617 m^3/h, a required power of 104 W and a measured CADR value for artificial saliva aerosols based on a water-glycol mixture of 233, 261, 320, 412 and 645 m^3/h for PM_{10}, $PM_{2.5}$, PM_1, $PM_{0.5}$ and $PM_{0.25}$, respectively, based on standard 20-min tests [86] in a test room of 24.2 m^3. In line with the findings in Ref. [97], the CADR is reduced as the particle size increases because larger particles fall under the influence of gravity and have a relatively higher deposition rate. Test room measurements indicated that the ACs did not produce substantial amounts of harmful byproducts NO_x and O_3. The Grimm sensors were mounted at measuring heights of 1.367 m and 1.247 m. The 110 APS were mounted on vertical poles at heights of 0.5, 1.0 and 1.5 m (Fig. 4).

4.2. Measurement protocol

40 healthy test subjects were recruited in the age range 18–60 years via a broadcast email invitation offering a modest cash incentive. The subjects signed an informed consent form prior to participating in the study. Both the subjects and the 15 members of the research team and support staff were subjected to a stringent protocol. The subject recruitment and safety protocol were approved by the Ethical Review Board of Eindhoven University of Technology with file number ERB2020BE29r, by the Safety Region of Brabant Southeast and the National Institute for Public Health and the Environment (RIVM) in the Netherlands. First, the subjects, research team and support staff were tested against COVID-19, quarantined for two days in single rooms in a hotel in Eindhoven city center and finally subjected to additional safety precautions on the measurement day of 11 July 2020. While all 55 persons tested negative for COVID-19, after stringent application of the safety protocol, 5 test subjects were excluded from the measurement campaign and 35 subjects remained. These 35 subjects performed cardio and/or weight machine exercises in sessions of 30 min (Figs. 4 and 5).

Six of the experimental scenarios or 30-min sessions are listed in Table 3. The scenarios can be grouped in three sets: Set 1: ventilation on and air cleaning off; Set 2: ventilation off and air cleaning off; Set 3: ventilation off and air cleaning on. Within every set, the parameter is the physical exercise: present or not. In those scenarios when physical exercise was not conducted, all subjects were removed from the room and directed to a large sports hall where they waited for the next exercise session. In between sessions, the subjects were provided with drinking water and sandwiches.

All exercise sessions were performed in the same way. The subjects were divided into two groups: cardio workout (CW) (16 subjects) and strength training (ST) (19 subjects). Within the strength training group,

Table 3
Six experimental sessions/scenarios in chronological order.

Scenario	Set	Physical exercise and people present (Yes/No)	Ventilation On/Off	Air cleaning On/Off
1	1	Yes	On	Off
2	1	No	On	Off
3	2	Yes	Off	Off
4	2	No	Off	Off
5	3	Yes	Off	On
6	3	No	Off	On

Fig. 5. Photo of (a) measurement set-up and (b) ongoing session with 35 test subjects.

10 subjects followed the protocol for muscle endurance (STME) and 9 subjects followed the protocol for muscle mass (STMM). There were three 30-min sessions in which the subjects had to follow a cardio workout (once or twice) and performed a strength training (one or twice). The CW performed their training for 30 min at an intensity between 60 and 75% of heart rate reserve. This was measured by a TICKR heart rate belt connected to the machine. An additional task was that subjects should be able to continue talking to each other not to end up with a too high exercise intensity. Both the STME and the STMM performed three sets of 20 or 10 repetitions on three different machines. Each repetition started with a start signal and lasted 3 min. After the execution of the exercise, the subjects were given rest until the next start signal. On the last machine they performed an extra set to complete the 30 min. In the CW the subjects had a choice of machine. The following CW machines were used in every session: 10 treadmills (LifeFitness, Elevation series), 2 Powermill climbers (LifeFitness, Elevation series) and 4 upright exercise bikes (LifeFitness, Elevation series). STME performed this protocol on the following machines (LifeFitness, Circuit Series): leg extension, seated row, chest press, seated leg curl, ab crunch, lat pulldown, triceps press, squat, shoulder press, biceps curl. STMM performed this protocol on the following machines (LifeFitness, Optima Series): leg extension, seated leg curl, chest press, seated row, hip abduction, hip adduction, biceps curl, shoulder press, machine fly. Fig. 5b shows an ongoing session.

4.3. Measurement results

Fig. 6 displays the measured aerosol particle concentrations by the two Grimm APS (values from both sensors averaged) at the end of every 5-min interval in each of the six 30-min measurement sessions. Every row of two figures represents one set, as outlined above. The results are presented as concentrations in the size fractions 10–2.5 μm, 2.5–1 μm, 1–0.5 μm, 0.5–0.25 μm and the fraction below 0.25 μm. To aid in interpreting the semi-logarithmic graphs, Table 4 holds the differences between the concentration at the end and at the beginning of each session. For these six sessions, the ranges of the absolute values of the air

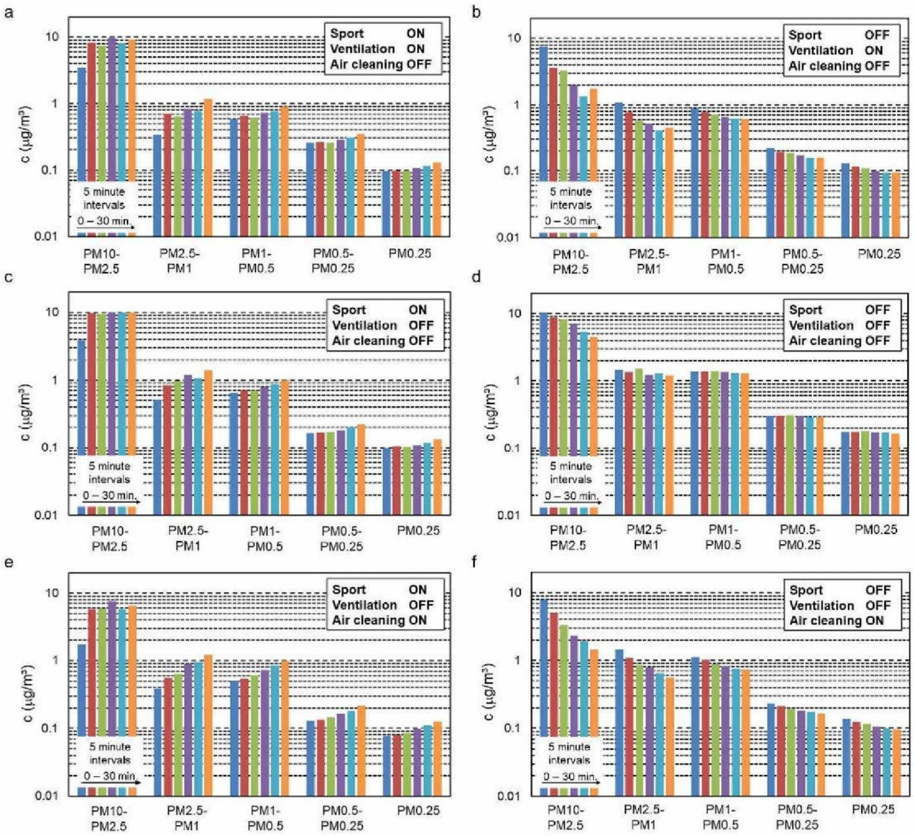

Fig. 6. Aerosol particle concentrations at the end of every 5-min interval in the six 30-min measurement sessions.

Table 4
Change in aerosol particle concentrations (μg/m³) over 30-min sessions/scenarios.

	10–2.5 μm	2.5–1 μm	1–0.5 μm	0.5–0.25 μm	<0.25 μm
Scenario 1: Sport ON/Vent ON/ACs OFF	5.54	0.83	0.33	0.09	0.03
Scenario 2: Sport OFF/Vent ON/ACs OFF	−5.68	−0.63	−0.29	−0.06	−0.03
Scenario 3: Sport ON/Vent OFF/ACs OFF	6.09	0.87	0.35	0.06	0.03
Scenario 4: Sport OFF/Vent OFF/ACs OFF	−6.05	−0.27	−0.09	−0.01	−0.01
Scenario 5: Sport ON/Vent OFF/ACs ON	4.77	0.82	0.48	0.09	0.05
Scenario 6: Sport OFF/Vent OFF/ACs ON	−6.49	−0.63	−0.38	−0.07	−0.04

temperature averaged over the 110 AQS2020PRO sensors, were: 18.6–19.6, 19.6-19.5, 19.6–20.7, 21.0-20.9, 21.3–22.2 and 22.3–22.3 °C for measurement sessions 1 to 6, respectively. Those of the relative humidity were: 44.0–46.3, 46.3-44.7, 44.8–49.5, 51.1-50.6, 45.5–49.8 and 50.0–50.0%, respectively. The CO_2 measurement results are shown in Fig. 7. The following observations are made:

- As a general comment, evaporation is not considered a factor here because this process is very fast, therefore all measured concentrations are expected to be those of the droplet nuclei.
- Fig. 6a shows that when physical exercise was performed and the ventilation system was engaged (with ACs off), the concentrations of aerosol particles in all size fractions increased almost monotonically. The ventilation system was clearly not effective in avoiding the rise in aerosol concentrations within the 30-min period. After 30 min, the subjects ceased their exercise.
- Fig. 6b demonstrates that after the physical exercise had ceased and after everybody had left the room, the ventilation system was effective in reducing the aerosol concentrations – almost monotonically – in all size fractions during the period of 30 min.
- Fig. 6c depicts the rise in aerosol concentrations when physical exercise was performed and neither ventilation nor ACs were engaged. The increase in the fraction 2.5–10 μm was most pronounced in the first 10 min, while afterwards the concentration in this fraction remained quite constant. In the other size fractions there was an almost monotonic increase.
- Fig. 6d shows that when physical exercise had ceased, people had left the room and ventilation remained turned off, there was a substantial concentration decrease especially in the largest size fraction versus a much more limited decrease in the smaller fractions, both of which are attributed to natural deposition in the calm indoor environment.
- Fig. 6e shows the increase when exercise was performed, ventilation was turned off but the ACs were engaged. It is clear that also air cleaning alone, at the flow rate provided, was not sufficient to limit the rise in aerosol concentrations within the 30-min time period.
- Fig. 6f shows that the ACs were also effective in reducing the aerosol particle concentrations after the exercise had halted, people had left the room but the two ACs remained active.
- Comparing Fig. 6b with 6f and rows 2 and 6 in Table 4, the aerosol particle concentration reductions by ventilation versus ACs were quite similar, with the ACs appearing to have been even more effective than ventilation in several size fractions. This in spite of the fact that the ventilation ACH was 2.20 h^{-1} while the air cleaning ACH was 1.39 h^{-1}, which is a 58% difference. Note however that ventilation also injects a small portion of PM into the room (i.e. the concentration in the outdoor air after filtering in the mechanical ventilation system – see section 6).
- Fig. 7 depicts the 5-min CO_2 concentrations throughout each of the six sessions as an average of the values measured by the 110 AQS2020PRO APS at 0.5, 1.0 and 1.5 m height. The first session shows an almost doubling of the concentration due to the physical exercise in spite of the ventilation system being active. The second session shows the concentration decay due to ventilation. In the third and fifth session, there are strong rises in concentration due to the absence of ventilation. Note that the ACs do not affect the CO_2 concentration, as shown for sessions 4 and 6 where this concentration remains fairly constant.

5. Simplified mathematical model for CO_2

A simplified mathematical model can be used to assess the effective ventilation rate. The model assumes a uniform CO_2 concentration in the room with volume V, in other words: perfect mixing of the generated CO_2 and of the supplied ventilation air with the CO_2. It also assumes a steady release of CO_2 by the subjects. With these assumptions, the mass balance for CO_2 can be written as:

$$V\frac{dc}{dt} = G - Q_V(c - c_0) \tag{3}$$

With c the CO_2 concentration (ppm), G the CO_2 emission rate (ppm.m^3/h), Q_V the ventilation rate (m^3/h) and c_0 the CO_2 concentration (ppm) in the supplied ventilation air. For scenario 1 (physical exercise and ventilation), the solution of this first-order ordinary differential equation is:

$$c_1 = c_0 + \frac{G_1}{Q_V} + \left(c_{0,1} - c_0 - \frac{G_1}{Q_V}\right)exp\left[-\left(\frac{Q_V}{V}\right)t\right] \tag{4}$$

For scenario 2 (only ventilation), the solution is:

$$c_2 = c_0 + c_{0,2}\, exp\left[-\left(\frac{Q_V}{V}\right)t\right] \tag{5}$$

For scenarios 3 and 5 (physical exercise without ventilation), the solutions are:

$$c_3 = c_{0,3} + \left(\frac{G_3}{V}\right)t \tag{6}$$

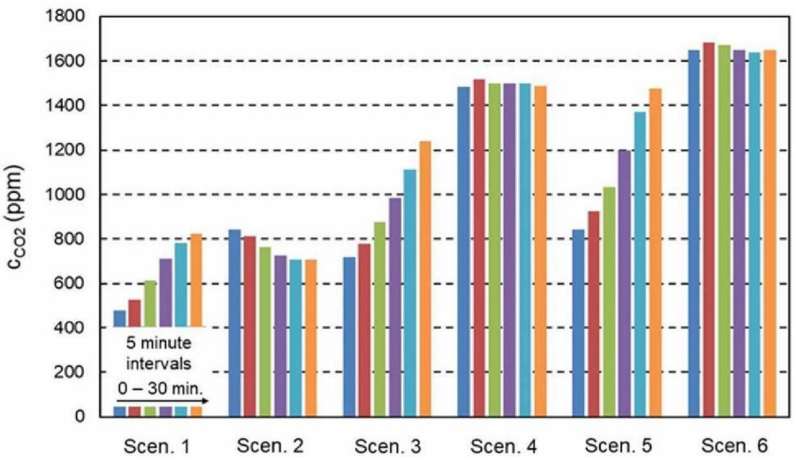

Fig. 7. CO_2 concentrations at the end of every 5-min interval in the six 30-min measurement sessions.

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$$c_5 = c_{0,5} + \left(\frac{G_4}{V}\right)t \tag{7}$$

Least squares fitting of Eq. (5) to the data of CO_2 in Fig. 7 yields Q_V = 995 m^3/h. The CO_2 production by the subjects in scenarios 1, 3 and 5 is obtained by fitting Eqs. (4), (6) and (7) to the data in Fig. 7, yielding G_1 = 1.96 kg/h; G_3 = 2.00 kg/h; G_5 = 2.56 kg/h. The CO_2 production for a person in rest is about 0.033 kg/h [98,99], implying a production rate of 1.16 kg/h for 35 persons. The values for G_1, G_3 and G_5 suggest that the combined production of the 35 exercising subjects is about 70%–220% higher than for 35 persons in rest. A more accurate approach for estimation of CO_2 generation rates by building occupants at different levels of physical activity was provided by Persily and de Jonge [100]. Assuming body mass of 65 kg and 70 kg for female and male subjects respectively, a "met" of 4 (moderate effort) yields 1.75 kg/h CO_2 production for 35 persons, while a "met" of 8 (vigorous effort) yields 3.50 kg/h. The values of G_1, G_3 and G_5 are indeed situated in between these two estimates. The value of Q_V implies that the effective ventilation rate is only 51% of the actual supply ventilation flow rate of 1948.6 m^3/h. This is attributed to fact that the simplified mathematical model assumes a uniform CO_2 source, a uniform concentration distribution and a uniform effect of the ventilation system. In reality, the CO_2 generation occurred at test person height and the measurements were conducted close to the CO_2 source, while both the ventilation supply openings and the exhaust openings were positioned near the ceiling. Q_V = 995 m^3/h could therefore be considered as the "effective" or local ventilation flow rate for the zone in the lower part of the room, in which the test persons were present. This "effective" ventilation rate is more than twice that required by the Dutch Building Code (i.e. 433 m^3/h), however, evaluation of ventilation systems with regard to building codes generally occurs based on the total supply ventilation flow rate. The variability in CO_2 emission could be attributed to subjects having performed more or less intensive exercise from one session to another, subject fatigue, subjects switching from cardio to weight machines and some inter-subject variability in CO_2 emission under similar physical exercise.

6. Simplified mathematical model for aerosol particle concentrations

6.1. *Aerosol particle production, deposition, ventilation and air cleaning*

We consider the five size fractions also used in Fig. 6: 10–2.5 μm, 2.5–1 μm, 1–0.5 μm, 0.5–0.25 μm and below 0.25 μm. Let G denote the aerosol particle production rate by physical exercise, which is the sum of the production rates by respiration, resuspension, machine component friction, clothing friction and the like. Q_V denotes the ventilation flow rate, Q_{AC} the total AC flow rate, η_{AC} the AC efficiency, K_N the natural deposition loss rate under calm indoor airflow conditions (ventilation and ACs off), K_V the deposition loss rate in the ventilation flow regime (ventilation on, ACs off), K_{AC} the deposition loss rate in the AC flow regime (ventilation off, ACs on), V the room volume and c_0 the concentration in the incoming ventilation air. Assuming well-mixed conditions and a steady emission of aerosol particles in all five size fractions by the 35 subjects, the mass balances for the six scenarios in Fig. 6 for a given size fraction are:

$$V\frac{dc_1}{dt} = G_1 - Q_V(c_1 - c_0) - K_V V c_1 \tag{8}$$

$$V\frac{dc_2}{dt} = -Q_V(c_2 - c_0) - K_V V c_2 \tag{9}$$

$$V\frac{dc_3}{dt} = G_3 - K_N V c_3 \tag{10}$$

$$V\frac{dc_4}{dt} = -K_N V c_4 \tag{11}$$

$$V\frac{dc_5}{dt} = G_5 - \eta_{AC} Q_{AC} c_5 - K_{AC} V c_5 \tag{12}$$

$$V\frac{dc_6}{dt} = -\eta_{AC} Q_{AC} c_6 - K_{AC} V c_6 \tag{13}$$

The corresponding solutions are:

$$c_1 = \frac{G_1 + Q_V c_0}{Q_V + K_V V} + \left(c_{0,1} - \frac{G_1 + Q_V c_0}{Q_V + K_V V}\right) exp\left[-\left(\frac{Q_V + K_V V}{V}\right)t\right] \tag{14}$$

$$c_2 = \frac{Q_V c_0}{Q_V + K_V V} + \left(c_{0,2} - \frac{Q_V c_0}{Q_V + K_V V}\right) exp\left[-\left(\frac{Q_V + K_V V}{V}\right)t\right] \tag{15}$$

$$c_3 = \frac{G_3}{K_N V} + \left(c_{0,3} - \frac{G_3}{K_N V}\right) exp\left[-\left(\frac{K_N V}{V}\right)t\right] \tag{16}$$

$$c_4 = c_{0,4}\, exp\left[-\left(\frac{K_N V}{V}\right)t\right] \tag{17}$$

$$c_5 = \frac{G_5}{\eta_{AC} Q_{AC} + K_{AC} V} + \left(c_{0,5} - \frac{G_5}{\eta_{AC} Q_{AC} + K_{AC} V}\right) exp\left[-\left(\frac{\eta_{AC} Q_{AC} + K_{AC} V}{V}\right)t\right] \tag{18}$$

$$c_6 = c_{0,6}\, exp\left[-\left(\frac{\eta_{AC} Q_{AC} + K_{AC} V}{V}\right)t\right] \tag{19}$$

Considering the left-hand sides of these equations as known by the data in Fig. 6, these six equations have seven unknowns: G_1, G_3, G_5, K_V, K_N, $\eta_{AC}Q_{AC}$ and K_{AC}. Note that $\eta_{AC}Q_{AC}$ cannot be considered known from the CADR tests in the small test room of 24.2 m^3, as reported in subsection 4.1, because Noh and Oh [97] showed that for the same AC device, the experimental CADR decreased as the size of the test chamber increased. To solve the system of equations, the sum $\eta_{AC}Q_{AC} + K_{AC}V$ is taken as a single variable. Least squares fitting of Eqs. (15), (17) and (19) to the data in Fig. 6 yields the values of $Q_V + K_VV$, K_NV and $\eta_{AC}Q_{AC} + K_{AC}V$ for every size fraction. Using these values into Eqs. (14), (16) and (18) yields the values of G_1, G_3 and G_5. K_VV is calculated based on Q_V = 995 m^3/h (see section 5). Table 5 holds the results. It also shows the deposition loss rates K_N and K_V based on V = 886 m^3. The last row shows the measured c_0 concentration values. The following observations are made:

- The low measured c_0 values are representative of a large degree of air filtering in the mechanical ventilation system.

Table 5
Flow rates associated with aerosol particle production, deposition, ventilation and air cleaning, for five size fractions. Deposition loss rates and the concentrations in the incoming ventilation air are also given.

	10–2.5 μm	2.5–1 μm	1–0.5 μm	0.5–0.25 μm	<0.25 μm
$Q_V + K_V V$ (m^3/h)	4721	2656	1664	1629	1599
$K_V V$ (m^3/h)	1704	394	156	127	126
$\eta_{AC} Q_{AC} + K_{AC} V$ (m^3/h)	4306	2277	989	814	812
G_1 (μg/h)	47361	3398	1362	488	143
G_3 (μg/h)	23440	1951	796	134	73
G_5 (μg/h)	32415	3871	2289	330	192
Q_V (m^3/h)	995	995	995	995	995
$K_V V$ (m^3/h)	3726	1661	669	634	604
K_V (h^{-1})	4.21	1.87	0.76	0.72	0.68
K_N (h^{-1})	1.92	0.45	0.18	0.14	0.14
c_0 (μg/m^3)	0.006	0.053	0.520	0.151	0.088

- Aerosol particle removal due to deposition in scenarios 2 (K_V) and 4 (K_N) rapidly decreases with decreasing size fraction. This is expected given the lower mass and associated smaller settling velocities of the smaller aerosol particles. The K_N values found here are very similar to those by Mølgaard et al. [101]. Several studies indicated deposition rates of 0.02–0.55 h^{-1} for $PM_{2.5}$ where the area and roughness of the deposition surfaces plays an important role [102–104]. Shaughnessy and Sextro [105] reported data from Thatcher et al. [106] and Xu et al. [107] where K_N for the size fraction 10–2.5 μm ranged from 1 to 10 h^{-1}, for 2.5–1 μm from 0.3 to 1 h^{-1}, for 1–0.5 μm from 0.1 to 0.3 h^{-1}, for 0.5–0.25 μm from 0.05 to 0.1 h^{-1} and finally for the size fraction below 0.25 μm from 0.035 to 0.05 h^{-1}. Apart from the two smallest size fractions, the K_N values in Table 5 are situated in these ranges. The larger values in the two smallest size fractions could be attributed to the large number of surfaces in the gym room.
- Aerosol particle removal due to deposition in scenario 4 (K_N; ventilation off, ACs off) is much less pronounced than in scenario 2 (K_V; ventilation on, ACs off), which is attributed to the indoor airflow pattern in the latter scenario generated by the ventilation system. Indeed, Friedlander and Johnstone [108] demonstrated the strong increase in deposition from turbulent gas streams with increase in the flow Reynolds number, attributed to the larger eddies and larger inertial forces favoring deposition. For the size fraction 10–2.5 μm, the deposition rate is 2.2 times larger in scenario 2 than in 4, while for the size fraction 0.5–0.25 μm, it is 4.8 times larger.
- Earlier, it was shown by comparing Fig. 6b with 6f and rows 2 and 6 in Table 4, that the aerosol particle concentration reductions by ventilation versus ACs were quite similar, with the ACs appearing a bit more effective than ventilation in several size fractions. This in spite the fact that the ventilation ACH was 2.20 h^{-1} while the AC ACH was 1.39 h^{-1}, which is a 58% difference. This is confirmed by the fact that the sum $Q_V + K_V V$ is larger than the sum $\eta_{AC}Q_{AC} + K_{N,AC}V$. This is attributed to the lower effectiveness of the ventilation system which is attributed to two reasons: (1) the presence of the ventilation inlet and outlets near the ceiling and (2) the fact that the incoming ventilation air also contained – albeit fairly low – concentrations of aerosol particles. It is also attributed to the fact that the AC units were positioned in the region where the aerosol particles were generated, which can explain their relatively larger effectiveness.
- The aerosol particle production rates are very different among scenarios 1, 3 and 5, with the differences also differing per size fraction. This could be attributed to inter-subject variability in aerosol particle emission under similar physical exercise regimes but also by subjects having performed more or less intensive exercise from one session to another, subject fatigue and subjects switching from cardio to weight machines. It could also be attributed, at least partly, due to the use of only two measurement points for aerosol particle concentrations.
- In terms of the magnitude of aerosol particle production, You et al. [109] measured the short-term emission rates of particles by persons with different clothing and activity intensities in a sealed chamber. The activities did not involve gym machines but included walking, upper body and arm movements. Based on their data for a cotton suit and for slight to strong activity intensity and assuming a particle density of 1000 kg/m^3, the following ranges can be derived for 35 persons: 5635–39238 μg/h for the size fraction 10–2.5 μm, 2004–2227 μg/h for 2.5–1 μm, ≈2738 μg/h for 1–0.5 μm and finally 760–844 μg/h for the size fraction below 0.5 μm. Taking into account that the 35 persons in the gym performed moderate rather than strong activity and that the numbers by You et al. [109] do not include particles generated by the friction between components of the cardio and weight machines, the values of G_1, G_3 and G_5 in Table 5 can be considered in line with the findings by You et al. [109].

6.2. Combined effect of ventilation and air cleaning

A scenario that was not considered in the experimental campaign was the combination of ventilation and air cleaning. Therefore, the simplified model is applied to investigate this additional scenario with ventilation and air cleaning combined and using the aerosol particle production rate from the first scenario ($G_7 = G_1$):

$$c_7 = \frac{G_7 + Q_V c_0}{Q_V + K_V V + \eta_{AC}Q_{AC} + K_{AC}V} + \left(c_{0,7} - \frac{G_7 + Q_V c_0}{Q_V + K_V V + \eta_{AC}Q_{AC} + K_{AC}V}\right) exp\left[-\left(\frac{Q_V + K_V V + \eta_{AC}Q_{AC} + K_{AC}V}{V}\right)t\right] \quad (20)$$

It is assumed that the combination of ventilation (with supply and exhaust near the ceiling) and air cleaning (near ground level) also combines the deposition rates by both technologies. The simplified model was also used for other scenarios, as shown in Fig. 8 that presents the results of six scenarios for a 60-min period, all with the same aerosol generation rate G_1. Fig. 8a is the calculated result for scenario 1. Fig. 8b and c present scenarios 3′ and 5′ that are identical to scenarios 3 and 5 but now with $G_{3'} = G_{5'} = G_1$. Fig. 8d presents scenario 7 (ventilation and air cleaning combined). Fig. 8e and f present two additional scenarios in which the number of ACs is raised from 2 to 4 and 6 units, respectively. All figures show that the concentrations tend towards an asymptote over time, as dictated by the exponential functions in the above-mentioned equations. Table 6 lists the asymptotic values as reached in every scenario at $t = \infty$, and Fig. 9 shows these asymptotic values in percentages of the values of scenario 3' (only deposition). The following observations are made:

- Fig. 8 shows that the duration during which concentrations keep rising significantly is largest for scenario 3' (Fig. 8b; no ventilation, no ACs, only natural deposition in calm indoor airflow conditions). Evidently this is also the scenario in which the highest concentrations are obtained. Table 6 indicates that these concentrations go up to 27.80, 8.61, 8.72, 3.83 and 1.13 $\mu g/m^3$ for the size fractions 10–2.5 μm, 2.5–1 μm, 1–0.5 μm, 0.5–0.25 μm and below 0.25 μm, respectively. The concentrations in the largest size fraction keep rising significantly for about 4.83 h, while those in the smallest size fraction keep rising beyond 15 h (not shown in figure).
- Fig. 8 also shows that the duration at which near-equilibrium conditions are obtained is shortest for scenario 9 in which most intensive air cleaning is engaged. Evidently this is also the scenario in which the lowest concentrations are obtained. Table 6 indicates that these concentrations remain limited to 2.69, 0.36, 0.41, 0.16 and 0.06 $\mu g/m^3$ for the size fractions 10–2.5 μm, 2.5–1 μm, 1–0.5 μm, 0.5–0.25 μm and below 0.25 μm, respectively. The concentrations in the largest size fraction keep rising significantly for only 0.63 h, while those in the smallest size fraction keep rising significantly for about 0.83 h.
- For all other scenarios, the duration towards near-equilibrium and the near-final concentrations are situated between those of scenarios 3′ and 9. In scenario 1, ventilation alone reduces the final concentrations of scenario 3' (no ventilation, no ACs) by factors 2.8, 6.6, 7.7, 9.8 and 8.1 for the size fractions 10–2.5 μm, 2.5–1 μm, 1–0.5 μm, 0.5–0.25 μm and below 0.25 μm, respectively. In scenario 5′, air cleaning alone (with 2 ACs) yields slightly lower reduction factors: 2.5, 5.8, 6.3, 6.4 and 6.3, in relation to scenario 3'. Combining ventilation and air cleaning in scenario 7 reduces the final concentrations of scenario 3' (no ventilation, no ACs) by factors of 5.3, 12.3, 12.3, 14.7 and 11.3 for the five consecutive size fractions. Adding more AC units increases these factors further. 4 AC units (scenario 8) correspond to ACH = 2.78 h^{-1}, which is still below the recommendation by Ref. [87] that the air cleaner ACH should be between 3 and

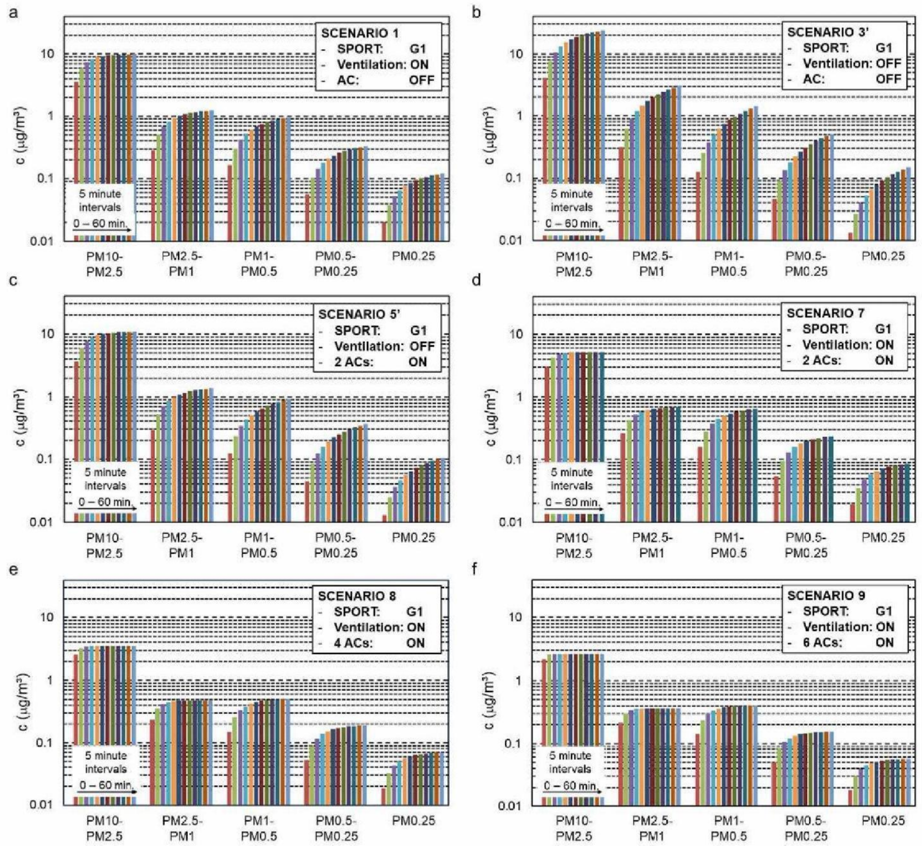

Fig. 8. Calculated aerosol particle concentrations at the end of every 5-min interval in 60-min sessions for six scenarios: 1, 3′, 5′, 7, 8 and 9.

Table 6
Calculated asymptotic values of aerosol particle concentrations (μg/m³) for six scenarios: 1, 3′, 5′, 7, 8 and 9.

	10–2.5 μm	2.5–1 μm	1–0.5 μm	0.5–0.25 μm	<0.25 μm
Scenario 1	10.03	1.30	1.13	0.39	0.14
Scenario 3′	27.80	8.61	8.72	3.83	1.13
Scenario 5′	11.00	1.49	1.38	0.60	0.18
Scenario 7	5.25	0.70	0.71	0.26	0.10
Scenario 8	3.55	0.48	0.52	0.20	0.07
Scenario 9	2.69	0.36	0.41	0.16	0.06

6. In this case, the concentrations of scenario 3′ are reduced with factors of 7.8, 17.9, 16.8, 19.2 and 16.1, for each of the consecutive size fractions. Finally, 6 AC units (scenario 9) yields ACH = 4.17 h^{-1} which is above the lower limit of the recommendation in Ref. [87]. The resulting reduction factors are 10.3, 23.9, 21.3, 23.9 and 18.8. Note that [87] advises ACH = 6 h^{-1} which would lead to even lower asymptotic concentration values. Fig. 9 shows the percentages of the concentrations in the five size fractions, compared to scenario 3' (only deposition). Ventilation alone or air cleaning alone reduces the concentrations in the largest size fraction with more than 60% and in the other size fractions with more than 80%. Combining ventilation and air cleaning (2 AC units) yields reductions of more than 80% and 90% in the largest and other size fractions, respectively. Ventilation combined with 6 AC units gives reductions of 90 an 95% for the largest and smaller size fractions, respectively. Note that 6 AC units yields ACH = 4.17 h^{-1} which is just above the lower limit of the recommendation in [87].

7. Discussion

A major gap in the scientific literature is information about the aerosol particle emission by persons performing physical exercise. A previous study indicated that deep exhalation could yield a 4 to 6-fold increase in aerosol particle emission and rapid inhalation a further 2- to 3-fold increase in emission [13], yielding a maximum 18-fold increase. Another study revealed that the number of expired aerosol particles showed a 2 to 18-fold increase after exhalations to residual long volume compared with exhalations without airway closure [14]. Therefore, concerns about high aerosol particle concentrations in indoor sports centers, fitness centers and gyms are justified. Regardless, more research is needed to assess aerosol particle emissions by persons performing physical exercise at different levels of intensity and heart rate.

To the best of our knowledge, there was no study in the scientific literature that specifically focused on respiratory aerosol production in fitness centers. There was even relatively little published research about air quality in fitness centers in general, as opposed to residential buildings and other types of public spaces such as schools and offices [62–64]. The few studies that were available in the scientific literature had measured PM concentrations without a focus on saliva aerosol particles and without an attempt to discriminate between endogenous and exogenous particles. To provide some first preliminary insights in the proportions between endogenous versus exogenous particles, in the

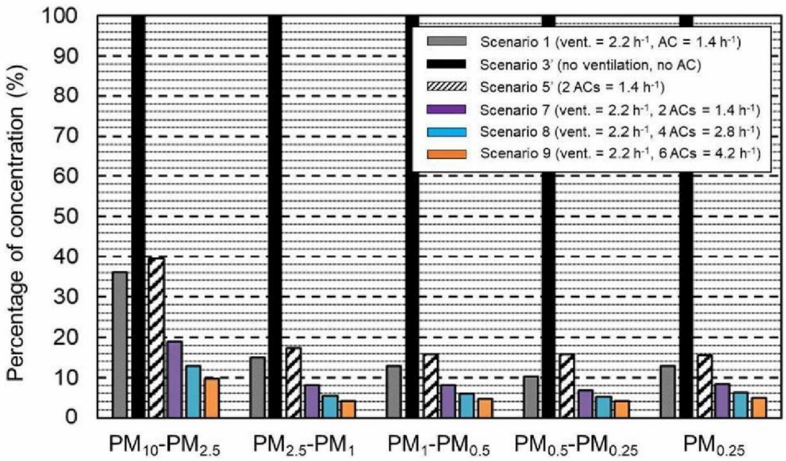

Fig. 9. Calculated asymptotic aerosol particle concentrations for six scenarios: 1, 3′, 5′, 7, 8 and 9, expressed as percentages compared to scenario 3′.

present study, a small test was performed. While some clear trends could be discerned, especially for the size fractions below 2.5 μm, especially the large inter-subject variability was noted. This however was in line with earlier studies that also indicated very large inter-subject variability [13,14,20,31]. Much more research is needed on endogenous versus exogenous aerosol particle emission as the lack of knowledge about their relative proportions will continue to complicate advice concerning saliva aerosol emission and reduction in view of limiting infection risk. Due to the inability to discriminate between endogenous and exogenous particles in the gym study in the present paper, the focus in the paper is on the combination of these two types.

