Study of the low moving efficiency of bioaerosol with insufficient air inflow and exhaust in the public toilets

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Abstract. Due to insufficient ventilation, public toilets have become incubators for cross-infection during the pandemic. WHO has proposed an approach to improve indoor ventilation, including ventilation in isolated spaces like toilets, by applying the 10L/s/person criteria, and keeping fans running for effective ventilation. However, less air inflow in many public toilets causes the insufficient ventilation. We have ever found many colony forming units (CFUs) staying surrounding floor and junctures, and the inside of a lidless trash can in the toilet. If the minimal exhaust air is not equal to inlet air, the bioaerosol will stay in the toilets. Therefore, the speed of air inflow is suggested to be somewhat higher and reach 0.5m/s or more to facilitate ventilation in public toilets and reduce the risk of cross-infection.

1 Introduction

The flushing toilet was the invention that ended the plague in the 18th century. However, due to insufficient ventilation, public toilets have become incubators for cross-infection during the pandemic. On average, there are around 1011 to 1013 of E. Coli and some low-risk bacteria eliminated through feces by each person (Griffin 1940). Due to poor living habits, toilets have become a good place for bacteria to grow in urine and feces (Lee 2021). In addition, some other items like trash cans and miscellaneous items placed in toilets have even facilitated bacteria growth to the extent that hazardous mutations from harmless bacteria have developed to cause some diseases, including dysentery, damaging human bodies (Chi 2003). Before using public toilets for urinating, washing your face or body, or for brushing your teeth, some people need to remove items of clothing and protective masks. Some pollutants on people's clothes and masks then spread in the air and become very contagious sources of infection. According to a report published by WHO in March, 2020 (WHO Mar. 2020) the SARS-CoV-2 virus may spread through body contact, droplets, air, contaminated materials, feces to mouth, blood, mother to baby and animals to people (WHO Jul. 2020). Due to incorrect concepts or flaws in public toilet design, water flow and drainage plans (Hung 2006), equipment installation, use, maintenance and management, users are exposed to the environment where contagious sources spread (Lin 2021). This is how toilets become incubators for cross-infection.

Lee (Lee 2013) has investigated 111 public toilets and found that poor designs the public toilets, inappropriate ventilation and equipment settings result in user complaints. Space for toilets is necessary but does not constitute major space in the architecture so it’s usually allocated to some secondary or residual space in the construction planning of the building. Poor ventilation and insufficient sunlight can result from this. In addition, mis-arranged pipelines of sanitary equipment, lack of house trap design or broken water seals in the trap due to evaporation, which connect the toilet space to the sewage treatment tank or sewers, cause channels for bacteria and viruses to grow and spread to other toilet spaces that also have broken water seals (McKinney 2006). Sanitary equipment may be planned without considering user behavior, or that urine may drip or leak, excreta may splash or the flush may spray on the ground or wall near contaminated equipment, especially when the space has tiles as the surface of cement between tiles may accumulate dirt and become a good environment for germs to grow. In some countries, due to limited sewer systems, used toilet papers should not be flushed down the toilet but placed in a trash can next to the toilet. However, the excreta of carriers left on the toilet paper may cause germs to grow. There is also the matter of when toilet roll in thrown into the trash can; it can disturb other bits of toilet roll already in the bin and cause germs to bounce into the air, which can then adhere to aerosols (Tang 2020) and spread around as the air flows. Under the conditions of insufficient natural ventilation, mechanical ventilation is frequently used to eliminate the indoor bad odors and biological aerosols but is still insufficient due to poor air inflow or static pressure of the device. If the water seal in the house trap is broken, viruses will remain(McKinney 2006).
WHO has proposed an approach to improve indoor ventilation. EU standard EN16798-1 recommends applying 10L/s/person of ventilation (ventilation rate) in an independent space or keeping the exhaust fan running continuously to ensure effective ventilation (WHO 2021). However, according to the study conducted by Yuguo Li, to reduce the spread of SARS-CoV-2 virus over short distances, the ventilation flow rate should be no less than 3L/s. The impact is similar to ventilation within the range of 4L/s-10L/s (Li 2021). When the carrier stays in the public toilet, his or her droplets, excreta or biological aerosols remain in the space. If the toilets cannot be properly ventilated due to poor ventilation and poor user behavior, equipment and materials, it is very easy to become an incubator for viral cross-infection, especially when such a strong, contagious Delta variant of the virus can attack people through quick contact. Therefore, applying the ventilation flow suggested by Yuguo Li to assess whether current public toilets possess adequate ventilation is the major point to discussed in this study. Improvement is much more feasible than the ventilation suggested by WHO. There is also less risk of wind strike effects and noises of equipment. 

The study is designed as an environmental investigation of current public toilets to confirm the causes and location of biological contaminated sources. It also focuses on exploring the relationship between the ventilation volume and CFUs in the space to postulate the accumulating and remaining conditions of SARS-CoV-2 virus, which is one of the biological contaminated sources in the environment, to propose a method of preventing toilet spaces from becoming a place for cross-infection during the COVID-19 pandemic.

