Verslag

Super spreading events and the development of the COVID-19 pandemic: what is the role of indoor air quality?

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On Thursday 17th September 2020 the Contact Groep Chemie (CGC) in collaboration with the Nederlandse Vereniging voor Medische Milieukunde (NVMM) organized a seminar about the role of aerogenic transmission of the SARS-CoV-2 virus in super spreading events. Due to the restrictions on face-to-face meetings this seminar was provided online. The meeting was attended by approximately 70 participants.

Recent studies of super spreading events have demonstrated that viruses are released during exhalation, talking, coughing and sneezing in microdroplets small enough to remain airborne and pose an exposure risk when carrying a high virus load. However, the contribution of aerogenic transmission of SARS-CoV-2 remains a controversial topic. In March-April 2020 there were reports of certain events where many persons were linked to the same source of infection (index patient). In these settings airborne transmission may not always be the only transmission route but certainly an important explanation for the spatial patterns of group infections. What can the super spreading events tell us about the role of the indoor air quality in the development of the pandemic? Based on the analysis of a range of such super spreading events a pattern occurs that relates to conditions such as high occupancy, poor supply of fresh air and some specific activities such as talking loudly and singing. What can super spreading events teach us about the transmission of the virus? How did these clusters of infections contribute to the pandemic in early 2020 and how important are these events overall, i.e. In future development of the endemic (Li et al., 2004)? How can sufficient and effective ventilation and regulated occupancy contribute to reducing the indoor risk of infection?

The first speaker on this topic is professor Lidia Morawska, PhD, director of the International Laboratory for Air Quality and Health which is also a WHO collaborating center for air quality and health. She is also co-director of the Australia – China Centre for Air Quality Science and Management, at the Queensland University of Technology, Brisbane Australia. Dr. Morawska introduces the topic by providing some historic context in her contribution entitled: *“How aerosols contribute to the transmission of SARS-CoV-2?”* In 2003 she was invited as expert to come to Hong Kong to the location of an outbreak of a respiratory virus that caused the SARS1 outbreak in the Amoy Gardens complex of apartment building where over 300 residents were infected.

By itself respiratory infections are quite common as indicated from statistics from the UK: Per year colds occur in infants and preschool children with a frequency of 4 to 8 times per year and for adults 2 to 5 times, according to the statistics already available post SARS1, in 2005. The impact of respiratory infections in the US is enormous and results in health care costs of $10 billion and costs from absence due to illness of $19 billion (2005 data). A reduction of 10 to 14% of the frequency of common cold would already lead to a possible economic benefit of $3 to 4 billion (2005 data). However, the mechanisms of airborne infection are not yet fully understood, nor the extent known to which infection normally take place by each of the different routes. Nevertheless, there a clear role of building design has been identified in relation to infection prevention, something that amongst others the legendary Florence Nightingale already addressed in several of her publications around 1850. It was already believed in 2005 that setting the key building parameters according to the current understanding of their optimal ranges, would result in lowering of the potential for infection spread. Whether this is the limit of what can practically be achieved in minimization of infection spread, is not known.

There is general support for the need for application of the science of infection spread towards developing quantitative knowledge guiding building design and operation. However, there is still strong opposition for a role of airborne transmission as indicated by what the US centers for disease control (CDC) published online (CDC, 2018): *“Airborne transmission over longer distances, such as from one patient room to another has not been documented and is thought not to occur.”* The current SARS-CoV-2 pandemic certainly results in an increased interest to study the role of transmission by air. One of the obstacles in the discussion about the role of aerosols in virus transmission is the differences in definition of terms like ‘droplets’ and ‘aerosols’ used by experts from natural sciences and experts with a medical background. The WHO takes a position in the debate as indicated by Q&A posted on the website of the WHO: *“The disease spreads primarily from person to person through small droplets from the nose or mouth….” and “These droplets are relatively heavy, do not travel far and quickly sink to the ground. … This is why it is important to stay at least 1 meter away from others.”* The priorities in mitigation are based on a large role for transmission by large droplets and surface-to-surface contamination, i.e., social distancing, washing hands and surface disinfection. The effect of wearing a mask was at the beginning of the pandemic considered controversial and for a role of ventilation undermined as some point at the consequences: high expenses, difficult to implement because of the many parties involved. More recently (29 July 2020) WHO stated that— "WHO recommends an increased ventilation rate through natural or mechanical means, preferably without recirculation of the air".