The scenarios considered in the present study are neither a worst-case nor a most beneficial scenario. On the one hand, in actual gym settings, many persons performing physical exercise will apply long breaks between exercises, either to rest or to talk to other people. In that regard, the present study considered fairly vigorous and continuous exercise, in an attempt to obtain a steady release of both endogenous and exogenous aerosol particles. On the other hand, in intensive cycling sessions such as spinning, the intensity and the heart rates are higher than those in the present study that included a combination of cardio and weight machines. The measured CO_2 emission rates confirm that the present scenarios are in between vigorous and moderate exercise.

A wide variety of gyms and ventilation systems exist. Nevertheless, most gyms are characterized by a large height and most gym have mixing ventilation systems with supply and exhaust openings near the ceiling. In order to generalize the results on ventilation effectiveness from the present study, a number of additional gyms will need to be investigated, after which potentially a common denominator could be defined and some general advices could be established in terms of required ventilation and/or air cleaning flow rates.

Similarly, a wide variety of ACs exist. As mentioned in this paper, ACs need to have both a sufficiently high efficiency and a proper capacity (flow rate) in order to be effective. ACs have a sometimes less good reputation because of the presence of some very deficient and even harmful types on the market. However, also high-quality ACs have been developed and are commercially available. High-quality certification and international standardization are imperative.

Aerosol particle deposition is an important factor. The present study suggests that the engagement of ventilation or air cleaning, by inducing an overall more turbulent airflow pattern in the room, substantially enhances the deposition, in line with a previous study [108].

In view of the COVID-19 pandemic and potential future pandemics, ventilation of indoor environments, gyms included, will need to be reconsidered. At the same time, energy efficiency should be upheld to the largest degree possible, in view of limiting climate change. Suggestions by politicians, scientists and opinion makers that ventilation has to be massively incremented to avoid potential aerosol SARS-CoV-2 infection, would unavoidably give rise to large investment costs to upgrade ventilation systems and large energy consumption and losses (if heat recovery is not massively deployed) and the associated costs. Therefore, we suggest to not engage in expensive upgrades of existing mechanical ventilation systems, on condition that they already enable – pandemics aside – a healthy and comfortable indoor environment, using ventilation rates that are above the minima required by building codes. Instead, these expensive and already available systems can be supplemented with lower-cost mobile professional AC units. The present study has shown that the effectiveness of high-quality AC units can be similar to that of a mechanical ventilation system (with aerosol filtering) with a 60% higher flow rate. AC units do not require the air to be heated, cooled or (de)humidified, as it is indoor air being handled and exhausted back into the room. Ventilation air coming from outside will often need extra energy for heating, cooling and (de)humidifying, even if heat recovery is applied. However, it should be stressed that ventilation at the minimum flow rates as required by building codes remains imperative, because many ACs do not remove gasses, such as CO_2.

A gym is rather complex indoor environment in the sense that it has a large height, the sources are present near the floor while generally the ventilation supply and exhaust openings are present near the ceiling. Therefore, future work should consider measuring aerosol particle concentrations not only at two positions at similar height as in the present study, but also measuring concentration gradients along the height of the room. Given the large height, vertical concentration gradients could be present, irrespective of the type of mixing ventilation system or ACs that are present. Future work will include CFD simulations to provide more inside into the vertical gradients and the related effectiveness of ventilation and AC units.

The results from this study in terms of AC units supplementing ventilation can also be applied in other indoor environments. For rooms with lower height such as class rooms and offices, for example, the complexity could be smaller. For indoor environments with larger height however, such as football stadiums, basketball halls and concert halls, the complexity could be much larger. The authors are currently conducting a similar project for the Johan Cruijff Football stadium, home of the Amsterdam Ajax Football team and of the Dutch National Football Team [110].

The introduction mentioned three main questions for which, to date, no clear quantitative answer had been provided. The present study attempted to provide some information in terms of ventilation and air cleaning effectiveness in a realistic environment. It does not provide information about infection risk. Future work should develop strategies to allow various types of indoor activities to be safely maintained during pandemics. A first practical engineering strategy in this regard for indoor sports centers (including gyms) was presented by Blocken et al. [111]. This work should be supplemented with an infection risk analysis as well.

8. Summary and conclusions

SARS-CoV-2 can spread by close contact through large droplet spray and indirect contact via contaminated objects. There is mounting evidence that it can also be transmitted by inhalation of infected saliva aerosol particles. These particles are generated when breathing, talking, laughing, coughing or sneezing. It can be assumed that aerosol particle concentrations indoors should be kept low in order to minimize the potential risk of airborne virus transmission. This paper presents measurements of aerosol particle concentrations in a gym, where saliva aerosol production is pronounced. 35 test persons performed physical exercise and aerosol particle concentrations, CO_2 concentrations, air temperature and relative humidity were obtained in the room of 886 m^3. A separate test was used to provide some information on the amount of human endogenous versus exogenous aerosol particles. This test showed large inter-subject variability, with one person emitting much more exogenous than endogenous particles, while another emitted similar amounts of both types. Aerosol particle removal by mechanical ventilation and mobile air cleaning (AC) units was measured. The gym test showed that ventilation with ACH = 2.2 h^{-1}, i.e. 4.5 times the minimum of the Dutch Building Code, was insufficient to stop the significant aerosol concentration rise over a 30-min measurement session. Air cleaning alone with ACH = 1.39 h^{-1} had a similar effect as ventilation alone. This difference can be attributed to the lower effectiveness of the ventilation system due to two reasons: (1) the presence of the ventilation inlet and outlets near the ceiling and (2) the fact that the incoming ventilation air also contained – albeit fairly low – concentrations of aerosol particles. It was also attributed to the fact that the AC units were positioned in the region where the aerosol particles were generated, which can explain the relatively larger effectiveness of ACs. Simplified mathematical models were engaged to provide further insight into ventilation, air cleaning and deposition. It was shown that combining ventilation and intensive air cleaning with up to six AC units with a total ACH of 4.17 h^{-1} – as recommended in the scientific literature – can reduce the concentrations by factors of 2.3 up to 3.7 depending on aerosol size, compared to ventilation alone, and by factors of 10.3 up to 23.9 depending on aerosol size, compared to a situation without ventilation and AC units. It is suggested that if aerosol particle concentrations need to be reduced in view of the COVID-19 pandemic, this should not necessarily be done by an expensive upgrade of the existing mechanical ventilation system. Instead, it could also be achieved by supplementing this system with mobile professional high-quality AC units. When the AC units are installed near ground-level in gyms with large height (e.g. 5 m), they can have a higher effectiveness than the ventilation system and together with the existing ventilation system, they can reduce the aerosol particle concentrations below a pre-defined threshold. This lowers investment and operational costs because AC units do not require the air to be heated, cooled or (de)humidified, as it is indoor air being handled and exhausted back into the room. Ventilation air coming from outside will often need extra energy for heating, cooling and (de)humidifying, even if heat recovery is applied. However, it should be stressed that ventilation at (at least) the minimum flow rates required by building codes remains imperative, because many ACs do not remove gasses, such as CO_2.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] European Centre for Disease Prevention and Control, COVID 19 Situation update 2nd week 2021. https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases, 2020. Retrieved on 27 January 2021.
[2] J. Chan, S. Yuan, K. Kok, et al., A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster, Lancet 395 (2020) 514–523.
[3] Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N. Engl. J. Med. 382: 1199-1207.
[4] C. Huang, Y. Wang, X. Li, et al., Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China, Lancet 395 (2020) 497–506.
[5] R.M. Burke, C.M. Midgley, A. Dratch, et al., Active monitoring of persons exposed to patients with confirmed COVID-19 — United States, January–February 2020, MMWR Morbid. Mortal. Weekly Rep. 69 (9) (2020) 245–246.
[6] World Health Organization, Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19) 16-24 February 2020, World Health Organization, Geneva, 2020. Available from: https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf.
[7] World Health Organization, Modes of Transmission of Virus Causing COVID-19: Implications for IPC Precaution Recommendations. Scientific Brief, World Health Organization, Geneva, 2020. Available from: www.who.int/news-room/commentaries/detail/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations.

[8] Y. Liu, Z. Ning, Yu Chen, et al., Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals, Nature 582 (2020) 557–560. https://www.nature.com/articles/s41586-020-2271-3.
[9] N. van Doremalen, D.H. Morris, M.G. Holbrook, et al., Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1, New England J. Med. 382 (2020) 1564–1567.
[10] L. Morawska, J. Cao, Airborne transmission of SARS-CoV-2: the world should face the reality, Environ. Int. 139 (2020) 105730.
[11] M. Hadei, P.K. Hopke, A. Jonidi, A. Shahsavani, A letter about the airborne transmission of SARS-CoV-2 based on the current evidence, Aerosol Air Qual. Res. 20 (2020) 911–914.
[12] S. Asadi, N. Bouvier, A.S. Wexler, W.D. Ristenpart, The coronavirus pandemic and aerosols: does COVID-19 transmit via expiratory particles? Aerosol. Sci. Technol. 54 (6) (2020) 635–638.
[13] G.R. Johnson, L. Morawska, The mechanism of breath aerosol formation, J. Aerosol Med. Pulm. Drug Deliv. 22 (3) (2009) 229–237.
[14] A.C. Almstrand, B. Bake, E.L. Ljungstrom, et al., Effect of airway opening on production of exhaled particles, J. Appl. Physiol. 108 (2010) 584–588.
[15] S. Asadi, A.S. Wexler, C.D. Cappa, et al., Effect of voicing and articulation manner on aerosol particle emission during human speech, PloS One 15 (1) (2019), e0227699.
[16] R. Mittal, R. Ni, J.H. Seo, The flow physics of COVID-19, J. Fluid Mech. 894 (2020). Article nr. F2.
[17] Z.Y. Han, W.G. Weng, Q.Y. Huang, Characterizations of particle size distribution of the droplets exhaled by sneeze, J. R. Soc. Interface 10 (88) (2013) 20130560.
[18] S. Asadi, A.S. Wexler, C.D. Cappa, et al., Aerosol emission and superemission during human speech increase with voice loudness, Sci. Rep. 9 (2019), 2019.
[19] C.I. Fairchild, J.F. Stampfer, Paricle concentration in exhaled breath - summary Report, Am. Ind. Hyg. Assoc. J. 48 (1987) 948–949.
[20] R.S. Papineni, F.S. Rosenthal, The size distribution of droplets in the exhaled breath of healthy human subjects, J. Aerosol Med. 10 (1997) 105–116.
[21] D.A. Edwards, J.C. Man, P. Brand, et al., Inhaling to mitigate exhaled bioaerosols, Proc. Natl. Acad. Sci. Unit. States Am. 101 (50) (2004) 17383–17388.
[22] Z.T. Ai, A.K. Melikov, Airborne spread of expiratory droplet nuclei between the occupants of indoor environments: a review, Indoor Air 28 (2018) 500–524.
[23] W.F. Wells, On air-borne infection. Study II. Droplets and droplet nuclei, Am. J. Hyg. 20 (1934) 611–618.
[24] M.P. Wan, C.Y.H. Chao, Transport characteristics of expiratory droplets and droplet nuclei in indoor environments with different ventilation airflow patterns, J. Biomech. Eng. 129 (2007) 341–353.
[25] X. Xie, Y. Li, A.T.Y. Chwang, et al., How far droplets can move in indoor environments - revisiting the Wells evaporation-falling curve, Indoor Air 17 (2007) 211–225.
[26] W.C. Hinds, Aerosol Technology, John Wiley & Sons, New York, 1982.
[27] CDC, Guidelines for Isolation Precautions in Hospitals, Hospital Infection Control Advisory Committee, Centers for Disease Control and Prevention, Atlanta, GA, USA, 1996. Available at: http://wonder.cdc.gov/wonder/prevguid/p0000419/p0000419.asp. retrieved on 16 November 2020.
[28] A. Mangili, M.A. Gendreau, Transmission of infectious diseases during commercial air travel, Lancet 365 (2005) 989–996.
[29] M.D. Christian, M. Loutfy, L.C. McDonald, et al., Possible SARS coronavirus transmission during cardiopulmonary resuscitation, Emerg. Infect. Dis. 10 (2004) 287–293.
[30] M. Nicas, W. Nazaroff, A. Hubbard, Toward understanding the risk of secondary airborne infection: emission of respirable pathogens, J. Occup. Environ. Hyg. 2 (3) (2005) 143–154.
[31] L. Morawska, G.R. Johnson, Z.D. Ristovski, et al., Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities, J. Aerosol Sci. 40 (3) (2009) 256–269.
[32] H. Holmgren, B. Bake, A.C. Olin, E. Ljungström, Relation between humidity and size of exhaled particles, J. Aerosol Med. Pulm. Drug Deliv. 24 (5) (2011) 253–260.
[33] L. Bourouiba, E. Dehandschoewercker, J.W.M. Bush, Violent expiratory events: on coughing and sneezing, J. Fluid Mech. 745 (2014) 537–563.
[34] L. Bourouiba, Turbulent gas clouds and respiratory pathogen emissions: potential implications for reducing transmission of COVID-19. JAMA Insights, Clinical Review & Education, 2020.
[35] P.V. Nielsen, Flow in Air Conditioned Rooms. English Translation and Revision of PhD Thesis, Technical University of Denmark, Copenhagen, 1976.
[36] S. Kato, S. Murakami, A. Mochida, S. Akabayashi, Y. Tominaga, Velocity-pressure field of cross-ventilation with open windows analyzed by wind tunnel and numerical simulation, J. Wind Eng. Ind. Aerod. 44 (1992) 2575–2586.
[37] Q. Chen, Prediction of room air motion by Reynolds-stress models, Build. Environ. 31 (1996) 233–244.
[38] Q. Chen, N.T. Chao, Comparing turbulence models for buoyant plume and displacement ventilation simulation, Indoor Built Environ. 6 (1997) 140–149.
[39] P.V. Nielsen, Computational fluid dynamics and room air movement, Indoor Air 14 (Suppl. 7) (2004) 134–143.
[40] T. van Hooff, B. Blocken, Coupled urban wind flow and indoor natural ventilation modelling on a high-resolution grid: a case study for the Amsterdam ArenA stadium, Environ. Model. Software 25 (1) (2010) 51–65.
[41] P. Karava, T. Stathopoulos, A.K. Athienitis, Airflow assessment in cross-ventilated buildings with operable facade elements, Build. Environ. 46 (2011) 266–279.
[42] R. Ramponi, B. Blocken, CFD simulation of cross-ventilation for a generic isolated building: impact of computational parameters, Build. Environ. 53 (2012) 34–48.
[43] B. Blocken, Computational Fluid Dynamics for Urban Physics: importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations, Build. Environ. 91 (2015) 219–245.
[44] B.A. Craven, G.S. Settles, A computational and experimental investigation of the human thermal plume, J. Fluids Eng.-Trans. ASME 128 (6) (2006) 1251–1258.
[45] Y. Li, G.M. Leung, J.W. Tang, et al., Role of ventilation in airborne transmission of infectious agents in the built environment - a multidisciplinary systematic review, Indoor Air 17 (1) (2007) 2–18.
[46] CDC, SARS-CoV-2 & Potential Airborne Transmission, Centers for Disease Control and Prevention, 2020. https://www.cdc.gov/coronavirus/2019-ncov/more/scientific-brief-sars-cov-2.html. Retrieved on 21 October 2020.
[47] European Centre for Disease Prevention and Control, Heating, Ventilation and Air-Conditioning Systems in the Context of COVID-19. 22 June 2020, 2020. www.ecdc.europa.eu/en/publications-data/heating-ventilation-air-conditioning-systems-covid-19. Retrieved on 22 October 2020.
[48] ASHRAE 2020. ASHRAE Issues Statements on Relationship between COVID-19 and HVAC in Buildings, 2020. https://www.ashrae.org/about/news/2020/ashrae-issues-statements-on-relationship-between-covid-19-and-hvac-in-buildings. Retrieved on 22 October 2020.
[49] REHVA 2020, How to operate HVAC and other building service systems to prevent the spread of the coronavirus (SARS-CoV-2) disease (COVID-19) in workplaces, REHVA COVID-19 guidance document (2020). www.rehva.eu/fileadmin/user upload/REHVA COVID 19 guidance document V3 03082020.pdf. Retrieved on 22 October 2020.
[50] A.J. Carlisle, N.C.C. Sharp, Exercise and outdoor ambient air pollution, Br. J. Sports Med. 35 (2001) 214–222.
[51] A. Andrade, F.H. Dominski, M.L. Pereira, et al., Infection risk in gyms during physical exercise, Environ. Sci. Pollut. Control Ser. 25 (2018) 19675–19686.
[52] S. Chang, E. Pierson, P.W. Koh, et al., Mobility network models of COVID-19 explain inequities and inform reopening, Nature 589 (2020) 82–107.
[53] S. Jang, S.H. Han, J.Y. Rhee, Cluster of Coronavirus Disease Associated with Fitness Dance Classes, South Korea vol. 26б, Emerging Infectious Diseases, Research Letter, 2020, https://doi.org/10.3201/eid2608.200633.
[54] B. Serrure, R. Verrycken, How the epidemic got derailed in Antwerp, in: Dutch: Hoe de Epidemie Ontspoorde in Antwerpen), Newspaper De Tijd, 2020, 1 August 2020, https://www.tijd.be/dossiers/coronavirus/hoe-de-epidemie-ontspoorde-in-antwerpen/10242577.html. Retrieved on 17 August 2020.
[55] F. Ye, S. Xu, Z. Rong, et al., Delivery of infection from asymptomatic carriers of COVID-19 in a familial cluster, Int. J. Infect. Dis. 94 (2020) 133–138.
[56] C. Rothe, M. Schunk, P. Sothmann, et al., Transmission of 2019-ncov infection from an asymptomatic contact in Germany, N. Engl. J. Med. 382 (10) (2020) 970–971.
[57] S.M. Nyenhuis, J. Greiwe, J.S. Zeiger, et al., Exercise and fitness in the age of social distancing during the COVID-19 Pandemic, J. Allergy Clin. Immunol.: In Pract. (2020), https://doi.org/10.1016/j.jaip.2020.04.039. Epub ahead of print.
[58] P. Chen, L. Mao, G.P. Nassis, et al., Coronavirus disease (COVID-19): the need to maintain regular physical activity while taking precautions, J. Sport Health Sci. 9 (2) (2020) 103–104.
[59] G.J. Rubin, S. Wessely, The psychological effects of quarantining a city, Br. Med. J. 368 (2020) m313.
[60] P. Hover, P. van Eldert, Fitnessbranche in Nederland 2018: kerncijfers vraag- en aanbodzijde (in Dutch), Mulier Instituut, Utrecht, 2019 factsheet 2019/1.
[61] Platform ondernemende sportaanbieders. https://www.ondernemendesportaanbieders.nl/overzicht-statistieken, 2020. Retrieved on 17 August 2020.
[62] C.A. Alves, A.I. Calvo, A. Castro, et al., Indoor air quality in two university sports facilities, Aerosol Air Qual. Res. 13 (2013) 1723–1730.
[63] A. Andrade, F.H. Dominski, Indoor air quality of environments used for physical exercise and sports practice: systematic review, J. Environ. Manag. (2018) 577–586.
[64] H. Salonen, T. Salthammer, L. Morawska, Human exposure to air contaminants in sports environments, Indoor Air 30 (2020) 1109–1129.
[65] C.A. Ramos, J.F. Reis, T. Almeida, F. Alves, et al., Estimating the inhaled dose of pollutants during indoor physical activity, Sci. Total Environ. 527–528 (2015) 111–118.
[66] N. Canha, M.C. Freitas, S.M. Almeida, et al., Indoor school environment: easy and low cost to assess inorganic pollutants, J. Radioanal. Nucl. Chem. 286 (2) (2010) 495–500.
[67] N. Canha, M. Martinho, M. Almeida Silva, et al., Indoor air quality in primary schools, Int. J. Environ. Pollut. (1/2/3/4) (2012) 396–410.
[68] M. Braniš, J. Safranek, Characterization of coarse particulate matter in school gym, Environ. Res. 111 (4) (2011) 485–491.
[69] C.A. Ramos, H.T. Wolterbeek, S.M. Almeida, Exposure to indoor air pollutants during physical activity in fitness centers, Build. Environ. 82 (2014) 349–360.
[70] K. Slezakova, C. Peixoto, M. Oliveira, et al., Indoor particulate pollution in fitness centres with emphasis on ultrafine particles, Environ. Pollut. 233 (2018) 180–193.
[71] D. Etheridge, M. Sandberg, Building Ventilation: Theory and Measurements, Wiley, 1996. -13: 978-0471960874.
[72] AIVC, Air Infiltration and Ventilation Centre, International Energy Agency, 2020. Retrieved on 11 May 2020, https://www.aivc.org/resources/faqs/what-ventilation.
[73] H. Awbi, Ventilation of Buildings, Spon Press, 2003.
[74] Q. Chen, Ventilation performance prediction for buildings: a method overview and recent applications, Build. Environ. 44 (4) (2009) 848–858.
[75] B. Blocken, 50 years of computational wind engineering: past, present and future, J. Wind Eng. Ind. Aerod. 129 (2014) 69–102.

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[76] Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, Building code. Bouwbesluit online (in Dutch), Retrieved on 11 May 2020, https://rijksoverheid.bouwbesluit.com/Inhoud/docs/wet/bb2012/hfd3, 2012.
[77] J.P.E. Ariëns, T.A. Joosten, W. Schriemer, et al., Guidebook sports accommodations (in Dutch), in: Handboek Sportaccommodaties. ISA Sport, NOC*NSF, Arko Sports Media BV, 2008.
[78] Stichting Onbeperkt Sportief, Guidelines for accessibility of indoor sports accommodations (in Dutch), Retrieved on 10 May 2020, http://www.onbeperktsportief.nl/content/toegankelijke-indoor-sportaccommodaties, 2014, 84.
[79] ASHRAE, Pandemic COVID-19 and airborne transmission, Environ. Health Committ.(EHC) Emerging Issue Brief (2020). https://www.ashrae.org/file%20library/technical%20resources/covid-19/eiband-airbornetransmission.pdf. Retrieved on 13 May 2020.
[80] ASHRAE, Ventilation for acceptable indoor air quality, ANSI/ASHRAE Standard 62 (2019) 1–2019.
[81] ASHRAE, ASHRAE Position Document on Filtration and Air Cleaning, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2015. http://www.ashrae.org/file%20library/about/position%20documents/filtration-and-air-cleaning-pd.pdf. http://www.ashrae.org/file library/about/position documents/filtration-and-air-cleaning-pd.pdf'www.ashrae.org/file%20library/about/position%20documents/filtration-and-air-cleaning-pd.pdf.
[82] W.J. Fisk, D. Faulkner, J. Polonen, et al., Performance and costs of particle air filtration technologies, Indoor Air 12 (2002) 223–234.
[83] Y.S. Cheng, J.C. Lu, T.R. Chen, Efficiency of a portable indoor air cleaner in removing pollens and fungal spores, Aerosol Sci. Technol. 29 (2) (1998) 92–101.
[84] R. Green, A. Simpson, A. Cutovic, et al., The effect of air filtration on airborne dog allergen, Allergy 54 (5) (1999) 484–488.
[85] S.J. Emmerich, S.J. Nabinger, Measurement and simulation of the IAQ impact of particle air cleaners in a single-zone building, Int. J. Heating, Ventilating, Air-Condition. Refrig. Res. 7 (3) (2001) 223–244.
[86] AHAM, Method for measuring performance of portable household electric room air cleaners, in: Approved American National Standard – Association of Home Appliance Manufacturers, ANSI/AHAM AC-1, 2015.
[87] C. Asbach, A. Held, A. Kiendler-Scharr, et al., Position paper of the Gesellschaft für Aerosolforschung on understanding the role of aerosol particles in SARS-CoV-2 infection, Assoc. Aerosol Res. 17 (2020). December 2020.
[88] C. Kähler, T. Fuchs, R. Hain, Können mobile Raumluftreiniger eine indirekte SARS-CoV-2 Infektionsgefahr durch Aerosole wirk sam reduzieren? 5 August 2020, 2020. https://www.unibw.de/lrt7/raumluftreiniger.pdf.
[89] M.S. Waring, J.A. Siegel, R.L. Corsi, Ultrafine particle removal and generation by portable air cleaners, Atmos. Environ. 42 (2008) 5003–5014.
[90] Y. Zhang, J. Mo, Y. Li, et al., Can commonly used fan driven air cleaning technologies improve indoor air quality? A literature review, Atmos. Environ. 45 (2011) 4329–4343.
[91] H.J. Kim, B. Han, Y.J. Kim, et al., Submicrometer particle removal indoors by a novel electrostatic precipitator with high clean air delivery rate, low ozone emissions, and carbon fiber ionizer, Indoor Air 23 (2013) 369–378.
[92] J. Gunschera, D. Markewitz, B. Bansen, et al., Portable photocatalytic air cleaners: efficiencies and by-product generation, Environ. Sci. Pollut. Control Ser. 23 (2016) 7482–7493.
[93] K.F.G. Olofson, P.U. Andersson, M.L. Hallquist, et al., Urban aerosol evolution and particle formation during winter time temperature inversions, Atmos. Environ. 43 (2009) 340–346.
[94] Grimm Aerosol Technik, Portable Aerosol Spectrometer, Model 11-D, Grimm Aerosol Technik Ainring GmbH & Co.KG, Ainring, Germany, 2020.
[95] PlasmaMade, 2020. Retrieved on 21 October 2020, https://www.plasmamade.nl.
[96] CloudGarden, Product sheet Cloud Garden climate sensor CG.TRHCV.D, Cloud-Garden-Klimaatsensor-Nederlands-incl-technische-specs (2020) pdf. Retrieved on 17 August 2020.
[97] K.C. Noh, M.D. Oh, Variation of clean air delivery rate and effective air cleaning ratio of room air cleaning devices, Build. Environ. 84 (2015) 44–49.
[98] ASHRAE, HVAC Application 2007, American Society of Heating, Refrigerating and Air-Conditioning Engineerings, Inc., Atlanta, 2007.
[99] J.D. Spengler, J. Vallarino, E. McNeely, H. Estephan, In-flight/onboard Monitoring: ACER's Component for ASHEAE 1262, Part 2, National Air Transportation Center of Excellence for Research in the Intermodal Transport Environment, Boston, MA, 2012 (RITE).
[100] A. Persily, J. de Jonge, Carbon dioxide generation rates for building occupants, Indoor Air 27 (2017) 868–879.
[101] B. Mølgaard, A.J. Koivisto, T. Hussein, et al., A new clean air delivery rate test applied to five portable indoor air cleaners, Aerosol. Sci. Technol. 48 (4) (2014) 409–417.
[102] C.M. Long, H.H. Suh, P.J. Catalano, et al., Using time and size resolved particulate data to quantify indoor penetration and deposition behavior, Environ. Sci. Technol. 35 (10) (2001) 2089–2099.
[103] C.Y.H. Chao, M.P. Wan, E.C.K. Cheng, Penetration coefficient and deposition rate as a function of particle size in non-smoking naturally ventilated residences, Atmos. Environ. 37 (30) (2003) 4233–4241.
[104] L. Wallace, Indoor particles: a review, J. Air Waste Manag. Assoc. 46 (2) (1996) 98–126.
[105] R.J. Shaughnessy, R.G. Sextro, What is an effective portable air cleaning device: a review, J. Occup. Environ. Hyg. 3 (4) (2006) 169–181.
[106] T.L. Thatcher, A.C. Lai, R. Moreno-Jackson, et al., Effects of room furnishings and air speed on particle deposition rates indoors, Atmos. Environ. 36 (2002) 1811–1819.
[107] M. Xu, M. Nematollahi, R.G. Sextro, et al., Deposition of tobacco smoke particles in a low ventilation room, Aerosol Sci. Technol. 20 (1994) 194–206.
[108] S.K. Friedlander, H.F. Johnstone, Deposition of suspended particles from turbulent gas streams, Ind. Eng. Chem. 49 (7) (1957) 1151–1156.
[109] R. You, W. Cui, C. Chen, B. Zhao, Measuring the short-term emission rates of particles in the "Personal Cloud" with different clothes and activity intensities in a sealed chamber, Aerosol Air Qual. Res. 13 (2013) 911–921.
[110] Eindhoven University of Technology, You tube channel. https://www.youtube.com/watch?v=qS2MnmRLAAI.
[111] B. Blocken, T. van Druenen, T. van Hooff, et al., Can indoor sports centers be allowed to re-open during the COVID-19 pandemic based on a certificate of equivalence? Build. Environ. (2020) 107022. Article nr.

4) Blog over de mogelijkheid om de horeca verder te heropenen op 1 mei 2021 (Publicatiedatum: 05/04/2021)

Op Paasmaandag 2021 publiceerde ik deze blog op *Linked In* met de bedoeling om via een reeks haalbare maatregelen de horeca, zowel buiten als binnen, veilig te kunnen heropenen op 1 mei. Deze blog is, wat ventilatie en luchtreiniging betreft, gebaseerd op het wetenschappelijke artikel in het vorige hoofdstuk van deze brief.

De blog is hier onder bijgevoegd. Deze kan ook online worden gelezen via:

https://www.linkedin.com/pulse/kan-de-horeca-terug-veilig-open-en-blijven-tijdens-bert-blocken

Kan de horeca terug veilig open en open blijven tijdens de COVID-19-pandemie?


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SAMENVATTING

Op een onderbreking na is de horeca nu al vele maanden dicht. COVID-19 woedt hevig, ziekenhuizen en hun personeel staan onder zware druk. Maar ook horecauitbaters staan onder zware druk. De horeca faciliteert ontmoetingen tussen mensen en is daarom belangrijk voor het sociale weefsel in onze samenleving. Het staat echter buiten discussie dat de horeca, zonder veiligheidsmaatregelen, kan bijdragen aan COVID-19-besmettingen. Maar als we een reeks van strikte veiligheidsmaatregelen in acht nemen, zou de horeca dan toch niet snel en op veilige wijze terug open kunnen en open kunnen blijven in de COVID-19-pandemie? Rekening houdend met de diverse overdrachtsvormen van het virus en enkele bijkomende maatregelen, is ons antwoord hierop "ja". Die maatregelen worden hieronder opgesomd. Nadien volgt in deze blog een uitgebreide onderbouwing, geschreven in lekentaal. Het besluit is dat mits goede wil en inzet van de overheid en de nodige discipline van de uitbaters en bezoekers, de horeca veilig open moet kunnen blijven.

HOE KAN DE HORECA SNEL EN VEILIG TERUG OPEN?

Geen enkele maatregel is zaligmakend en biedt 100% veiligheid, behalve eenzame afzondering op een verder onbewoonde locatie. Vandaar het belang om diverse veiligheidslagen, en dus diverse maatregelen tegelijk te voorzien. Een plakje Zwitserse kaas heeft heel wat gaten, maar als je meerdere plakjes op elkaar legt wordt het aantal gaten van de stapel steeds kleiner. Uiteraard is maximale bezetting van restaurants en cafés niet mogelijk tijdens een pandemie. Veel is niet mogelijk, maar we moeten ons richten op wat wel kan. Hierbij een reeks noodzakelijke maatregelen, die allemaal tegelijk toegepast moeten worden voor de nodige veiligheid. Deze maatregelen zijn niet gratis maar een aantal hiervan werden ook al toegepast door de horeca. Vooral maatregel nr. 8 voor horeca binnen vraagt een investering, al zijn er tegenwoordig al goede luchtreinigers verkrijgbaar voor ongeveer 500 € per stuk en moet de overheid initiatief nemen om de aankoop van luchtreinigers door horecauitbaters grotendeels te subsidiëren. De combinatie van deze maatregelen zou voldoende moeten zijn voor een veilig restaurant- of cafébezoek.

HORECAMAATREGELEN BUITEN

1. Bij transport naar en van de horecalocatie worden alle huidige maatregelen in acht genomen. Afstand op openbaar vervoer, mondmaskers, etc.
2. In de horecazaak kan men enkel zitten, niet staan.
3. Mondmaskers worden gedragen totdat men zit. Als men terug rechtstaat om bvb. naar het toilet te gaan, wordt het mondmasker terug gedragen.
4. Bezoekers ontsmetten handen bij binnenkomst en na toiletbezoek en oppervlakken in de zaak worden regelmatig ontsmet.
5. De tafels staan zo ver uit elkaar dat de afstand tussen enerzijds de personen aan tafel A en anderzijds de personen aan tafel B minstens 1,5 m is.
6. Als het gezelschap aan een tafel niet bestaat uit mensen uit dezelfde "bubbel", wordt op de tafel een plexiglasscherm vastgeklikt, van minstens 1 m hoog, dat er voor zorgt dat er geen directe druppeluitwisseling mogelijk is tussen de personen aan dezelfde tafel (zie figuur 1). Bubbelregistratie kan eventueel vooraf via een gebruiksvriendelijke website. Dankzij deze schermen hoeven personen aan dezelfde tafel geen 1,5 m te houden. Je zal wel iets harder moeten spreken om elkaar goed te verstaan. Wat helpt is dat er in totaal minder aanwezigen zullen zijn dan in een niet-COVID-19-periode.
7. Politie, stewards of andere functionarissen oefenen regelmatig controle uit. Dit kan voor 1 mei gerealiseerd worden.

Figuur 1: Tafel met plexiglas schermen voor personen niet behorend tot zelfde "bubbel".

HORECAMAATREGELEN BINNEN

Voor binnen wordt een achtste maatregel toegevoegd:

8. Ventilatie en luchtreiniging zorgen samen voor een luchtverversingsfrequentie van minstens zes keer per uur. Dit getal is gebaseerd op de richtlijnen van de Duitse Aerosolgemeenschap [1] en op verificatie door ons eigen onderzoek [2] (directe gratis toegang hier: doi.org/10.1016/j.buildenv.2021.107659). Luchtverversingsfrequentie zes per uur wil zeggen dat het volledige binnenvolume aan lucht zes keer per uur vervangen wordt door buitenlucht OF gereinigd wordt door luchtreinigers in de zaak (Figuur 2). Hieronder leggen we uit hoe dit bereikt kan worden. Intelligentere systemen, zoals een tafel met ingebouwde luchtreiniger, kunnen extra veiligheid bieden.

Figuur 2: Luchtreinigers in de vorm van alleenstaande, mobiele units: van links naar rechts: van klein naar groot (in hoogte).

Uit ons recente onderzoek naar de verwijdering van aerosolen uit een fitnessruimte werd aangetoond dat een luchtwisseling van iets meer dan zes keer per uur door combinatie van ventilatie en luchtreiniging genoeg was om de aerosolenconcentratie te reduceren met meer dan 90% [2] (zie Figuur 3). Dit was een stress-test voor ventilatie en luchtreiniging, want sportende personen stoten meer aerosolen uit dan mensen die in de horeca aan een tafeltje zitten [3,4].

