RESPIRATORY DISEASES, VIRUSES AND COVID-19 IN PARTICULAR

THE INFLUENCE THAT BUILDING VENTILATION CAN HAVE ON SAVING THE HUMAN RACE

VENTÜER

Introduction

The world is sick, and it's getting worse. At the time of writing this, there have been 378,84 cases of COVID-19 coronavirus, of which 16,510 have died and 102, 064 have recovered. The remaining 260,268 have an 86% chance of recovering, but before they do there is every chance they will pass the infection on to many others.

What can Building Designers, Contractors & Owners do to help?

If you have the ability to influence the ventilation system of the building in which you live, work or play then you have the ability make a difference to this situation.

There are five environmental conditions which impact the health and comfort levels of indoor environments: Temperature, Humidity, CO2 Levels, Air Changes and Air Cleanliness. Of these, there are two which internationally recognised studies have established make a significant difference to the transmission rates of viral diseases;

1. **Air Changes**
2. **Relative Humidity**

Air Changes

Let's start by looking at the impact of Air Changes.

What are air changes? Simply put, the ACH (air changes per hour) rate is the rate at which all of the air within a room is removed and replaced with fresh outside air. Depending on the use of the building, the design ACH rate could be as high as 30 (commercial bakery kitchens or smoking lounges for example) or as low as 0.75 (residential dwellings designed to Passivhaus standard). The changing of the air can be through the use of open windows and natural wind pressure, or via mechanical fan-driven ventilation systems.

How does the air change rate of a building affect disease transmission?

The transmission of many infectious diseases, COVID-19 among them, begins when a sick person coughs, sneezes or otherwise expels bodily fluids such as saliva and mucous that carry the pathogen. These infected droplets are then at risk of being inhaled or absorbed by another person who then becomes ill as result.

NB - not all of the infectious particles remain airborne. Many will fall and settle on surfaces such as furniture and floors, and the importance of cleaning these surfaces cannot be under stated.

Many of the droplets do remain airborne however, and these rapidly become smaller through evaporation. At a size of less than 5 microns, they become buoyant and will remain airborne indefinitely. Below is an image showing the means by which droplets expelled by and infected person can be transmitted to others.

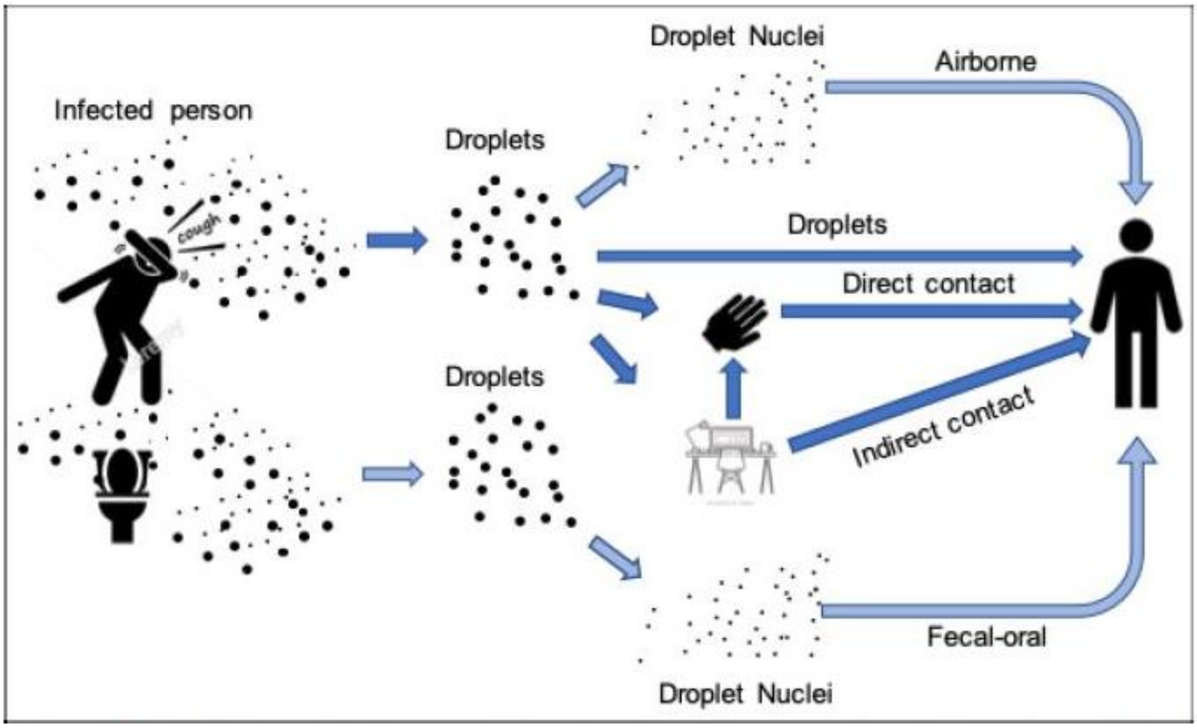

Image credit REHVA COVID-19 guidance document, March 17, 2020

These droplet nuclei are killers, and without removing them from the air there can be no safety for the building occupants.

