# CAN $CO_2$ MONITORING HELP KEEP US SAFE AGAINST COVID-19?

**Gas Sensing Solutions Ltd.** **Revision 1.0, 14 January 2022**

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## INTRODUCTION

The Covid-19 pandemic has highlighted a number of challenges related to the airborne transmission of viruses, particularly now that lockdown restrictions are easing, and we are gathering more indoors. Recently, there has been mounting evidence [1] the SARS-CoV-2 virus can be readily transmitted by aerosols exhaled by an infected person, with particles being detected in the air several hours later. *Figure 1* demonstrates the different mechanisms of airborne virus transmission by an infected person and how ventilation can be considered an important method of removing virus particles from an indoor environment.

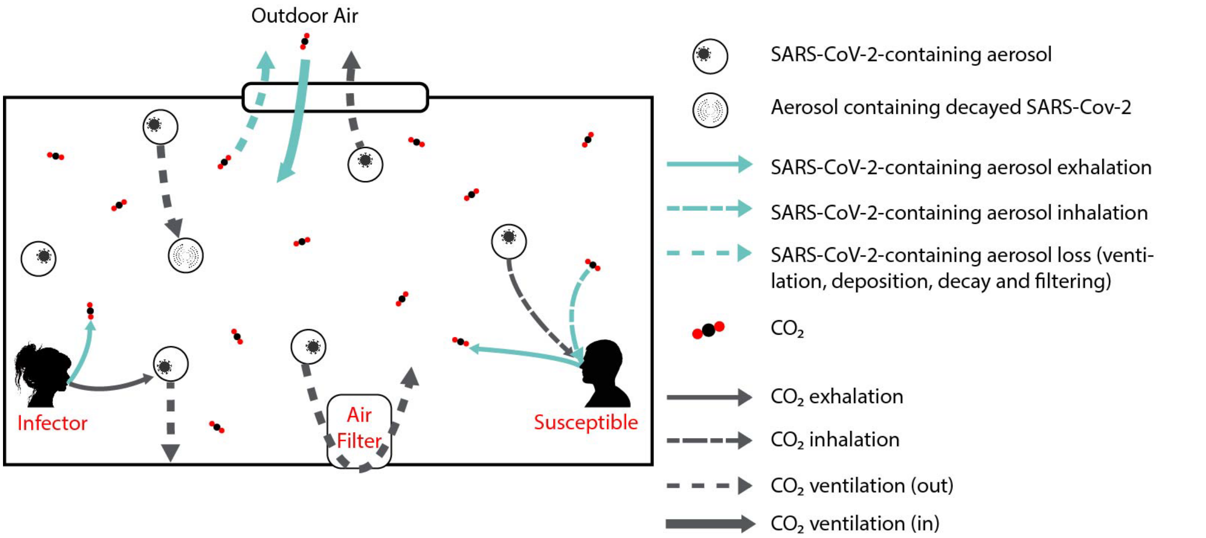


*Figure 1: Illustration of mechanisms for increasing and decreasing $CO_2$ levels and virus transmission in a ventilated indoor environment. The grey arrows denote movement of virus particles, and the blue arrows illustrate $CO_2$. The mechanisms for decreasing virus particles are by natural decay and removal by ventilation or filtration. [1]*

Indoor environments can easily be monitored, by using high-performance low-cost $CO_2$ sensors, such as the CozIR® range by GSS. Data from the sensors can be used to assess the quality of indoor air and help precipitate action to reduce Covid-19 transmission.

**MODELLING OF AIRBORNE VIRUS TRANSMISSION (COVID-19)**

Many modern descriptions of airborne virus transmission are based on the Wells-Riley equation, which in its early form was used to model the spread of measles in the 1970s [2]. The basic equation is given below.

$$P = 1 - e^{-n}$$

*P* is the probability of infection by susceptible person according to the quantity of virus doses that they inhale, defined by *n*. The assumption in adapting this expression for practical use is that the amount of $CO_2$ exhaled by an infected person and subsequently inhaled by a susceptible person is related to the amount of active virus that the susceptible person is exposed to. Based on this assumption, the amount of excess $CO_2$ introduced into a particular indoor environment by exhalation over a given period (in this case 1 hour) can therefore be used as a proxy to calculate the probability of infection. The equation below, derived by Peng and Jimenez, can be used to estimate the risk of transmission relative to the amount of excess $CO_2$ introduced into an indoor environment by exhalation by an infected person [1].