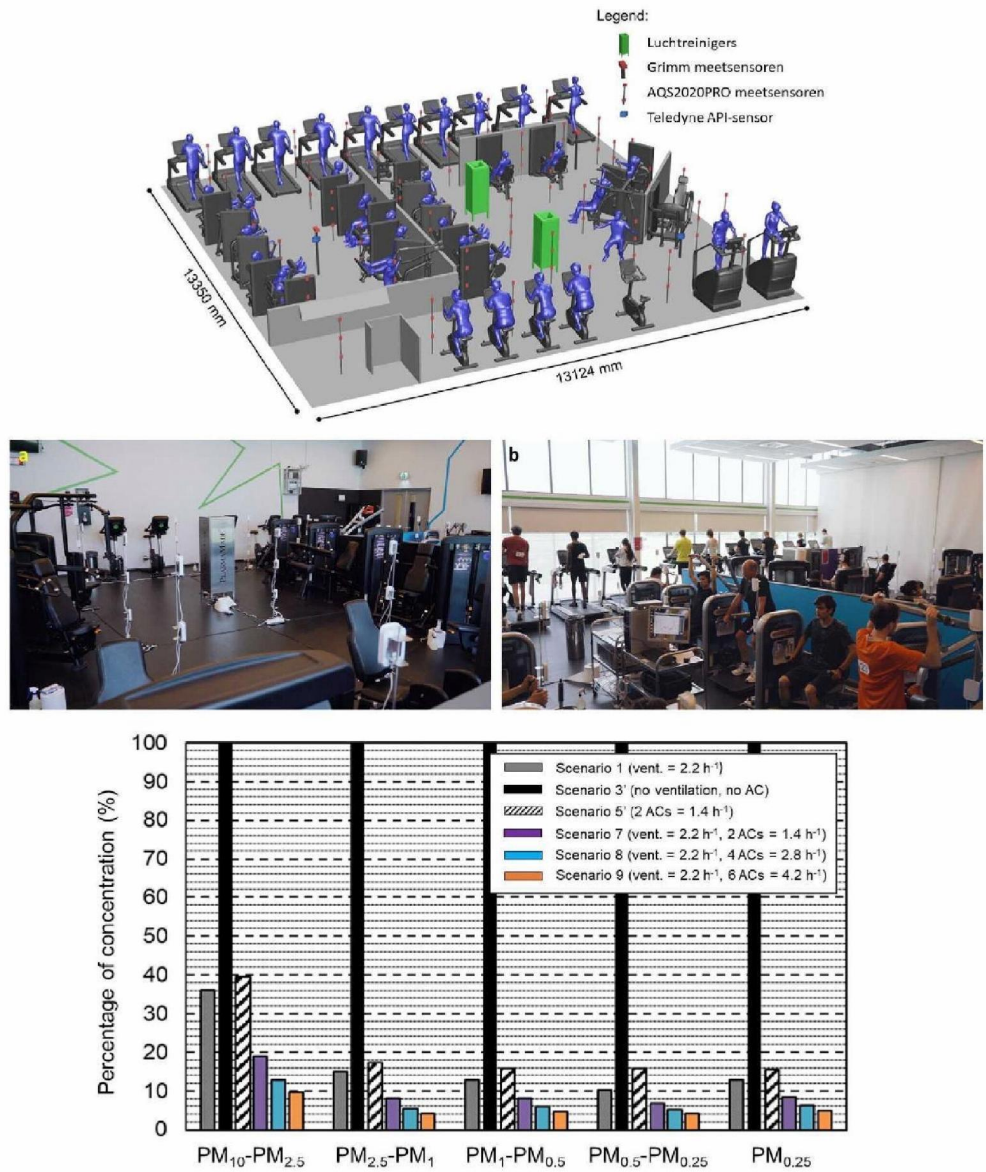
WAT MOET DE OVERHEID DOEN OM DIT MOGELIJK TE MAKEN?

Drie acties:

1. Snel een systeem in werking stellen waarbij de luchtverversingsfrequentie van zes keer per uur vastgesteld kan worden. Bijvoorbeeld een eenvoudige en gebruiksvriendelijke website lanceren waarop elke horecauitbater de eigenschappen van zijn/haar ventilatiesysteem invult. Een deskundige en/of ambtenaar kan dit daarna ter plaatse vaststellen, snel en eenvoudig op een 10-tal minuten. Op korte termijn kunnen alle zaken in België en Nederland beoordeeld worden. De overheid geeft dan een kwaliteitslabel luchtkwaliteit aan deze zaak, ofwel adviezen om dit kwaliteitslabel te halen. Dat label moet ook dienen voor volgende golven en volgende pandemieën.Indien nodig kunnen luchtreinigers geïnstalleerd worden op minder dan een uur.

2. De overheid moet aan een groep van onafhankelijke wetenschappelijke experts van de diverse landelijke universiteiten of onderzoeksinstituten vragen om bvb. 50 luchtreinigers van diverse fabrikanten te testen en te evalueren. Op basis hiervan grootschalige aankopen organiseren van de beste producten en deze aan laag tarief aanbieden aan horecauitbaters.

3. De overheid zet een systeem op om restaurants en cafés financieel steunen om hun ventilatie en luchtreiniging op order te brengen. Restaurants en cafés die hun ventilatie en luchtreiniging op orde brengen moeten ook beloond worden, bijvoorbeeld met de garantie dat bij een volgende golf of volgende pandemie van een gelijkaardige virus deze zaken pas als laatsten of helemaal niet meer gesloten worden.



Figuur 3: Boven: Schematische opstelling van het experiment met 35 sportende proefpersonen in de fitnessruimte van de Technische Universiteit Eindhoven. Midden: Foto's van meetopstelling zonder en met sportende personen. Onder: Reducties (in percent) door toepassing ventilatie, luchtreiniging en combinatie van beiden. Blauwe balkjes zijn voor 5 luchtverversingen per uur, oranje balkjes zijn voor 6,4 luchtverversingen per uur. Bron: [2].

ONDERBOUWING

COVID-19 transmissieroutes

SARS-CoV-2 kan overgedragen worden via direct en nabij contact, als druppels uitgestoten door het ademhalingssysteem van een persoon terecht komen op/in de ogen, neus of mond van een ander persoon. Overdracht kan ook via besmette oppervlakken, hoewel wetenschappers inmiddels het belang van deze transmissieroute in vraag stellen [5,6]. SARS-CoV-2 kan ook overdragen via aerosoldruppeltjes, dit zijn kleine druppels die door mensen worden uitgestoten en die door hun geringe grootte vrijwel onmiddellijk verdampen, en wegens hun lage massa lang in de lucht kunnen blijven zweven. Ze kunnen zo veel langere afstanden afleggen dan de 1,5 m sociale afstand. Onderzoek heeft aangewezen dat het virus aanwezig kan zijn in deze kleine druppeltjes en dat het een levensvatbaarheid heeft van ongeveer een uur (halfwaardetijd) [7]. Belangrijk dus.

Aerosolen: problematisch of niet?

Eigenaardig genoeg werd het belang van de aerosoldruppels in de overdracht van het virus lang ontkend of ten minste geminimaliseerd. Om onduidelijke redenen. Zo is het zeer moeilijk om bepaalde massabesmettingen te verklaren zonder de aerosolroute, dus enkel op basis van de uitwisseling van druppels op korte afstand (typisch kleiner dan 1,5 m) of via besmette oppervlakken. Wanneer na een jodelconcert in Zwitserland met 600 aanwezigen een 300-tal van deze personen besmet blijkt [8], dan is het moeilijk zich in te beelden dat deze personen elkaar allemaal innig hebben omhelst of allemaal – bij wijze van spreken – uit hetzelfde glas hebben gedronken. Met grote waarschijnlijkheid was de ventilatie ter plaatse onvoldoende en heeft een te hoge concentratie aan aerosoldeeltjes geleid tot deze massabesmetting. Zou dit ook een verklaring kunnen zijn voor de vele besmettingen in slecht geventileerde rust- en verzorgingstehuizen? Mogelijk.

De verkeerde verdachte (?)… en de irrelevante discussie

De bovenstaande argumentatie wordt bevestigd door belangrijke vaststellingen van onder meer wetenschappers en de CDC (Centers for Disease Control) in de Verenigde Staten en door publicaties in het toptijdschrift Nature. Een paar recente publicaties in Nature geven aan: "COVID-19 wordt zelden overgedragen via oppervlakken. Waarom blijven we dan extreem ontsmetten?" [5], "We hebben ons vergist: het virus zit niet zozeer op oppervlakken maar in de lucht" [6] en "Waarom binnenruimtes nog steeds primaire COVID-19-hotspots zijn" [9]. Kort samengevat: aerosolen zijn belangrijk, en misschien zijn de aerosoldruppeltjes wel de belangrijkste oorzaak van besmettingen in binnenruimtes. Eind mei vorig jaar liet de topviroloog [redacted], die Angela Merkel adviseert, al optekenen: "ventileren wordt belangrijker dan handen wassen" [10]. Kort daarna sloten vele – maar lang niet alle – virologen in Europa zich bij hem aan. Nog steeds echter ontkent een kleine groep van virologen dat de aerosolen een grote rol spelen, vaak met het argument: "het is nog niet onomstotelijk wetenschappelijk aangetoond dat de aerosolen een belangrijke rol spelen". Misschien past hierbij de volgende repliek: "het is ook nog niet onomstotelijk wetenschappelijk aangetoond dat de aerosolen géén belangrijke rol spelen". En de volgende: "Omdat ze belangrijk kunnen zijn, zijn we het aan de maatschappij verplicht om de nodige voorzorgen te nemen". Dat is het voorzorgsprincipe, en dat is precies het standpunt dat al sinds maart vorig jaar zowel door het European Center for Disease Control and Prevention (ECDC) en de CDC in de Verenigde Staten wordt gehanteerd maar door te veel personen, organisaties en overheden werd - en soms zelfs nog steeds wordt - genegeerd, nu al 12 maanden na datum.

Ventilatie en…

Sinds het begin van de pandemie pleiten ingenieurs en ondernemers wereldwijd al lang voor meer aandacht voor aerosolen en ventilatie. Later sloten andere experts zich hier bij aan, met het dwingende advies: "we moeten méér ventileren" of "we moeten goed ventileren". Maar hoeveel is "meer" en hoeveel is "goed"? CO2-meters kunnen een eerste indicatie geven, hoewel de meting erg afhangt van de plaats waar de meter hangt. De Duitse aerosolgemeenschap raadt aan: vier tot zes luchtverversingen per uur, met voorkeur voor zes in het kader van de COVID-19-pandemie [1]. Ons onderzoek met de stress-test in het fitnesscentrum heeft aangetoond dat zes luchtverversingen per uur de aerosolenconcentraties kan reduceren met bijna 90% en meer, afhankelijk van de druppelgrootte [2]. Zes luchtverversingen per uur betekent dat het hele luchtvolume in een ruimte zes keer vervangen wordt door buitenlucht. Dat is erg veel. Misschien haalbaar in de zomer, maar in de herfst of lente, laat staan de winter, moet al die inkomende koude lucht verwarmd worden… dat lijkt onbegonnen werk, en dat is het ook in vele gevallen.

Met een mechanisch ventilatiesysteem en warmterecuperatie zou dit wel haalbaar kunnen zijn, maar hoeveel scholen en woonzorgcentra in België en Nederland hebben zo'n systeem? Een mechanisch ventilatiesysteem installeren betekent ventilatorblok, luchtkanalen tegen het plafond, toevoer- en afvoeropeningen en roosters, etc. Kost veel geld, duurt lang om te installeren. Naar (ruwe) schatting, voor een gemiddelde school: 20000 € per klaslokaal. Financieel niet haalbaar voor nagenoeg alle scholen, zelfs met deels subsidie door de overheid. Is er geen betere oplossing?

...de blinde vlek: luchtreiniging

Die betere oplossing was wel al bekend, maar slechts bij een beperkte kring ingenieurs en ondernemers, die nauwelijks aan bod zijn gekomen in de media en niet op het netvlies van de overheid staan. Die oplossing is luchtreiniging. Een luchtreiniger is een apparaat dat ofwel in de kanalen van een mechanisch ventilatiesysteem kan worden geplaatst, ofwel als mobiele alleenstaande unit op de vloer in een ruimte. Die technologie bestaat al decennia. **Ze wordt al decennialang toegepast in clean rooms en in operatiekamers in ziekenhuizen, wanneer een zeer grote luchtzuiverheid vereist is.** Er werden in de voorbije jaren vele onafhankelijke studies uitgevoerd en gepubliceerd die het nut van deze apparaten hebben aangetoond, althans van de degelijke exemplaren [2,11-23].

De meeste luchtreinigers halen de deeltjes uit de lucht, zowel de vaste deeltjes (in de volksmond: "fijn stof") als de (voordien) vloeibare deeltjes (aerosoldruppeltjes). Voor de zuiveringstechnologie zelf zijn er diverse mogelijkheden, zoals HEPA-filters, plasmatechnologie en elektrostatische precipitatie. Zoals bij vele andere apparaten geldt ook bij luchtreinigers: er zijn goede apparaten, slechte apparaten en schadelijke apparaten. Goede luchtreinigers halen deeltjes uit de lucht met een hoge efficiëntie (groter dan 85%) en zonder generatie van schadelijke bijproducten. Schadelijke apparaten genereren wel ongewenste bijproducten. Goede luchtreinigers zijn al beschikbaar voor ongeveer 500 €. Mogelijk zijn er wel meerdere nodig, voor een groot klaslokaal bijvoorbeeld vier. 2000 € is wel nog steeds tien keer minder dan de 20000 € installatiekosten van het ventilatiesysteem in het hogervermelde klaslokaal. Luchtreiniging is ook goedkoper in gebruik, omdat de behandelde lucht niet van buiten komt en niet opgewarmd hoeft te worden.

Combinatie van ventilatie en luchtreiniging

Gebouwen moeten volgens de wet geventileerd worden. Zelfs als er luchtreinigers geïnstalleerd worden, is een minimum ventilatie vereist. Niet enkel om aan de wet te voldoen, maar ook om CO_2 en andere gassen af te voeren, die door de meeste luchtreinigers niet worden verwijderd. Let daarom op met CO_2-meters: wanneer er luchtreinigers worden toegepast, kan het zijn dat de CO_2-meters hoge waarden geven terwijl de lucht toch goed gezuiverd wordt.

TENSLOTTE: 10 VRAGEN EN ANTWOORDEN

1. We horen voortdurend verschillende opinies. Waarom zouden wij het bovenstaande advies moeten volgen?

Dit is gratis en vrijblijvend advies: niemand is verplicht om het te volgen. Dit advies volgt uit uitgebreid literatuuronderzoek en uit ons eigen onderzoek en 22 jaar ervaring in aerodynamica (windstroming en ventilatie) in en rond gebouwen. Dit advies is bedoeld als recept voor de horeca om veilig open te kunnen blijven, zo snel mogelijk en met zo weinig en laag mogelijke investeringen. Voor buitenterrassen kan men zeer snel de nodige maatregelen in de praktijk omzetten.

2. Sommige publicaties stellen dat luchtreinigers lucht met besmette aerosolen van de ene persoon naar de andere kan blazen en dat dit een risico kan zijn. Zijn ze daarom gevaarlijk?

Aerosolen van de ene naar de andere persoon blazen kan evenzeer gebeuren buiten, door de wind, of binnen, door natuurlijke of mechanische ventilatie. Het is gevaarlijker om helemaal geen ventilatie of luchtreiniging te voorzien, want dan wordt de aerosolenconcentratie **overal in de ruimte** groot. Geen enkele oplossing is 100% veilig, en of je nu buiten of binnen zit en hoeveel ventilatie of luchtreiniging je ook toepast, het is nooit verstandig om met je gezicht pakweg 20 cm in de buurt van het gezicht van een andere persoon te komen. Ventilatie en luchtreiniging blijven belangrijke maatregelen. Niet voor niets worden luchtreinigers al decennialang toegepast in clean rooms en in operatiekamers in ziekenhuizen, wanneer en zeer grote luchtzuiverheid vereist is en besmetting absoluut vermeden moet worden.

3. Hoe weet ik of een luchtreiniger een goede luchtreiniger is?

Dat is momenteel nog een moeilijk punt. Europese certificering moet nog rigorous doorgevoerd worden. We werken momenteel aan een vergelijkende studie van luchtreinigers. Best kies je geen luchtreinigers van dubieuze fabrikanten of websites. Fabrikanten van luchtreinigers die onafhankelijk wetenschappelijk zijn getest plaatsen meestal het bewijs van die testen op hun website met vermelding van het onderzoeksinstituut of de universiteit. Let er ook hier op dat het moet gaan om gerenommeerde instituten of universiteiten. Dat is dan vaak een goede indicatie.

4. Hoe weet ik hoeveel luchtreinigers ik nodig heb?

Eerst bereken je hoeveel luchtverversingen per uur je huidige ventilatiesysteem biedt. Bvb. het bestaande systeem levert 1000 m³ per uur en het volume van je zaak is 500 m³ per uur. Dat is al 2 luchtverversingen per uur. Als je het ventilatiesysteem sterker kan instellen, is dat een goede optie. Indien niet, dan kan je die 4 extra nodige luchtverversingen per uur aanvullen met luchtreiniging. Je hebt dan 2000 m³ per uur aan luchtreiniging nodig. Hoeveel m³ per uur één luchtreiniger levert, lees je in de specificaties van dat toestel.

5. Waar in mijn zaak moet ik de luchtreinigers plaatsen?

Best in het midden van de zaak, en als je er meerdere plaatst, verspreid over de zaak. Niet allemaal bij elkaar in een hoek van de zaak, want dan is het effect vooral beperkt tot die hoek.

6. Heb ik luchtreinigers buiten nodig?

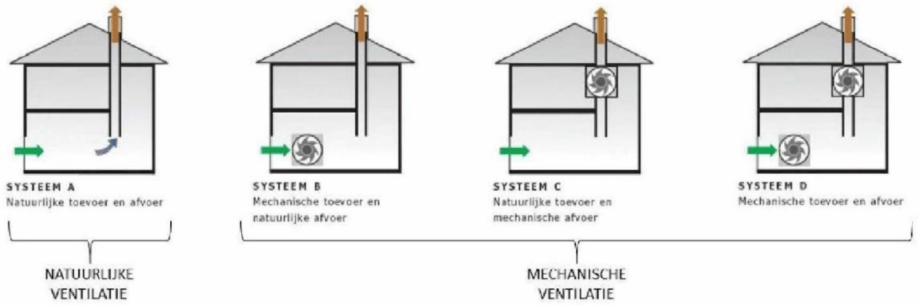
Tenzij het gaat om een bijna volledige afgeschermde buitenruimte of veranda, heb je normaal buiten geen luchtreinigers nodig, op voorwaarde dat de tafels minstens 1,5 m uit elkaar staan en met plexiglas schermen uitgerust zijn, omdat de aerosolen dan snel verdund worden in de buitenlucht.

7. Is het niet voldoende als ik in de zomer mijn ramen open zet?

Dat hangt er van af. Als het enkel gaat om ramen in dezelfde gevel, dan zal de ventilatie vooral goed zijn bij de tafels nabij die ramen. De ventilatie dieper in de zaak zal beperkt zijn. Als je ramen kan open zetten in tegen over elkaar gelegen gevels, dan wordt de ventilatie meestal een stuk beter. Maar het blijft "natuurlijke ventilatie", dus je moet hopen op wind en op temperatuurverschillen om ventilatie te krijgen.

8. Wat is het verschil tussen natuurlijke en mechanische ventilatie?

Natuurlijke ventilatie is ventilatie zonder gebruik te maken van een ventilatorblok. Het is ventilatie die gedreven wordt door de wind en/of door temperatuurverschillen tussen binnen en buiten. Natuurlijke ventilatie hangt dus af van het weer, is grillig en moeilijk voorspelbaar. In een pandemie waarbij aerosolen een rol spelen, is natuurlijke ventilatie een risico. Mechanische ventilatie is ventilatie gedreven door een ventilatorblok. De hoeveelheid ventilatie kan dus ingesteld worden (zie Figuur 4).



Figuur 4: Natuurlijke ventilatie versus mechanische ventilatie.

9. Waarom bent u zo'n fan van luchtreiniging? Heeft u daar aandelen misschien?

Ik ben geen fan. "Fan zijn van" houdt een subjectieve mening in. Ik adviseer objectief het toepassen van luchtreiniging in combinatie met (al dan niet bestaande) mechanische ventilatie omdat dat voor vele horecazaken maar ook voor scholen en andere gebouwen vaak de enige manier is om de aerosolenconcentraties te beperken. Ventilatie met open ramen is vaak beperkt, en zelfs dan moeten die ramen best de hele tijd open blijven. In de winter, lente en herfst krijg je dan heel hoge kosten voor verwarming. Een nieuw ventilatiesysteem plaatsen of een bestaand upgraden kost veel geld én tijd. Luchtreinigers zijn goedkoper én sneller te installeren. Zorgvuldig selecteren, kopen, afhalen, stekker in het stopcontact en klaar. Wel om de paar maanden de filterunit vervangen in geval van HEPA-filters.
Ik heb geen enkel financieel voordeel door dit advies. Het maakt mij ook niet uit bij welke fabrikant men koopt, als het maar goede producten zijn.

10. Wat weet een burgerlijk ingenieur bouwkunde en expert in aerodynamica over virussen en besmettingen?

Zeker niet zoveel als een viroloog, microbioloog of epidemioloog. Maar dat is ook niet nodig. Een pandemie is per definitie een multidisciplinair probleem en elke discipline heeft daarin haar eigen taak. Zodra virologen, microbiologen en epidemiologen hadden vastgesteld dat het gaat om verspreiding via druppels uit het ademhalingsstelsel en besmette oppervlakken, konden fysici en ingenieurs hun kennis inzetten over de verspreiding van druppels in de lucht en in en rond gebouwen. Dat is ook wat deze blog doet. Deze blog vermeldt daarom ook geen getallen ivm infectierisico's en dergelijke, spreekt niet over de eigenschappen van het virus, maar wel over de verspreiding van druppels. Het virus reist niet alleen, het reist mee met een druppel door de lucht of via een oppervlak. Stop de druppel of ontsmet het oppervlak, dan stop je ook het virus.

DISCLAIMER

Deze blog is geschreven in lekentaal. Voor meer specialistische informatie, in verband met ventilatie-efficiëntie, Clean Air Delivery Rates van luchtreinigers, standardisering, etc, wordt men verwezen naar - onder meer - onderstaande literatuur.

REFERENTIES

[1] Asbach C, Held A, Kiendler-Scharr A, et al. 2020. Position paper of the Gesellschaft für Aerosolforschung on understanding the role of aerosol particles in SARS-CoV-2 infection. Association for Aerosol Research. 17 December 2020.

[2] Blocken B, van Druenen T, Ricci A, Kang L, van Hooff T, Qin P, Xia L, Alanis Ruiz C, Arts JH, Diepens JFL, Maas GA, Gillmeier SG, Vos SB, Brombacher A. 2021. Ventilation and air cleaning

to limit aerosol particle concentrations in a gym during the COVID-19 pandemic. Building and Environment 193: Art. 107659.

[3] Johnson GR, Morawska L. 2009 The mechanism of breath aerosol formation. J. Aerosol Med. Pulm. Drug Deliv. 22(3): 229-237.

[4] Almstrand AC, Bake B, Ljungstrom EL, et al. 2010. Effect of airway opening on production of exhaled particles. Journal of Applied Physiology 108: 584-588.

[5] News feature in Nature. 2021. COVID-19 rarely spreads through surfaces. So why are we still deep cleaning? Nature 590, 26-28. 29 January 2021. https://doi.org/10.1038/d41586-021-00251-4

[6] Editorial in Nature. 2021. Coronavirus is in the air — there's too much focus on surfaces. Nature 590(7). https://doi.org/10.1038/d41586-021-00277-8

[7] van Doremalen N, Morris DH, Holbrook MG, et al. 2020. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. New England Journal of Medecine 382: 1564-1567.

[8] Het Laatste Nieuws. 2020. Jodelconcert in Zwitsers kanton leidt tot honderden besmettingen: "Helft van de tests is positief. https://www.hln.be/buitenland/jodelconcert-in-zwitsers-kanton-leidt-tot-honderdenbesmettingen-helft-van-de-tests-is-positief~a6edc178/. 15 oktober 2020.

[9] Lewis D. 2021. Why indoor spaces are still prime COVID hotspots. Nature 592, 22-25. 30 March 2021. doi: https://doi.org/10.1038/d41586-021-00810-9

[10] Het Laatste Nieuws. 2020. Kamers verluchten nog belangrijker dan handen wassen volgens Duitse topviroloog. https://www.hln.be/medisch/kamers-verluchten-nog-belangrijker-dan-handen-wassen-volgensduitse-topviroloog~a800ae92/ 25 mei 2020.

[11] Okubo M, Yamamoto T, Kuroki T, Fukumoto H. 2001. Electric air cleaner composed of nonthermal plasma reactor and electrostatic precipitator. Transactions on Industry Applications 37(5): 1505-1511.

[12] Batterman S, Godwin C, Jia C. 2005. Long duration tests of room air filters in cigarette smoker's homes. Environmental Science and Technology 39: 7260-7268.

[13] Gunschera J, Markewitz D, Bansen B, et al. 2016. Portable photocatalytic air cleaners: efficiencies and byproduct generation. Environmental Science and Pollution Research 23: 7482-7493.

[14] Shaughnessy RJ, Sextro RG. 2006. What is an effective portable air cleaning device? A review. Journal of Occupational and Environmental Hygiene 3:4, 169-181.

[15] Grinshpun SA, Adhikari A, Honda T, et al. 2007. Control of aerosol contaminants in indoor air: combining the particle concentration reduction with microbial inactivation. Environmental Science and Technology 41: 606-612.

[16] MacIntosh DL, Myatt TA, Ludwig JF, et al. 2008. Whole house particle removal and clean air delivery rates for in-duct and portable ventilation systems. Journal of the Air & Waste Management Association 58:11, 1474-1482.

[17] Zhang Y, Mo J, Li Y, et al. 2011. Can commonly-used fan-driven air cleaning technologies improve indoor air quality? A literature review. Atmospheric Environment 45: 4329-4343.

[18] [redacted], Han B, Kim YJ, et al. 2013. Submicrometer particle removal indoors by a novel electrostatic precipitator with high clean air delivery rate, low ozone emissions, and carbon fiber ionizer. Indoor Air 23: 369-378.

[19] Molgaard B, Koivisto AJ, Hussein T, Hämeri. H. 2014. A new clean air delivery rate test applied to five portable indoor air cleaners. Aerosol Science and Technology 48(4): 409-417.

[20] Noh KC, Oh MD. 2015. Variation of clean air delivery rate and effective air cleaning ratio of room air cleaning devices. Building and Environment 84: 44-49.

[21] Ciuzas D, Prasauskas T, Krugly E, et al. 2016. Indoor air quality management by combined ventilation and air cleaning: an experimental study. Aerosol and Air Quality Research 16: 2550-2559.

[22] Kupper M, Asbach C, Schneiderwind U, et al. 2019. Testing of an indoor air cleaner for particulate pollutants under realistic conditions in an office room. Aerosol and Air Quality Research 19: 1655-1665.

[23] Shiue A, Hu SC, Tseng CH, et al. 2019. Verification of air cleaner on-site modeling for PM2.5 and TVOC purification in a full-scale indoor air quality laboratory. Atmospheric Pollution Research 10: 209-218.

5) REHVA Criteria for room air cleaners for particulate matter (Publicatiedatum: onbekend)

REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

Criteria for room air cleaners for particulate matter

Recommendation from the Nordic Ventilation Group

Introduction

Portable air cleaners can be used to reduce the concentration of particulate matter in room air. They may also reduce the risk of infections due to pathogens in the indoor air, as a significant amount of viral material is spread as small droplets or dried droplets which behave like small airborne particles. These viral particles can be removed from room air using portable air cleaners, by circulating the air through the unit. To be safe and effective the cleaner must fulfill certain performance criteria. If they produce ozone or hydrogen peroxide, then they may pose safety concerns.

For this, the following parameters must be considered:

- Clean air delivery rate (CADR)
- Noise
- Energy efficiency
- Placement of the air cleaner
- Generation of pollutants (the possible negative effect of the air cleaner on the indoor air quality, such as ozone generation).
- Operation
- Service and maintenance

General information

The air purifier must meet all regulatory requirements and be approved from an electrical safety point of view by the European Union or national authorities.

Data which demonstrates the safe and effective performance of the unit must be obtained from third party testing and presented by a third-party certification body. An example of a certification program that operated by Eurovent Certita Certification (1) and (2).

Clean air delivery rate (CADR)

"Clean air delivery rate - CADR" is the air flow, free of specific pollutant, which is supplied to the room by the cleaner. It can be estimated as a product of air flow through the unit and the removal efficiency of the unit for a specific pollutant (usually particulate matter). Regarding the removal efficiency of the cleaner, the most critical size for particulate matter is 0,3-0,5 µm.

Particle removal efficiency is calculated by subtracting the measured average ratio of downstream-to-upstream particle concentrations from unity.

CADR can be expressed for any other pollutant as well. Eurovent Certita Certification has identified

(2) the following pollutants: particles of 0.3 µm to 0.5 µm, particles of 1.0 µm to 2.0 µm, particles of 3.0 µm to 5.0 µm size, Acetone, Acetaldehyde, Heptane, Toluene, Formaldehyde, *Staphylococcus epidermidis, Aspergillus niger* and *Fel-D1* cat allergen.

The effect of CADR for the unit(s) placed in the room on the overall level of pollutants present in the room depends on the size and ventilation rate (outdoor air) of the room.

To achieve a meaningful additional reduction of viral particles in the indoor air CADR (measured for particle size of 0.3 - 0.5 µm) should be 2 times greater than the outdoor air flow by the ventilation system (2) in rooms with a ventilation rate more than 1 ACH. This CADR reduces the concentration of a pollutant by 70%. In rooms with a lower ventilation rate (lower than 1 ACH) the CADR must be at least 2 ACH.

For example:

If the room air volume is 200 m^3 and the air change rate 3 ACH, the effective CADR must be 2x3x200 m^3/h = 1200 m^3/h = 333 L/s or more.

For residential use the Swedish Asthma and Allergy Association recommends CADR = 4 x (ventilation rate) (3) When the outdoor air ventilation rate is 0,5 ACH then CADR should be 4x0,5 ACH = 2 ACH.

In a bedroom with a floor area of 15 m^2 a room height of 2,7 m and design ventilation rate 0,5 ACH, the CADR should be 4x2,7x15x0,5= 81 m^3/h=22,5 L/s.

The combined effect of the ventilation and air cleaner on the concentration of pollutants generated indoors is the sum of the CADR and the ventilation rate.

Noise

Noise generated by the cleaner is usually expressed in sound power generated by the device. The sound pressure level in the room depends on the sound power and acoustic properties of the room.

The sound power of the cleaning unit running on the effective speed shall not cause excessive sound pressure levels in the room. If the sound pressure level is too high, the user may switch the cleaner off or turn it to a lower, less effective, speed, with the consequence that pollutant levels in the space will increase. Sound pressure levels in a typical room (absorption app 10 m^2-sab) are a few (1-3) decibels lower than the sound power level of the unit. The sound pressure level should not exceed nationally regulated levels, and should typically be 30dB(A) in bedrooms, 35 dB(A) in living rooms, 35 dB(A) in single offices, 40 dB(A) in landscape offices and 35 dB(A) in classrooms (Cat II in CEN 16798-1 (4)).

The sound pressure values must be tested and stated for the effective CADR of the unit, so that users know the anticipated acoustic performance of the unit at the intended CADR.

Energy efficiency

The energy efficiency of the air cleaner must be reported, based on the relevant standard test, and is defined as air flow rate per unit of electrical power, L/s per W or m^3/h per W. Classes used by Eurovent Certita Certification range from A class >13 $m^3/h/W$ to class E < 2 $m^3/h/W$.

Placement of the air cleaner

In the performance test, the air cleaner is usually placed in the middle of the test chamber. A mixing fan is used to achieve a uniform concentration in the test room. If the cleaner is placed in the room so that the air flow through it is obstructed or so that there is a short circuit from supply to return in test conditions, its cleaning effectiveness in practical applications may be reduced compared to the test result. To avoid this the cleaner must be placed in a room so that the furniture or walls do not disturb the intended air flow pattern.

Generation of pollutants (by-product)

If the cleaner is using electricity in the cleaning process, for example for photocatalysis, electrostatic filters, UV-A or UV-C lamps and plasma/ionization units there should also be a test report on the ozone levels. Ozone levels must be below 0,05 ppm in the test room where the CADR of the air cleaner is measured. The measured results of potentially harmful byproducts should be made available on request. It should be noted that sensitive people (e.g. those who are asthmatic or have allergies) may have symptoms even at lower O_3- concentrations than 0,05 ppm. Ozone is also a driver of other indoor chemical reactions and the products of this ozone-initiated chemistry are often a greater threat to human health than their precursors.

The ASHRAE's position document on air cleaning (5) concludes that any ozone emission that is non-trivial (beyond a trivial amount that any electrical device can emit) creates a risk. Consequently, devices that use the reactivity of ozone for the purpose of air cleaning should not be used in occupied spaces and devices that emit ozone as a by-product of their operation should be used with extreme caution if emissions are non-trivial, and at best be replaced by alternatives which do not produce ozone.

The US EPA concludes that currently available scientific evidence shows that, at concentrations that do not exceed public health standards, ozone is generally ineffective in controlling indoor air pollution (6).

The UK Scientific Advisory Committee for Emergencies review of air cleaning devices (7) concludes that application of air cleaning devices may be a useful strategy to reduce airborne transmission risks in poorly ventilated spaces. It also notes that air cleaning devices have limited benefit in spaces that are already adequately ventilated and are not necessary for adequately ventilated buildings unless there are identified specific risks.

Operation

The cleaner shall be used at a fan speed which is appropriate for the room where it is located. Most air cleaners collect dust and other pollutants in the unit. The filter media or the collecting plates may become a source of odor and pollutants if not maintained or replaced according to the manufacturer's instructions. In any case, manufacturers' instructions shall be followed by the users and when cleaning the units or filters appropriate precautions shall be taken to protect those maintaining the unit.

Service and maintenance

Spare parts like filter units must be readily available and easily replaced. Operation and maintenance information should be available, including the instructions of the replacement period of components.

The used filter units of the air cleaner must be handled as hazardous waste, along with any protective clothing and breathing masks used by the maintenance personnel.

References

1. https://www.eurovent-certification.com/en/third-party-certification/certification-programs/acl-air-cleaners
2. Technical certification rules for the mark Afnor, Certification identification no.: NF 536, approved 5th of August, 2020
3. Criteria for recommendation of Air Purifier, Astma and Allergy Förbundet, Sweden, 2020.
4. EN 16798-1 Energy performance of buildings - Part 1: indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.
5. ASHRAE Position Document on Filtration and Air Cleaning, 2015
6. https://www.epa.gov/indoor-air-quality-iaq/ozone-generators-are-sold-air-cleaners
7. Scientific Advisory Committee on Emergencies Environment and Modelling Group (SAGE EMG) UK, Potential application of Air Cleaning devices and personal decontamination to manage transmission of COVID-19, November 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/939173/S0867_EMG_Potential_application_of_air_cleaning_devices_and_personal_decontamination_to_manage_transmission_of_COVID-19.pdf

Colophon

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6) Wat/wie is de Duitse Aerosolgemeenschap?

Website: https://www.info.gaef.de/

The "Gesellschaft für Aerosolforschung e.V." (GAeF) was founded in 1972 in order to promote all areas of aerosol research, to provide information on an interdisciplinary basis amongst members and the public, to provide an international forum for collaboration and support scientific education and teaching at all levels. GAeF has members from all over the world and encourages aerosol scientists to join the society.