2 Methodology

We also conducted an investigation of the ventilation status in public toilets to measure the air velocity in the toilets using a hot wire anemometer, especially for inlet and exhaust patterns, the route of ventilation and the flow rate of ventilation etc. to explore effective ventilation. By way of a simple equation of ventilation (1) to postulate whether the ventilation is enough to eliminate viruses by the flow rate of the ventilation measured. If not, the ventilation is deemed insufficient.

\[ CMH = \text{ACH} \times V = A \times v \] (1)

where, \( CMH \) = air change in cubic meter per hour (m³/h), \( \text{ACH} \) = air change per hour (h⁻¹), \( V \) = volume of the space (m³), \( A \) = area of the ventilation outlet (m²), \( v \) = air velocity (m/h)

3 Results

The patterns of ventilation can be classified into four different types via the investigation: (A) no windows nor exhaust fan, (B) windows without exhaust fan, (C) both windows and exhaust fans, and (D) no windows with exhaust fan equipped (the most common). The investigation shows that the most common combination is no window but the exhaust fan is equipped (D), demonstrating that the mechanical exhaust system plays an important role in overall ventilation but it’s providing insufficient air inflow and is unable to effectively ventilate toilets. Although there is a rule in the 43rd Article of the Building Technical Regulations in Taiwan (CPA 2019), the design and construction chapter, which states that the area of the residence entrance must be 5% more than the area of the floor, there is no mandatory rule that mentions that exhaust fan devices are required in toilets with poor ventilation, nor is there a minimal ventilation limit rule. Therefore, exhaust fans installed in many public toilets should have additional exhaust pipes to eliminate moisture and biological aerosols, as shown in Figure 1. However, it was found in the investigation that there were more than 50% of devices that were not completely connected to the ventilation, as shown in Figure 2. Since the devices were not well installed, the humidity and biological aerosols in public toilets were not eliminated from the buildings though they were passing through the exhaust fans. As a result, humidity and biological aerosols remained in the ceiling and grew many different microorganisms. Due to existing interior design, it proved difficult to examine the serious nature of biological contamination materials growing there.
toilets so bacteria or viruses produced by users accumulate easily and are not driven away from this small space. If the user were a carrier, the next user would be at risk of cross-infected but have no idea from where the transmission chain originated.

This study conducted on-site measurements based on the four ventilation types grouped by the investigation. The measurements were conducted under a space setting in the toilet (W1m x L1.5m x H2.4m) and a fan set at a location of 80cm away from the door outside the toilet to provide air inflow to the door with the strongest wind velocity (about 3.67m/s). Wind velocity was measured at points at different ranges to the door and the inside shutter, as shown in Figure 3.

Four different ventilation types were represented by different colors and the types of doors are shown in Figure 4. The size of the window was W30cm x H45cm and is positioned across from the door. The distance between the bottom of the window and the ground is 160cm. Wind velocity on the exhaust fan was 85CMH and the radius of the exhaust pipe is 10cm; this is installed on the ceiling above the toilet. Considering that the depth of the door after it was opened was 80cm with the toilet right behind, the wind velocity at the location of the toilet was measured (taking the average of three measurements). As indicated in Figure 4, common ventilation type D, when the wind velocity hit the location at 80cm away from the inner shutter of the door, was only 0.01m/s. According to the calculations (1), if we closed the window but left the exhaust fans turned on in ventilation type D toilets, the ventilation would be less than 0.1 L/s. Even in ventilation type C, with open windows and turn on exhaust fans, the ventilation rate was still insufficient by 0.2 L/s. As a result, even though the ventilation design of the exhaust equipment is sufficient, the influences of the ventilation route in shortcut, the size of exhaust pipes and insufficient air inflow may contribute to retaining a huge amount of bioarosol in public toilets. If the minimal ventilation were set at 3L/s and the air velocity 0.38m/s, the wind velocity of the air inflow would be recommended higher than 30% as positive pressure ventilation in 0.5m/s to drive away infectious sources.

4 Discussion

According to the equation (1), if we close the window but turn on the exhaust fans in the ventilation type D toilets, the ventilation rate would be less than 0.1 L/s. Even in ventilation type C, with open windows and turn on exhaust fans, the ventilation rate was still insufficient by 0.2 L/s. As a result, even though the ventilation design of the exhaust equipment is sufficient, the influences of the ventilation route in shortcut, the size of exhaust pipes and insufficient air inflow may contribute to retaining a huge amount of bioarosol in public toilets. If the minimal ventilation were set at 3L/s and the air velocity 0.38m/s, the wind velocity of the air inflow would be recommended higher than 30% as positive pressure ventilation in 0.5m/s to drive away infectious sources.

5 Conclusions

Whatever the natural or mechanical ventilation, the wind velocity of each point must be more than 0.5m/s to effectively exhaust the air out of the toilet or to kill or filter out bacteria to reduce the risk of cross-infection.

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