Aerosols from the airways originate from different sources with a generic underlying mechanism of atomization which is explained by air flowing fast over an air-liquid interface involving the following sources: saliva in the mouth is aerosolised during interaction of the tongue, teeth palate and lips during speech articulation, fluid bathing the larynx is aerosolised during voicing due to vocal fold vibrations and vibrations and fluid fluid blockages form in respiratory bronchioles during exhalation that burst during subsequent inhalation produce fine particles. Hence, speech and breathing leads to aerosols being formed in three overlapping particles size modes: the oral speech articulation movement (OSAM) mode which extends from 1 to 1000 µm, the laryngeal vibration (LV) mode which covers aerosols up to 25 µm, and the finest fraction formed by the bronchial fluid film burst (BFFB) mode with aerosols smaller than 5 µm. Aerosol emission and super-emission during human speech increases with voice loudness. The liquid consists of water and contain salts, mucus and pathogens. Water evaporates very fast when droplets are suspended in air at room temperature leading to only 20-40 % of the original size remaining. Particles <10 µm will remain airborne because of their low mass. These smaller particles are also likely to contain higher SARAS-CoV-2 loads because they originate from the deeper parts of the airways, whereas larger ballistic droplets are likely to contain less virus because they originate from the mouth. The particles generated by respiratory activities are small enough to stay suspended in the air for a long time unless they are removed from the air by ventilation (and other processes).

Several studies have shown modelled risks for infection by influenza, tuberculosis and the rhino virus as a function of the air exchange rate that suggest that ventilation with fresh air is an effective intervention. Dr. Anthony S. Fauci who advised the Trump administration during the pandemic summarized this new insight of medical professionals as follows: *"There was some real misunderstanding about respiratory droplets and so-called aerosolised particles. The aerosol and particles physicists that have approached us now have told us that we really have got it wrong over many years… Bottom line is this: there is much more aerosol than we thought."* Dr. Morawska was the lead author of an open letter to the to the medical community and to the relevant national and international bodies (including WHO) (Morawska et al., 2020): This letter was supported by 239 scientists from 34 countries and appeared online on July 5th. On 7 July 2020 the WHO responded during an online press conference: *"The World Health Organization acknowledged ~ evidence emerging ~ of the airborne spread of the novel coronavirus, after a group of scientists urged the global body to update its guidance on how the respiratory disease passes between people."*

The next speaker was professor Shelly Miller PhD of the Department of Mechanical Engineering of the University of Colorado, Boulder Colorado, US. She delivered her contribution *"Superspreading events: how to minimize aerosol transmission"* online. From Wuhan we know that most transmissions occur in indoor settings at home, at the workplace or during transport. Only one transmission was linked to an event that occurred outdoors, hence the focus on the indoor environment. The important role of indoor events as superspreading events is illustrated by three case reports. The first case describes a super spreading event in Hong Kong that started on March 7th 2020 and involved 160 individuals who were infected, accounting for 10.2% of all confirmed cases in the city. The source was a collection of bars in the city centre where a number of 22 staff, 14 musicians and 39 customers were infected.

In Japan 62 case clusters were traced back to 22 primary case patients. In 82% of these case clusters, it could be determined when transmission occurred and in 41% of these patients did not have any symptoms at the time of transmission. Half of them were 20-39 y old and 30 % of the clusters occurred in healthcare facilities, nurseries and also in private homes, restaurants and bars. Some clusters involved music-related events such as live music concerts.