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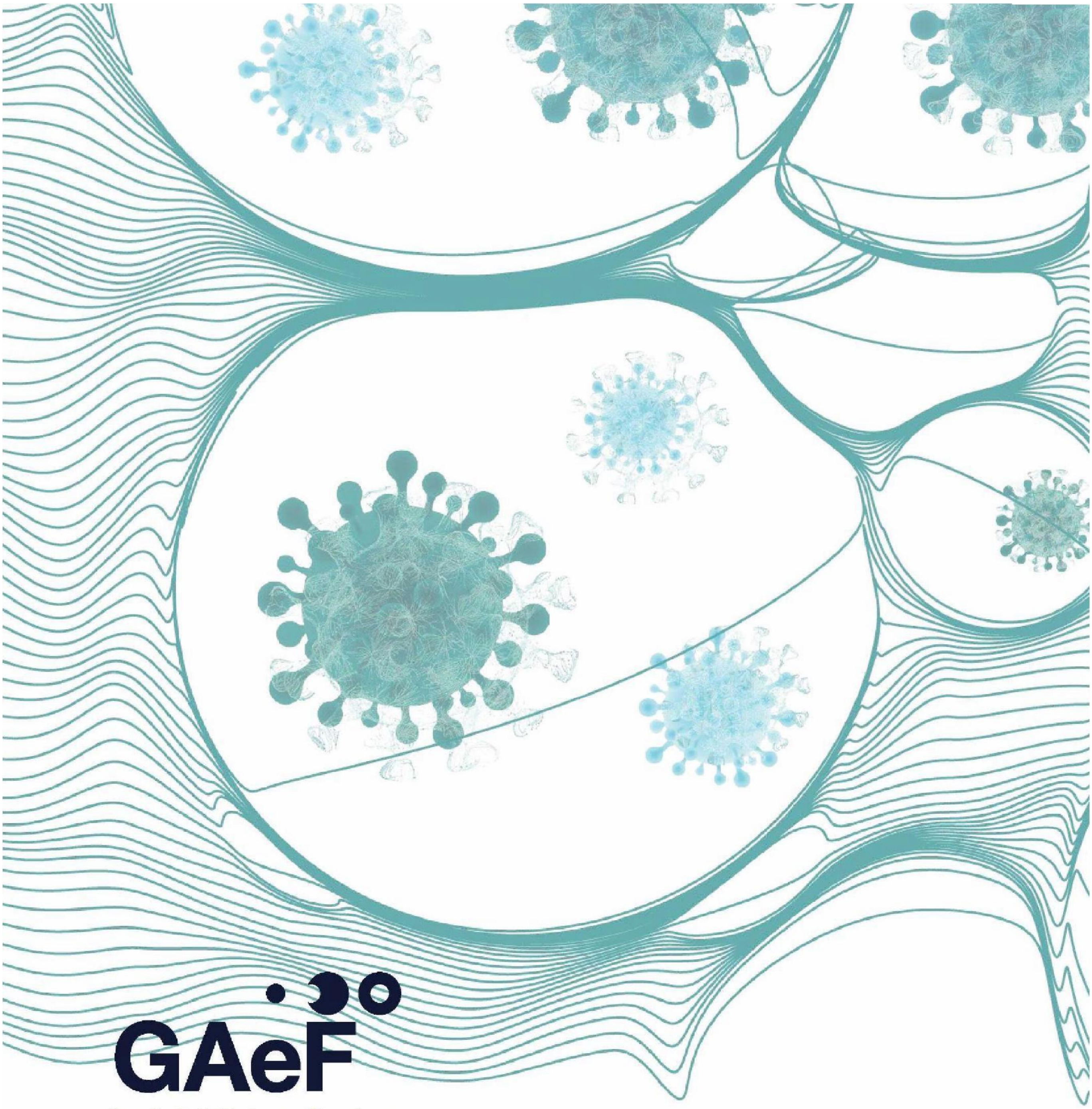
TU/e

7) **Position paper van de Duitse Aerosolgemeenschap (Publicatiedatum: 17/12/2020)**



GAeF

Gesellschaft für Aerosolforschung
Association for Aerosol Research

Position paper of the Gesellschaft für Aerosolforschung

on understanding the role of aerosol particles in SARS-CoV-2 infection

Contact and press enquiries: [redacted]@gaef.de
Further information on the GAeF: www.info.gaef.de

17 December 2020

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Table of contents

Who is the Gesellschaft für Aerosolforschung?

The Gesellschaft für Aerosolforschung (GAeF) was founded in 1972 as a non-profit association of pioneers of aerosol research in German-speaking countries (Germany, Austria, Switzerland) and beyond. Its mission is to promote scientific aerosol research both nationally and internationally. For example, the GAeF regularly organizes the European Aerosol Conference with up to 1000 participants, the last one - online for the first time - in September 2020. The members of the society include leading national and international researchers as well as many students and PhD students from all aerosol research fields (atmospheric environmental aerosol, aerosol technology, aerosol measurement technology, medical aerosol, basic research). The GAeF has about 350 members from 35 countries and is coordinated with all other European societies for aerosol research in the European Aerosol Assembly (https://www.info.gaef.de/eaa) and is also globally networked in the International Aerosol Research Assembly (IARA, http://www.iara.org).

More information is available at https://www.info.gaef.de

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Executive Summary

Many studies have already shown that viruses can spread via aerosol particles. An aerosol is a mixture of air with solid or liquid particles dispersed in it. To understand the role of aerosol particles as a transmission path of SARS-CoV-2, knowledge of the different processes in an aerosol is therefore of particular importance. With this paper, GAeF would like to contribute to a better understanding of the term "aerosol" and the relevant aerosol processes. In the context of this paper only the essential basics will be discussed. For a deeper understanding of the partly complex processes, please refer to the literature mentioned at the end of the paper. The paper summarises a large number of studies on the formation of virus-laden aerosol particles and their spread. Based on this, it can be concluded that exhaled aerosol particles may play a prominent role in the spread of viruses in the corona pandemic. Finally, this paper discusses possible measures to reduce the spread of aerosol particles. The measures discussed are based on the current public debate including ventilation, air purifiers, HVAC systems and masks. Advice is given on the correct and sensible use of these measures.

An aerosol is always dynamic, as particles are newly formed, transported in or with the air, removed from the air or change in the airborne state. Aerosol particles have sizes between approx. 0.001 and several 100 micrometres (and not < 5 µm as currently defined in many publications) and spread relatively quickly with air currents, even over longer distances. Larger aerosol particles sink to the ground, depending on their size and density, while small aerosol particles can remain in the air for a very long time (see Section 3). Every person emits liquid aerosol particles of various sizes through breathing and when speaking, coughing and sneezing (see Section 4). If a person is infected with a virus, such as SARS-CoV-2, these aerosol particles can contain viruses that can be released into the air and inhaled by other people. SARS-CoV-2 has a size of 0.06 to 0.14 micrometres, but the exhaled liquid aerosol particles are larger. The liquid aerosol particles can shrink by evaporation, depending on the ambient conditions (see Section 3.3). Particle size is relevant for particle transport and particle separation. The highest risk of infection exists in closed indoor spaces, as aerosol particles can accumulate there. Here in particular, appropriate measures must be taken to reduce the concentration of aerosol particles (see Section 5).

Against the background of aerosol science, the GAeF classifies the current measures to contain the pandemic as follows:

- In principle, no measure can work on its own! According to the current state of knowledge, the interaction of the most varied measures is the best way to minimise the risk of infection.
- Keeping distance is important, because with increasing distance, directly exhaled viruses are diluted and the probability of infection decreases. The often prescribed minimum distance can be used as a guide, but it should be increased and supplemented by other measures (see below), especially for longer meetings and also indoors with reduced air movement.
- Masks help to filter some of the exhaled particles (and viruses). This reduces the concentration of exhaled particles (and viruses) in a room and thus the risk of infection. It should be noted here that the exhaled aerosol particles are relatively large due to adhering moisture and can therefore also be efficiently retained by simple masks (see Figure 6). However, since these particles shrink with longer dwell time in the room air, simple mouth-nose masks are less efficient for self-protection. Respiratory masks are required for this purpose, which show a high degree of separation even for fine particles, e.g. of classes FFP2, N95 or KN95. These are efficient for both self-protection and protection of others unless they have an exhalation valve. Masks with an exhalation valve, on the other hand, are only for self-protection and therefore contradict the solidarity concept that fellow human beings are protected by collective mask wearing (see Section 6).

- Face shields which are used without additional masks are largely useless with regard to aerosol particles, as the air with particles (and viruses) flows unfiltered around the shields. In everyday clinical practice, facial shields are worn in addition to masks to prevent droplet infection via the mucous membranes of the eyes. Mobile or permanently installed Plexiglas barriers are also largely ineffective against the spread of aerosols indoors. These can only prevent the small-scale spread of an aerosol in the short term, e.g. in the checkout area of a supermarket, but offer no protection in the longer term. Face shields and Plexiglas panels essentially serve as spit and splash protection against large droplets.
- Outdoors, there are practically no infections caused by aerosol transmission. However, droplet infections can still occur, especially in crowds, if minimum distances are not observed and/or masks are not worn. In closed rooms, ventilation is essential to replace the exhaled air in a room with fresh air from outside. Frequent airing and cross-ventilation is just as effective as leaving the window open all the time. From an energy point of view, however, it is more efficient to ventilate the room, especially in winter. CO_2 monitors can help to monitor indoor air quality. They indicate when it is necessary to ventilate and when the air in a room has been sufficiently changed during ventilation. However, they can only be used as an indicator and even if the proposed CO_2 limit concentrations are met, they do not prevent direct infection by people in the immediate vicinity.
- Air purifiers can make a useful contribution to reducing the concentration of particles and viruses in a room. When procuring air purifiers, care must be taken to ensure that they are adequately dimensioned for the room and application in question in order to significantly reduce the particle and virus load. The air throughput of the unit is more important than the pure efficiency of the filter. For energy and cost reasons, the use of highly efficient filters can even be counterproductive (see Section 5.2). Permanently installed ventilation systems can also be useful, provided they filter the air to reduce the particle and virus load in a room. To avoid infections, it is advisable to operate them with 100 % fresh air if possible (see Section 5.3).

From the point of view of the Gesellschaft für Aerosolforschung, there is a considerable need for research, especially at the interdisciplinary borders to research fields of epidemiology, infectiology, virology, ventilation technology and fluid mechanics. The implementation of targeted studies should be made possible at short notice with special funding and research programmes (see Section 7).

This paper was written originally in German by members of the Gesellschaft für Aerosolforschung and is supported by a large number of international aerosol experts (see Section 8). Both the English and German version as well as all images in the paper are available for free download at the following link: https://www.info.gaef.de/positionspapier. The "Gesellschaft für Aerosolforschung e. V." must be named as the source, whenever an image is used.

1. Goal of this paper

The present position paper is addressed to representatives of the media, authorities, administration and politics, as well as to the interested public. With this paper, the Gesellschaft für Aerosolforschung (GAeF, https://www.info.gaef.de) would like to contribute to the management of the pandemic caused by the SARS-CoV-2 virus by aiding the understanding of possible transmission routes. In the context of research into transmission paths, aerosol transmission has been discussed for some time as an important route of infection in addition to smear and droplet infection [1, 2]. The virus can survive for several hours in an airborne state [3]. From the GAeF's point of view, however, some things are mixed up in the public discussion. As the possible transmission routes are close to measures to prevent transmission, GAeF would like to contribute the necessary expert knowledge in a generally understandable way. The topic is viewed purely from the perspective of aerosol research and no medical, epidemiological, virological or conclusions on infectiology are drawn. In our view, increased cooperation between the various disciplines is necessary to clarify the transmission routes, even beyond the current pandemic.

2. What is an aerosol?

The word aerosol is an artificial word, composed of the ancient Greek word ἀήρ (aēr) for "air" and the Latin word solutio for "solution. Physically speaking, an aerosol is a heterogeneous mixture of particles together with the gas or gas mixture surrounding them (here: air, see Figure 1). The airborne particles can be solids such as soot or mineral dust as well as liquid droplets. In a stable aerosol, the liquid or solid components are homogeneously distributed as suspended particles. Correspondingly, for example, our ambient air together with the fine dust[1] suspended in it is an aerosol. In this paper, the term "aerosol particles" or "particles" for short is therefore used for all airborne particles. Often, however, especially in the current public discussion, the term aerosol is used incorrectly when only referring to aerosol particles (e.g. [4]). Since the majority of air consists of gaseous molecules such as nitrogen and oxygen, the solid or liquid particles are the special feature of aerosols. Aerosol particles are so small and light that they can float in the air for a certain time depending on their size. Aerosol particles can remain in the outside air for many hours or days and thus be transported over long distances.

One litre of air normally contains many millions of aerosol particles, which influence, among other things, the climate and the formation of clouds [5] as well as chemical reactions in the atmosphere [6]. In higher concentrations, they can also affect human health [7] as fine dust. In the course of a day, an adult person inhales an average of about one hundred billion particles. The effect of aerosol particles depends on their number, size, mass and chemical composition. These properties, in turn, are influenced in different ways by a wide variety of natural and man-made sources [8]. The size range of aerosol particles is not precisely defined, but is typically specified for particle diameters from about 1 to 2 nanometres (nm, millionths of a millimetre, i.e. 0.001-0.002 µm) to >100 micrometres (µm, thousandths of a millimetre) [9, 10]. The majority of atmospheric aerosol particles (such as soot or ammonium sulphate particles) are smaller than 1 µm. Mineral dust or sea salt particles, but also bacteria are usually larger than 1 µm. The size of pollen is between 10 µm and 60 µm. SARS-CoV-2 viruses have sizes between about 0.06 µm and 0.14 µm [11], and may also be slightly smaller [12]. For comparison: human hairs have diameters between 20 µm and 80 µm.

Viruses are formed in or on tissue. They cannot detach themselves individually from a surface. Consequently, viruses typically do not exist as individual particles, also called virions, in an aerosol, but are transported in the air in larger solid or liquid particles. Particularly in the medical literature and also in the public discussion on SARS-CoV-2, the misleading and arbitrary distinction between aerosol particles with diameters < 5 µm and droplets with diameters > 5 µm is frequently found, which assumes a different behaviour of aerosol particles and droplets. This differentiation of aerosol particles and droplets is not useful either with regard to the transport behaviour [13, 14] (see Section 3.1) or the infectiousness of the particles (see Section 4), especially since the liquid components of the aerosol particles

1 Particles with a so-called "aerodynamic diameter" smaller than 10 µm (PM10) or 2.5 µm (PM2.5) are also known as fine dust

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evaporate quickly. In any case, the size distribution of the particles is decisive. In the literature, there are various classifications of size classes, which are, however, often determined by the measurement technology used and not exclusively by the particle behaviour relevant to the infection.

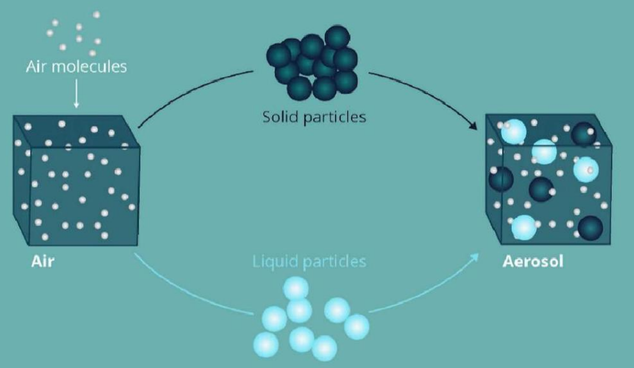

Figure 1: Definition of an aerosol: air with liquid and/or solid particles dispersed therein

3. COVID-19-relevant fundamentals of aerosol physics

3.1 Fundamentals of particle motion

The relevance of aerosol physics for the understanding of the infection process was recently highlighted by Drossinos and Stilianakis [13] in an editorial for the journal Aerosol Science and Technology. An essential component of aerosol physics is the movement of aerosol particles, which is highly dependent on the size of the particles [4, 9]. Since aerosol particles do not always have a defined geometrical shape, the geometrical diameter of a sphere is only used to describe the particle size in the simplest and idealised case. In order to take into account the influence of the particle geometry (aerodynamic resistance) and the chemical composition (density of the particle), the size of particles is usually specified as the socalled aerodynamic diameter. The aerodynamic diameter is defined as the diameter of a spherical particle with a density of 1 gram per cubic centimetre (e.g. a drop of water), whose behaviour corresponds to that of a real particle moving in the air flow.

Aerosol particles are transported with the often turbulent air flow and are thus quickly distributed both indoors and outdoors. In order to understand particle transport, it is also necessary to describe the particle movement relative to the air flow, which is determined by the forces acting on the particles in an aerosol. Depending on the temperature, air molecules are in constant thermal movement with random direction and speed and thus collide with the aerosol particles distributed in the air. This causes them to transfer energy and momentum and thus leads to frequent changes in the speed and direction of movement of the particles. This so-called Brownian molecular movement results in diffusive transport [15, 16], which increases as the particle diameter decreases and is particularly relevant for particles with diameters of less than 0.1 µm. In this particle size range, diffusion is the most important transport mechanism over short distances, which is important for particle filtration [17] or particle deposition, i.e. the depositing/removal of particles, for example in the lungs [18]. For particles larger than approx. 0.1 µm, diffusion plays an increasingly subordinate role as the particle size increases, and gravity becomes more important. Whenever particles move relative to the surrounding air, a braking frictional force acts in the opposite direction to the movement, due to the aerodynamic resistance. Thus, when aerosol particles sink due to gravity in still air, a stable sedimentation speed is quickly established, which depends on the particle geometry and density, i.e. the aerodynamic diameter of the particles. In still air, a 1 µm spherical aerosol particle with the density of water would take about 7.5 hours to sink to the ground from a height of 1 meter. A 10 µm particle would need only about six minutes. Some examples of the time it takes for particles to sink one metre under gravity alone are shown in

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Figure 2. This deposition rate assumes that the particle size does not change during transport. Exhaled liquid aerosol particles, on the other hand, typically release water and shrink as a result. For a better understanding of this process, please refer to Section 3.3.

The numbers in Figure 2 refer to still air. However, particles are also transported by air movement outdoors and indoors (advection and turbulent transport) and may therefore remain in the air much longer than shown in the figure if upwardly directed forces counteract the gravitational force. Through the so-called advection (horizontal transport) with the air flow, aerosol particles can be transported over very long distances outdoors. With the turbulent air movement, aerosol particles are also transported vertically. Indoors, typical flow velocities of around 0.1 m/s can keep particles up to an aerodynamic diameter of 20 µm in suspension for a long time [19] and distribute them quickly throughout the room. In the process, exhaled air, which may contain particles laden with viruses, is mixed with the room air and rapidly diluted. If, however, the room air is not exchanged (ventilation) or filtered (ventilation system or air cleaner), it accumulates over time. In contrast, the exhaled particle concentration in the outside air is quickly diluted and removed, so that no accumulation occurs. Only for particles with diameters well over 100 µm can a ballistic trajectory be assumed to describe the transport, so that these particles sediment quickly and are no longer airborne. This describes the spread of particles that are ejected at high speed when coughing or sneezing, as with a thrown ball (see Section 4.2 and Figure 3).

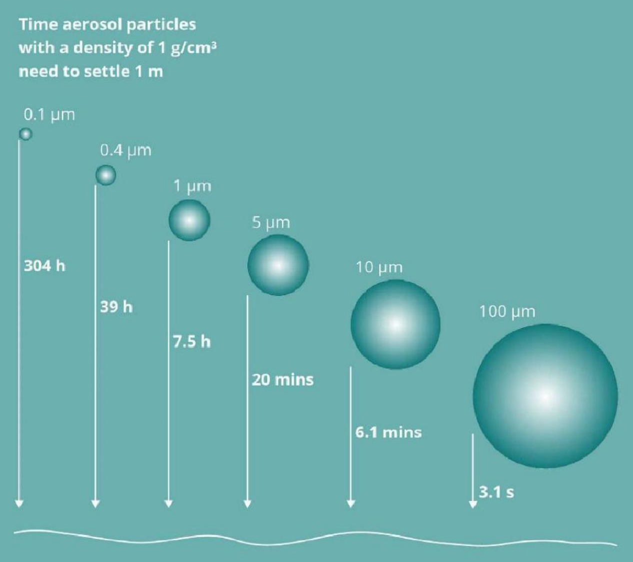

Figure 2: Exemplary illustration of the gravity-induced sedimentation of spherical particles with a density of 1 g/cm³ in still air
representation not to scale

3.2 Particle deposition

Various processes result in aerosol particles being removed from the air. Particle deposition, i.e. the deposition of aerosol particles on the ground or on surfaces, plays a very important role. For larger particles (typically > 1 µm) gravity is relevant for the deposition, i.e. the sinking of the particles to the ground. At high relative humidities, even originally small particles can, due to their chemical composition, absorb and accumulate moisture and thus sediment faster [20, 21]. Conversely, liquid particles shrink at low humidity. Smaller particles (approx. < 0.1 µm), on the other hand, can be deposited on surfaces due to Brownian molecular movement. If air flows are directed at obstacles, larger particles cannot follow the change in direction due to their inertia, these large particles are deposited on the obstacle by the impact [9]. If aerosol particles can follow the air flow around an obstacle but are deposited because of their size and proximity to the obstacle, this is called interception [9]. These separation mechanisms are specifically exploited in particle filters to remove particles from the air [17]. Particle filters are explained in Section 5.1.

Depending on the local conditions, particle deposition is typically lowest in a particle size range of about 0.1 - 0.3 µm (the proportions are shown graphically in the particle filtration section of Figure 5). This means that these particles remain in an airborne state for a very long time and can float in the air for more than 24 hours in closed rooms without air exchange.

3.3 Evaporation of liquid particles

Aerosol particles are in constant exchange with the surrounding water vapour. This is particularly true for liquid aerosol particles, which often consist largely of water. The particles strive for an equilibrium with the water vapour in the air. How much water an aerosol particle contains depends on its composition and relative humidity. This applies in particular to exhaled liquid particles that are particularly relevant in the context of COVID-19. In the respiratory tract there are warm and humid conditions (relative humidity of about 100 %), so that aerosol particles have a high water content there. After exhalation, water evaporates from the particles. This process was described by Wells in 1934 [22]. The particles dry and shrink at a rate that depends on the particle surface, air temperature and relative humidity [23]. For particles of the same composition, the larger surface to volume ratio means that smaller particles evaporate faster [24]. Drewnick et al. [25] have calculated that an initially 100 µm diameter pure water droplet needs 15 s at a relative humidity of 50 % to shrink by evaporation to the size of a SARS-CoV-2 virus (0.14 µm), a 10 µm water droplet 0.1 s and a 1 µm droplet only 0.003 s. At 90 % relative humidity, the water droplets need about four to five times as long. This change in size influences both transport and filtration properties. Therefore, the size change of the particles after exhalation must be taken into account. While the exhaled particle size - that is the size of the particle immediately after exhalation - is relevant for deposition in a mask during exhalation, the size reduced by drying must be taken into account for the duration of the aerosol particles' stay in the ambient air and for their deposition in masks for self-protection, in air purifiers and in ventilation systems.

4. When and how are viruses or virus-containing aerosol exhaled?

Aerosol particles are released in the human respiratory tract. Obviously, this happens when sneezing and coughing. However, particles are also generated during normal breathing, speaking, singing, whispering and shouting. The particle sizes mentioned below refer to freshly exhaled particles, but they can shrink due to evaporation after exhalation (see previous Section 3.3).

A much discussed mechanism of viral infection with respiratory involvement is pure breathing. Since we breathe 24 hours a day and an adult inhales and exhales between 10 and 25 m³ of air each day [9], even low aerosol concentrations during release are sufficient to release considerable quantities of potentially viral aerosol particles into the environment. Compared to the typical particle concentrations prevailing in indoor and outdoor areas, however, these quantities are small, so that the exhaled particles make only a negligible contribution to the fine dust concentration. A healthy person breathes out between one hundred and several hundred aerosol particles per litre[2] of air during normal resting breathing, which are produced in the peripheral lung during inhalation by "reopening collapsed airways". The phenomenon was first described in 1988 by Gebhart et al. [26], and Johnson and Morawska [27] confirmed the mechanism in 2009. Olin et al [28, 29, 30, 31] then investigated in detail what these exhaled particles are made of and found that they are mainly lung fluid (*surfactant*), with viruses also found in the particles. Hohlfeld et al. [32, 33, 34] were able to determine the particle size, which is between 0.2 and 0.4 µm. However, since many studies on exhaled aerosol particles only measure from a size of 0.3 µm or 0.5 µm due to metrological restrictions, many publications report number concentrations for exhaled particles that are clearly too low. Current studies have shown that the number of exhaled particles can rise dramatically to values of several tens to hundreds of thousands of particles per litre of air in the case of a respiratory tract infection. However, this does not necessarily happen in every infected person. After the infection has subsided, they only exhale a few particles per litre of air [35, 36].

Another mechanism for spreading viruses via the airborne pathway is speaking and singing [37, 38]. In these activities, several thousand to a hundred thousand aerosol particles per litre are produced by the vibration of the vocal cords and the movement of the tongue, teeth and lips [39]. However, these particles are usually larger than those generated by breathing. Asadi et al. [40] found that the particles have a size of about 1 µm and that more particles are produced with increasing volume. Previously unpublished studies by Jensen et al. showed particle sizes around 2 µm[3].

2 1 l = 1000 cm³

3 Personal communication with Prof. Dr. Keld A. Jensen, NRCWA, Copenhagen, Denmark

4.1 The spread of viruses by breathing air

In 2008, the group led by Patricia Fabian and Donald Milton from the University of Massachusetts was able to detect influenza viruses in exhaled aerosol particles [41]. The authors showed that 87 % of the exhaled aerosol particles had sizes of less than 1 µm. Later, Milton et al [42] again detected influenza viruses in the air exhaled by infected patients. In 35 out of 37 influenza-infected patients, they found significant amounts of influenza viruses in the small particle size range caused by normal breathing, while they could only detect viral RNA when coughing in 16 out of 37 patients. The amounts of virus material collected were also many times smaller than those found in the small aerosol particles during normal breathing.

Lindsley et al [43] were also able to detect significant amounts of influenza A viruses in the exhalate. Although the authors found slightly more viruses in coughing than in normal breathing, they noted that coughing occurs much less frequently than breathing, and therefore the spread of viruses probably occurs much more frequently and effectively through normal breathing.

Fabian et al. [44] also found rhinoviruses in the exhalation of infected patients. These were mainly found in the smallest particles that could be measured. The fact that the spread of different viruses occurs through the normal breathing of infected persons has now also been proven by various other research groups. For SARS-CoV-1 viruses, the results can be found in the studies by Wang et al [45] and Gralton et al [46]. Mitchell et al [47] found rhinovirus, RSV, influenza A, influenza B, parainfluenza viruses 1, 2 & 3 and human metapneumovirus, Yip et al [48] influenza A viruses. Shiu et al [49] found influenza A RNA in aerosol in ambient air in a children's ward in a patient's room. It can be assumed that the findings of these investigations can also be transferred to SARS-CoV-2 viruses.

Morawska and Cao [50] point to the many observations which make it extremely plausible that the SARS-CoV-2 epidemic is also influenced at least to a large extent by the transmission of exhaled viruses and that this must be taken into account in the measures to contain the pandemic.

Van Doremalen et al [3] investigated how long SARS-CoV-2 viruses remain active in an aerosol. They found half-lives of between 1 and 1.1 hours. Smither et al. [51] found half-lives of between about half an hour and three hours in daylight, depending on the humidity. In darkness, however, the viruses were stable for a long time. Brlek et al. [52] were able to show that athletes in a squash hall in Slovenia became infected with SARS-CoV-2 after an infected person played squash there. Fears et al. [53] showed that airborne SARS-CoV-2 viruses can remain infectious for over 16 hours under certain circumstances.

Ma et al. [36] found in a study that there are individuals who exhale up to 400,000 viruses per minute. Numerous studies have also found viruses and virus RNA in the air in hospital rooms and even in hospital corridors, although they found no virus in exhalation in 75 % of patients. Lednicky et al [54] were able to detect infectious SARS CoV-2 viruses in airborne aerosol particles at a distance of 4.8 m from a Covid-19 patient in hospital. Zhou et al. [55] found SARS-CoV-2 viruses in the exhaustive respiratory condensate of two of the nine patients examined who were to be discharged from hospital after suffering from covid-19 disease. The concentration was about 100 viruses per litre of respiratory air.

In a study of infection chains, Qian et al. [56] found that COVID-19 infection is essentially an indoor phenomenon and that almost no infections occur outdoors, i.e. outside enclosed spaces. Out of more than 7000 observed and documented infections, only one single infection occurred outdoors. This is probably due to the fact that a rapid dilution of virus-laden aerosol particles is to be expected in outdoor areas, which reduces the risk of infection (see Section 3.1). However, especially in large crowds with small distances between people, an infection cannot be ruled out even outdoors.

Based on the large number of available studies and findings, it can be assumed that exhaled aerosol particles also play a prominent role in the spread of the viruses in the corona pandemic. Sections 5 and 6 therefore deal with how the spread of viruses can be contained.

4.2 Droplet infection

When coughing, sneezing, talking or singing, drops larger than 100 µm in diameter are emitted, which, as explained above, no longer behave like aerosol particles. However, these can play an important role in direct droplet transfer. Due to their much larger volume compared to aerosol particles, they can contain more viruses, which means that droplet infection often plays a dominant role. The trajectory of such particles is strongly dependent on the emission speed and direction. Figure 3 shows examples of trajectories of 200 µm droplets for ejection velocities such as those that can occur in particular when coughing. When sneezing, the ejection velocities are often even higher, so that the particles can be transported even further. For the calculation it was assumed that the drops are ejected at a mouth height of 1.70 m and that the drop size does not change during transport. It can be seen that the distance rule of 1.5 m is very sensible with regard to such particles, or perhaps even rather tight. Face visors or poorly fitting masks, which are only slightly effective for small aerosol particles, can be effective for these large droplets. It should be noted that for droplets larger than 100 µm the dilution is irrelevant, so with regard to direct droplet infection it is not important whether the persons are outside or inside.

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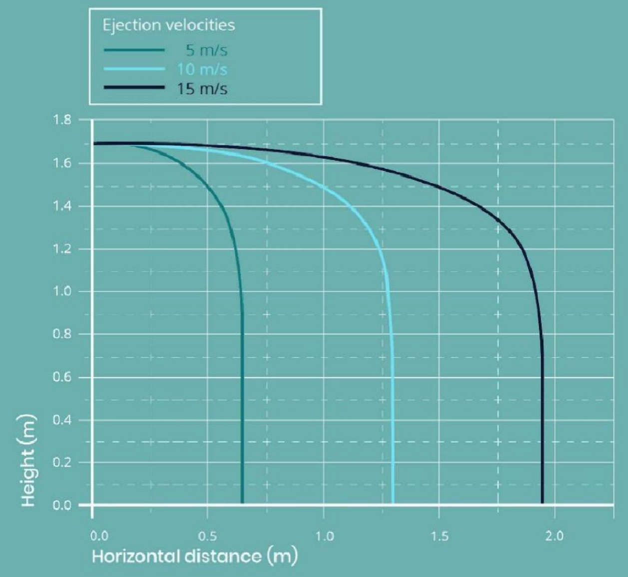

Figure 3: Trajectories of droplets with a diameter of 200 µm and the density of water ejected at different velocities at a height of 1.70 m (based on [57])

5. Ways to reduce the concentration of viruses in indoor air

There are various ways of reducing the concentration of viruses in room air. While measures such as ventilation and filtration aim to reduce the concentration of viruses, the irradiation of air or filters with UV light is used to inactivate viruses.

An effective process for reducing the concentration of particles in a room - and thus in a similar way to the concentration of virus-containing aerosol particles - is dilution with cleaner, less particle-laden, i.e. virus-free air. In outdoor areas, dilution takes place constantly through natural air movements. Indoors, dilution can be achieved by efficient ventilation. For this purpose, windows should be opened and air movement should be provided. The most effective way to do this is by airing the room from side to side, i.e. apart from the windows in the room, skylights and/or doors should be opened, as well as windows and doors in adjoining rooms. The ventilation time required depends on the size of the room, the number and size of the windows and the difference in temperature between inside and outside. If necessary, the exchange of air can be forced mechanically, e.g. by a fan. It should be borne in mind that although the outside air is virus-free as a rule, it is not free of other air pollutants. Although the concentration of viruses can be lowered by ventilation, the general air quality in the interior may even deteriorate.

The need for ventilation can be monitored, for example, by continuously measuring the carbon dioxide (CO_2) concentration in the interior. Sufficiently accurate CO_2 monitors (also known as CO_2 traffic lights) are commercially available at low cost. Since CO_2 is produced during respiration in the same way as virus-contaminated aerosol particles, the CO_2 concentration can, under certain conditions, also be taken as an indicator for the concentration of exhaled aerosol particles. However, this only applies in cases in which no active filtering of the indoor air, e.g. with air purifiers (see Section 5.2) or ventilation systems in recirculation mode (see Section 5.3), is performed. In these cases, aerosol particles are extracted from the air, but not the CO_2. This would mean that ventilation would tend to be too frequent, which can be unfavourable from an energy point of view. However, the risk of infection would tend to decrease. The CO_2 concentration at which ventilation should start is currently under discussion. According to the Commission on Indoor Air Hygiene of the German Federal Environment Agency, a CO_2 concentration of less than 1000 ppm (0.1 vol%) indicates hygienically adequate air exchange under normal conditions [58]. The German Social Accident Insurance (Deutsche Gesetzliche Unfallversicherung) advises that this value should be kept as low as possible in day-care centres [59]. The natural CO_2 concentration in outside air is approx. 410 ppm and cannot fall below this value indoors either.

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Although ventilation can reduce the particle concentration and viral load indoors, it cannot prevent direct droplet infection between two people if the distance is too small.

Further possibilities for reducing the concentration of particles and viruses exist in filtration solutions, which are described below.

5.1 Fundamentals of air filtration

Particulate filters are usually made of *nonwovens*. According to EN 29092, nonwovens are networks of three-dimensionally arranged fibres. Aerosol particles are separated in filters by different mechanisms. The frequently encountered idea that particle filters function like "sieves" or "fishing nets" and thus only retain large particles is fundamentally wrong, because very small particles in particular can be filtered out with very high efficiency due to their Brownian molecular movement [60, 61]. If an aerosol flows through the open areas between the fibres in a filter, three different mechanisms lead to the separation of particles on the fibres [9]: Impaction, interception and diffusion [17], see Figure 4 and Section 3.2.

These three mechanisms have different effects on particles of different sizes. Impaction, i.e. inertial separation of particles, is the dominant separation mechanism for particles >1 µm. The influence of interception also increases with increasing particle size. The diffusion due to Brownian molecular movement, on the other hand, increases with decreasing particle size and is the essential and highly efficient separation mechanism in filters for particle sizes <0.1 µm. As soon as a particle hits a fibre, it sticks to it. It is largely impossible for particles separated in a filter or on other surfaces to detach again, as unrealistically high forces would be required to do so [62].

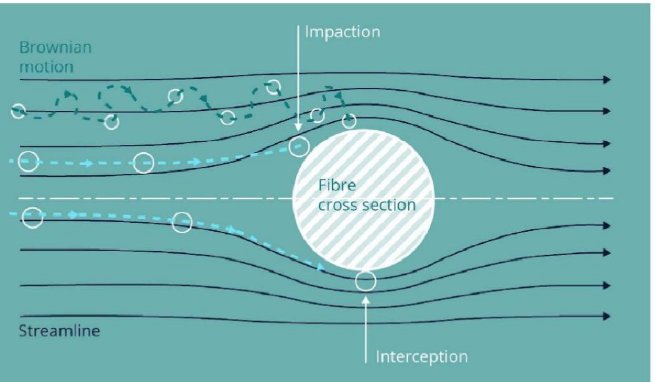

Figure 4: Particle collection mechanisms in a fibre filter (based on [61])

The superposition of these three separation mechanisms results in a typical U-shaped separation curve (see Figure 5). Depending on filter and inflow velocity, the resulting minimum separation efficiency (also known as *most penetrating particle size*, MPPS) is typically between 0.1 µm and 0.3 µm. Conversely, this means that particles of all other sizes, even very small ones, are separated even more efficiently. With conventional room air filters, the minimum efficiency is 30-90 % depending on the filter class. With highly efficient HEPA (*High Efficiency Particulate Air*) filters according to EN 1822-1 or ISO 29463, the minimum filter efficiency is at least 99.95 %, depending on the filter class. These standard-compliant specifications always refer to the nominal flow rate[4] of the filters. If a filter is operated with a lower volume flow, large particles are separated with lower efficiency due to decreasing impact, whereas small particles are separated with higher efficiency because they have more time for diffusive separation. The separation minimum therefore migrates to larger particles. When operating a filter with a flow rate higher than the nominal flow rate, the reverse is true.

In general, a denser, thicker or multi-layer filter medium is required to achieve a higher degree of separation. However, this also increases the flow resistance (pressure loss) of the filter [63] and thus, e.g. in the case of breathing masks, the breathing resistance and, when operating filters for air purifiers or ventilation systems, the energy requirement.