The most effective way to rid indoor air of infectious particles is to remove it and replace it. Once expelled to the outside, the airborne pathogens become so diluted that they pose very little risk.

Simply by regularly changing the air within your building, removing the existing (potentially contaminated) indoor air and replacing it with fresh outdoor air you will significantly reduce the risk of virus transmission.

What number of air changes per hour should be achieved in order to maintain a healthy indoor environment?

It depends mostly on the number of people in the room. The World Health Organisation guidelines for healthcare facilities suggest that precaution rooms should achieve 160 L/S of fresh air per person, general wards should achieve 60 L/S of fresh air per person and corridors or other spaces without a fixed number of people should achieve 2.5 L/S/M3. The European Standard DIN 1946-2 includes the following recommendations:

Recommended Air Changes by Room Usage - DIN1946-2		
Room	Minimum Outside Air Stream per Person (m^3/h)	Recommended Number of Air Changes per Hour
Toilets	30	4 (private) 10 (public)
Showers	60	6 (private) 10 (public)
Offices	40-60	6
Restaurants	50	12
Canteens	30	12
Classrooms	30	5
Conference Facilities	30	8
Multi-purpose Halls	30	5
Gyms	30	5
Waiting Rooms	30	6
Hotel Rooms	-	4
Public Garages	-	5
Commercial Kitchens	-	25
Private Kitchens	-	20
Launderettes	-	18
Swimming Pools (private)	-	6 - 7
Workshops	-	10

As a minimum, we suggest that a minimum ACH rate of 15 should be targeted where there is the risk of infectious diseases being present.

Air Change vs Air Filtering

Why *change* the air and not simply *filter* it? After all, we know that outdoor air comes with its own problems – pollens, smog and other chemical pollutions – why don't we simply filter the pathogens out of the otherwise clean indoor air?

The main problem with relying on filtering and recirculation of indoor air is the size of the airborne particles. The coronavirus particles themselves are less than 0.1 of a micron in size, and even if they are being carried by other particles these can still be less than 5 microns in size. A filter capable of removing particles of this size will be required to be an ULPA grade filter, which is very restrictive to airflow meaning that large fans are required to move the air – creating both noise and energy consumption issues.

The filters themselves will also very quickly get clogged unless several stages of pre-filters are used, and then there is the risk of pathogen build-up on the final filter. Do *you* want to be handling a filter that has potentially collected a large amount of highly infectious material?

No, the better way is to avoid trying to filter the air and simply replace it entirely.

Relative Humidity

As well as Air Change rates, the Relative Humidity levels of indoor air can have a large impact on transmission and infection rates of respiratory diseases.

There have been multiple studies done internationally on this subject, some of which are listed below.

- Schaffer et al. (1976) revealed that viral transmission at low (<40%) and high (>80%) relative humidity was much higher than at medium relative humidity (about 50%).
- Lowen et al. (2007) and Shaman and Kohn (2009) conclude that low humidity and low temperature strongly increase influenza transmission between guinea pigs and hypothesize this is caused by rapid formation of droplet nuclei and increased survival of the infectious agent.
- Noti et al. (2013) found that at low relative humidity (23%), influenza retains maximal infectivity (71% to 77%) and that inactivation (infectivity 16% to 22%) of the virus at higher relative humidity (43%) occurs rapidly (60 min) after coughing. This study used manikins and aerosolization in a nebulizer, using a cell culture medium.7

Text Credit ASHRAE Position Document on Airborne Infectious Diseases 2014

To date these studies have focused largely on the results – i.e. the correlation between transmission rates and the humidity levels. While the data definitely proves that maintaining a Relative Humidity level between 40 and 60% is critical to healthy indoor environments, there is not yet a lot of scientific proof for *why* it happens. All we know for sure is that there *is* a link between humidity and infection, and that if we maintain it between 40 and 60% our building occupants are much safer.

Some of the suggested causes for the link between humidity and infection are as follows.

- Dry air can irritate nasal and throat passages, leading to increased coughing and sneezing by the infected person.
- Droplets expelled by coughing or sneezing remain larger when the air is more humid and fall to the ground more quickly. This means that the risk of inhalation by another person or transmission through centrally ducted ventilation systems is much reduced.
- Some viruses are much more active at low humidity levels and become ineffective – i.e. less dangerous – as the humidity is increased.