$$\Delta c^*_{CO_2} = \frac{0.0001/1h \times NE_{p,CO_2}}{(1-\eta_{im})(N-1)E_p(1-m_{ex})(1-m_{in})B} \times \frac{\frac{1}{\lambda_0} - \frac{1-e^{-\lambda_0 D}}{{\lambda_0}^2 D}}{\frac{1}{\lambda} - \frac{1-e^{-\lambda D}}{\lambda^2 D}}$$

The key terms are, $\Delta c^*_{CO_2}$ , which is the amount excess inhaled $CO_2$ required to increase infection probability by 0.01%, $\lambda_0$ is the ventilation rate, $E_{p,CO_2}$ is the inhaled excess $CO_2$, $D$ is the duration of exposure (1 hour), $B$ is the breathing rate of the susceptible person, $m_{in}$ and $m_{ex}$ are mask filtration efficiency for inhalation and exhalation, respectively, $\eta_{im}$ accounts for the immunity of the susceptible person, $\lambda$ includes all mechanisms of virus losses in the environment (including ventilation), $N$ is the number of occupants in the room.

This equation contains the relevant parameters to assess the proportional transmission risks of a given environment, including mask wearing and room occupancy. An example of the resulting data for different environments is presented below in *Figure 2*.


*Figure 2: Probability of infection per excess ppm of $CO_2$ for a duration of 1 hour in different indoor environmental conditions. A: University class with 10 occupants, B: Varying levels of physical activity, C: Varying occupancy and room volumes. [1]*

Looking firstly at part **A** of *Figure 2*, the probability of transmission is calculated for the same university lecture room under different conditions, the room size and occupancy are equivalent in each case. The first thing to note is the risk of transmission is higher if the instructor is infectious (default in all other cases), relative to if one of the students is infectious. This is due to the instructor projecting a greater number of virus particles (and therefore $CO_2$) into the environment by talking to the class, assuming that the students are generally silent. It is assumed both instructor and students are wearing standard face coverings unless otherwise stated.

Another aspect of the graph worth noting is the significant increase in transmission probability when wearing no mask, especially when compared to using a N95 respirator mask. In the case of the N95 mask, the inhalation filtration rate is over double that of the standard face covering, highlighting the superior protection for the wearer. Perhaps the most interesting aspect of the model is that doubling the duration of exposure (2hrs) and ventilation rate has a relatively small impact on the transmission probability. In this case, as long as there is sufficient ventilation to allow constant removal of the virus particles (and coincidently $CO_2$), increasing the ventilation rate is not worth the additional cost and effort. The data does show that additional virus removal (i.e., a HEPA filter) on the other hand does have a significant impact.

The data in section **B** summarises how the level of physical exertion and speaking volume impact transmission probability, increasing in both cases with a combination of high exertion and speaking volume being the highest transmission probability.

Section **C** presents transmission probabilities for different indoor environments. The case of the choir highlights that higher $CO_2$ exchange between occupants brought on by singing (i.e., increased rate of respiration) increases the relative transmission risk when compared with low exertion scenarios such as the subway or supermarket. The case of the stadium presents the most significant risk due the much greater occupancy level (>30 000 occupants), even when the much larger room volume is also considered.

Given the transmission risk is relative to the excess $CO_2$ level, it is clear that for situations where a large number of people are mixing and/or exertion levels are high, it is important to be able to monitor $CO_2$ levels to assess and reduce virus transmission risk.

### $CO_2$ MONITORING AND VENTILATION

From the analysis of the modelled data in *Figure 2*, it suggests that monitoring and controlling $CO_2$ can play an important and practical role in virus transmission control. Being able to demonstrate that $CO_2$ measurements can be used as a proxy for virus transmission probability, it suggests that active $CO_2$ monitoring for a number of different indoor environments may be useful as a means of controlling virus spread, especially during the Covid-19 pandemic.

### ASSESSING $CO_2$ LEVELS AND RELATIVE VIRUS TRANSMISSION RISK

The first step is to assess the $CO_2$ levels throughout a typical day, for instance a working day in an office building. The UK Government health and safety executive (HSE) recommends the use of NDIR based sensors, such as the CozIR® range from GSS. Their guidelines for $CO_2$ levels indoors are noted below [3].