So-called electret filters are a special feature in this context. Their fibres are electrically charged during manufacture [64, 65]. Some airborne particles carry a natural electrical

4 *Flow rate for which this filter is designed. This is typically specified in the data sheet of the filter.*

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charge [66] and can thus be removed from the air with greater efficiency than with purely mechanical filtration. However, uncharged particles are also polarised in the resulting electrical field within the filter and are thus also increasingly separated [64, 67]. These two electrical effects have different effects on different particle sizes, so that the separation curve of an electret filter usually has several local minima [68, 69]. Since the introduction of electrically charged fibres has no noticeable influence on the pressure drop, electret filters are particularly interesting for applications in which a high pressure drop is to be avoided, while at the same time achieving high separation efficiency [70]. They are used, for example, in breathing masks [71, 72] or for household room air cleaners [73].

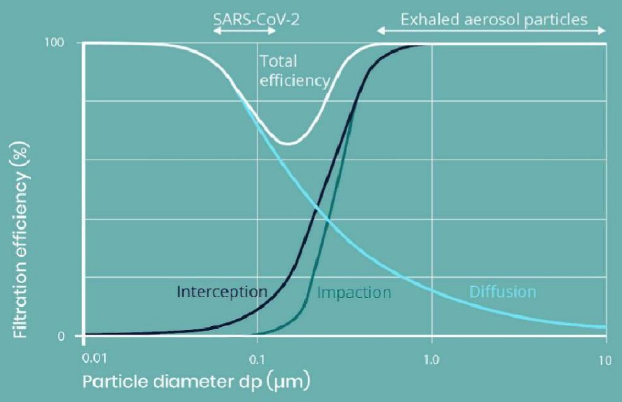

Figure 5: Filtration efficiency of a highly efficient air filter as a function of particle diameter (based on [60]); the total efficiency of the filter (black curve) is determined by the separation mechanisms diffusion (green curve), interception (blue curve) and impaction (red curve); the course of the separation efficiency of filters with lower efficiency is similar, but lower and may not reach (almost) 100 % for very small and very large particles

During the operation of air filters, particles are deposited on or in the fleece, causing the free pore-like air volumes to narrow. Due to the denser filter medium, the filter efficiency increases with increasing operating time, but also the pressure drop [74] and thus the energy requirement and breathing resistance. In the case of electret filters, the loading of the filter is also accompanied by an electrical discharge of the filter [75, 76]. The influence of decreasing charge on the separation efficiency is generally greater than the increase in mechanical efficiency due to particle separation, so that the overall separation efficiency of electret filters decreases during operation [76]. The discharge of the filters is also accelerated by air humidity [77, 78] and especially by solvent vapours [79, 80, 81]. The storage and service life of electret filter is therefore more limited than that of non-charged filters. However, a possible discharge during storage is described in the scientific literature as low [82] to negligible [83]. Currently there is no technical solution to recharge electret filters after use.

5.2 Effectiveness of air purifiers

Air purifiers are mobile devices that can be positioned anywhere in a room. They are equipped with a fan that draws in the air from the room, passes it through filters and returns the cleaned air to the room. In terms of particle concentration, they thus have virtually the same effect as ventilation with clean outside air by reducing or keeping the particle concentration low over time [84]. Air purifiers have become increasingly popular as household appliances in recent years. In the context of the COVID 19 pandemic, larger air purifiers, often referred to as professional air purifiers, e.g. for classrooms or industrial workplaces, have also come onto the market. The advantages of air purifiers compared to ventilation are that no heat escapes from the room, especially in the cold season, and their effectiveness is independent of the particle concentration in the outside air. For this reason, air purifiers are regarded as an additional component for minimising the risk of infection, especially in rooms where regular ventilation is not possible [1]. Disadvantages of air purifiers are possible additional acquisition costs, power consumption and noise emissions of the fan. Noise emissions in particular can significantly reduce acceptance in everyday life [85]. Another disadvantage is that air is only circulated and not exchanged. However, this does not happen with closed windows either. In contrast to ventilation and the associated input of oxygen, the concentration of exhaled CO_2 therefore accumulates in the room. In addition, just as with ventilation, direct droplet infection between two people cannot be prevented if the distance is too small.

Most air purifiers have non-woven filters to separate particles [86]. In the case of household appliances, these are often electret filters to achieve a low flow resistance. This has the advantage that more air can be circulated with the same power consumption but lower noise emission. However, regular filter changes are necessary, as the initial efficiency can drop considerably due to discharge of the filters [81]. Newer "professional" air purifiers, on the other hand, often have highly efficient, but uncharged filters of HEPA classes H13 or H14[5] with correspondingly higher pressure drop. Many air purifiers also contain activated carbon to separate gaseous pollutants and

5 *The filter designations are taken from the European standard EN1822-1. According to the international standard ISO 29463, E11 filters are designated ISO 15 E, H13 ISO 35 H and H14 ISO 45 H*

odours [87]. However, the activated carbon has no significant influence on particle separation. In some cases, additional functions are also offered for the inactivation of micro-organisms by UV light, plasma or ozone. It has been known for decades that UV irradiation of viruses can lead to their inactivation [88] and is used in many air purifiers [89, 90]. The efficiency of UV irradiation to inactivate other corona viruses has already been demonstrated [91]. However, the studies listed in the review by Heßling et al. [91] were not carried out on airborne viruses but on viruses deposited on surfaces. The radiation dose is decisive for efficient inactivation. Heßling et al. assume that a dose of 0.0037 J/cm^2 is required to inactivate 90 % of the viruses. Hamzavi et al. [92] report that a dose of 1 J/cm^2 is required to inactivate 99.9 % of the viruses on respirators. While viruses deposited on filters with the aid of UV radiation can thus be efficiently inactivated, it is currently unclear whether the findings can be transferred to airborne viruses. The method also harbours potential risks: UV rays cause damage to human skin when irradiated directly. In addition, UV radiation can lead to the formation of ozone in the room air. Accordingly, such methods should not be used if there are people in the room who could be exposed to UV radiation or ozone.

Evidence provided by manufacturers on the effectiveness of their air cleaners should always be critically reviewed. Current testing standards for air purifiers, such as the Chinese GB/T 18801:2015 or the US ANSI/AHAM AC-1:2015, do not include standardised test methods for testing the effectiveness of UV radiation or the use of ozone or plasma. There is currently no European testing standard for air purifiers. An international IEC standard to replace the national standards is currently in preparation.

The effectiveness of air purifiers is usually assessed by means of the *Clean Air Delivery Rate* (CADR), which is determined in a standardised way by means of decay rates in a test chamber [93]. The CADR indicates how many cubic metres of cleaned air the air purifier provides per hour and thus corresponds to the product of filter efficiency and volume flow rate that the unit circulates. However, especially in the case of household appliances, the CADR is usually only given for the highest fan speed, which is usually not used at all or only for a short time due to noise. The corresponding information on lower fan speeds is often not available for these appliances. In addition to the manual setting of the fan speed, many domestic air cleaners have automatic modes that control the air flow independently based on particle concentration measurements taken by the unit. Since, in the case of typical particle pollution indoors, virus-containing particles make up only a small proportion of the total particles and the built-in sensors cannot distinguish between virus-containing and virus-free particles, the automatic mode should not be used when using air cleaners to prevent infections.

The decisive factor is therefore not only the highest possible filter efficiency, but always the combination with sufficient air turnover. For example, the same cleaning performance (CADR) can be achieved with an H13 filter with 99.95 % separation efficiency as with an E11 filter with 95 % separation efficiency at an air flow rate that is about 5 % higher. However, since the pressure drop of the H13 filter is typically about twice as high as that of the E11 filter [94], about twice as much power is required. In addition, an air purifier with an H13 filter is more complex and more expensive. If an H14 filter with a minimum efficiency of 99.995 % is used, this balance is even less favourable. The use of H13 and H14 filters

therefore has no technical advantages and is neither economically nor energetically sensible. It can also be counterproductive to retrofit existing air purifiers with highly efficient filters, if the reduction of the volume flow rate due to the higher pressure drop exceeds the gain in filter efficiency and the CADR ultimately even decreases [95]. The use of highly efficient filters in air cleaners is therefore often at the expense of energy efficiency and noise emissions or at the expense of effectiveness and is therefore not generally recommended. Exceptions may be air purifiers that extract air in the direct vicinity of a (potentially) infected person and return the purified air back into the room. There are also more recent developments of highly efficient H13 filters made of PTFE membranes, which have a significantly reduced pressure drop compared to conventional non-woven filters, so that high air flow rates can also be achieved with an H13 filter.

Basically, two scenarios are conceivable for the operation of air purifiers: If, during operation, persons in the room (e.g. during school lessons or meetings), among whom an infected person is present, exhale viruses or virus-containing particles, an equilibrium concentration of viruses in the room is established over time, assuming a homogeneous distribution[6] [96]. The higher the CADR of the air purifier, the lower the equilibrium concentration, but it can never be exactly zero. If the viruses are evenly distributed in the room, the resulting equilibrium concentration depends only on the quantity of viruses exhaled (source) and the quantity of viruses removed per unit of time (sink). The latter depends only on the CADR, not on the room volume.

6 This assumption is not always given in reality, because in unfavourable flow situations it may not be possible to achieve homogeneous mixing in a short time.

Kriegel et al. [97] calculated that at a CADR of 750 m^3/h, the risk of infection per hour of time spent in a room with an infected person can be reduced to 10 %. The risk of infection is thus minimised, but other protective measures, such as ventilation or wearing masks, must never be completely neglected [98]. On the other hand, air purifiers can be used, e.g. during school breaks or between meetings in an empty room, to reduce an existing initial concentration. The higher the air exchange rate[7], the faster this is achieved. This is the quotient of CADR and room volume. The test standards mentioned above recommend about three to six air changes per hour. The higher value is also currently recommended in the context of the COVID 19 pandemic [99]. For a 2.5 m high room with an area of 20 m^2 (50 m^3 room volume), an air purifier with a CADR of 300 m^3/h would be required. In principle, even higher air exchange rates result in an even faster decrease in particle concentration but are still associated with higher energy consumption and noise emissions. It is therefore always necessary to find a suitable compromise for the respective application.

When positioning air purifiers in the room, it should be ensured that they can freely draw in the room air and blow the purified air back into the room, otherwise the purified air cannot be distributed evenly throughout the room [100]. Accordingly, air purifiers should not be positioned behind objects or furniture or under tables. The decrease of the aerosol concentration over time strongly depends on the aerodynamic flow conditions in the room under consideration, the position of the installed unit in the room and its volume flow. In very large rooms, flow obstacles on the

7 Strictly speaking, the term air exchange rate is not correct in this context because the air is circulated and not exchanged. Nevertheless, it is commonly used to describe this situation.

ceiling can also have a negative effect on the uniform distribution of the air [99]. As an alternative to a single unit with high CADR, several units with lower CADR can be used [96], whereby care should be taken to ensure that one unit does not directly draw in the purified air discharged by another unit. The use of several air purifiers can also lead to the exhaled air of individual persons being sucked in more directly, thus reducing the distribution of viruses in the room.

5.3 Effectiveness of ventilation systems

In contrast to mobile air purifiers, ventilation systems are fixed installations installed in buildings to improve indoor air quality. They are often referred to as heating, ventilation and air conditioning (HVAC) systems. Depending on the design, HVAC systems can be designed as pure fresh air or circulating air systems or as a combination of both. In the case of a pure recirculating air system, the combination of volume flow and the filter used is always relevant for the effectiveness of the air purification (as with air purifiers), whereas for pure fresh air systems the efficiency of the filter is of greater importance, since the air passes through it only once and the purified air then displaces the indoor air. However, this only applies to general air pollutants. If, on the other hand, the virus concentration in the outside air is considered negligible, then the choice of filter for reducing the virus load in a room with a fresh air system is irrelevant. Fresh air systems have the advantage that gases emitted in the interior, such as exhaled carbon dioxide, are removed from the room. However, pure fresh air systems are less favourable from an energy point of view, since air drawn in from outside must be tempered to the indoor conditions, e.g. in a heat exchanger [101].

Filters used in HVAC systems are tested and classified according to the international standard ISO 16890. This classification into the filter groups ISO ePM1, ISO ePM2.5 and ISO ePM10 as well as ISO Coarse mainly aims at the separation efficiency for different fine dust fractions of typical urban or rural outdoor air. Filters classified as ePMx must have a minimum separation efficiency of 50 % for the respective fine dust fraction. The separation efficiency determined in standard tests is added to the respective filter class. An HVAC filter of class "ISO ePM2.5 65 %" separates at least 65 % of PM2.5. As electret filters are often used for HVAC systems, the minimum efficiency always refers to the average value of the charged and uncharged filter.

A combination of an ISO Coarse and a higher efficiency filter is often used, with the coarse dust filter protecting the fine filter. To supply rooms with particularly high air quality requirements, e.g. clean rooms or operating theatres, EPA (E10 - E12), HEPA (H13 or H14) or ULPA (U15 - U17) filters in accordance with EN 1822-1 and ISO 29463 standards can be used instead of ISO ePM filters, but their use is always associated with increased energy consumption due to the higher air flow resistance for the same air flow rate.

In the context of the current COVID 19 pandemic, ventilation systems are of particular importance. It has been known for some time that the recirculation of air in a ventilation system can lead to an accumulation of pathogens in a room if it is not adequately filtered [102]. In spring 2020, the outbreaks of COVID-19 in the Westphalian meat industry produced precisely this scenario, since the air for cooling was recirculated without filtration

[103]. The outbreak in a restaurant in Guangzhou, China, is also attributed to the air being circulated by an air conditioning system without filtration [104]. Similarly, on the cruise ship Diamond Princess, the corona virus is believed to have spread via the ventilation system with inadequate filtration, leading to high rates of infection, although passengers were quarantined in their cabins [105].

Based on these findings, the use of recirculation is now generally not recommended and instead the supply of 100 % fresh air with the highest possible volume flow and heat exchange is recommended [1]. Accordingly, on 20 October 2020, the German federal government launched a funding programme in which a total of 500 million euros will be provided for the conversion and upgrading of ventilation and air-conditioning systems in public buildings and places of assembly [106]. This programme explicitly calls for the conversion of air recirculation systems into air supply systems. From the point of view of GAeF, these measures make sense, but a sense of proportion should be maintained in the operation of the systems and in the selection of filters. The introduction of viruses or other pathogens with the outside air is unlikely, so that the use of highly efficient, e.g. H13 or H14 filters is not necessary and should be avoided from the point of view of energy saving and climate protection. In recirculation mode, a distinction must be made between whether the system supplies a single room or several rooms. For a single room the use of a highly efficient filter is not necessary (see discussion of air purifiers in Section 5.2). If, on the other hand, the system supplies several rooms, then the use of highly efficient filters can be useful to prevent the possible spread of viruses from one room to another. In hospitals, for example, there is usually a two-stage filtration system. The first stage usually separates mainly coarse particles. For all sensitive zones such as operating theatres and isolation rooms, there is then a second stage with stricter requirements, in which filters with higher efficiency are used for smaller particles.

An exhaust air system for classrooms recently developed by the Max Planck Institute for Chemistry in Mainz, which can be produced by the pupils themselves with quite simple means, provides for the extraction of air above the pupils' heads, since exhaled air rises due to thermal effects [107]. Fresh air is supplied directly using outside air. A comparable extraction system could also be useful for conventional ventilation systems. With this concept, very good values were achieved for the extraction of test particles with simulated heat convection at the point of generation at about two air changes per hour [78].

In general, ventilation systems require regular maintenance and filter replacement. As a rule, the filters are only checked via the pressure drop of the filters. In the case of electret filters, however, the pressure drop may not be the right measure for a filter change, but rather the loss of filter efficiency. Permanent monitoring of the filter efficiency can be achieved by means of low-cost dust sensors [108], which have been available for several years, but are not currently state of the art. Such a development is particularly desirable for large ventilation systems that supply rooms used by many people, such as hotels, exhibition centres or lecture halls.

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6. Effectiveness of masks

The German Federal Institute for Drugs and Medical Devices (BfArM) basically divides masks into three categories [109]:

Filtering facepieces
which include FFP1, FFP2 and FFP3 respirators, but also equivalent half-masks such as KN95 from China and N95 from the USA

Medical face masks of classes Type I, Type II and Type IIR
hese include mouth and nose guards and surgical masks

Mouth and nose covers
which include so-called everyday fabric or community masks

The standards applicable to filtering facepieces and medical face masks are listed in Table 1 with the main test conditions. There are currently no testing standards for community masks, only proposals from various standardisation bodies. A selection is also listed in Table 1.

Category	Standard/Guideline	Class	min. efficiency	max. pressure drop inhalation/exhalation	Test aerosol (median diameter)	Validity	Comments
Filtering facepiece	EN149:2001-A1:2009 in conjunction with EN 13274-7:2019	FFP1	80%	210 Pa, at 95 l/min 300 Pa, at 160 l/min	NaCl (0,08 ±0,03 µm) AND paraffin (0,37±0,08 µm) at 95 l/min	Europe	Test of the entire mask
		FFP2	94%	240 Pa, at 95 l/min 300 Pa, at 160 l/min			
		FFP3	99%	300 Pa, 95 l/min 300 Pa, at 160 l/min			
	GB 2626-2006	KN95	95%	350 Pa, at 85 l/min 250 Pa, at 85 l/min	NaCl (0,075 ±0,02 µm) at 85 l/min	China	
	42 CFR part 84	N95	95%	343,2 Pa, at 85 l/min 245,2 Pa, at 85 l/min	NaCl (0,075 ±0,02 µm) at 85 l/min	USA	
Medical face mask	EN 14683	Type I	95%	196 Pa, at 27,2 cm/s	Water droplets > 1 µm containing bacteria at 28,3 l/min	Europe	Test of filter media samples (49 cm² for efficiency, 4,9 cm² for pressure drop)
		Type II	98%	196 Pa, at 27,2 cm/s			
		Type IIR	98%	294 Pa, at 27,2 cm/s			
Cloth Face Maske	CWA 17553	level 90%	90%	240 Pa, at 95 l/min 300 Pa, at 160 l/min	3±0,5 µm	Europe	Testauf set up according to existing standards, e.g. EN149 or EN14683
		level 70%	70%				
	SNR 3000	level 70%	70% at 1 µm	294 Pa at 27,2 cm/s	1±0,1 µm, at 8 cm/s	Switzerland	To be published in Q1/2021
	UNI/PdR 90.1:2020	CFC-NR	80% at MPPS	210 Pa, at 95 l/min	DEHS, Size range 0,3 - 10 µm (size resolved measurement)	Italy	not reuseable
		CFC-R					reuseable
		CFC-BIO					biodegradable

Table 1: Overview of common testing standards for different particle-filtering half masks and medical viewing masks, as well as documents from various standardisation committees for the testing of mouth-nose-coverings

The use of a mouth-nose cover is currently recommended in many areas and is compulsory in most European countries when using public transport and in many countries, e.g. in Germany and Austria (with interruptions) since spring 2020 also when entering a shop. If suitable masks are used properly and over a large area, they can effectively contain the spread of viruses via the air [110, 111, 112, 113]. Nevertheless, there is a great need among the population for more information on which mask type provides what protection against the transmission of the virus. At present, the three types of masks listed above are available to the public for protection against particles containing viruses. Particle separation in masks depends only on the particle size (see Figure 4), but not on whether the particles are biologically active or inactive [114]. It should be noted here that freshly exhaled aerosol may have a different size distribution from ambient aerosol due to the higher air humidity. It is therefore important to consider not only the self-protection provided by the individual mask, but also the external protection.

In general, any mask is better than no mask at all, especially with regard to the protection of others, i.e. the protection of fellow human

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beings [115]. It must be taken into account that masks are essentially designed to retain potentially virus-laden particles when exhaled. However, they also offer a certain degree of self-protection during inhalation, even if this is usually much less, because the liquid particles shrink between exhalation and inhalation. In order to ensure a high degree of protection when several people meet, it is very important that everyone uses the most efficient mask possible and wears it correctly, i.e. as close as possible to the mouth and nose. Figure 6 shows the deposition efficiencies of an FFP2, two medical type II masks and some fabric masks. It can be seen that an FFP2 mask has the highest efficiency and the fabric masks the lowest. The two Type II masks behave very differently for particles smaller than 0.3 µm. For micrometer sized particles, however, these masks are very efficient. Fabric masks, on the other hand, only show high separation efficiencies with a particle size of several micrometres.

In order to protect itself effectively against viruses, the mask must filter fine particles well and also fit tightly. At the same time, masks are not a panacea, but must always be used in accordance with the hygiene guidelines, which include keeping your distance and the usual hygiene measures. In addition, care should be taken not to touch the mask when removing it, as otherwise viruses may get onto the hands and spread via smear infection.

There are also face shields, but these have no filtering effect whatsoever and only stop particles of several micrometres in size, which are ejected at high speed when coughing or sneezing, for example, by impaction. Smaller particles, on the other hand, are retained inadequately or not at all [116]. Face visors are only used as protection against spitting and splashing of large droplets. These visors are therefore only recommended as an additional measure, e.g. for medical and nursing staff, to protect their own eyes from large, possibly infectious droplets [117, 118]. A similar effect could be achieved with protective goggles.

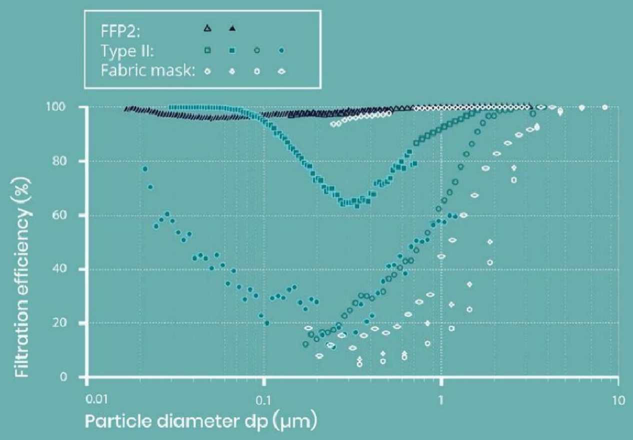

Figure 6: Separation efficiency of different mask types as a function of particle size, measured with optical aerosol spectrometers; the separation of very small particles in FFP2 and type II masks was also determined by means of electrical mobility analysis (filled symbols); data sources: FFP2 - Prof. Dr. H.J. Schmid, University of Paderborn, Type II - Prof. Dr. E. Weingartner, FH Nordwestschweiz and Dr. C. Asbach, IUTA, fabric masks: Prof. Dr. P. Tronville and Dr. J. Marval, Politecnico di Torino, Prof. Dr. E. Weingartner, FH Nordwestschweiz and Dr. C. Asbach, IUTA

6.1 Filtering facepieces

Filtering facepieces come from the field of occupational health and safety and are available, for example, to medical personnel for their work. They serve as self-protection against the inhalation of harmful particles, ranging from coarse dust to ultra-fine particles, depending on the protection level [119]. Masks certified accordingly must meet strict test standards that provide for different test aerosols (see Table 1). Viruses such as SARS-CoV-2 do not float through the air as free particles, but always with an envelope of lung fluid, saliva and/or mucus as exhaled droplets [120]. Even if this envelope shrinks over time through evaporation, the virus will not be completely exposed, even at low relative humidity. The diameter of these droplets is therefore much larger (see Section 4) than the diameter of the virus and also larger than the media diameter of the test mucus prescribed by the standards. It can therefore be assumed that the actual filtration efficiency for these particles is much higher than that of the MPPS of the applicable standard.

It is important that particle filtering half masks have a valid certificate. Manufacturers of FFP half masks must have their products tested in accordance with the mandatory EN 149:2001+A1:2009 standard before they are placed on the European market. Only test equipment that fully complies with all the requirements of the standard may be used to demonstrate compliance. This is important because, due to the shortage of masks in spring 2020, there are many falsely advertised or completely counterfeit products on the market that do not provide the specified protection. The user can recognise a tested and approved mask by the CE mark, the subsequent four-digit *Notified Body Number* (NBnr) of the testing laboratory and the mention of the applicable standard, e.g. EN 149:2001 on the product and packaging. A list of mislabelled masks has been published by the CDC on their website (https://www.cdc.gov/niosh/npptl/usernotices/counterfeitResp.html).

However, even the best respiratory masks with high separation efficiency only offer good self-protection against virus-containing particles if there is non-permeable contact between the skin of the person wearing them and the mask. However, people's faces differ considerably, for example in shape, size and nose type. As a result, not every respiratory protective mask will fit every person tightly and provide adequate protection [121]. In addition, there are many different models with different cuts, shapes and sizes in every protection level. A poor and insufficiently tight fit considerably reduces the protection of the wearer and can be responsible for illness despite a certified mask with high deposition efficiency. The ISO standard 16975-3 now exists for checking the seal of masks, and in some countries, such as the UK and the USA, a mandatory seal test is therefore required for all workers who have to wear a respiratory protective mask at work, e.g. in hospitals or nursing homes. Only a fit test can check whether a particular model and size of mask matches the individual face of the wearer and whether the mask can actually be used for self-protection. Specially adapted aerosol measuring techniques are used for this purpose. To pass this test, the mask must be put on correctly, the nose clip pressed on correctly and the appropriate mask shape and size must be selected. As an example, the British regulatory authority HSE created guideline INDG479 to be a national regulation for the tightness test for respiratory protective devices [122]. For extensive implementation, the accreditation programme "Fit2Fit" (https://www.fit2fit.org) was also developed there in cooperation with interest groups by HSE as proof of the competence of suppliers of fit testing to guarantee a particularly high safety standard.

Some breathing masks have a valve to facilitate exhalation. They do not filter the air as it is exhaled and therefore contribute to the spread of viruses. Although the valves are designed in such a way that the exhaled air is discharged downwards [123], small particles can still remain in the air for long periods of time, for example due to turbulent flow or [redacted] molecular motion. Masks with exhalation valves are unsuitable for external protection and should therefore not be used in the context of pandemic control.

Although the maximum dust-holding capacity of the masks is typically not reached during normal use to protect against infection, the masks can be used for a wide range of applications. However, regardless of possible contamination of the mask, the useful life of the masks is limited, as they are usually made of electret filter material [75]. Accordingly, an expiry date for the maximum storage period is often indicated on the packaging of respiratory protection masks. When worn, the filter efficiency decreases over time as the filter material loses its electrical charge, e.g. due to the humidity of the exhaled air. At the same time, these masks cannot be reused, as the high efficiency of the mask with simultaneously low breathing resistance is only achieved by the electret material. Grinshpun et al. also found that sterilisation of masks both in autoclaves and with an ethanol solution significantly reduced filter efficiency and also increased breathing resistance [124].

6.2 Medical face masks

These disposable masks come from the medical sector and are subject to the Medical Products Act. According to EN 14683, "Type II" or "Type IIR" hygiene masks must achieve a minimum bacterial filter effect of 98 % and "Type I" masks 95 % (see Table 1). Since bacteria are relatively large compared to viruses (several micrometres in diameter), the filtering performance of hygiene masks for fine particles, e.g. viruses, is often lower than that of breathing masks. In addition, these masks do not seal tightly against the face, so that leakage flows occur during breathing which are not filtered. The effect of these leakage flows is not taken into account in the deposition curves in Figure 6, since these measurements were performed with tight filter holders.

If micrometre-sized virus-containing droplets are ejected by sneezing or coughing, hygiene masks retain a relatively large proportion of these, thus ensuring appropriate protection against foreign bodies. They thus help to reduce the risk of infection for people in the vicinity. In a study of 37 influenza-infected patients, Milton et al. [42] investigated whether respiratory masks retain particles that are produced during coughing. This was quite successful for the coarse aerosol particle fraction (defined here as >5 µm), because viral material was only detected in 4 of 37 patients when the patients wore surgical masks. This was not true for the fine aerosol particle fraction. In 29 of the 37 patients, viruses were still found even when wearing a respiratory mask. However, the amount of virus exhaled could be reduced by 55 % by wearing a surgical mask. In addition, wearing a mask, especially when coughing or sneezing, spreads the airflow over a larger area and reduces the speed of the exhaled particles and their range. A good fit of the mask on the face, i.e. over the mouth and nose, is crucial.

6.3 Mouth-nose-covers

Mouth and nose covers are fabric masks, also known as community or everyday masks, and consist of one or more layers of fabric with usually unspecified filter properties. The masks can be used several times and are partly washable. Measurements of the filtration efficiency on various commercially available fabric masks show a mixed picture: Only a few products have a comparable or higher efficiency than hygiene masks, while other fabric masks allow smaller particles between 0.1 and 0.5 µm to pass through to a high degree [125, 126]. It is only with very small particles (< 0.1 µm) that the filter efficiency of these substances also improves again due to diffusion separation (see Section 5.1). Drewnick et al. [126] investigated the suitability of different materials that can be found in the household

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as filter media for everyday masks. Of the textile materials investigated, silk was the least efficient and two-layer tricot fabric the most efficient. The two-layer tricot fabric achieved a separation efficiency of about 75 % at a particle size of 1 µm. The authors also tested the material of a vacuum cleaner bag, which showed by far the highest efficiency, in MPPS at approx. 0.1 µm of >90 %.

The efficiency of fabric masks cannot usually be assessed by the purchaser. In general, however, two or multi-layer masks show higher particle separation than single-layer masks, denser fabrics separate particles better than looser materials, and non-woven fabrics show better separation behaviour than woven fabrics. However, since thinner, looser materials have lower breathing resistance, the differences between the materials can be largely compensated for by increasing the number of layers of fabric, so that the deposition values of surgical masks can be achieved [126, 25].

Currently there are no valid standards on how to test and classify fabric masks. However, initiatives have been launched in Switzerland [127] and Italy [128, 129] to remedy this situation. The French standardisation authority AFNOR also recommends that fabric masks be tested according to EN149 in conjunction with EN 13274-7:2019, i.e. comparable to FFP masks [130]. At the European level, a workshop (CWA 17553) of the European standards authority CEN has reached a consensus on how to test fabric masks [131]. The criteria of these specifications are listed in Table 1.

7. Current research needs

From the point of view of the Gesellschaft für Aerosolforschung, there is an acute need for research in order to better understand infection via the aerosol path on the one hand, and to be able to take improved measures to contain the pandemic to protect the population from the pandemic on the other. Many of these research fields require the concerted cooperation of the different scientific disciplines involved.

The most urgent open research needs from the GAeF's point of view are:

- Cooperation between the aerosol research fields and medical-epidemiological research as well as ventilation technology and fluid mechanics should be promoted in order to combine expertise from all areas in the best possible way.
- In the course of these collaborations, parallel research into transmission paths is crucial, in addition to dealing with the consequences of the pandemic, since research can only be conducted „in situ" in a pandemic situation.
- Since the particle size distribution is relevant for almost all areas of transmission, it should be better recorded by suitable measuring methods and influencing parameters (e.g. relative humidity and temperature of the environment) should also be recorded. These data represent an important basis for computer-aided modelling of the infection process.
- For research in the period after the pandemic, suitable model systems must be found and the transferability of results with different virus strains investigated.
- Respiratory problems and reduced lung volume are often reported as symptoms and late complications of Covid-19 disease. The influence of air pollution on these symptoms and the general course of the disease needs further research.
- This should be supported by the use of theoretical simulation models and accompanying model experiments on the spread and transmission of aerosol-bearing viruses and other aerosol-borne pathogens to evaluate possible protection, hygiene, ventilation and air purification measures.
- More knowledge about the „acute phase" with the highest aerosol production and highest virus production would help to better adapt quarantine measures.
- The duration of infectivity of aerosol-carried viruses and other aerosol-carried pathogens has not been sufficiently researched so far. This probably also requires the development of new methods, in particular to be able to assess infectivity in comparison to other transmission routes. The latter also includes the question of the minimum virus doses required for infection.
- The effectiveness of UV radiation against airborne viruses has hardly been researched so far. In particular, there is a lack of information on the exposure required (intensity × exposure time) to inactivate airborne viruses. This is particularly

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important in the context of air purifiers or ventilation systems without separating filters, where there are usually only very short residence times. Furthermore, possibilities to test this on a real scale are currently still lacking.

- Ventilation concepts, especially for schools but also for other public buildings and places of assembly, must be evaluated with regard to this and other aerosol-borne diseases, in order to minimise economic damage. Aspects of energy efficiency and, accordingly, climate protection must also be taken into account.

- Possible by-products of air purification systems such as ozone or volatile organic compounds and their effect on secondary aerosol formation in indoor spaces should be investigated both experimentally in laboratory studies and in real indoor spaces.

- Indoor air quality in general is an important field of research to be strengthened, in addition to outdoor air quality monitoring, as people spend a large part of their time indoors (typically over 90 % in Europe).

- Systematic investigations on the tight fit of masks of all mask types, in particular during exhalation, and under realistic conditions, are still largely lacking.

In order to be able to deal with these and other research topics in a timely and comprehensive manner, the efforts already undertaken should be expanded and research resources should be made available at short notice. The allocation of these research funds should be based in particular on interdisciplinary issues, with the aim of developing a congruent and continuous catalogue of measures for future pandemic situations. Measured against the global economic losses of the current pandemic, it should become clear what advantage early and broad-based scientific studies can offer for the future.

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9. Bibliography

[1] L. Morawska, J. Tang, W. Bahnfleth, P. Bluyssen, A. Boerstra, G. Buonanno, J. Cao, S. Dancer, A. Floto, F. Franchimon, C. Haworth, J. Hogeling, C. Isaxon, J. Jimenez, J. Kurnitski, Y. Li, M. Loomans, G. Marks und L. e. a. Marr, „How can airborne transmission of COVID-19 indoors be minimised?," Environment International, Bd. 142, p. 105832, 2020.

[2] Y. Li, H. Qian, J. Hang, X. Chen, L. Hong, P. Liang, J. Li, S. Xiao, J. Wei, L. Liu und M. Kang, „Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant," medRxiv (preprint), p. https://doi.org/10.1101/2020.04.16.20067728 , 2020.

[3] N. van Doremalen, D. Morris, M. Holbrook, A. Gamble, B. Williamson, A. Tamin, J. Harcourt, N. Thornburg, S. Gerber, J. Lloyd-Smith, E. de Wit und V. Munster, „Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1," New England Journal of Medicine, Bd. 382, pp. 1564-1567, 2020.

[4] J. Seinfeld und S. Pandis, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, Bd. 3rd edition, Wiley, 2016, p. 1152.

[5] V. McNeill, „Atmospheric Aerosols: Clouds, Chemistry, and Climate," Annual Review of Chemical and Biomolecular Engineering, Bd. 8, pp. 427-444, 2017.

[6] T. Hoffmann, C. Zetzsch und M. Rossi, „Chemie von Aerosolen," Chemie in unserer Zeit, Bd. 41, pp. 232-246, 2007.

[7] P. Bruckmann und T. Eikmann, „Feinstäube und menschliche Gesundheit," Chemie in unserer Zeit, Bd. 41, pp. 248-253, 2007.

[8] J. Schnelle-Kreis, M. Sklorz, H. Hermann und R. Zimmermann, „Atmosphärische Aerosole: Quellen, Vorkommen, Zusammensetzung," Chemie in unserer Zeit, Bd. 41, pp. 220-230, 2007.

[9] W. Hinds, Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles, New York: Wiley, 1999.

[10] M. Kulmala, „How particles nucleate and grow," Science, Bd. 302, pp. 1000-1001, 2003.

[11] Y.-H. Jin, L. Cai, Z.-S. Cheng, H. Cheng, T. Deng, Y.-P. Fan, C. Fang, D. Huang, L.-Q. Huang, Q. Huang, Y. Han, B. Hu, F. Hu, B.-H. Li, Y.-R. Li, K. Liang, L.-K. Lin, L.-S. Luo, J. Ma, L.-L. Ma, Y.-Z. Peng, Y.-B. Pan und e. al., „A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-nCoV) infected pneumonia (standard version)," Military Medical Research, Nr. 7, p. 4, 2020.

[12] J. Jiang, Y. Fu, L. Liu und M. Kulmala, „Transmission via aerosols: Plausible differences among emerging coronaviruses," Aerosol Science and Technology, Bd. 54, pp. 865-868, 2020.

[13] Y. Drossinos und N. Stilianakis, „What aerosol physics tells us about airborne pathogen transmission," Aeroosl Science and Technology, Bd. 54, pp. 639-643, 2020.

[14] L. Bourouiba, „Turbulent Gas Clouds and Respiratory Pathogen Emissions - Potential Implications for Reducing Transmission of COVID-19," JAMA, Bd. 323, pp. 1837-1838, 2020.