The third super spreading event describes the Skagit Valley chorale rehearsal outbreak that occurred on March 10th in Washington State and is described in a paper that was recently published (Miller et al., 2020). The 2.5 h rehearsal was attended by 61 members. The following precautions were taken: hand sanitizer, no hugging, no handshakes. The attendants were seated on chairs placed 0.75 to 1.4 m apart and 50 % of the chairs were not occupied. The building had mechanical ventilation and heating system that was operated only during part of the rehearsal. Natural ventilation by window and doors were not used due to the low outdoor temperature of 7°C. Hence, overall air exchange rate was estimated to be below 1 h^{-1}. The index case had mild cold symptoms. Due to the low prevalence of COVID-19 in Skagit Valley it is considered highly unlikely that other members had non-symptomatic infections. While seated during the rehearsal the index case was only during parts of the rehearsal at 1 m distance from 2 members to each side and from 4 other member within 2 m behind. There was one break of 10 minutes when some gathered in groups of 3-4 members. The index case indicated to have conversed minimally. Respiratory symptoms set in the period 11 to 22 of March 2020. Of the entire group 33 had PCR confirmed infections, 20 unconfirmed but probable (testing capacity was unavailable to many). Dr. Miller used the Wells-Riley equation (see further details below) as a function of the air exchange rate and showed that the risk of exposure to infectious aerosols drops quickly with increase ventilation resulting in a reduction to a risk of 40% at an air exchange rate of 6 per hour. The duration of exposure is also an important risk factor. Modelling showed that reducing time from 2.5 to 0.5 h leads to a reduction of the risk to below 10%. From ventilation studies it is known that ventilation should provide at least 5 liters of fresh air per minute per person to prevent acute respiratory infections. Some studies advice at least 25 L/min/person to prevent symptoms attributed to poor air quality as e.g., sick building symptoms leading to short-term sick leave and decreased productivity.

The third and last speaker is dr. ir. Atze Boerstra of bba binnenmilieu. He is affiliated to the TU Delft Faculty of Architecture and obtained a PhD from the TU Eindhoven related to indoor environmental quality in offices. Atze is also one of the initiators and authors of the REHVA COVID guidance HVAC document that was first published in March 2020. The title of his talk is *"Learning from superspreading events worldwide and from one Dutch case study".* He introduced a further spreading event related to a Buddhist meeting in China in January 2020 where attendants traveled two times 50 minutes by bus (Shen et al., 2020). In the first bus and during the meeting nobody was infected. However, 18 passengers of total of 68 persons that were traveling on a second bus became infected. One passenger had a confirmed infection and presumably infected other passengers. The passengers who became infected were sitting randomly in the bus including some persons who sitting at a distance of up to 10 m away from the index case. Of the persons sitting next to the index case one became infected whereas the other person did not become infected. Because of the cold outside the driver put the ventilation on recirculation mode at least part of the travel time which probably explains (at least partly) the high cross-infection rate.

Dr. Boerstra explains that in a room where an infected person meets an uninfected person ventilation can have two effects: diluting the concentration of aerosols and also the effect of airflow moving aerosols towards or away from a recipient. According to Boerstra the question if the SARS-CoV-2 virus is airborne should be addressed depending upon the circumstances. Probably there are situations in which the virus is not likely transmitted via the air (via micro-droplets), such as in a hospital with high air exchange rates where the air is also filtered by use of high-efficient filter systems. In such environments the transmission by close or direct contact or by surface contamination might be the most important transmission route. In contrast, the airborne route might be the dominant route when persons may stay together in a poorly ventilated room for extended duration such as in a car or in the living room of a nursing home. Many events that were identified as contributing to the spread of the virus were indoor gatherings of people who were close together. Especially meetings with loud background music and other situations where people sang or talked loudly (e.g. in karaoke bars, nightclubs, indoor carnival celebrations, après ski bars) were linked to superspreading events. Superspreading events also seem to be linked to religious events (esp. those that involve singing or chanting considerable amounts of time) e.g. as seen in South Korea with meetings of the Shincheonji sect or during church services in Germany and in The Netherlands. What these places have in common is the crowd, small/medium size spaces with low ceilings, involvement of loud talking/shouting and singing and in most cases limited fresh air supply.