- Outdoor fresh air is around 400ppm
- Indoors, a consistent $CO_2$ value of < 800ppm indicates good ventilation
- Indoor levels of 1500ppm $CO_2$ over the occupied period indicates poor ventilation and measures to reduce this level should be taken
- Indoors where there is continuous talking or singing, or elevated levels of physical activity, $CO_2$ levels should be maintained below 800ppm

The sensor should be positioned in the room to give a reading representative of ambient levels. This means positioning the sensor away from either $CO_2$ sources (e.g., people breathing or gas heaters) or other sources of ventilation (e.g., open window or ventilation unit) to get a true representation of the ambient air quality.

GSS $CO_2$ sensors use proprietary infrared LEDs for class leading low power consumption, which allows the monitors to be battery powered and therefore portable. Such a unit can be easily moved to assess multiple locations and scenarios. It is also important to consider that other environmental parameters such as barometric pressure and ambient temperature changes as well as how the room is being used affect how $CO_2$ levels vary, and care must be taken to isolate how each parameter effects the measured air quality.

The parameters that affect $CO_2$ levels have already been demonstrated in *Figure 2,* the most important of which are listed below.

- Number of room occupants
  - more people = increased $CO_2$
- Size of the room
  - $CO_2$ levels in smaller rooms will increase faster than in larger rooms
- Level of ventilation
  - Areas with poor ventilation will have increased $CO_2$ when occupied and will decrease more slowly when unoccupied
- Rate of exhalation
  - exertion and exercise increase $CO_2$ level

By choosing a low-power portable system, the level of $CO_2$ can be monitored to assess the risks throughout a typical day to decide on how to improve environment. Improvements will typically take the form of increased ventilation, either naturally or mechanically, but could also mean evaluating other parameters such as maximum room occupancy levels.

**NATURAL VENTILATION**

If a room is shown to have elevated levels of $CO_2$, the easiest solution in many cases is natural ventilation in the form of opening windows and doors. This is sometimes the only realistic solution, especially for many older buildings where more sophisticated solutions are difficult and expensive to integrate. The $CO_2$ monitor can be mounted somewhere reasonably central in the room, away from windows and heat sources, and an alarm can be set to notify the occupants of the optimal time to open and close windows. This is especially important in colder climates where there is a balance of ventilation and keeping the room comfortably warm, having a $CO_2$ monitor helps the occupants to achieve this.

## MECHANICAL VENTILATION

The next stage in ventilation is to have some means of moving the air around a room mechanically, either by recirculation, installed ventilation or demand driven ventilation.

## RECIRCULATION

This involves moving the air around a room, isolated from a fresh air source. This is typically a mechanical desk-top or tower fan with no connection to outside air. The result here is slight cooling of the air but no notable change to $CO_2$ levels and no real benefit in terms of virus transmission - it may even increase risk by increasing the mobility of the airborne particles. One aspect that can be considered is to install a medical grade filter into a recirculation system to remove airborne particles and therefore reduce transmission risk. This would be appropriate where access to outside air is not possible, although $CO_2$ monitoring becomes unreliable since the $CO_2$ levels are not likely to be easily maintained at the desired (400-800ppm) level.

## INSTALLED VENTILATION

The next step up in effectiveness (and complexity) is installed ventilation that replaces the indoor air with fresh air, typically by mechanical means (i.e., HVAC – Heating Ventilation & Air Conditioning). This allows the $CO_2$ levels to be monitored as a proxy for virus transmission risk since the flow of fresh air prevents the $CO_2$ levels from stagnating. The mechanical ventilation system can be set to run continuously, timed for periods of occupancy, or using feedback control (i.e., demand driven).

## DEMAND DRIVEN VENTILATION

This is the most sophisticated form of ventilation where sensor feedback (temperature, humidity, and $CO_2$) is used to control the flow of air in and out of the indoor space. In terms of virus transmission, the system can be set to maintain the $CO_2$ level within specified limits (e.g., 400-800ppm) to reduce the risk of transmission. This has the added bonus of being more energy efficient, by not running the ventilation when $CO_2$ levels are relatively low (i.e., close to 400ppm).

## CONCLUSION

It has been demonstrated that there is a tangible link between measured $CO_2$ levels indoors and the probable risk of airborne virus transmission. The data presented shows how certain environmental conditions (such as mask wearing, room size, occupancy level, level of physical exertion) can change the risk level relative to amount of $CO_2$. Using this information and accurate measurement of $CO_2$ by sensors such as CozIR®-family by GSS, it is possible to make informed decisions and allow individuals and organisations to assess and control ventilation, to ensure Government guidelines are followed, to improve indoor health and most importantly to reduce the risk of virus transmission.

**References**

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