[15] A. Einstein, „Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen," Annalen der Physik, Bd. 322, pp. 549-560, 1905.

[16] M. Smoluchowski, „Zur kinetischen Theorie der Brownschen Molekularbewegung und der Suspensionen," Annalen der Physik, Bd. 326, pp. 756-780, 1906.

1695933

[17] R. Brown, Air Filtration - An integrated approach to the theory and applications of fibrous filters, Exeter: Pergamon Press, 1993.

[18] J. Heyder, J. Gebhart, G. Rudolf, C. Schiller und W. Stahlhofen, „Deposition of particles in the human respiratory tract in the size range 0.005-15 µm," Journal of Aerosol Science, Bd. 17, pp. 811-825, 1986.

[19] V. Vuorinen, M. Aarnio, M. Alava, V. Alopaeus, N. Atanasova, M. Auvinen, B. H. Balasubramanian, E. P., R. Grande, N. Hayward, A. Hellsten, S. Hostikka, J. Hokkanen, O. Kaario, A. Karvinen, I. Kivistö, M. Korhonen und e. al., „Modelling aerosol transport and virus exposure with numerical simulations in relation to SARS-CoV-2 transmission by inhalation indoors," Safety Science, Bd. 130, p. 104866, 2020.

[20] A. Ahlawat, A. Wiedensohler und S. Mishra, „An overview on the role of relative humidity in airborne transmission of SARS-CoV-2 in indoor environments," Aerosol and Air Quality Research, Bd. 20, pp. 1856-1861, 2020.

[21] K. Lin und L. Marr, „Humidity-dependent decay of viruses, but not bacteria, in aerosols and droplets follows disinfection kinetics," Environmental Science and Technology, Bd. 54, pp. 1024-1032, 2020.

[22] W. Wells, „On Air-borne Infection. Study II. Droplets and Droplet Nuclei," American Journal of Hygiene, Bd. 20, pp. 611-618, 1934.

[23] D. Parienta, L. Morawska, G. Johnson, Z. Ristovski, M. Hargreaves, K. Mengersen, S. Corbett, C. Chao, Y. Li und D. Katoshevski, „Theoretical analysis of the motion and evaporation of exhaled respiratory droplets of mixed composition," Journal of Aerosol Science, Bd. 42, pp. 1-10, 2011.

[24] D. Kincaid und T. Longley, „A water droplet evaporation and temperature model," Transactions of the ASAE, Bd. 32, pp. 457-463, 1989.

[25] F. e. a. Drewnick, „Abscheideeffizienz von Mund-Nasen-Schutz Masken, selbstgenähten Gesichtsmasken,potentiellen Maskenmaterialiensowie „Community Masken"," 20 05 2020. [Online]. Available: https://www.mpic.de/4670174/filtermasken_zusammenfassung.pdf. [Zugriff am 25 11 2020].

[26] J. Gebhart, J. Anselm, J. Heyder und W. Stahlhofen, „The Human Lung as Aerosol Generator," Journal of Aerosols in Medicine, Bd. 1, pp. 196-197, 1988.

[27] G. Johnson und L. Morawska, „The mechanism of breath aerosol formation," Journal of Aerosol Medicine and Pulmonary Drug Delivery, Bd. 22, pp. 229-237, 2009.

[28] B. Bake, E. Ljungström, A. Claesson, H. Carlsen, H. M. und A. Olin, „Exhaled Particles after a Standardized Breathing Maneuver," Journal of Aerosol Medicine and Pulmonary Drug Delivery, Bd. 30, pp. 267-273, 2017.

[29] B. Bake, P. Larsson, G. Ljungkvist, E. Ljungström und A. Olin, „Exhaled particles and small airways," Respiratory Research, Bd. 20, pp. 1-14, 2019.

[30] P. Larsson, E. Mirgorodskaya, L. Samuelsson, B. Bake, A. Almstrand, A. Bredberg und A. Olin, „Surfactant protein A and albumin in particles in exhaled air," Respiratory Medicine, Bd. 106, pp. 197-204, 2012.

[31] S. Kokelj, J. Kim, M. Andersson, E. G. B. Bake und A. Olin, „Intra-individual variation of particles in exhaled air and of the contents of Surfactant protein A and albumin," PLoS One, Bd. 15, p. e0227980, 2020.

[32] K. Haslbeck, K. Schwarz, J. Hohlfeld, J. Seume und W. Koch, „Submicron droplet formation in the human lung," Journal of Aerosol Science, Bd. 41, pp. 429-438, 2010.

[33] K. Schwarz, H. Biller, H. Windt, W. Koch und J. Hohlfeld, „Characterization of exhaled particles from the healthy human lung - A systematic analysis in relation to pulmonary function variables," Journal of Aerosol Medicine and Pulmonary Drug Delivery, Bd. 23, pp. 371-379, 2010.

[34] K. Schwarz, H. Biller, H. Windt, W. Koch und J. Hohlfeld, „Characterization of exhaled particles from the human lungs in airway obstruction," Journal of Aerosol Medicine and Pulmonary Drug Delivery, Bd. 28, pp. 52-58, 2015.

[35] G. Scheuch, „Breathing is enough: For the spread of influenza virus and SARS-CoV-2 by breathing only," Journal of Aerosol Medicine and Pulmonary Drug Delivery, Bd. 33, pp. 230-234, 2020.

[36] J. Ma, X. Qi, H. Chen, X. Li, Z. Zhang, H. Wang, L. Sun, L. Zhang, J. Guo, L. Morawska, G. S., P. Biswas, R. Flagan und M. Yao, „COVID-19 patients in earlier stages exhaled millions of SARS-CoV-2 per hour," Clinical Infectious Dieseases, p. https://doi.org/10.1093/cid/ciaa1283, 2020.

[37] F. Gregson, N. Watson, C. Orton, A. Haddrell, L. McCarthy, T. Finnie, N. Gent, G. Donaldson, P. Shah, J. Calder und e. al., „Comparing the Respirable Aerosol Concentrations and Particle Size Distribu-tions Generated by Singing, Speaking and Breathing," ChemRxiv (preprint), p. https://chemrxiv.org/articles/preprint/Comparing_the_Respirable_Aerosol_Concentrations_and_Particle_Size_Distributions_Generated_by_Singing_Speaking_and_Breathing/12789221/1, 2020.

[38] D. Mürbe, M. Fleischer, J. Lange, H. Rotheudt und M. Kriegel, „Aerosol emission is increased in professional singing," (Preprint), pp. https://depositonce.tu-berlin.de/handle/11303/11490, 2020.

[39] C. Stadnytskyi, C. Bax, A. Bax und P. Anfinrud, „The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission," PNAS, Bd. 117, pp. 11875-11877, 2020.

[40] S. Asadi, A. Wexler, C. C. S. Barreda, N. Bouvier und W. Ristenpart, „Aerosol emission and superemission during human speech increase with voice loudness," Scientific Reports, Bd. 9, pp. 1-10, 2019.

[41] P. Fabian, J. McDevitt, W. DeHaan, R. Fung, B. Cowling, K. Chan, G. Leung und D. Milton, „Influenza virus in human exhaled breath: An observational study," PLoS One, Bd. 3, p. e2691, 2008.

[42] D. Milton, M. Fabian, B. Cowling, G. M. und J. McDevitt, „Influenza Virus Aerosols in Human Exhaled Breath: Particle Size, Culturability, and Effect of Surgical Masks," PLoS Pathology, Bd. 9, p. e1003205, 2013.

[43] W. Lindsley, B. F. und D. e. a. Beezhold, „Viable influenza A virus in airborne particles expelled during coughs versus exhalations," Influenza and OtherRespiratory Viruses, Bd. 10, pp. 404-413, 2016.

[44] P. Fabian, J. McDevitt, W. Lee, E. Houseman und D. Milton, „An optimized method to detect influenza virus and human rhinovirus from exhaled breath and the airborne environment," Journal of Environmental Monitoring, Bd. 11, pp. 314-317, 2009.

[45] B. Wang, A. Zhang, J. Sun, H. Liu, J. Hu und L. Xu, „Study of SARS transmission via liquid droplets in air," Journal of Biomedical Engineering, Bd. 127, pp. 32-38, 2005.

[46] J. Gralton, E. Tovey, M. Mclaws und W. Rawlinson, „Respiratory virus RNA is detectable in airborne and droplet particles," Journal of Medical Virology, Bd. 85, pp. 2151-2159, 2013.

[47] A. Mitchell, B. Mourad, E. Tovey, L. Buddle, [redacted], L. Morgan und B. Oliver, „Spirometry filters can be used to detect exhaled respiratory viruses," Journal of Breath Research, Bd. 10, p. 046002, 2016.

[48] L. Yip, M. Finn, A. Granados, K. Prost, A. McGeer, J. Gubbay, J. Scott und S. Mubareka, „Influenza virus RNA recovered from droplets and droplet nuclei emitted by adults in an acute care setting," Journal of Occupational and Environmental Hygiene, Bd. 16, pp. 341-348, 2019.

[49] E. Shiu, W. Huang und D. Ye, „Frequent recovery of influenza A but not influenza B virus RNA in aerosols in pediatric patient rooms," Indoor Air, Bd. 30, pp. 805-815, 2020.

[50] L. Morawska und J. Cao, „Airborne transmission of SARS-CoV-2: The world should face the reality," Environment International, Bd. 139, p. 105730, 2020.

[51] S. Smither, L. Eastough, J. Findlay und M. Lever, „Experimental aerosol survival of SARS-CoV-2 in artificial saliva and tissue culture media at medium and high humidity," EMerging Microbes & Infections, Bd. 9, pp. 1415-1417, 2020.

[52] A. Brlek, Š. V. S. Vidovič, K. Turk und Z. Simonović, „Possible indirect transmission of COVID-19 at asquash court, Slovenia, March 2020: case report," Epidemiology and Infection, Bd. 148, pp. 1-3, 2020.

[53] A. Fears, W. Klimstra, P. Duprex, A. Hartman, S. Weaver, K. Plante, D. Mirchandani, J. Plante, P. Aguilar, D. Fernández, A. Nalca und e. al., „Persistence of Severe Acute Respiratory Syndrome Coronavirus 2 in Aerosol Suspensions," Emerging Infectious Dieses, Bd. 26, pp. 2168-2171, 2020.

[54] J. Lednicky, M. Lauzardo, Z. Fan, A. Jutla, T. Tilly, M. Gangwar, M. Usmani, S. Shankar, K. Mohamed, A. Eiguren-Fernandez, C. Stephenson, M. Alam, M. Elbadry, J. Loeb, K. Subramaniam, T. Waltzek, K. Cherabuddi und e. al., „Viable SARS-CoV-2 in the air of a hopsital room with COVID-19 patients," medRxiv (preprint), p. https://doi.org/10.1101/2020.08.03.20167395, 2020.

[55] L. Zhou, M. Yao, X. Zhang, B. Hu, X. Li, H. Chen, L. Zhang, Y. Liu, M. Du, B. Sun, Y. Jiang, K. Zhou, J. Hong, N. Yu, Z. Ding, Y. Xu, M. Hu, L. Morawska, S. Grinshpun, P. Biswas, R. Flagan, B. Zhu, W. Liu und Y. Zhang, „Breath- air- and surface-borne SARS-CoV-2 in hospitals," Journal of Aerosol Science, p. in press (https://doi.org/10.1016/j.jaerosci.2020.105693), 2020.

[56] H. Qian, T. Miao, L. Liu, X. Zheng, D. Luo und Y. Li, „Indoor transmission of SARS-CoV-2," medRxiv (preprint), p. https://doi.org/10.1101/2020.04.04.20053058doi, 2020.

[57] S. Das, J.-e. Alam, S. Plumari und V. Greco, „Transmission of airborne virus through sneezed and coughed droplets," AIP Physics of Fluids, Bd. 32, p. 097102, 2020.

[58] Kommission Innenraumhygiene des UBA, „Richtiges Lüften reduziert Risiko der SARS-CoV-2-Infektion," Umweltbundesamt, 13 08 2020. [Online]. Available: https://www.umweltbundesamt.de/presse/pressemitteilungen/richtiges-lueften-reduziert-risiko-der-sars-cov-2. [Zugriff am 02 12 2020].

[59] Deutsche Gesetzliche Unfallversicherung, „Kitas richtig Lüften mit Hilfe der CO2-App," Deutsche Gesetzliche Unfallversicherung (DGUV), 30 09 2020. [Online]. Available: https://www.dguv.de/de/mediencenter/pm/pressearchiv/2020/quartal_3/details_3_406030.jsp. [Zugriff am 02 12 2020].

[60] A. Todea, F. Schmidt, T. Schuldt und C. Asbach, „Development of a method to determine the fractional deposition efficiency of full scale HVAC and HEPA filter cassettes for nanoparticles >3.5 nm," Atmosphere, Bd. 11, p. 1191, 2020.

[61] C. Wang und Y. Otani, „Removal of nanoparticles from gas streams by fibrous filters: A review," Industrial & Engineering Chemistry Research, Bd. 52, pp. 5-17, 2013.

[62] J. Israelachvili, Intermolecualr and Surface Forces (3rd edition), Amsterdam: Elsevier, 2011.

[63] X. Wang, [redacted], C. Lee und J. Kim, „Prediction of air filter efficiency and pressure drop in air filtration media using a stochastic simulation," Fibers and Polymers, Bd. 9, pp. 34-38, 2008.

[64] S.-C. Wang, „Electrostatic forces in fibrous filters - a review," Powder Technology, Bd. 118, pp. 166-170, 2001.

[65] R. Thakur, D. Da und A. Das, „Electret Air Filters," Separation & Purification Reviews, Bd. 42, pp. 87-129, 2013.

[66] N. A. Fuchs, „On the stationary charge distribution on aerosol particles in a bipolar ionic atmosphere," Pure and Applied Geophysics, Bd. 56, pp. 185-193, 1963.

[67] F. Romay, B. Liu und S. Chae, „Experimental study of electrostatic capture mechanisms in commercial electret filters," Aerosol Science & Technology, Bd. 28, pp. 224-234, 1998.

[68] R. Lathrache und H. Fissan, „Fractional penetrations for electrostatically charged fibrous filters in the submicron particle size range," Particle Characterization, Bd. 3, pp. 74-80, 1986.

[69] M. Kerner, K. Schmidt, S. Schumacher, V. Puderbach, C. Asbach und S. Antonyuk, „Evaluation of electrostatic properties of electret filters for aerosol deposition," Separation and Purification Technology, Bd. 239, p. 116548, 2020.

[70] J. Van Turnhout, W. Hoenefeld, J. Adamse und L. Van Rossen, „Electret filters for high-efficiency and high-flow air cleaning," IEEE Transactions on Industry Applications, Bd. IA 17, pp. 240-248, 1981.

[71] L. Janssen und J. Bidwell, „Performance of four class 95 electret filters against diesl particulate matter," Journal of the International Society for Respiratory Protection, Bd. 23, pp. 21-29, 2006.

[72] G. Bostock, „Electret filter for respiratory protection," in Electret Filters, Production and Properties, Proceedings of the International Workshop on Electret Filters, Production and Properties, Warsaw, Poland, January 29 and 30, 1999, 1999, pp. 59-68.

[73] S. Schumacher, D. Spiegelhoff, U. Schneiderwind, H. Finger und C. Asbach, „Performance of new and artificially aged electret filters in indoor air cleaners," Chemical Engineering & Technology, Bd. 41, pp. 27-34, 2018.

[74] D. Bémer und S. Calleé, „Evolution of the efficiency and pressure drop of a filter media woth loading," Aerosol Science and Technology, Bd. 33, pp. 427-439, 2000.

[75] L. Janssen, J. Bidwell, H. Mullins und T. Nelson, „Efficiency of degraded electret filters: Part I - Laboratory testing against NaCl and DOP before and after exposure to workplace aerosols," Journal of the International Society for Respiratory Protection, Bd. 20, pp. 71-80, 2003.

[76] M. Lehtimäki und K. Heinonen, „Reliability of Electret Filters," Building and Environment, Bd. 29, pp. 353-355, 1994.

[77] A. Viraneva, T. Yovcheva, E. Gencheva und G. Mekishev, „Low pressure and humidity influences on the electret surface potential decay," Journal of Physics: Conference Series, Bd. 253, p. 012069, 2010.

[78] E. Motyl und B. Łowkis, „Effect of air humidity on charge decay and lifetime of PP electret nonwovens," Fibres & Textiles in Eastern Europe, Bd. 14, pp. 39-42, 2006.

[79] H.-J. Choi, E.-S. Park, J.-U. Kim, S.-H. Kim und M.-H. Lee, „Experimental study on charge dacy of electret filter due to organic solvant exposure," Aerosol Science & Technology, Bd. 49, pp. 977-983, 2015.

[80] J. Kim, J. Hinestroza, W. Jasper und R. Barker, „Effect of solvent exposure on the filtration performance of electrically charged polypropylene filter media," Textile Research Journal, Bd. 79, pp. 343-350, 2009.

[81] S. Schumacher, R. Jasti und C. Asbach, „Einfluss von Entladungsmethode und Aerosolmaterial auf die Abscheideeffizienz von Elektretfiltern," Gefahrstoffe - Reinhaltung der Luft, Bd. 78, pp. 316-322, 2018.

[82] T. Lin, C. Tseng, Y. Huang, H. Lin, C. Lai und S. Lee, „Effectiveness of N95 facepiece respirators in filtering aerosol following storage and sterilization," Aerosol and Air Quality Research, Bd. 20, pp. 833-843, 2020.

1695933

[83] D. Viscusi, M. Bergmann, E. Sinkule und R. Shaffer, „Evaluation of the filtration performance of 21 N95 filtering face piece repsirators after prolonged storage," American Journal of Infection Control, Bd. 37, pp. 381-386, 2009.

[84] D. Ciuzas, T. Prasauskas, E. Krugly, A. Jurelionis, L. Seduikyte und D. Martucevicius, „Indoor air quality management by combined ventilation and air cleaning: An experimental study," Aerosol and Air Quality Research, Bd. 16, pp. 2550-2559, 2016.

[85] J. Pei, C. Dong und J. Liu, „Operating behavior and corresponding performance of portable air cleaners in residential build-ings, China," Building and Environment, Bd. 147, pp. 473-481, 2019.

[86] J. Siegel, „Primary and secondary consequences of indoor air cleaners," Indoor Air, Bd. 26, pp. 88-96, 2016.

[87] H. J. Kim, B. Han, Y. J. Kim, Y. H. Yoon und T. Oda, „Efficient test method for evaluating gas removal performance of room air cleaners using FTIR measurement and CADR calculation," Building and Environment, Bd. 47, pp. 385-393, 2012.

[88] E. Budowsky, S. Bresler, E. Friedman und N. Zheleznova, „Principles of selective inactivation of viral genome," Archives of Virology, Bd. 68, pp. 239-247, 1981.

[89] J. Kim und J. Jang, „Inactivation of airborne viruses using vacuum ultraviolet photocatalysis for a flow-through indoor air purifier with short irradiation time," Aerosol Science and Technology, Bd. 52, pp. 557-566, 2018.

[90] K. Shiraki, H. Yamada, Y. Yoshida, A. Ohno, T. Watanabe, T. Watanabe, H. Watanabe, H. Watanabe, M. Yamaguchi, F. Tokuoka, S. Hashimoto, M. Kawamura und N. Adachi, „Improved photocatalytic air cleaner with decomposition of aldehyde and aerosol-associated influenza virus infectivity in indoor air," Aerosol and Air Quality Research, Bd. 17, pp. 2901-2912, 2017.

[91] M. Heßling, K. Hönes, P. Vatter und C. Lingenfelder, „Ultraviolet irradiation doses for coronavirus inactivation - review and analysis of coronavirus photoinactivation studies," GMS Hygiene and Infection Control, Bd. 15, pp. 1-8, 2020.

[92] I. Hamzavi, A. Lyons, I. Kohli, S. Narla, A. Parks-Miller, J. Gelfand, H. Lim und D. Ozog, „Ultraviolet germicidal irradiation: Possible method for respiratordisinfection to facilitate reuseduring the COVID-19 pandemic," Journal of the American Academy of Dermatology, Bd. June 2020, pp. 1511-1512, 2020.

[93] H. Finger, U. Schneiderwind und C. Asbach, „Bewertung mobiler Raumluftreinigungsgeräte," Gefahrstoffe - Reinhaltung der Luft, Bd. 75, pp. 497-502, 2015.

[94] W. Jeon, B. Lee, H. Yun, J. Kim, S. Kang und Y. Seo, „Characterization of pressure drop through two-stage particulate air filters," Science and Technology for the Built Environment, Bd. 26, pp. 835-843, 2020.

[95] J. Kim und M. Lee, „Effect of filter collection efficiency on the clean air delivery rate in an air cleaner," Indoor Air, Bd. (accepted for publication), 2020.

[96] J. Curtius, M. Granzin und J. Schrod, „Testing mobile air purifiers in a school classroom: Reducing the airborne transmission risk for SARS-CoV-2," medRxiv (preprint), p. https://www.medrxiv.org/content/10.1101/2020.10.02.20205633v2, 2020.

[97] M. Kriegel, U. Buchholz, P. Gastmeier, P. Bischoff, I. Abdelgawad und A. Hartmann, „Predicted infection risk for aerosol transmission of SARS-CoV-2," medRxiv (preprint), p. https://doi.org/10.1101/2020.10.08.20209106, 2020.

[98] L. Marr, S. Miller, K. Prather, C. Haas, W. Bahnfleth, R. Corsi, J. Tang, H. Herrmann, K. Pollitt, J. Ballester und J. Jimenez, „FAQs on Protecting Yourself from COVID-19 Aerosol Transmission," 07 11 2020. [Online]. Available: https://tinyurl.com/FAQ-aerosols . [Zugriff am 16 11 2020].

[99] C. Kähler, T. Fuchs und R. Hain, „Können mobile Raumluftreiniger eine indirekte SARS-CoV-2 Infektionsgefahr durch Aerosole wirk-sam reduzieren?," 05 08 2020. [Online]. Available: https://www.unibw.de/lrt7/raumluftreiniger.pdf. [Zugriff am 11 11 2020].

[100] M. Küpper, C. Asbach, U. Schneiderwind, H. Finger, D. Spiegelhoff und S. Schumacher, „Testing of an Indoor Air Cleaner for Particulate Pollutants under Realistic Conditions in an Office Room," Aerosol and Air Quality Research, Bd. 19, pp. 1655-1665, 2019.

[101] J. Joo, Q. Zheng, G. Lee, J. Kim und S. Kim, „Optimum energy use to satisfy indoor air quality needs," Energy and Buildings, Bd. 46, pp. 62-67, 2012.

[102] P. Azimi und B. Stephens, „HVAC filtration for controlling infectious airborne disease transmission in indoor environments: Predicting risk reductions and operational costs," Buidling and Environment, Bd. 70, pp. 150-160, 2013.

[103] T. Guenther, M. Czech-Sioli, D. Indenbirken, A. Robitailles, P. Tenhaken, M. Exner, M. Ottinger, N. G. A. Fischer und M. Brinkmann, „Investigation of the superspreading event preceding the largest meat processing plant-related SARS-Coronavirus 2 outbreak in Germany (July 17, 2020)," 2020. [Online]. Available: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3654517. [Zugriff am 06 11 2020].

[104] J. Lu, J. Gu, C. Xu, W. Su, Z. Lai, D. Zhou, C. Yu, B. Xu und Z. Yang, „COVID-19 outbreak associated with air conditioning in restaurant, Guangzhoum China, 2020," Emerging Infectious Diseases, Bd. 26, pp. 1628-1631, 2020.

[105] O. Almilaji und P. Thomas, „Air recirculation role in the infection with COVID-19, lessons learned from Diamond Princess cruise ship," 09 Juli 2020. [Online]. Available: https://doi.org/10.1101/2020.07.08.20148775 . [Zugriff am 06 11 2020].

[106] B. f. W. u. E. und B. f. W. u. A. , „Gemeinsame Pressemitteilung: 500 Millionen Euro für Raumlufttechnische Anlagen in öffentlichen Gebäuden und Versammlungsstätten zur Eindämmung des Corona-Virus," 19 10 2020. [Online]. Available: https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2020/10/20201019-500-millionen-euro-fuer-raumlufttechnische-anlagen-in-oeffentlichen-gebaeuden-und-versammlungsstaetten-zur-eindaemmung-des-corona-virus.html. [Zugriff am 06 11 2020].

[107] T. Klimach und F. Helleis, „Vorläufige Dokumentation Abluftanlage für Klassenräume," 10 11 2020. [Online]. Available: https://www.mpic.de/4782901/doku_lueftung_mpic_10112020.pdf. [Zugriff am 12 11 2020].

[108] C. Asbach, B. Hellack, S. Schumacher, M. Bässler, M. Spreitzer, T. Pohl, C. Monz, S. Bieder, T. Schultze und A. Todea, „Anwendungsmöglichkeiten und Grenzen kostengünstiger Feinstaubsensoren," Gefahrstoffe - Reinhaltung der Luft, Bd. 78, pp. 242-250, 2018.

[109] Bundesinstitut für Arzneimittel u. Medizinprodukte, „Hinweise des BfArM zur Verwendung von Mund-Nasen-Bedeckungen, medizinischen Gesichtsmasken sowie partikelfiltrierenden Halbmasken (FFP1, FFP2 und FFP3) im Zusammenhang mit dem Coronavirus (SARS-CoV-2 / Covid-19)," 12 11 2020. [Online]. Available: https://www.bfarm.de/SharedDocs/Risikoinformationen/Medizinprodukte/DE/schutzmasken.html. [Zugriff am 28 11 2020].

[110] L. Lee, E. Lam, C. Chan, S. Chan, M. Chiu, W. Chong, K. Chu, M. Hon, L. Kwan, K. Tsang, S. Tsoi und C. Wu, „Practice and technique of using face mask amongst adults in the community: a cross-sectional descriptive study," BMC Public Health, Bd. 20, p. 948, 2020.

[111] D. Chu, E. Akl, S. Duda, K. Solo, S. Yaacoub und H. Schünemann, „Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a

systematic review and meta-analysis," The Lancet, Bd. 395, pp. 1973-1987, 2020.

[112] W. Lyu und G. Wehby, „Community Use Of Face Masks And COVID-19: Evidence From A Natural Experiment Of State Mandates In The US," Health Affairs, Bd. 39, pp. 1419-1425, 2020.

[113] C. Leffler, E. Ing, J. Lykins, M. Hogan, C. McKeown und A. Grzybowski, „Association of Country-wide Coronavirus Mortality with Demographics, Testing, Lockdowns, and Public Wearing of Masks," The American Journal of Tropical Medicine and Hygiene, pp. https://doi.org/10.4269/ajtmh.20-1015, 2020.

[114] R. Eninger, A. Adhikari, T. Reponen und S. Grinshpun, „Differntiating between physical and viable penetrations when challenging respirator filters with bioaerosols," Clean - Soil, Air, Water, Bd. 36, pp. 615-621.

[115] V. Cheng, S. Wong, V. Chuang, S. So, J. Chen, S. Sridhar, K. To, J. Chan, I. Hung, P. Ho und K. Yuen, „The role of community-wide wearing of face mask for control of coronavirus disease 2019 (COVID-19) epidemic due to SARS-CoV-2," Journal of Infection, Bd. 81, pp. 107-114, 2020.

[116] W. Lindsley, J. Noti, F. Blachere, J. Szalajda und D. Beezhold, „Efficacy of face shields against cough aerosol droplets from a cough simulator," Journal of Occupational and Environmental Hygiene, Bd. 11, pp. 509-518, 2014.

[117] M. Ferioli, C. Cisternino, V. Leo, L. Pisani, P. Palange und S. Nava, „Protecting healthcare workers from SARS-CoV-2 infection: practical indications," Frontiers in Clinical Practice - Respiratory Infections, Bd. 29, p. 200068, 2020.

[118] P. Peng, P. Ho und S. Hota, „Outbreak of a new coronavirus: what anaesthetists should know," Britisch Journal of Anaesthesia, Bd. 124, pp. 497-501, 2020.

[119] R. Eninger, T. Honda, T. Reponen, R. McKay und S. Grinshpun, „What does respirator certification tell us about filtration of ultrafine particles?," Journal of Occupational and Environmental Hygiene, Bd. 5, pp. 286-295, 2008.

[120] L. Marr, J. Tang, J. Van Mullekom und S. Lakdawala, „Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence," Journal of the Royal Society, Interface, p. https://doi.org/10.1098/rsif.2018.0298, 2019.

[121] S. Grinshpun, H. Haruta, R. Eninger, T. Reponen, R. McKay und S. Lee, „Performance of an N95 filtering facepiece particulate respirator and a surgical mask during human breathing: two pathways for particle penetration," Journal of Occupational and Environmental Hygiene, Bd. 6, pp. 593-603, 2009.

[122] Health and Safety Executive, „Guidance on respiratory protective equipment (RPE) fit testing," 2020 03 2019. [Online]. Available: https://www.hse.gov.uk/pubns/indg479.pdf. [Zugriff am 28 11].

[123] S. Verma, M. Dhanak und J. Frankenfield, „Visualizing droplet dispersal for face shields and masks with exhalation valves," Physics of Fluids, Bd. 32, p. 091701, 2020.

[124] S. Grinshpun, M. Yermakov und M. Khoudoun, „Autoclave sterilization and ethanol treatment of re-used surgical masks and N95 respirators during COVID-19: impact on their performance and integrity," Journal of Hospital Infection, Bd. 105, pp. 608-614, 2020.

[125] E. Weingartner, „Masken auf dem Prüfstand: Wie gut schützen sie vor feinen Aerosolen?," [Online]. Available: https://www.fhnw.ch/de/die-fhnw/hochschulen/ht/institute/forschungsprojekte/beurteilung-der-filterwirkung-von-materialien-fuer-ein-und-mehrwegmasken. [Zugriff am 11 11 2020].

[126] F. Drewnick, J. Pikmann, F. Fachinger, L. Moormann, F. Sprang und S. Borrmann, „Aerosol filtration efficiency of household materialsfor homemade face masks: Influence of materialproperties, particle size, particle electrical charge,face velocity, and leaks," Aerosol Science and Technology, p. https://doi.org/10.1080/02786826.2020.1817846, 2020.

[127] SNV, „Überblick über Normung von Community-Masken," 01 11 2020. [Online]. Available: https://www.snv.ch/de/news/news-details/ueberblick-ueber-normung-von-community-masken.html. [Zugriff am 11 11 2020].

[128] UNI, „UNI/PdR 90.1:2020: Maschere di comunità - Parte 1: Requisiti, tipologia e marcatura," 01 07 2020. [Online]. Available: http://store.uni.com/catalogo/uni-pdr-90-1-2020. [Zugriff am 29 11 2020].

[129] UNI, „UNI/PdR 90.1:2020: Maschere di comunità - Parte 1: Requisiti, tipologia e marcatura," 01 07 2020. [Online]. Available: http://store.uni.com/catalogo/uni-pdr-90-2-2020. [Zugriff am 29 11 2020].

[130] AFNOR, „AFNOR SPEC S76-001: Barrier masks - Guide to minimum requirements, methods of testing, making and use," 27 03 2020. [Online]. Available: https://masques-barrieres.afnor.org/home/PdfMasque?token=eed57dce-d956-445f-8fa6-8943d105f7e7&culture=en-GB. [Zugriff am 01 12 2020].

[131] European Committee for Standardization, „CEN Workshop Agreement (CWA 17553): Community face coverings - Guide to minimum requirements, methods of testing and use," Juni 2020. [Online]. Available: ftp://ftp.cencenelec.eu/EN/ResearchInnovation/CWA/CWA17553_2020.pdf. [Zugriff am 28 11 2020].

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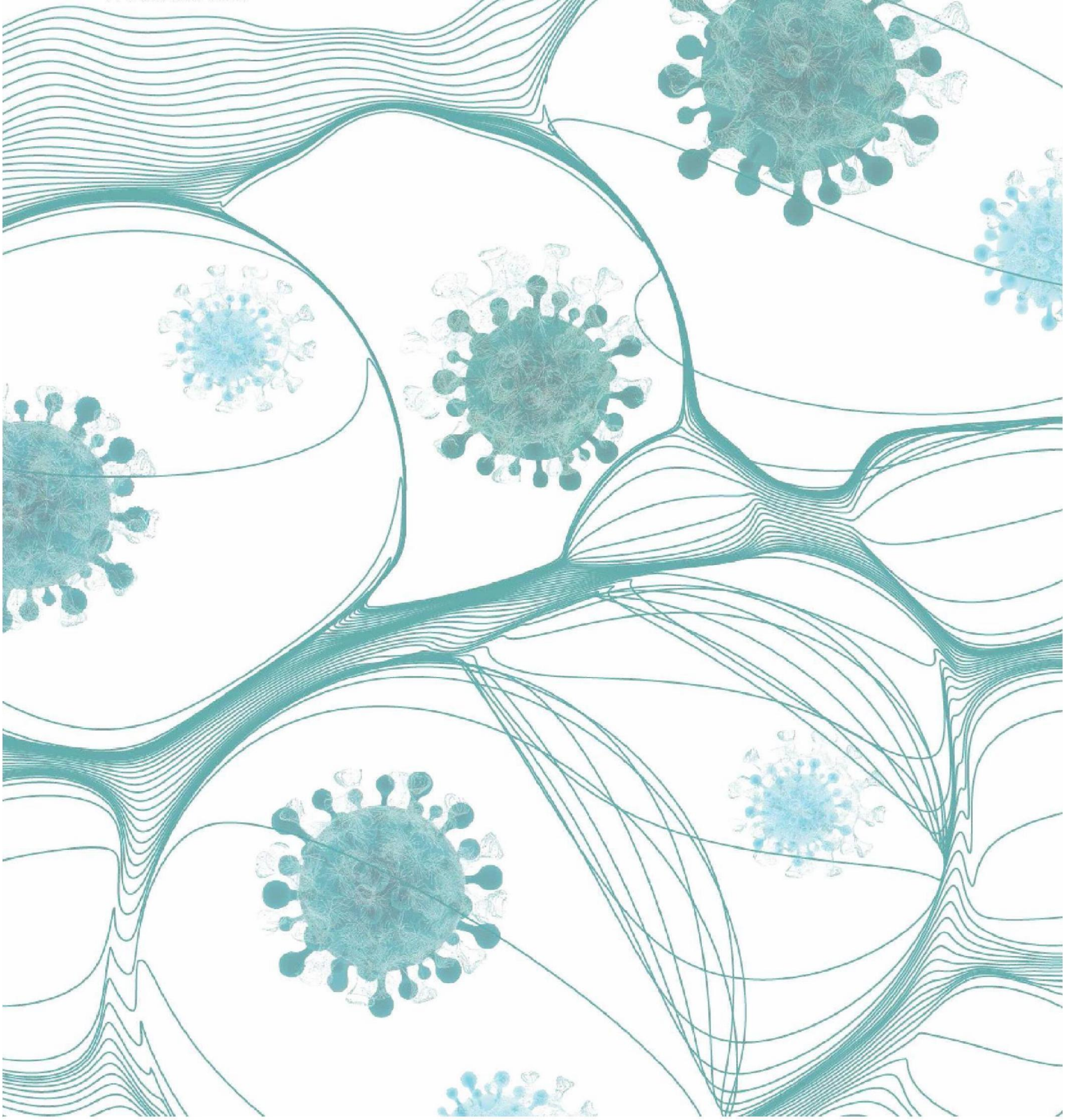
17 December 2020



8) Open brief van de Duitse Aerosolgemeenschap aan Bondskanselier Angela Merkel (Publicatiedatum: 11/04/2021)

In haar open brief aan Angela Merkel geeft de Duitse Aerosolgemeenschap 6 adviezen, waarbij het 5de het gebruik van luchtreinigers is:

"Luchtreinigers en -filters moeten overal worden geïnstalleerd waar mensen lange tijd in gesloten ruimten moeten doorbrengen (woonhuizen, scholen, bejaarden- en verpleegtehuizen, verzorgingsinstellingen, kantoren en andere werkplekken)."

