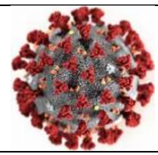
National COVID-19 Science Task Force (NCS-TF)



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On the use of CO2 sensors in schools and other indoor environments

Executive summary

While the role of aerosol-based transmission of SARS-CoV-2 is difficult to quantify, it is now well established that aerosols contribute to its transmission, particularly in indoor environments with poor ventilation, high occupancy, prolonged stays and/or high viral emission activities (see Policy Brief on Aerosols). CO2 sensors provide a simple, inexpensive approach to directly measure the air quality in an indoor environment and trigger appropriate action, such as opening windows or leaving a room. While there are certain limitations to using CO2 concentration as a proxy for aerosol concentration, the benefits of using CO2 sensors far outweigh these limitations, and their utility has been broadly recognized by technical committees, aerosol experts as well as national and international institutions. In particular, the ability to (i) measure air quality directly and continuously over time, and (ii) immediately take appropriate action can contribute to the safety of using indoor environments and to avoid more costly interventions. This document lays out the benefits and caveats for the use of CO2 sensors, and argues that CO2 sensors represent, particularly in schools, an underutilized, low-hanging fruit in the fight against the COVID19 pandemic.

Main text

The role of aerosols in transmission

Alongside droplets and fomites (i.e., surface-based transmission), aerosols are recognized as one of the vectors of transmission of SARS-CoV-2 (1,5). As described in our Policy Brief devoted to Aerosols from 29 October 2020 (5), it has remained challenging to quantify the role of each transmission mode, yet it is well established that aerosols can play an important role in transmission in settings where their dilution into the environment is poor (1,5). This includes indoor environments when one or more of these factors occur: poor ventilation, high occupancy, prolonged stays and/or high viral emission activities (5). These factors contribute to driving up the aerosol concentration in an indoor environment, such as a classroom.

The rationale for using CO2 sensors

Because aerosols cannot be seen by the naked eye, the threat of aerosol-based transmission is an invisible one. Therefore, measuring the concentration of aerosols in a room exhaled by humans would be desirable. This measurement is however very challenging and not scalable. Instead, direct, continuous measurements of the air quality in a room can be obtained in a simple and inexpensive manner through the use of CO2 sensors. The underlying idea is that the concentration of CO_2 in a room is a useful (if not perfect, see below) proxy for the concentration of aerosols exhaled by humans. In general, measurements of CO_2 indoors are easily conducted and often used as a proxy for air quality and form the basis of ventilation standards for buildings in many countries (6).

Each time we breathe out, the air that has been in our lungs differs chiefly from inhaled (and hence ambient) air by its lower concentration of oxygen and its higher concentrations of CO_2 and water vapour. Because CO_2 is less abundant than oxygen and (unlike humidity) of known, approximately constant proportion in ambient air, variations in CO_2 concentration are most easily detected and provide the most meaningful proxy of the proportion of ambient air that has recently transited through a respiratory system. In an outdoor environment, this higher CO_2 concentration gets rapidly diluted by air currents and turbulence. In an indoor environment, CO_2 can instead accumulate over time (4), to a level that depends on many factors, but primarily on how many people are in the room, for how long they occupy the room, what activity they are engaged in, and how well the room is ventilated. A CO_2 sensor measures the concentration of CO_2 in the room, expressed typically in parts per million (ppm). A high CO_2 concentration thus indicates poor air quality (1, 4) and the need to ventilate a room (3, 4). The measurement typically occurs continuously over time and requires no supervision.

A wide range of CO_2 sensors is available on the market. It is not the aim of this document to discuss the pros and cons of each, yet it is noted that NDIR (non-dispersive infrared) CO_2 sensors are recommended (1). Operationally, CO_2 sensors often have a threshold system: CO_2 values below the threshold indicate good air quality and CO_2 values above the threshold indicate poorer air quality, pointing to the need to take action to improve air quality in that room, for example by opening windows or otherwise enhancing ventilation, and/or temporarily leaving the room. In some CO_2 sensors, the threshold system is implemented as a traffic-like system: green for acceptable CO_2 concentrations, yellow for intermediate CO_2 concentrations, and red for high CO_2 concentrations.

<u>Which CO_2 threshold value to use</u>

The selection of a threshold value for the CO_2 concentration above which one considers the air quality to be poor is a compromise between feasibility (how often an intervention such as ventilating the room is needed) and safety (how low in potentially infectious aerosols the air is). Yet, most authoritative references converge on a value of the threshold CO_2 concentration in the range of 800 to 1200 ppm, sometimes up to 1400-1500 ppm, with lower values of 800 to 1000 ppm being recommended during a pandemic (1, 3, 4, 8, 9). Values of 2000 ppm or above are definitely too high (1).

<u>Breathing air that was in someone else's lungs</u>

To understand the meaning of these threshold values, it is useful to consider that (i) the natural concentration of CO_2 in fresh air is in the order of 400 ppm (1,7) and (ii) the concentration of CO_2 in the air we exhale is in the order of 40000 ppm (1,7). This means, for example, that in a room with a CO_2 concentration of 1000 ppm (and no other CO_2 sources than people), 400 ppm of the 1000 ppm are 'natural', while the remaining 600 ppm have been exhaled by the room occupants. Thus, in that room with 1000 ppm, 1.5% (600 ppm / 40000 ppm) of the air that everyone breathes has previously been in someone else's lungs. For a threshold of 800 ppm, that value drops to 1%. For a threshold of 1200, 1400 or 2000 ppm it increases to 2%, 2.5% and 4%, respectively.