It has been studied and established that the size of airborne droplets has an exponential correlation with their “float time” – the length of time they remain airborne. The image below demonstrates this.

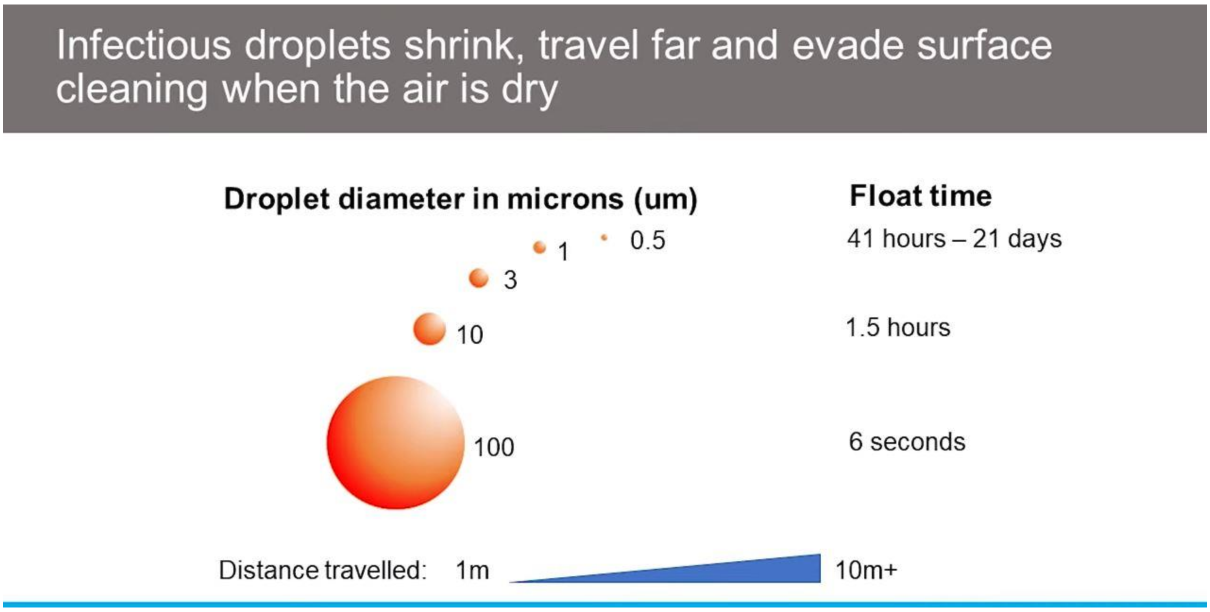

Image credit Dr Stephanie Taylor / ASHRAE Tech Hour

Irrespective of the reason *why*, there remains enough data to prove importance of ensuring that relative humidity is maintained between 40 – 60%. And while many buildings within New Zealand will naturally fall within this bracket when using their existing HVAC systems, increasing the air change rates as recommended above can have a significant impact on it. Outdoor air, depending on whereabouts you live, could be anywhere between 30 – 90%. It is important to measure the RH level and compensate with humidifiers or dehumidifiers if it falls outside the recommended “safe range”.

So how do we measure these indoor environmental conditions, and what can we do about it if our building is currently outside the safe range?

Measuring Air Changes Per Hour

In buildings with mechanical (fan forced) ventilation systems this is an easy calculation. Using an airflow capture hood, or “balometer” as the device is commonly known, measure the volume of air entering the building through the inlet grilles and the volume leaving through the exhaust grilles. Generally the total incoming air flow will be the same as the exhaust air flow, however depending on the configuration and settings of your ventilation system you may find there is some imbalance.

NB – it is important to actually measure the air flow rates, and not simply base your calculations on the stated performance of the fans. The pressure drop created by the air distributions system may be higher than the original system designers anticipated, and the fans may not be moving the volume of air that was intended.

Once you have the total volume of air that is entering and leaving your building, simply divide this number by the internal size of the building and the result will be the ACH level. A couple of worked example of this are below.

- Building A has a floor area of 200 square metres and a ceiling height of 2.7 metres, resulting in a total volume of 540 cubic metres. The mechanical ventilation system has been measured and found to be transferring a total of 810 cubic metres per hour (depending on your measuring equipment this could also be expressed as 225 litres per second).

ACH rate for Building A = 810 ÷ 540 = 1.5

- Building B has a floor area of 532 square metres and an average ceiling height of 2.5 metres, resulting in a total volume of 1330 cubic metres. The mechanical ventilation system has been measured and found to be transferring a total of 7182 cubic metres per hour.