Offener Brief **11. April 2021**

An die Bundeskanzlerin der Bundesrepublik Deutschland, Dr. Angela Merkel

Die Ministerpräsidenten und Ministerpräsidentinnen der Länder

Den Bundesgesundheitsminister Jens Spahn

Die Gesundheitsminister und Gesundheitsministerinnen der Länder

Ansteckungsgefahren aus Aerosolwissenschaftlicher Perspektive

Sehr geehrte Frau Bundeskanzlerin Dr. Merkel, sehr geehrter Herr Bundesminister Spahn, sehr geehrte Damen und Herren Ministerpräsidenten, sehr geehrte Damen und Herren,

die Corona Pandemie lässt uns auch nach mehr als zwölf Monaten nicht los. Sie ist zu einer schweren Belastung für Bürgerinnen und Bürger geworden. Deren Gefühlslage schwankt zwischen Hoffnung und Verzweiflung, wie jeder aus seinem persönlichen Umfeld zu berichten weiß. Hoffnung macht die Wissenschaft: Aus der Aerosolforschung sind vielfältige Erkenntnisse zur Übertragung der SARS-CoV-2 Viren über den Luftweg publiziert worden, zusammengefasst und aufbereitet in einem im Winter 2020 erschienenen Positionspapier der Gesellschaft für Aerosolforschung (GAeF, s. Anhang). Leider werden bis heute wesentliche Erkenntnisse unserer Forschungsarbeit nicht in praktisches Handeln übersetzt. Stattdessen werden eher symbolische Maßnahmen wie die Maskenpflicht beim Joggen erlassen, die keinen nennenswerten Einfluss auf das Infektionsgeschehen erwarten lassen.

Dabei ist deren zentraler Baustein mittlerweile Konsens in der Wissenschaft: Die Übertragung der SARS-CoV-2 Viren findet fast ausnahmslos in Innenräumen statt. Übertragungen im Freien sind äußerst selten und führen nie zu ‚Clusterinfektionen', wie das in Innenräumen zu beobachten ist. Zu diesen Gruppeninfektionen gehören bevorzugt Altenheime, Wohnheime, Schulen, Veranstaltungen, Chorproben oder Busfahrten.

Wir mussten aber als Aerosolforscher die Erfahrung machen, dass die öffentliche Debatte immer noch nicht den wissenschaftlichen Erkenntnisstand abbildet. Viele Bürgerinnen und Bürger haben deshalb falsche Vorstellungen über das mit dem Virus verbundene Ansteckungspotential. „Draußen ist es gefährlich", so deren Eindruck nicht zuletzt aus der Berichterstattung über die von der Politik getroffenen Maßnahmen zur Pandemiebekämpfung. Es werden Treffen in Parks verboten, Rhein- und Mainufer gesperrt, Innenstädte und Ausflugsziele für den Publikumsverkehr abgeriegelt. Auch die aktuell diskutierten Ausgangssperren müssen in diese Aufzählung irreführender Kommunikation aufgenommen werden. Wir teilen das Ziel einer Reduzierung problematischer Kontakte in Innenräumen, aber die Ausgangssperren versprechen mehr als sie halten können. Die heimlichen Treffen in Innenräumen werden damit nicht verhindert, sondern lediglich die Motivation erhöht, sich den staatlichen Anordnungen noch mehr zu entziehen. Die Reduzierung problematischer Kontakte in Innenräumen gelingt deshalb nur mit überzeugenden Argumenten für einen gelingenden Selbstschutz.

Wenn wir die Pandemie in den Griff bekommen wollen, müssen wir die Menschen sensibilisieren, dass **DRINNEN die Gefahr lauert**. In den Wohnungen, in den Büros, in den Klassenräumen, in Wohnanlagen und in Betreuungseinrichtungen müssen Maßnahmen ergriffen werden. Die andauernden Debatten über das Flanieren auf Flusspromenaden, den Aufenthalt in Biergärten, das Joggen oder das Radfahren haben sich längst als kontraproduktiv erwiesen. Wenn unseren Bürgerinnen und Bürgern alle Formen zwischenmenschlicher Kontakte als gefährlich vermittelt werden, verstärken wir paradoxerweise die überall erkennbare Pandemiemüdigkeit. Nichts stumpft uns Menschen bekanntlich mehr ab als ein permanenter Alarmzustand.

Wir müssen uns deshalb um die Orte kümmern, wo die mit Abstand allermeisten Infektionen passieren - und nicht unsere begrenzten Ressourcen auf die wenigen Promille der Ansteckungen im Freien verschwenden. Dabei lassen sich durch die kluge Koordinierung von Maßnahmen die Übertragungen effektiv reduzieren. Diese sind auch ohne eine naturwissenschaftliche Ausbildung nachvollziehbar: Es sind unsere goldenen Regeln zur Infektionsvermeidung.

1.) Infektionen finden in Innenräumen statt, deshalb sollten sich möglichst wenige Menschen außerhalb ihres Haushaltes dort treffen. Zusätzlich muss man beachten, dass in Innenräumen auch dann eine Ansteckung stattfindet, wenn man sich nicht direkt mit jemandem trifft, sich aber ein Infektiöser vorher in einem schlecht belüfteten Raum aufgehalten hat!
2.) Man sollte die Zeiten der Treffen und die Aufenthaltszeiten in Innenräumen so kurz wie möglich gestalten.
3.) Man sollte durch häufiges Stoß- oder Querlüften Bedingungen wie im Freien schaffen.
4.) Das Tragen von effektiven Masken ist in Innenräumen nötig. In der Fußgängerzone eine Maske zu tragen, um anschließend im eigenen Wohnzimmer eine Kaffeetafel ohne Maske zu veranstalten, ist nicht das, was wir als Experten unter Infektionsvermeidung verstehen. Dabei ist zu beachten, dass der Dichtsitz der Maske für ihre Effektivität mindestens genauso wichtig ist, wie die Abscheideeffizienz des Materials.
5.) Raumluftreiniger und Filter sind überall dort zu installieren, wo Menschen sich länger in geschlossenen Räumen aufhalten müssen (Wohnheime, Schulen, Alten- und Pflegeheime, Betreuungseinrichtungen, Büros und andere Arbeitsplätze).
6.) In großen Hallen und Räumen ist die Ansteckungsgefahr viel geringer als in kleinen Versammlungsräumen. Wenn man also wieder Theater, Konzerte, und Gottesdienste stattfinden lassen will, sollte das in großen gut gelüfteten Hallen stattfinden oder wenn möglich ins Freie ausgewichen werden.

Die Kombination dieser Maßnahmen führt zum Erfolg. Wird das entsprechend kommuniziert, gewinnen damit die Menschen in dieser schweren Zeit zugleich ein Stück ihrer Bewegungsfreiheit zurück. Wer sich zum Kaffee in der Fußgängerzone trifft, muss niemanden in sein Wohnzimmer einladen. Dort ist die Einhaltung der bekannten Hygieneregeln zu erwarten, zu Hause dagegen nicht.

Mit freundlichen Grüßen

Dr. Christof Asbach
Präsident der Gesellschaft für Aerosolforschung (GAeF)

Dr. Gerhard Scheuch
Ehemaliger Präsident der ISAM (International Society for Aerosols in Medicine)

Dr. Sebastian Schmitt
Kassenwart der Gesellschaft für Aerosolforschung (GAeF)

Dr. Birgit Wehner
Generalsekretärin der Gesellschaft für Aerosolforschung (GAeF)

Dr. Andreas Held
Stellvertretender Präsident der GAeF

Anhang: Positionspapier GAeF

1695933

9) Nederlandse vertaling van de brief van de Duitse Aerosolgemeenschap aan Bondskanselier Angela Merkel

Bron: Duitse Aerosolgemeenschap, vertaald door een vertaler Duits-Nederlands.

De corona pandemie laat ons ook na 12 maanden nog steeds niet los. Ze is een zware belasting voor alle burgers geworden. Hun gevoelstoestand wankelt tussen hoop en wanhoop op, zoals iedereen uit zijn persoonlijke omgeving laat weten.

De wetenschap brengt hoop: Uit de aerosolen wetenschap zijn vele bewijzen over de transmissie van Sars-CoV-2 via de lucht gepubliceerd, samengevat en verwerkt tot een paper van de Vereniging van Aerosolenwetenschap (GAeF). Helaas worden tot op de dag van vandaag de essentiële bevindingen van onze onderzoeken niet in de praktijk omgezet. In de plaats daarvan werden eerder symbolische maatregelen zoals de mondmaskerplicht die tijdens het joggen ingevoerd, Waarvan men geen noemenswaardig effect op het infectiegebeuren verwacht.

De centrale bouwsteen is ondertussen consensus geworden in de wetenschap: de verspreiding van het Sars-CoV-2 virus vindt haast zonder uitzondering plaats in binnenruimten. Besmettingen in openlucht zijn uiterst zeldzaam en leiden nooit tot zogenaamde "clusterbesmettingen", zoals ze wel te zien zijn in binnenruimten. Tot deze groep's besmettingen behoren vooral WZC's, peda's, scholen, evenementen, koorrepetities en busritten.

Als aërosolonderzoekers hebben wij echter moeten constateren dat het publieke debat nog steeds niet de stand van de wetenschappelijke kennis weergeeft. Veel burgers hebben daarom misvattingen over het besmettingspotentieel van het virus. "Buiten is het gevaarlijk ", aldus hun indruk, vooral door de berichtgeving over de maatregelen die politici hebben genomen om de pandemie te bestrijden. Samenkomsten in parken zijn verboden, oevers van de Rijn en de Main zijn afgesloten, binnensteden en toeristische bestemmingen worden afgesloten voor het publiek. De avondklok die momenteel ter discussie staat, moet ook in deze lijst van misleidende communicatie worden opgenomen. Wij delen de doelstelling om problematische contacten binnenshuis te verminderen, maar de avondklok belooft meer dan ze kan waarmaken. Dit houdt geheime lockdownfeestjes binnenshuis niet tegen, integendeel, het zet aan tot nog meer ongehoorzaamheid tegenover de maatregelen van de staat. Het terugdringen van problematische contacten binnenshuis lukt dus alleen met overtuigende argumenten voor succesvolle zelfbescherming.
Als we greep willen krijgen op de pandemie, moeten we de mensen ervan bewust maken dat het gevaar BINNEN op de loer ligt. Er moet actie worden ondernomen in huizen, kantoren, klaslokalen, appartementencomplexen en zorginstellingen. De voortdurende discussies over flaneren langs rivierpromenades, vertoeven in biertuinen, joggen of fietsen zijn allang contraproductief gebleken. Paradoxaal genoeg zullen wij, als onze burgers te horen krijgen dat alle vormen van menselijk contact gevaarlijk zijn, de pandemische vermoeidheid die alom zichtbaar is, nog versterken.

Zoals we weten, verveelt niets mensen meer dan een permanente staat van alarm. Daarom moeten we ons concentreren op de plaatsen waar veruit de meeste infecties plaatsvinden - en onze beperkte middelen niet verspillen aan de paar per duizend infecties buitenshuis. In dit verband kan de transmissie doeltreffend worden verminderd door een verstandige coördinatie van de maatregelen.

1) Besmettingen vinden binnenshuis plaats, dus zo weinig mogelijk mensen moeten elkaar daar buiten het huishouden ontmoeten. Bovendien is het belangrijk op te merken dat besmetting binnenshuis plaatsvindt, zelfs als u iemand niet rechtstreeks ontmoet, maar een besmettelijk persoon eerder in een slecht geventileerde ruimte is geweest.

2) Men moet de tijdstippen van bijeenkomsten en de tijd die binnen wordt doorgebracht zo kort mogelijk houden.

3) Men moet omstandigheden creëren zoals buiten door frequent "stootluchten" of kruisventilatie.

4) Het dragen van doeltreffende maskers is binnenshuis noodzakelijk. Een masker dragen in het voetgangersgebied en vervolgens zonder masker een koffietafel in je eigen huiskamer organiseren, is niet wat wij als deskundigen onder infectiepreventie verstaan. Daarenboven dient te worden opgemerkt dat de goede pasvorm van het masker minstens even belangrijk is voor de doeltreffendheid ervan als de afscheidingsefficiëntie van het materiaal.

5) Luchtreinigers en -filters moeten overal worden geïnstalleerd waar mensen lange tijd in gesloten ruimten moeten doorbrengen (woonhuizen, scholen, bejaarden- en verpleegtehuizen, verzorgingsinstellingen, kantoren en andere werkplekken).

6) In grote zalen en ruimten is het gevaar van besmetting veel kleiner dan in kleine vergaderzalen. Als men dus weer theaters, concerten en kerkdiensten wil houden, moet dit in grote goed geventileerde zalen gebeuren of, indien mogelijk, naar buiten worden verplaatst.

De combinatie van deze maatregelen leidt tot succes. Als dit op de juiste manier wordt gecommuniceerd, krijgen mensen ook weer wat van hun bewegingsvrijheid terug in deze moeilijke tijd. Mensen die elkaar in de voetgangerszone ontmoeten voor een kopje koffie, hoeven niemand in hun huiskamer uit te nodigen. Daar wordt de naleving van de bekende hygiëneregels verwacht, maar thuis niet.

10) Open brief van de Duitse Vereniging voor Natuurkunde (Publicatiedatum: 18/01/2021)

1695933

Deutsche Physikalische Gesellschaft e. V.

DER PRÄSIDENT

Verteiler:

Ministerpräsidentinnen und -präsidenten der Bundesländer

Kultusministerkonferenz (KMK)

Lehrerverbände:
Deutsche Lehrerverband (DL), Verband Bildung und Erziehung (VBE), Bundesverband der Lehrkräfte für Berufsbildung (BvLB), Deutscher Philologenverband (DPhV), Verband Deutscher Realschullehrer (VDR), Verband Hochschule und Wissenschaft (VHW), Katholische Erziehergemeinschaft (KEG)

Gewerkschaft Erziehung und Wissenschaft (GEW)

Deutsche Akademie der Naturforscher Leopoldina

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Dachverband der Geowissenschaften (DVGeo), Deutsche Mathematiker-Vereinigung (DMV), Gesellschaft Deutscher Chemiker (GDCh), Verband Biologie, Biowissenschaften und Biomedizin in Deutschland (VBIO), Deutscher Verein zur Förderung des mathematischen und naturwissenschaftlichen Unterrichts (MNU)

18. Januar 2021

OFFENER BRIEF

Klassenräume besser belüften – Ein Vorschlag

Bildungseinrichtungen betreiben derzeit einen großen Aufwand, um Lüftungskonzepte umzusetzen. Eine neuere Veröffentlichung (*J. M. Brauner et al.*) deutet darauf hin, dass Schulen und andere öffentliche Einrichtungen signifikant zum Covid-19-Infektionsgeschehen beitragen. Dieses wiederum wird wesentlich durch die Konzentration von Aerosolen, die mit Viren beladen sind, in Klassenräumen bestimmt.

Gleichzeitig zeigen inzwischen viele Untersuchungen und Studien, dass technische Lösungen mit kontrolliertem Luftwechsel die Verringerung der Aerosole im Raum gewährleisten können. Dabei gibt es Lösungen, die mit überschaubarem Kosten-, Installations- und Betriebsaufwand sowie mit ausreichender Wartung in Schulen und öffentlichen Gebäuden realisierbar sind.

Maßnahmen zur technischen Belüftung fördern die jüngst von Viola Priesemann et al. in *The Lancet* publizierten Empfehlungen zur Eindämmung der Covid-19-Pandemie.

Erläuterung:

Der Einsatz von Geräten zur Belüftung ist jeder Art passiver Lüftung durch bloßes Öffnen von Fenster und Türen weit überlegen, da bei der technischen Belüftung der Luftaustausch bzw. die Luftreinigung in kontrollierter Art und Weise geschieht, während dies bei der momentan empfohlenen passiven Lüftung von Klassenräumen mit Außenluft über die Fenster in einem typischen Klassenzimmer nicht zu erreichen ist, da diese nicht zuletzt stark von Wind, Temperatur, Fensteröffnungen, Lage der Heizkörper etc. abhängt. Unter der Annahme, dass alle 20 Minuten eine 5-Minuten-Lüftung mit einem idealisierten 10-fachen Luftaustausch mit Frischluft pro Stunde[1] durchgeführt wird, ergibt sich nach einem Schultag mit sechs Unterrichtsstunden in einer Klasse mit 30 Schülern und Schülerinnen bei Erkrankung der Lehrkraft ein Tagesrisiko von ca. 4 %[2]. Nach drei Tagen unerkannter Krankheit beträgt das Risiko der Erkrankung eines Schülers oder einer Schülerin bereits 12 %. Das heißt, dass sich insgesamt etwa drei SchülerInnen angesteckt haben und ihrerseits die Personen in ihrer nächsten Umgebung unerkannt gefährden.

Die Annahme eines 10-fachen Luftwechsels wie oben dargestellt ist idealisiert. Messungen am Max-Planck-Institut für Dynamik und Selbstorganisation zeigen eine Variation des natürlichen Luftwechsels von 2- bis 20-fach pro Stunde innerhalb eines Tages.

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[1] Luftwechselrate siehe https://www.baua.de/DE/Angebote/Publikationen/Berichte/F2072.pdf?__blob=publicationFile&

[2] Berechnet mit aerosol.ds.mpg.de – Annahmen: 30 Schüler / Alter 7 Jahre / 20 % Sprechen – Lehrkraft: infektiös / Alter 35 Jahre / 80 % lautes Sprechen und 3 % Schreien – Raum 190 m³ – 50 % Deposition in der Lunge – Dosis für 63 % Ansteckungswahrscheinlichkeit 450 – obere 95 % der Emissionsmesswerte.

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Grundsätzlich ist zwischen Stoßlüftung, Verdrängungslüftung und Mischlüftung zu unterscheiden (Physik Journal Dez. 2020):

- Bei der Stoßlüftung wird die Luft des Raums schnell ausgetauscht. Dies ist kontrolliert nur mit einem Außenventilator (an Fenster oder Wand) möglich. Die Stoßlüftung führt in der kalten Jahreszeit jedoch zu großen Temperaturunterschieden im Raum und ist daher nicht ideal.

- Bei der Verdrängungslüftung wird kalte Luft in den Raum eingebracht und die von den Personen erwärmte warme Luft oben abgesaugt. Die Luft wird dabei nur geringfügig gemischt. Eine solche Lösung mit nativer Außenluft ist nur möglich, so lange die Außentemperaturen wesentlich geringer sind als die Raumtemperaturen. Diese Art der Lüftung ist energetisch am günstigsten, wenn die „verbrauchte" Luft an der Decke abgeführt wird. Dies ist sowohl mit lokalen Abzügen (siehe MPI Chemie Mainz) wie auch durch einen Außenventilator (an Fenster/Wand) auf Deckenhöhe möglich.

- Alternativ bietet sich Mischventilation an. Hier wird die Raumluft turbulent im Raum vermischt und mit Frischluft oder gereinigter Luft verdünnt. Jegliche Art von Raumluftventilator bewirkt eine turbulente Mischung der Luft im Raum. Eine Kombination von Abluftventilator und Reinluftfilter kann so berechnet werden, dass die Ansteckungswahrscheinlichkeit deutlich geringer bleibt als bei passiver Lüftung. Die Raumluftventilation sowohl mit H13-/H14- als auch F9-Filtern ist ausreichend, da die Virionen, also Viruspartikel außerhalb von Zellen innerhalb der getrockneten Tröpfchen in Salzen oder Proteinen gebunden sind und daher kaum einzeln vorkommen (*Basu et al. 2020*). Gleichzeitig bleibt der CO_2-Gehalt unter den Grenzwerten. Ein willkommener Nebeneffekt ist, dass die gesamte Energie, die der Raumluftreiniger benötigt, in Wärme umgesetzt wird und den Raum aufheizt. Somit wird im Winter und in der Übergangszeit die gesamte Energie des Raumluftreinigers genutzt.

Zusammenfassend ist festzustellen:

- Technische Lüftung ist zuverlässig und gibt sehr guten Schutz.
- Mischlüftung mit einer Kombination aus Außenventilator und Raumluftreiniger gibt exzellenten Schutz.
- Nur in der kalten Jahreszeit lässt sich der Außenventilator allein zur Verdrängungsventilation einsetzen. In der warmen Jahreszeit muss die zugeführte Luft gekühlt werden.
- Stoßventilation bewirkt unangenehme Temperaturschwankungen.

Referenzen:
[1] *J. M. Brauner et al.*, Science DOI 10.1126/science.abd9338 (2020)
[2] *S. Basu et al.*, Phys. Fluids **32**, 1233217 (2020)
[3] *Viola Priesemann* et al.: https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)32625-8/fulltext
[4] Wissenschaftlicher Vortrag von Eberhard Bodenschatz „Tröpfchen und Aerosole": https://youtu.be/1QXUFi4UVql
[5] Heads App / Publikation der Untersuchungen: https://aerosol.ds.mpg.de
[6] Bericht der Universität der Bundeswehr München: https://www.unibw.de/lrt7/raumluftreiniger und https://www.unibw.de/lrt7/schulbetrieb-waehrend-der-pandemie.pdf
[7] https://www.unibw.de/lrt7/kommentar-zum-konzept-zum-lueften-in-schulen-des-uba

Deutsche Physikalische Gesellschaft e. V.

Dr. Lutz Schröter
Präsident

11) Ministerieel Besluit Minister van Volksgezondheid België over luchtreinigers (Publicatiedatum: 18/05/2021)

leur sont confiés et doivent en justifier l'utilisation selon les instructions données par le "Waarborg- en Sociaal Fonds voor de zeevisserij".

Art. 10. L'information concernant le nombre de jours indemnisés en cas de chômage temporaire pour raisons économiques ou pour cause de force majeure est transmise par l'organisme de paiement chargé du versement de ce chômage temporaire.

Art. 11. L'indemnité complémentaire dont le montant est fixé à l'article 4 de la présente convention collective de travail est soumise au précompte professionnel, au même titre que celle de la réglementation chômage.

Art. 12. L'indemnité complémentaire bénéficie de la mesure de protection contre la saisie bancaire (type "B") conformément à la réglementation en vigueur.

CHAPITRE VI. — *Contestations*

Art. 13. Une contestation née à la suite de l'application de la présente convention collective de travail sera soumise par la partie la plus diligente à la Commission paritaire de la pêche maritime (n° 143).

CHAPITRE VII. — *Durée de validité et dénonciation*

Art. 14. La présente convention collective de travail entre en vigueur le 1er janvier 2020 et est conclue pour une période d'un an. Sa durée est à chaque fois prorogée tacitement d'un an, sauf dénonciation par une des organisations représentées au sein de la Commission paritaire de la pêche maritime (n° 143), signifiée par lettre recommandée adressée au président de la Commission paritaire de la pêche maritime, au plus tard six mois avant le jour de l'échéance annuelle. Le préavis prend effet le jour suivant la date de l'envoi.

Vu pour être annexé à l'arrêté royal du 20 avril 2021.

Le Ministre du Travail,
P.-Y. DERMAGNE

toevertrouwde bedragen en moeten de aanwending ervan rechtvaardigen volgens de door het "Waarborg- en Sociaal Fonds voor de zeevisserij" gegeven onderrichtingen.

Art. 10. De informatie met betrekking tot het aantal gerechtigde dagen tijdelijke werkloosheid wegens economische redenen of overmacht wordt door de uitbetalingsinstelling die belast is met de uitbetaling van deze tijdelijke werkloosheid overgemaakt.

Art. 11. De aanvullende vergoeding waarvan het bedrag is bepaald onder artikel 4 van deze collectieve arbeidsovereenkomst is onderworpen aan bedrijfsvoorheffing, gelijk aan deze van de werkloosheidsreglementering.

Art. 12. De aanvullende vergoeding geniet van de beschermende maatregel tegen bankbeslag (type "B") overeenkomstig de vigerende wetgeving.

HOOFDSTUK VI. — *Betwistingen*

Art. 13. Een geschil ingevolge de toepassing van deze collectieve arbeidsovereenkomst zal door de meest gerede partij worden voorgelegd aan het Paritair Comité voor de zeevisserij (nr. 143).

HOOFDSTUK VII. — *Geldigheidsduur en opzegging*

Art. 14. Deze collectieve arbeidsovereenkomst gaat in vanaf 1 januari 2020 en wordt afgesloten voor een periode van één jaar. De duur ervan wordt telkens stilzwijgend met één jaar verlengd, behalve opzegging door één der organisaties die vertegenwoordigd zijn in het Paritair Comité voor de zeevisserij (nr. 143), betekend bij aangetekende brief aan de voorzitter van het Paritair Comité voor de zeevisserij, ten laatste zes maanden voor de jaarlijkse vervaldag. De opzeggingstermijn heeft uitwerking op de dag volgend op de datum van verzending.

Gezien om te worden gevoegd bij het koninklijk besluit van 20 april 2021.

De Minister van Werk,
P.-Y. DERMAGNE

SERVICE PUBLIC FEDERAL SANTE PUBLIQUE, SECURITE DE LA CHAINE ALIMENTAIRE ET ENVIRONNEMENT

[C − 2021/41483]

12 MAI 2021. — Arrêté ministériel déterminant provisoirement les conditions de la mise sur le marché des produits de purification de l'air dans le cadre de la lutte contre le SARS-CoV-2 en dehors des usages médicaux

Le Ministre de la Santé publique,

Vu la loi du 21 décembre 1998 relative aux normes de produits ayant pour but la promotion de modes de production et de consommation durables et la protection de l'environnement, de la santé et des travailleurs, l'article 5, § 3 ;

Vu l'avis n° 9616 du Conseil Supérieur de la Santé, émis le 3 février 2021 ;

Attendu que l'avis du Conseil Supérieur de la Santé n° 9616 considère qu'une ventilation adéquate des bâtiments avec de l'air neuf en dehors des bâtiments à fonction médicale est une condition nécessaire pour limiter la transmission de SARS-CoV-2 par voie aéroportée;

Considérant que le Conseil supérieur de la santé recommande l'aération et la ventilation des locaux fréquentés par le public lorsque la ventilation de base est insuffisante ou lorsque l'air est recirculé, mais prévient qu'aucune de ces deux mesures ne dispense de la mise en œuvre de mesures de lutte contre le SRAS-CoV-2, telles que le port d'un masque, le lavage des mains, le nettoyage des surfaces et le maintien d'une distance physique;

Attendu que le Conseil Supérieur de la Santé recommande l'exécution d'actions immédiates lorsque la concentration en CO_2 d'un local de bâtiment atteint la limite de 900 ppm. Ces actions visent entre autres à augmenter le débit de ventilation avec de l'air neuf, pour diluer la concentration de virus dans l'air et ainsi limiter la transmission de SARS-CoV-2 ;

Attendu que les personnes qui mettent sur le marché des produits mobiles et non-mobiles de purification de l'air doivent démontrer les allégations relatives aux niveaux d'efficacité en conditions réelles contre la SARS-CoV-2 et de non-dangerosité de leurs produits;

FEDERALE OVERHEIDSDIENST VOLKSGEZONDHEID, VEILIGHEID VAN DE VOEDSELKETEN EN LEEFMILIEU

[C − 2021/41483]

12 MEI 2021. — Ministerieel besluit houdende de voorlopige bepaling van de voorwaarden voor het op de markt brengen van luchtzuiveringssystemen in het kader van de bestrijding van SARS-CoV-2 buiten medische doeleinden

De Minister van Volksgezondheid,

Gelet op de wet van 21 december 1998 betreffende de productnormen ter bevordering van duurzame productie en consumptiepatronen en ter bescherming van het leefmilieu, de volksgezondheid en de werknemers, artikel 5, § 3;

Gelet op het advies nr. 9616 van de Hoge Gezondheidsraad, uitgebracht op 3 februari 2021;

Overwegende dat het advies nr. 9616 van de Hoge Gezondheidsraad oordeelt dat een gepaste ventilatie met verse lucht van gebouwen, andere dan gebouwen met een medische functie, een noodzakelijke voorwaarde is om de overdracht van SARS-CoV-2 via de lucht te beperken;

Overwegende dat de Hoge Gezondheidsraad aanbeveelt om de door het publiek bezochte ruimten te verluchten en te ventileren bij onvoldoende basisventilatie of bij recirculatie van lucht, maar waarschuwt dat geen van beide vrijstelling verleent voor de uitvoering van de maatregelen ter bestrijding van SARS-CoV-2, zoals het dragen van een masker, het wassen van de handen, het schoonmaken van oppervlakken en het bewaren van een fysieke afstand;

Overwegende dat de Hoge Gezondheidsraad aanbeveelt om onmiddellijk acties te ondernemen wanneer de CO_2-concentratie in de lokalen van een gebouw de grens van 900 ppm bereikt. Deze acties hebben onder meer tot doel om het ventilatiedebiet met verse lucht te verhogen, de virusconcentratie in de lucht te verdunnen en aldus de overdracht van SARS-CoV-2 te beperken;

Overwegende dat personen die mobiele en niet-mobiele luchtzuiveringssystemen op de markt brengen, moeten bewijzen leveren voor de beweringen met betrekking tot het niveau van doeltreffendheid tegen SARS-CoV-2 in reële omstandigheden en het ongevaarlijk zijn van hun systemen;

Attendu que la non-dangerosité porte sur l'ensemble des mesures qui peuvent être prises par le fabricant ou le responsable de la mise sur le marché pour garantir que l'utilisation des produits mobiles et non-mobiles de purification de l'air, en présence de personnes, n'a pas d'impact direct ou différé sur leur santé ;

Attendu que nous constatons sur le marché belge la vente de produits dangereux pour la santé des personnes tels que les lampes UVC en rayonnement direct, des produits qui génèrent de l'ozone, qui ionisent l'air ou qui utilisent le plasma froid. Le Conseil Supérieur de la Santé considère que ces produits sont dangereux pour la santé dans son avis du 3 février 2021 (publié le 15 février 2021). Le présent arrêté réglemente les conditions de mise sur le marché de ces produits, le cadre des actions de contrôle et de surveillance du marché. C'est la raison pour laquelle l'urgence a été invoquée pour une demande d'avis du Conseil d'État ;

Attendu que la lutte spécifique contre le SARS-CoV-2 nécessite, uniquement s'il n'est pas possible de ventiler et d'aérer de manière adéquate, des nouveaux moyens techniques qui démontrent une réelle efficacité dans la réduction de la quantité de SARS-CoV-2 dans l'air et que donc des allégations non spécifiques d'efficacité sur des groupes de microorganismes (virus, bactéries, levures) ou des polluants atmosphériques ne permettent pas au consommateur de lui garantir une efficacité du produit et une non-dangerosité lors de l'utilisation du produit ;

Attendu que la Task Force mise en place auprès du Commissariat Corona est chargée de favoriser la mise en œuvre des recommandations du Conseil Supérieur de la Santé en matière de ventilation et de purification de l'air ;

Vu l'avis de l'Inspecteur des Finances, donné le 25 février 2021;

Vu l'avis 69.030/3 du Conseil d'État, donné le 23 mars 2021, en application de l'article 84, § 1er, alinéa 1er, 3°, des lois sur le Conseil d'État, coordonnées le 12 janvier 1973 ;

Vu la communication à la Commission européenne, le 13 avril 2021 en application de l'article 5, paragraphe 1er et article 6, paragraphe7 de la directive (UE) 2015/1535 du Parlement européen et du Conseil du 9 septembre 2015 prévoyant une procédure d'information dans le domaine des réglementations techniques et des règles relatives aux services de la société de l'information;

Vu l'association des gouvernements régionaux à l'élaboration du présent arrêté, le 20 avril 2021;

Vu l'avis de L'Autorité de protection des données n° 63/2021 du 29 avril 2021.

Arrête :

Article 1er. Le présent arrêté s'applique aux conditions de mise sur le marché, en dehors des usages médicaux, des produits mobiles et non-mobiles de purification de l'air dans le cadre de la lutte contre le virus du SARS-CoV-2.

Art. 2. Pour l'application du présent arrêté, on entend par :

1° virus : virus du SARS-CoV-2, dont la dimension est de l'ordre de 0,125 micromètre ;

2° usages médicaux : les produits visées par le Règlement (UE) 2017/745 du Parlement européen et du Conseil du 5 avril 2017 relatif aux dispositifs médicaux, modifiant la directive 2001/83/CE, le règlement (CE) no 178/2002 et le règlement (CE) no 1223/2009 et abrogeant les directives du Conseil 90/385/CEE et 93/42/CEE;

3° produit mobile de purification de l'air: un ensemble composé d'un ou de plusieurs systèmes de purification tel(s) que visé(s) aux points 5°, 6° et 8°, qui est couplé ou non à une ventilation, qui est mobile et fonctionne de manière autonome, qui peut être installé dans un local d'un bâtiment ou dans un véhicule ;

4° produit non-mobile de purification de l'air: un ensemble composé d'un ou de plusieurs systèmes de purification tel(s) que visé(s) aux points 5°, 6° , 7° et 8°, qui est couplé ou non à une ventilation, qui est non-mobile et qui peut être installé dans le système de ventilation d'un bâtiment ou d'un véhicule ;

5° filtre HEPA : les filtres HEPA de la classe H13 qui ont une efficacité de rétention de 99,95% et de la classe H14 qui ont une efficacité de rétention de 99,995% selon les normes NBN EN 1822:2019 et EN ISO 29463 ;

6° précipitateur électrostatique : un précipitateur électrostatique permet de capturer des particules et aérosols en suspension par effet électrostatique. Les niveaux d'efficacité sont fixés selon l'utilisation, mobile comme à l'article 4 ou non-mobile comme à l'article 3 ;

Overwegende dat onder ongevaarlijk wordt verstaan: alle maatregelen die door de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen, kunnen worden genomen om ervoor te zorgen dat het gebruik van mobiele en niet-mobiele luchtzuiveringssystemen in de aanwezigheid van personen geen directe of uitgestelde gevolgen voor hun gezondheid heeft;

Overwegende dat we op de Belgische markt de verkoop zien van systemen die gevaarlijk zijn voor de menselijke gezondheid, zoals UVC-lampen met directe straling, systemen die ozon genereren, die de lucht ioniseren of koud plasma gebruiken. De Hoge Gezondheidsraad acht deze systemen in zijn advies van 3 februari 2021 (gepubliceerd op 15 februari 2021) gevaarlijk voor de gezondheid. Dit besluit regelt de voorwaarden verbonden aan het op de markt brengen van deze systemen, het kader voor marktcontrole- en toezichtacties. Om die reden werd een beroep gedaan op de spoedbehandeling van een adviesaanvraag bij de Raad van State;

Overwegende dat de specifieke strijd tegen SARS-CoV-2, enkel als het niet mogelijk is voldoende te ventileren en verluchten, nieuwe technische systemen vereist die een reële doeltreffendheid aantonen bij het verminderen van de hoeveelheid SARS-CoV-2 in de lucht en dat daarom niet-specifieke beweringen van doeltreffendheid tegen groepen micro-organismen (virussen, bacteriën, gisten) of luchtverontreinigende stoffen, de consument niet toestaan zich gegarandeerd te weten van de doeltreffendheid van het product en het ongevaarlijk zijn bij het gebruik van het product;

Overwegende dat de Task Force, ingesteld door het Corona Commissariaat, verantwoordelijk is voor het bevorderen van de uitvoering van de aanbevelingen van de Hoge Gezondheidsraad inzake ventilatie en luchtzuivering;

Gelet op het advies van de inspecteur van Financiën, gegeven op 25 februari 2021;

Gelet op advies 69.030/3 van de Raad van State, gegeven op 23 maart 2021, met toepassing van artikel 84, § 1, eerste lid, 3°, van de wetten op de Raad van State, gecoördineerd op 12 januari 1973;

Gelet op de mededeling aan de Europese Commissie op 13 april 2021 met toepassing van artikel 5, lid 1 en artikel 6, lid 7 van richtlijn (EU) 2015/1535 van het Europees Parlement en de Raad van 9 september 2015 betreffende een informatieprocedure op het gebied van technische voorschriften en regels betreffende de diensten van de informatiemaatschappij;

Gelet op de betrokkenheid van de gewestregeringen bij het ontwerpen van dit besluit op 20 april 2021;

Gelet op het advies van de Gegevensbeschermingsautoriteit nr. 63/2021 van 29 april 2021.

Besluit :

Artikel 1. Dit besluit is van toepassing op de voorwaarden voor het op de markt brengen van mobiele en niet-mobiele luchtzuiveringssystemen, buiten medische doeleinden, in het kader van de bestrijding van het SARS-CoV-2 virus.