<u>Limitations and caveats</u>

The use of CO_2 sensors as a means to limit aerosol-based transmission is based on the use of CO_2 as a proxy for the concentration of aerosols exhaled by humans. It is well known that this is not a perfect proxy (1). First, CO_2 measurements are not a reliable proxy of the risk to aerosol-based transmission per se (7), rather they can alert to the need for better ventilation in an indoor space, which helps prevent aerosol buildup. Second, in certain situations the concentration of CO2 is not a good indicator for the concentration of aerosols exhaled by humans. This happens primarily in three situations (1):

- When activities with high aerosol emission occur (e.g. singing, shouting, strenuous physical, activity): in this case, even when CO2 levels are acceptable, aerosol concentrations might be high. Thus, even when using CO2 sensors, high-emission activities should be avoided in confined indoor spaces.
- When the ventilation system is equipped with filtration systems capable of filtering out aerosols: in this case, aerosol concentration can be low even when CO2 levels are high (because the filters do not generally filter out the CO2). Thus, in spaces where air is filtered, a somewhat higher level of CO_2 could be accepted, although "generally not beyond 1000 ppm" (1).
- When other sources of CO2 are present in the room, such as combustion devices (which however in general should be anyway avoided).

A large fraction of indoor environments do not fall into any of the above three scenarios. In all those cases, monitoring CO2 as a proxy for aerosol concentration can be very beneficial.

Benefits of using CO2 sensors

The use of CO2 sensors as a tool to determine when ventilation in an indoor environment is insufficient, and action needs to be taken to ameliorate that, has several important benefits.

- **Simple and unobtrusive.** Off-the-shelf CO2 sensors are simple to install and operate. They are small and unobtrusive. They require neither extensive know-how for their deployment, nor much maintenance or care.
- **Direct assessment.** CO2 sensors provide a direct measurement of the actual CO2 concentration in a room at any given time. This measurement is thus more accurate and more situation-relevant than numerical models of air quality (e.g. SIMARIA), which are subject to certain assumptions and generalizations (e.g., real air flows are extremely difficult to capture accurately, as are thermal effects, etc.). Using models in support of and synergy with CO2 sensors could have merits.
- **Always on.** CO2 sensors measure continuously over time, without the need for any supervision. Other measures, such as outdoor teaching, achieve a similar result (minimizing aerosol-based transmission), but can only be deployed at selected times and not continuously.
- **Measurement triggers appropriate action.** CO2 sensors remove the uncertainty on whether a room is being properly ventilated, providing peace of mind to occupants and triggering simple actions when needed (e.g., ventilating the room, temporarily leaving the room, etc.), and only then.
- **Measurement identifies problematic cases.** CO2 sensors can identify situations where additional attention or intervention is needed (1), for example indoor environments that may be challenging to appropriately ventilate, so that action can be taken (e.g. installing ventilation, limiting occupancy, etc.).
- **Inexpensive.** While a wide range of CO2 sensors is available on the market, with different levels of sophistication, a ballpark cost of a reliable CO2 sensor is in the order of 100-200 CHF. This is minuscule compared to the cost of certain interventions (e.g. refurbishing a ventilation system, installing filters). Where cost becomes nonetheless prohibitive, a smaller number of CO2 sensors can be used and rotated among rooms (e.g. of a school), so that air quality in each room is monitored for a time sufficient to establish an effective ventilation routine, before the sensor is used in another room.
- **Benefits beyond the pandemic.** In environments like schools, monitoring CO2 has added benefits in avoiding increased CO2 levels, which are known to create tiredness in pupils and reduce learning abilities, and have been reported previously as rather prevalent among Swiss

classrooms. The benefit of CO2 sensors in schools will thus outlive the pandemic and provide a better learning environment in the long term.

Conclusions

In conclusion, CO2 sensors represent a simple, inexpensive and to-date vastly underutilized tool for potentially additionally contributing to the reduction of transmission of SARS-CoV-2, providing that the well established measures such as keeping distance, mask wearing and hand hygiene are adhered to. The use of CO2 sensors in schools, in particular, could contribute to maintaining schools open also in case of a worsening epidemiological situation. A desirable scenario would be for a school to equip each classroom, plus the common rooms (lunchroom, library, etc.), with a CO2 sensor. The training needed by school staff to respond to the warnings by the CO2 sensor is negligible. For pupils, this can represent a learning experience about the use of technology and a way to feel proactive about the pandemic. The visual feedback from CO2 sensors can also increase window opening, as found by a study conducted in classrooms (10). Additionally, the broad adoption of CO2 sensors in schools would further generate public awareness on the use of this simple and unobtrusive measure, and facilitate its broader utilization also in other settings (e.g. restaurants). Aerosol experts recommend that the use of CO2 sensors "becomes a standard measure of indoor air quality in all spaces where we breathe the same air as other humans" (1), which would allow a more rational opening of indoor spaces based on the quality of the air, rather than more arbitrary criteria such as occupancy (1).

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