ACH rate for Building B = 7182 ÷ 1330 = 5.4

If your building is totally naturally ventilated (through open windows or doors) or has a “mixed-mode” ventilation system where the mechanical fan-forced system is assisted by a degree of natural ventilation, then the measuring becomes much more complex. In order to accurately measure the air flow rates through such a building complex tests involving either heat tracking or tracer gas are required, however we recognise such procedures will be outside the capabilities of most building owners and facility managers.

One method of establishing a very rough estimate for natural air flow rate is to use the following formula:

Q = Cv * A * V

Where;

Q = air flow rate (m3/s)
Cv = effectiveness of the openings (assumed to be 0.5 for perpendicular winds and 0.25 for diagonal winds)
A = free area of inlet openings (m2)
V = wind velocity (m/s)

Two worked examples are as follows:

- Building A has a floor area of 250 square metres, a ceiling height of 2.4 metres, has four windows open in the façade that is directly facing the prevailing wind and an equal number in the leeward side. These windows are top-hung awning type windows 600mm high by 600mm wide and can open by 300mm, giving a total free area per window of 0.354 square metres. The average wind speed on the day is 5km/h (or 1.39 metres per second).

- **Cv (opening effectiveness)** = 0.5 (as the windows are perpendicular to the prevailing wind)
- **A (total free area)** = 1.416 (four windows each with 0.354m2 free area)
- **V (wind velocity)** = 1.39
- **Q** = 0.5 * 1.416 * 1.39 = 0.98 m3/second airflow (or 3528 m3/hour)

For Building A the approximate air change rate due to the open windows will be as follows:

ACH = 3528 ÷ 600 = 5.88

- Building B has a floor area of 175 square metres, a ceiling height of 2.4 metres, has two windows open in the façade that is facing at 45° to the prevailing wind and three windows open in the leeward side. These windows are top-hung awning type windows 500mm high by 500mm wide and can open by 150mm, giving a total free area per window of 0.1 square metres. The average wind speed on the day is 7.5km/h (or 2.08 metres per second).

- **Cv (opening effectiveness)** = 0.25 (as the windows are at an angle to the prevailing wind)
- **A (total free area)** = 0.2 m2 (using the lesser of the two window banks, two windows each with 0.1 m2 free area)
- **V (wind velocity)** = 2.08
- **Q** = 0.25 * 0.2 * 2.08 = 0.104 m3/second airflow (or 374 m3/hour)

For Building B the approximate air change rate due to the open windows will be as follows:

ACH = 374 ÷ 420 = 0.89

It can be easily seen that natural ventilation through opening windows is unreliable and unpredictable. The air change rates depend entire on the number and size of windows, the degree to which they can open, *whether they get opened or not*, the direction and speed of the wind and the ease at which the air can pass through the building. Mechanical ventilation, using suitably design fans and air distribution systems, is a much safer way to ensure sufficient ventilation.

NB – there are other factors which can have a small impact on the air change rates within a building, namely: tightness of the building envelope, the height of the building, temperature differentials and location of opening windows. For simplicities sake we have excluded these considerations from the above workings, as they will generally only affect the total ACH rate by approximately 0.5 – 1.

So you've measured your Air Change Rate, and found it lower than the recommended safe level for your building. What now?

If you are in a simple building (a house for example) and there are more windows that can be opened, then do this immediately. And while this approach will certainly help, it does have its limitations as have been previously discussed. There may be no wind for example, or you may have a limit to how many windows can be opened. Still – it will be better than doing nothing!

Installing a mechanical ventilation system (if your building does not have one) or upgrading the existing system if it does have one, is the next logical step. There are many ways that mechanical ventilation systems can be designed, and as every building is different there is no "one size fits all approach".

Ventüer can assist with the design and supply of bespoke ventilation systems – contact us now if you would like assistance with your building.

Measuring and maintaining Relative Humidity levels.

Relative Humidity levels can be easily measured through the use of a hygrometer. These are simple, cheap and easy to use. Many home weather stations also measure humidity levels for both indoor and outdoor air.

If the relative humidity of your building falls outside the safe range of 40 – 60%, there are numerous ways to adjust it. Depending on your situation and the design of your building, these can include;

- Ducted humidifiers or dehumidifiers (if the building has a centrally ducted ventilation system)
- Portable humidifying or dehumidifying units (for use in naturally ventilated homes and buildings)
- Your heat pump. Many buildings use split air-conditioning systems as simple and cost-effective means of heating and cooling. When in cooling mode, these units will extract humidity from the air via condensation.

Ventüer can provide advice specific to the unique conditions experienced by your building – contact us for further information.

Conclusion

Coming back to where we started: COVID-19 and other respiratory diseases pose a very real threat to the human race at the current time. Not all of us are able to provide healthcare assistance, or work on developing vaccines, however if we have the ability to influence the ventilation and relative humidity levels in our buildings then we have the ability to keep ourselves and the other occupants safe and preserve lives.