Art. 2. Voor de toepassing van dit besluit wordt verstaan onder:

1° virus: het SARS-CoV-2 virus met deeltjes met een orde van grootte van 0,125 micrometer;

2 ° medisch gebruik: producten die vallen onder Verordening (EU) 2017/745 van het Europees Parlement en de Raad van 5 april 2017 betreffende medische hulpmiddelen, tot wijziging van Richtlijn 2001/83/EG, Verordening (EG) nr. 178/2002 en Verordening (EG) nr. 1223/2009, en tot intrekking van Richtlijnen 90/385/EEG en 93/42/EEG van de Raad;

3° mobiel luchtzuiveringssysteem: een geheel bestaande uit een of meerdere zuiveringssystemen zoals bedoeld in punt 5°, 6° en 8°, al dan niet gekoppeld aan een ventilatiesysteem, dat mobiel is en autonoom functioneert en dat in een lokaal van een gebouw of in een voertuig kan worden geïnstalleerd;

4° niet-mobiel luchtzuiveringssysteem: een geheel bestaande uit een of meerdere zuiveringssystemen zoals bedoeld in punt 5°, 6°, 7° en 8°, al dan niet gekoppeld aan een ventilatiesysteem, dat niet-mobiel is en dat in een ventilatiesysteem van een gebouw of in een voertuig kan worden geïnstalleerd;

5° HEPA-filter: de HEPA-filters van klasse H13 met een retentiedoeltreffendheid van 99,95% en van klasse H14 met een retentie doeltreffendheid van 99,995% volgens de norm NBN EN 1822:2019 en EN ISO 29463;

6° elektrostatische precipitator: een elektrostatische precipitator vangt zwevende deeltjes en aerosolen op door middel van een elektrostatisch effect. De niveaus van doeltreffendheid worden bepaald in functie van het gebruik, mobiel zoals in artikel 4 of niet-mobiel zoals in artikel 3;

7° filtre EPA : les filtres EPA de la classe E12 qui ont une efficacité de rétention de 99,5% selon les normes NBN EN 1822:2019 et EN ISO 29463 ;

8° UVC : les UVC qui sont caractérisés par une longueur d'onde comprise entre 185 à 280 nanomètres. La zone pour l'inactivation du SARS-CoV-2 se situe entre 220 et 280 nm, la zone pour la production de l'ozone ce situe entre 185 et 240 nanomètres. Les UVC sont utilisés dans des systèmes fermés ou ouvert de produits mobiles et non-mobiles de purification de l'air. Les niveaux d'efficacité sont fixés selon l'utilisation, mobile comme à l'article 4 ou non-mobile comme à l'article 3 ;

9° le service public : le Service public fédéral Santé publique, Sécurité de la Chaîne alimentaire et Environnement, Direction générale de l'Environnement, Division Politique de Produit et Produits Chimiques.

10° allégation d'efficacité et de non dangerosité : communication écrite, y compris au moyen de symboles et qui concerne les niveaux efficacité de produits mobiles et non-mobiles de purification de l'air contre le SARS-CoV-2 et de la non-dangerosité de ceux-ci sur la santé de l'utilisateur, du public, dans les espaces où les effets de ces produits sont attendus.

Cette communication est apposée sur l'emballage ou sur tout autre support qui accompagne les produits mobiles et non-mobiles de purification de l'air, y compris les éléments de communication en ligne s'il est fait référence à cette communication en ligne sur les produits eux-mêmes ou sur leurs emballages, mais à l'exception de références qui ne concernent pas l'efficacité contre le SARS-CoV-2 et la non dangerosité renvoyant au site web de l'entreprise ;

11° ministre : le ministre qui à la Santé Publique dans ses attributions;

Art. 3. Les systèmes non-mobiles de purification de l'air répondent aux normes suivantes :

1° les produits non-mobiles de purification de l'air répondent à des normes techniques qui garantissent des niveaux d'efficacité du produit contre le SARS-CoV-2 et qui garantissent la non-dangerosité du produit sur la santé de l'utilisateur et le public, dans les espaces où les effets du produit sont attendus ;

2° les filtres répondent aux normes HEPA de la classe H13, HEPA de la classe H14 et EPA de la classe E12 ;

3° l'efficacité des précipitateurs électrostatiques est au minimum celle des filtres EPA de la classe E12;

4° la longueur d'onde des lampes UVC doit être garantie, par le fabricant ou le responsable de la mise sur le marché selon leur utilisation : entre 185 et 240 nm pour générer de l'ozone et entre 220 et 280 nm pour inactiver le SARS-CoV-2, avec une efficacité au moins équivalente à celle des filtres EPA de la classe E12;

5° Dans le cas de l'utilisation de filtres HEPA et EPA, ceux-ci sont intégrés dans un boitier au système de ventilation pour prévenir toute fuite possible de sorte que l'efficacité totale du système est égale à l'efficacité du filtre seul ;

6° Dans le cas de l'utilisation d'un précipitateur électrostatique, le système de collecteur de précipités est remplaçable. Les conseils et les conditions de leur remplacement sont fournis dans la documentation technique. La production d'ozone est affichée sur l'appareil ;

7° Lorsque l'air est purifié par des UV-C, les lampes sont placées dans un boîtier d'où aucune lumière ne peut s'échapper ou le système de purification d'air non mobile doit être conforme aux normes de sécurité EN ISO 15858. Le fabricant ou la personne responsable de la mise sur le marché fournit dans le manuel technique les conseils de maintenance, et la fréquence de remplacement des lampes UVC.

Art. 4. Les produits mobiles de purification de l'air répondent aux normes suivantes :

1° les produits mobiles de purification de l'air répondent à des normes techniques qui garantissent des niveaux d'efficacité du produit contre le SARS-CoV-2 et qui garantissent la non-dangerosité du produit sur la santé de l'utilisateur et le public, dans les espaces où les effets du produit sont attendus ;

2° les filtres répondent aux normes HEPA de la classe H13 ou HEPA de la classe H14;

3° l'efficacité des précipitateurs électrostatiques est au minimum celle des filtres HEPA de la classe H13;

7° EPA-filter: de EPA-filters van klasse E12 met een retentie doeltreffendheid van 99,5% volgens de norm NBN EN 1822:2019 en EN ISO 29463;

8° UV-C: systemen met UV-C-licht die worden gekenmerkt door een golflengte tussen 185 en 280 nanometer. De inactivatie zone voor SARS-CoV-2 situeert zich tussen 220 en 280 nm, de zone voor de productie van ozon ligt tussen 185 en 240 nanometer. De systemen met UV-C-licht worden gebruikt in gesloten of open systemen van mobiele en niet-mobiele luchtzuiveringssystemen. De niveaus van doeltreffendheid worden bepaald in functie van het gebruik, mobiel zoals in artikel 4 of niet-mobiel zoals in artikel 3;

9° de overheidsdienst: de Federale Overheidsdienst Volksgezondheid, Veiligheid van de Voedselketen en Leefmilieu, Directoraat-generaal Leefmilieu, afdeling Productbeleid en Chemische Producten.

10° bewering over de doeltreffendheid en het ongevaarlijk zijn: schriftelijke communicatie, ook door middel van symbolen, over de niveaus van doeltreffendheid van mobiele en niet-mobiele luchtzuiveringssystemen tegen SARS-CoV-2 en het ongevaarlijk zijn voor de gezondheid van de gebruiker, van het publiek, in ruimtes waar de effecten van deze systemen worden verwacht.

Deze communicatie wordt aangebracht op de verpakking of op elk ander informatiedrager die bij mobiele en niet-mobiele luchtzuiveringssystemen wordt geleverd, inclusief online communicatie-elementen als er wordt verwezen naar deze online communicatie op de systemen zelf of op hun verpakking, maar met uitzondering van verwijzingen die geen betrekking hebben op de doeltreffendheid tegen SARS-CoV-2 en het ongevaarlijk zijn, die verwijst naar de website van het bedrijf;

11° minister: de minister bevoegd voor Volksgezondheid;

Art. 3. Niet-mobiele luchtzuiveringssystemen beantwoorden aan de volgende voorwaarden:

1° de niet-mobiele luchtzuiveringssystemen voldoen aan technische normen die de niveaus van doeltreffendheid van het product tegen SARS-CoV-2 garanderen en die de ongevaarlijke aard van het product voor de gezondheid van de gebruiker en het publiek garanderen, in ruimtes waar de effecten van het product wordt verwacht;

2° de filters beantwoorden aan de HEPA-norm voor klasse H13, de HEPA-norm voor klasse H14 en de EPA-norm voor klasse E12;

3° de doeltreffendheid van de elektrostatische precipitatoren is minstens gelijk aan die van de EPA-filters van klasse E12;

4° de golflengte van de UV-C-lampen moet door de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen gegarandeerd worden volgens hun gebruik: tussen 185 en 204 nm voor het genereren van ozon en tussen 220 en 280 nm voor de inactivatie van SARS-CoV-2, met een doeltreffendheid die minstens gelijkwaardig is aan die van EPA-filters van klasse E12;

5° Wanneer HEPA- en EPA-filters worden gebruikt, zijn deze in een behuizing in het ventilatiesysteem geïntegreerd om eventuele lekken te voorkomen, zodat de totale doeltreffendheid van het systeem gelijk is aan de doeltreffendheid van de filter alleen;

6° Bij gebruik van een elektrostatische precipitator kan het precipitaat-opvangsysteem worden vervangen. De technische documentatie bevat advies en de in acht te nemen voorwaarden voor de vervanging van de filter. De ozonproductie wordt op het toestel vermeld;

7° Wanneer de lucht wordt gezuiverd met UV-C, bevinden de lampen zich in een behuizing waaruit geen licht kan ontsnappen of moet het niet-mobiele luchtzuiveringssysteem voldoen aan de veiligheidsnormen EN ISO 15858. De fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen vermeldt in de technische handleiding advies over het onderhoud, van de UV-C-lampen en de frequentie van de vervanging.

Art. 4. Mobiele luchtzuiveringssystemen beantwoorden aan de volgende voorwaarden:

1° de mobiele luchtzuiveringssystemen voldoen aan technische normen die de niveaus van doeltreffendheid van het product tegen SARS-CoV-2 garanderen en die de ongevaarlijke aard van het product voor de gezondheid van de gebruiker en het publiek garanderen, in ruimtes waar de effecten van het product worden verwacht;

2° de filters beantwoorden aan de HEPA-norm voor klasse H13 of de HEPA-norm voor klasse H14;

3° de doeltreffendheid van de elektrostatische precipitatoren is minstens gelijk aan die van de HEPA-filters van klasse H13;

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4° la longueur d'onde des lampes UVC doit être garantie, par le fabricant ou la personne responsable de la mise sur le marché, selon leur utilisation : entre 185 et 240 nm pour générer de l'ozone et entre 220 et 280 nm pour inactiver le SARS-CoV-2, avec une efficacité au moins équivalente à celle des filtres HEPA de la classe H13;

5° les débits d'air des produits mobiles de purification de l'air sont :

a) garantis par le fabricant ou la personne responsable de la mise sur le marché ;

b) mesurés à la sortie du produit. Dans le cas d'une purification avec des filtres HEPA, les débits d'air sont mesurés avec un ou des filtres HEPA de la classe H13 ;

c) exprimés en m³ par heure ;

d) exprimés entre une valeur minimum et une valeur maximum. Les valeurs minimum et maximum sont affichées sur le produit ;

e) garantis entre une valeur de deux à cinq renouvellements d'air par heure (ACH) pour un volume de local considéré.

6° le fabricant ou la personne responsable de la mise sur le marché communique le " Clean Air Delivery Rate » (CADR) de son produit. Le CADR est le résultat de la multiplication entre l'efficacité et le débit d'air (m³ par heure) du produit de purification d'air;

7° dans le cas de la purification avec des filtres HEPA, ceux-ci sont intégrés dans un boitier fermé hermétiquement au système de ventilation pour prévenir toute fuite possible, assurant une efficacité totale du système égale à l'efficacité du filtre seul ;

8° dans le cas de la purification avec un précipitateur électrostatique, le système de collecteurs de précipités est remplaçable. Les conseils et les conditions de leur remplacement sont fournis dans la documentation technique. La production d'ozone est affichée sur le produit de purification d'air ;

9° lorsque l'air est purifié par UV-C, les lampes sont placées dans un boîtier d'où aucune lumière ne peut s'échapper et conformes aux normes de sécurité reconnues EN IEC 60335-2-65 dans le cas d'un système fermé, ou aux normes de sécurité reconnues EN IEC 62471 et IEC PAS 63313 dans le cas d'un système ouvert. Le fabricant ou le responsable de la mise sur le marché fournit dans le manuel technique les conseils de maintenance et la fréquence de remplacement des lampes UVC .

Art. 5. § 1er Est interdite de mise sur le marché, les produits mobiles et non-mobiles de purification de l'air, destinés à être installés dans les locaux fréquentés par le public et qui se composent d'une ou plusieurs des techniques suivantes couplées ou non à une ventilation :

1° de l'ozone, les systèmes à plasma froid ;

2° les systèmes qui utilisent des UV-C et qui ne suivent pas les conditions fixées à l'article 3, 7° et à l'article 4, 8° ;

3° la combinaison d'UV et de solides photo-catalytiques (principalement le TiO2) ;

4° l'ionisation de l'air sans capture des précipités ;

5° la brumisation au peroxyde d'hydrogène.

§ 2. Le ministre peut autoriser des dérogations notamment sur base des recommandations de la Task force, mise en place auprès du Commissariat Corona chargée de favoriser la mise en œuvre des recommandations du Conseil Supérieur de la Santé en matière de ventilation et de purification de l'air .

Les dérogations concernent les produits mobiles et non-mobiles de purification de l'air visés au paragraphe 1e et sont obtenues à titre individuel.

Les demandes de dérogation sont introduites au service public sur le site web suivant :

www.corona-ventilation.be

Les demandes de dérogation sont évaluées sur base d'un dossier complet, détaillé et structuré de la manière suivante :

1° une synthèse du dossier structuré selon les points 2° à 9°. Les preuves et autres documents qui valident la conformité du produit de purification de l'air sont annexés à la synthèse.

2° identification du demandeur : le nom et prénom/ nom de l'entreprise, l'adresse professionnelle, le numéro de téléphone, l'adresse email professionnelle;

4° de golflengte van de UV-C-lampen moet door de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen, gegarandeerd worden volgens hun gebruik: tussen 185 en 204 nm voor het genereren van ozon en tussen 220 en 280 nm voor de inactivatie van SARS-CoV-2, met een doeltreffendheid die minstens gelijkwaardig is aan die van HEPA-filters van klasse H13;

5° de luchtdebieten voor mobiele luchtzuiveringssystemen:

a) worden gegarandeerd door de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen;

b) worden bij de uitlaat van het systeem gemeten. Wanneer HEPA-filters worden gebruikt voor de zuivering, worden de luchtdebieten gemeten met een of meerdere HEPA-filters van klasse H13;

c) worden uitgedrukt in m³ per uur;

d) worden uitgedrukt tussen een minimum- en een maximumwaarde. De minimum- en maximumwaarde worden op het systeem aangeduid;

e) garanderen tussen een waarde van twee tot vijf luchtverversingen per uur (ACH) voor een bepaald lokaalvolume.

6° de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen communiceert de " Clean Air Delivery Rate » (CADR) van zijn systeem. De CADR is het resultaat van de vermenigvuldiging tussen de doeltreffendheid en het luchtdebiet (m³ per uur) van het luchtzuiveringssysteem;

7° wanneer HEPA-filters worden gebruikt voor de zuivering, zijn deze in een hermetisch afgesloten behuizing in het ventilatiesysteem geïntegreerd om eventuele lekken te voorkomen, zodat gegarandeerd wordt dat de totale doeltreffendheid van het systeem gelijk is aan de doeltreffendheid van de filter alleen;

8° bij gebruik van een elektrostatische precipitator voor de zuivering, kan het precipitaatopvangsysteem worden vervangen. De technische documentatie bevat advies en de in acht te nemen voorwaarden voor de vervanging van de filter. De ozonproductie wordt op het luchtzuiveringssysteem vermeld;

9° wanneer de lucht wordt gezuiverd met UV-C, worden de lampen zich in een behuizing geplaatst waaruit geen licht kan ontsnappen en voldoen ze aan de erkende veiligheidsnormen EN IEC 60335-2-65 in het geval van een gesloten systeem, of aan de erkende veiligheidsnormen EN IEC 62471 en IEC PAS 63313 in het geval van een open systeem. De fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen vermeldt in de technische handleiding advies over het onderhoud van de UV-C-lampen en de frequentie van de vervanging.

Art. 5. § 1. Het is verboden om mobiele en niet-mobiele luchtzuiveringssystemen, bestemd om te worden geïnstalleerd in door het publiek bezochte ruimten op de markt te brengen die bestaan uit één of meerdere van de volgende technieken al dan niet in combinatie met ventilatie:

1° ozon, systemen met koude plasma;

2° systemen die gebruik maken van UV-C en die niet voldoen aan de voorwaarden bepaald in artikel 3, 7° en artikel 4, 8°;

3° de combinatie van UV en fotokatalytische vaste stoffen (hoofdzakelijk TiO2);

4° de ionisatie van de lucht zonder de precipitaten op te vangen;

5° de verneveling van waterstofperoxide.

§ 2. De minister kan afwijkingen toestaan meer bepaald op basis van de aanbevelingen van de Task force, ingesteld door het Corona Commissariaat en verantwoordelijk voor het bevorderen van de uitvoering van de aanbevelingen van de Hoge Gezondheidsraad inzake ventilatie en luchtzuivering.

De afwijkingen hebben betrekking op mobiele en niet-mobiele luchtzuiveringssystemen bedoeld in paragraaf 1 en worden bekomen op individuele basis.

De afwijkingsaanvragen worden ingediend bij de overheidsdienst op de volgende website:

www.corona-ventilation.be

De afwijkingsaanvragen worden beoordeeld op basis van een volledig, gedetailleerd en als volgt gestructureerd dossier:

1° een samenvatting van het dossier gestructureerd volgens de punten 2 ° tot 9°. Bewijsmateriaal en andere documenten die de conformiteit van het luchtzuiveringssysteem bevestigen, zijn aan de samenvatting toegevoegd.

2° identificatie van de aanvrager: naam en voornaam, zakelijk adres, telefoonnummer, zakelijk emailadres;

3° description du produit complet, ses constituants, un dessin technique et le mode de fonctionnement du produit complet ;

4° les essais, tests et rapports relatifs aux niveaux d'efficacité sur le produit complet ainsi que les conclusions qui conduisent le fabricant ou la personne responsable de la mise sur le marché, à garantir que son produit est efficace conformément au 3° de l'article 2 ;

5° la garantie des niveaux d'efficacité du produit sur le virus SARS-CoV-2 pour un temps d'utilisation donné et les mesures prises pour garantir ses niveaux d'efficacité dans le temps ;

6° la preuve scientifique de la non-dangerosité du produit sur la santé de l'utilisateur, du public, dans les espaces où les effets du produit sont attendus et les seuils à ne pas dépasser lors de cette exposition ;

7° décrire les conditions d'installation et d'utilisation du produit dans un environnement à traiter ;

8° décrire les conditions d'installation et d'utilisation où le produit ne peut pas être utilisé ;

9° décrire les conditions d'élimination des équipements contaminés par le virus.

Seules les demandes complètes sont recevables et seront traitées.

Le service public communique, au ministre, trente jours après une demande de dérogation, son avis motivé.

Le ministre peut refuser une demande de dérogation par manque de preuve d'efficacité du produit contre le SARS-CoV-2 ou par manque de preuve de la non-dangerosité du produit sur la santé de l'utilisateur, du public, dans les espaces où les effets du produit sont attendus.

Lorsque le ministre accepte une demande de dérogation, celle-ci est notifiée au demandeur et publiée sur le site web du service public. Seules les données relatives aux produits qui bénéficient d'une dérogation sont publiées sur le site web et aucune donnée à caractère personnel.

Art. 6. Aux fins du suivi de la surveillance du marché, les produits mobiles et non-mobiles de purification de l'air qui répondent aux normes des articles 3 ou 4 ou qui ont reçu une dérogation sont enregistrés par le fabricant ou la personne responsable de la mise sur le marché, au plus tard dix jours ouvrables après leurs mises sur le marché, sur le site web suivant : www.corona-ventilation.be

Les informations suivantes sont demandées :

1° nom du produit/nom commercial ;

2° le responsable de la mise sur le marché/fabricant : le nom et prénom/ nom de l'entreprise, l'adresse professionnelle, le numéro de téléphone, l'adresse email professionnelle;

3° la personne de contact : le nom, prénom, numéro de téléphone et adresse email professionnelle;

4° renseigner le moyen de lutte contre le virus : filtre HEPA/filtre EPA/précipitateur électrostatique/UVC ;

5° si une dérogation a été approuvée par le ministre, fournir la référence de la notification de la dérogation, la date de publication sur le site web du service public (jj/mm/aaaa) et le(s) technique(s) de lutte contre le virus SARS-CoV-2 qui a(ont) fait l'objet de la dérogation ;

6° les niveaux d'efficacité contre le SARS-CoV-2 selon les débits d'air garantis et entre une valeur de deux à cinq renouvellements d'air par heure (ACH) pour un volume de local considéré ;

7° la preuve scientifique de la non-dangerosité du produit sur la santé de l'utilisateur, du public, dans les espaces où les effets du produit sont attendus et les seuils à ne pas dépasser lors de cette exposition ;

8° dimensions de l'appareil (longueur x largeur x hauteur) ;

9° poids en kg ;

10° tension électrique utilisée en volt (V) et puissance à puissance nominale (kW).

3° beschrijving van het volledige product, zijn bestanddelen, een technische tekening en de werking van het volledige product;

4° de onderzoeken, de testen en de rapporten met betrekking tot het niveau van doeltreffendheid van het volledige product, evenals de conclusies die de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen ertoe brengen de effectiviteit van zijn product te garanderen in overeenstemming met 3 ° van artikel 2;

5° de garantie van de doeltreffendheid van het product tegen het SARS-CoV-2-virus gedurende een bepaalde gebruikstijd en de maatregelen die werden genomen om de doeltreffendheid ervan in de tijd te waarborgen;

6° wetenschappelijk bewijs van het ongevaarlijk zijn van het product voor de gezondheid van de gebruiker, het publiek, in ruimtes waar de effecten van het product te verwachten zijn en de drempels die niet overschreden mogen worden tijdens deze blootstelling;

7° de omstandigheden van de installatie en het gebruik van het product beschrijven in een te behandelen omgeving;

8° de installatie- en gebruiksvoorwaarden beschrijven waar het product niet kan worden gebruikt;

9° de voorwaarden beschrijven voor het verwijderen van door het virus besmet materiaal.

Alleen volledige aanvragen zijn ontvankelijk en worden in behandeling genomen.

De overheidsdienst deelt haar met redenen omkleed advies dertig dagen na de aanvraag tot afwijking mee aan de minister.

De minister kan een aanvraag tot afwijking weigeren bij gebrek aan bewijs van de doeltreffendheid van het product tegen SARS-CoV-2 of bij gebrek aan bewijs van het ongevaarlijk zijn van het product voor de gezondheid van de gebruiker, het publiek, in de ruimtes waar de effecten van het product worden verwacht.

Wanneer de minister een aanvraag tot afwijking accepteert, wordt dit aan de aanvrager ter kennis gegeven en op de website gepubliceerd van de overheidsdienst. Alleen gegevens met betrekking tot systemen waarvoor een afwijking geldt, worden gepubliceerd op de website en geen persoonsgegevens.

Art. 6. Met het oog op het markttoezicht worden de mobiele en niet-mobiele luchtzuiveringssystemen die aan de normen van artikelen 3 en 4 voldoen of die een afwijking hebben gekregen, door de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen ten laatste tien werkdagen na het op de markt brengen ervan op de volgende website geregistreerd:www.corona-ventilation.be

De volgende informatie wordt gevraagd:

1° productnaam/handelsnaam;

2° de verantwoordelijke voor het op de markt brengen/fabrikant: naam en voornaam/bedrijfsnaam, zakelijk adres, telefoonnummer, zakelijk emailadres;

3° de contactpersoon: naam, achternaam, telefoonnummer en zakelijk emailadres;

4° informatie verstrekken over hoe het virus kan worden bestreden: HEPA-filter/EPA-filter/elektrostatische precipitator/UV-C;

5° indien een afwijking werd goedgekeurd door de minister, wordt de referentie van de kennisgeving van de afwijking en de datum van publicatie op de website van de overheidsdienst (dd/mm/jjjj) vermeld alsook de techniek(en) om het SARS-CoV-2-virus te bestrijden waarop de afwijking betrekking had;

6° de doeltreffendheidsniveaus tegen SARS-CoV-2 volgens de gegarandeerde luchtdebieten en tussen een waarde van twee tot vijf luchtverversingen per uur (ACH) voor een bepaald lokaalvolume;

7° wetenschappelijk bewijs van het ongevaarlijk zijn van het product voor de gezondheid van de gebruiker, het publiek, in ruimtes waar de effecten van het product te verwachten zijn en de drempels die niet overschreden mogen worden tijdens deze blootstelling;

8° afmetingen van het toestel (lengte x breedte x hoogte);

9° gewicht in kg;

10° gebruikte elektrische spanning in volt (V) en vermogen bij nominaal vermogen (kW).

Art. 7. Lorsque le fabricant ou le responsable de la mise sur le marché de produits mobiles et/ou non-mobiles de purification de l'air, utilise des allégations d'efficacité et/ou de non-dangerosité, celles-ci sont communiquées au service public au plus tard vingt jours ouvrables après la mise sur le marché desdits produits mobiles ou non mobiles de purification de l'air.

Le fabricant ou le responsable de la mise sur le marché enregistre sur le site web www.corona-ventilation.be, un dossier complet, détaillé et structuré de la manière suivante :

1° l'identification du demandeur: le nom et prénom/ nom de l'entreprise, l'adresse professionnelle, le numéro de téléphone, l'adresse email professionnelle;

2° l'identification du nom commercial du produit, nom et coordonnées du fabricant ou de la personne responsable de la mise sur le marché (l'adresse professionnelle, le numéro de téléphone, l'adresse email professionnelle) ;

3° description du produit complet, ses constituants, un dessin technique et le mode de fonctionnement du produit complet ;

4° l'allégation d'efficacité contre le SARS-CoV-2 en néerlandais, français et allemand ainsi que les documents qui prouvent les niveaux d'efficacité. Ces documents constituent un dossier qui reprend les tests, les essais, les rapports d'essais qui garantissent les niveaux d'efficacité du produit commercial complet ;

5° l'allégation de non-dangerosité en néerlandais, français et allemand sur la santé de l'utilisateur, du public, dans les espaces où les effets sont attendus, ainsi que les documents qui prouvent la non dangerosité du produit commercial complet. Ces documents constituent un dossier qui reprend les tests, les essais, les rapports d'essais qui garantissent la non-dangerosité du produit commercial complet lors d'une exposition humaine normale et les seuils à ne pas dépasser lors de cette exposition.

Art. 8. Le service public est le seul responsable du traitement de données à caractère personnel dans le cadre des articles 5, 6 et 7. Le délais maximum de conservation des données à caractère personnel qui feront l'objet du traitement est de deux ans.

Art. 9. Le présent arrêté rentre in vigueur dix jours après la publication dans le *Moniteur belge* et cesse d'être en vigueur six mois après son entrée en vigueur.

Bruxelles, 12 mai 2021.

Le ministre de la Santé publique,
Fr. VANDENBROUCKE

Art. 7. Wanneer de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen van mobiele en/of niet-mobiele luchtzuiveringssystemen, beweringen van doeltreffendheid en/of het ongevaarlijk zijn, gebruikt, worden deze ten laatste twintig werkdagen na het op de markt brengen van de genoemde mobiele of niet-mobiele luchtzuiveringssystemen aan de overheidsdienst meegedeeld.

De fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen, registreert op de website www.corona-ventilation.be, een volledig, gedetailleerd en gestructureerd dossier als volgt:

1° de identificatie van de aanvrager: naam en voornaam/bedrijfsnaam, zakelijk adres, telefoonnummer, zakelijk emailadres;

2° de identificatie van de handelsnaam van het product, naam en contactgegevens van de fabrikant of de persoon die verantwoordelijk is voor het op de markt brengen (zakelijk adres, telefoonnummer, zakelijk emailadres);

3° een beschrijving van het volledige systeem, de onderdelen, een technische tekening en de werking van het volledige systeem;

4° de bewering over de doeltreffendheid tegen SARS-CoV-2 in Nederlands, het Frans en het Duits, evenals de documenten die de niveaus van doeltreffendheid bewijzen. Deze documenten vormen een dossier met de tests, proeven en testrapporten die de niveaus van doeltreffendheid van het volledige commerciële product garanderen;

5° de bewering van het ongevaarlijk zijn in Nederlands, het Frans en het Duits voor de gezondheid van de gebruiker, het publiek, in ruimtes waar de effecten te verwachten zijn, evenals de documenten die het ongevaarlijk zijn van het volledige commerciële product bewijzen. Deze documenten vormen een dossier met de tests, proeven en testrapporten die het ongevaarlijk zijn van het volledige commerciële product bij normale menselijke blootstelling garanderen en de drempels die tijdens deze blootstelling niet overschreden mogen worden.

Art. 8. De overheidsdienst is de enige verantwoordelijke voor de verwerking van persoonsgegevens in het kader van de artikelen 5, 6 en 7. De maximale bewaartermijn voor persoonsgegevens die worden verwerkt is twee jaar.

Art. 9. Dit besluit treedt in werking tien dagen na publicatie in het *Belgisch Staatsblad* en treedt buiten werking zes maanden na de inwerkingtreding ervan.

Brussel, 12 mei 2021.

De minister van Volksgezondheid,
Fr. VANDENBROUCKE

AGENCE FEDERALE POUR LA SECURITE DE LA CHAINE ALIMENTAIRE

[C − 2021/31445]

6 MAI 2021. — Arrêté ministériel fixant la date de la première réalisation de l'évaluation des risques au sein des exploitations porcines

Le Ministre de l'Agriculture,

Vu la loi du 24 mars 1987 relative à la santé des animaux, l'article 7, § 2 et 3, l'article 8, alinéa premier, 1°, et l'article 18*bis*, alinéa premier, inséré par la loi du 29 décembre 1990 et modifié par la loi du 1er mars 2007 ;

Vu l'arrêté royal du 18 juin 2014 portant des mesures en vue de la prévention des maladies du porc à déclaration obligatoire, l'article 7/1, § 3, inséré par l'arrêté royal du 11 mai 2020 ;

Vu l'avis 69.147/3 du Conseil d'État, donné le 29 avril 2021, en application de l'article 84, § 1er, alinéa premier, 2° des lois sur le Conseil d'État, coordonnées le 12 janvier 1973,

Arrête :

Article unique. La date de début de la période de quatre mois dans lequel l'évaluation des risques concernant l'introduction de maladies porcines à déclaration obligatoire visée à l'article 7/1 de l'arrêté royal du 18 juin 2014 portant des mesures en vue de la prévention des maladies du porc à déclaration obligatoire, doit avoir été effectuée, est fixée au premier jour du mois qui suit un délai de dix jours à compter du jour suivant la publication de cet arrêté ministériel au *Moniteur Belge.*

Bruxelles, le 6 mai 2021.

D. CLARINVAL

FEDERAAL AGENTSCHAP VOOR DE VEILIGHEID VAN DE VOEDSELKETEN

[C − 2021/31445]

6 MEI 2021. — Ministerieel besluit houdende de datum van eerste uitvoering van de risico-enquête op varkensbedrijven

De Minister van Landbouw,

Gelet op de dierengezondheidswet van 24 maart 1987, artikel 7, § 2 en 3, en artikel 8, eerste lid, 1°, en artikel 18*bis*, eerste lid, ingevoegd bij de wet van 29 december 1990 en gewijzigd bij de wet van 1 maart 2007;

Gelet op het koninklijk besluit van 18 juni 2014 houdende maatregelen ter voorkoming van aangifteplichtige varkensziekten, artikel 7/1, § 3, ingevoegd bij het koninklijk besluit van 11 mei 2020;

Gelet op advies 69.147/3 van de Raad van State, gegeven op 29 april 2021, met toepassing van artikel 84, § 1, eerste lid, 2°, van de wetten op de Raad van State, gecoördineerd op 12 januari 1973,

Besluit :

Enig artikel. De begindatum van de termijn van vier maanden waarbinnen de risico-enquête aangaande de insleep van aangifteplichtige varkensziekten bedoeld in artikel 7/1 van het koninklijk besluit van 18 juni 2014 houdende maatregelen ter voorkoming van aangifteplichtige varkensziekten, moet zijn uitgevoerd, wordt vastgesteld op de eerste dag van de maand na afloop van een termijn van tien dagen te rekenen van de dag volgend op de bekendmaking van dit ministerieel besluit in het *Belgisch Staatsblad.*

Brussel, 6 mei 2021.

D. CLARINVAL

12) Belangrijke opmerking over luchtreinigers: van goed over waardeloos tot schadelijk

In de voorbije maanden heeft mijn team heel wat luchtreinigers getest. Daaruit volgt dat er heel wat uitstekende apparaten beschikbaar zijn, die zeer goed presteren aan hoog rendement en laag energieverbruik. Er zijn echter ook apparaten beschikbaar die niet goed presteren, en zelfs ook apparaten die schadelijke bijproducten genereren, zoals ozon en stikstofoxiden.
Net als bij alle apparaten/technologie is een zorgvuldige en professionele selectie nodig, net als goed onderhoud. Dat geldt overigens ook voor ventilatie. Ventilatie kan ook ongezond zijn als het ventilatiesysteem niet goed wordt onderhouden en schimmelgroei en bacteriën zich kunnen ontwikkelen in de ventilatiekanalen.

13) Short biography Bert Blocken

Prof. dr. ir. Bert Blocken (*1974, Hasselt, Belgium) is a Belgian national and a Civil Engineer holding a PhD in Civil Engineering / Building Physics from KU Leuven in Belgium. He is Full Professor in the Department of the Built Environment at Eindhoven University of Technology (TU/e) in the Netherlands and part-time Full Professor in the Department of Civil Engineering at KU Leuven (Leuven University) in Belgium. He has led the design and construction of the Eindhoven Atmospheric Boundary Layer Wind Tunnel and currently acts as its Scientific Director. His main areas of expertise are urban physics, wind engineering and sports aerodynamics.

He has published 209 papers in international peer-reviewed journals. His h-index values are 57, 61 and 73 on Web of Science, Scopus and Google Scholar, respectively. He has graduated 22 PhD students. He developed TU/e's first Massive Open Online Course (MOOC) Sports & Building Aerodynamics on the Coursera platform. He received the 2011 and 2018 Best Bachelor Teacher Award from the students of the Department of the Built Environment at TU/e. According to the 2016 Academic Ranking of World Universities (Shanghai Ranking) & Elsevier, he is among the 150 most cited researchers world-wide both in the field of Civil Engineering and in the field of Energy Science & Engineering. He is listed as 2018, 2019 and 2020 Highly Cited Researcher by Clarivate Analytics (Web of Science) for production of multiple highly cited papers that rank in the top 1% by citations for field and year in Web of Science Core Collection, ranking him in about the top 0.1% researchers in his field according to Clarivate Analytics (https://hcr.clarivate.com/). He was listed as one of the 15 engineers world-wide "who mattered in 2020" by Engineering.com (https://new.engineering.com/story/engineers-who-mattered-in-2020). His first paper on COVID-19, ventilation and fitness centers was ranked by Altmetric in the top 0.003% of tracked articles (www.altmetric.com/top100/2020/) .

He is associate editor of the peer-reviewed journals Journal of Wind Engineering & Industrial Aerodynamics and Sports Engineering, and continuous Guest Editor of the Ten Questions Initiative of the peer-reviewed journal Building and Environment. He is member of the editorial board of the journals Building Simulation and the International Journal of Ventilation. He has acted as a reviewer for more than 70 different ISI journals. He is supervising a team of 6 senior researchers and 22 PhD students (see www.urbanphysics.net).

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