Dr. Boerstra analysed the Swinkels database that contained 1,408 superspreading events (situation mid August 2020), primarily originating from the US. The top five locations that together represent about 50 % of all reported cases involved nursing homes, rehabilitations centers, prisons, hospital facilities and meat processing facilities. Lower ranking events in the top 10 included weddings, funerals, family gatherings at home, bars/private parties and religious gatherings. Surprisingly schools were ranking only 15th in this database. A second database was also presented. This Leclerc/Knight database included 265 infection events reported mainly in Europe until mid-August 2020. The home environment was the highest-ranking location for cross-infections but with a rather low median of 4 infections caused per event. The five highest ranking categories in this second database explained half of the reported events. These included accommodations where migrants live, religious buildings and indoor sports facilities. Here nursing homes were the fifth highest ranking location type. Locations with high numbers of infections per outbreak were prisons (170), meat processing industry (70) and apartments for labor migrants (45). In the earlier SARS outbreak of 2003, the share of super spreading events to the total number of registered infections was estimated to be 71.1% for Hong Kong and 74.8% for Singapore (Li et al., 2014). These observations make it worthwhile to further study the role of these spreading events and consider preventive actions targeted at specific locations / activities.

Dr. Boerstra further explained the use of the Wells-Riley model which uses the term 'quantum' defined as a hypothetical infectious dose unit and introduced by Wells in 1955. This model can be used to get some insight in relation to the probability of an infection via the aerogenic route. This model consists of a Poisson function assuming discrete infectious particles in well-mixed air and the particle concentration to be dependent on the air exchange rate and surface deposition as loss factors (equation 1).

$$Pinf = 1- e^{(-I \times q \times P \times t)/Q)}$$

With:
$Pinf$ = infection risk in %
I = amount of infected person in the room (amount of 'sources')
q = virus load divided by source strength of one infected person (quanta/hour)
P = pulmonary ventilation (m^3/h)
T = exposure time (h)
Q = hourly room ventilation (m^3/h), equal to air exchange rate x room volume

Note that Q officially also relates to air treatment such as filtering and the loss of virus activity of the virus over time. For now, in the formula we just looked at the 'sink-effect' related to dilution / ventilation (simplified approach). This model can be used for a quick & dirty assessment of the risk of infection of airborne transmissible diseases. Riley and his team originally applied this model to an outbreak of measles in an elementary school classroom (Riley et al., 1978).

Dr. Boerstra finalizes his contribution by introducing a case in an office in Delft, the Netherlands were 14 employees of a start-up company worked in one large office. In this workplace one person infected 8 colleagues over a period of three days in March 2020. There were two recirculation units for cooling (not in use during that week) and a set of radiators under windows used for heating in winter. An on-site investigation showed that the 'dauerluftung' ventilation system (ventilation grilles for natural air supply, integrated in the façade) was closed because of the cold weather (draft problems). There was also some mechanical extraction of air in the toilets, pantries and from a production hall, but overall considered insufficient to also generate enough under pressure in the office space. The general conclusion was that the cross-infection event happened at least partly due to insufficient fresh air supply. The air exchange rate was estimated to have been 0.5 per hour or lower at the time when the infections occurred. Based on the Wells Riley model the infection risk for one 8 hour working day was estimated to be 20-45%. While the actual infection rate was 8/13 = around 60%. In order to avoid future cross-infections (or at least to make these less likely), the start-up company was advised to install a CO2 warning system ('traffic light solution') and a state of the art mechanical ventilation system in the office space with an air exchange rate of at least 2 before the 2020-2021 winter.

Literature

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