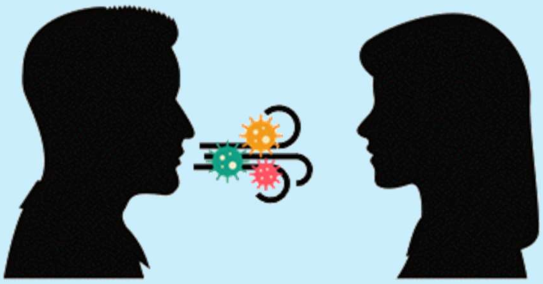
FLU, COVID-19, MEASLES, TUBERCULOSIS... DISEASES THAT TRANSMIT THROUGH THE AIR

UNDERSTANDING AIRBORNE TRANSMISSION



DRAFT

This document is the intermediary result of a scientific mediation project on airborne diseases. It is the fruit of the collegial work of a multi-disciplinary group including clinicians, virologists, pneumologists, pediatricians, epidemiologists, aerosol specialists, engineers, scientific mediators, etc. It can be seen as the demonstrator or prototype of a larger project, and has enabled, among other things, the development of a collaborative and iterative working methodology.

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Contact : info@letsair.org

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Infographic by letsair.org

EXAMPLES OF DISEASES FROM PATHOGENS

THAT CAN BE TRANSMITTED THROUGH THE AIR WE BREATHE

Viruses

- Adenovirus
- Bocavirus
- Varicella zoster virus
- Coronavirus
  MERS, SARS 1, SARS-CoV-2
- Influenza type A virus
  H1N1, H5N1, ...
- Influenza type B virus
- Morbillivirus
- Mumps virus
- Rhinovirus
- Rubivirus rubellae
- Respiratory Syncytial Virus
- Variola virus
- ...

Bacteria

- Bordetella pertussis
- Corynebacterium diphtheriae
- Legionella pneumophila
- Streptococcus pneumoniae
- Haemophilus influenzae type b
- Mycobacterium tuberculosis
- ...

Fungi

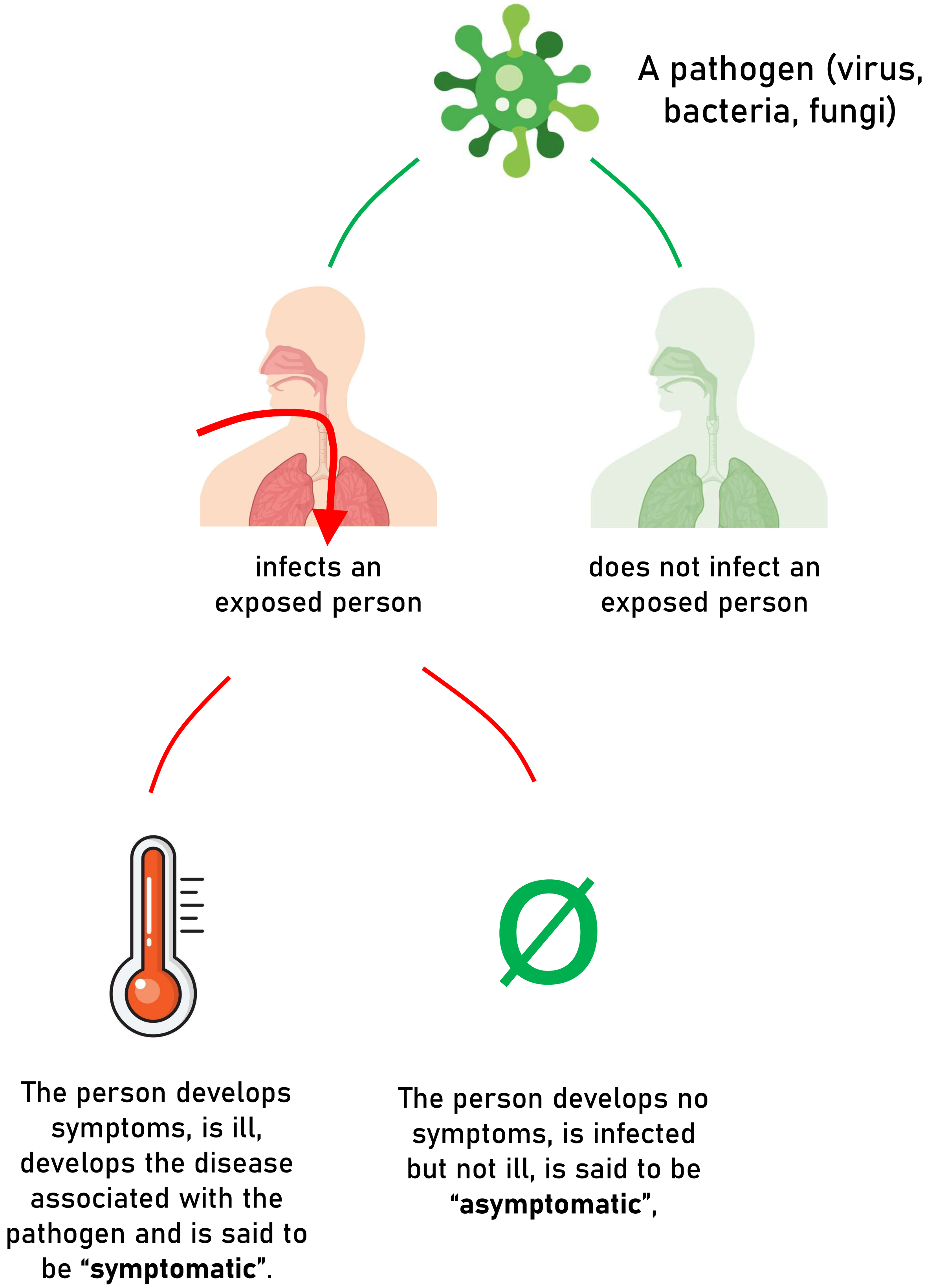
- ✓ Aspergillus
- ✓ Blastomyces dermatitidis
- ✓ Coccidioides immitis
- ✓ ...

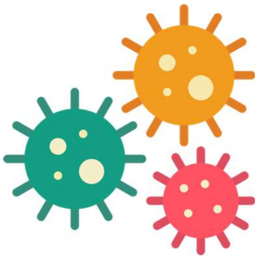
Associated Diseases

- Chickenpox
- Covid-19
- Influenza
- Measles
- Mumps
- Common cold
- Rubella
- Bronchiolitis
- Smallpox
- Whooping cough
- Diphteria
- Legionella
- Meningitis
- Tuberculosis
- Aspergillosis

= There is a vaccine
= There is a vaccine for some strains
= There is no vaccine

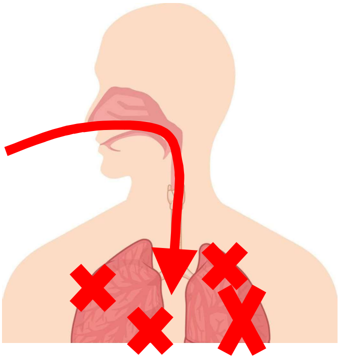
PATHOGENS, SYMPTOMS, DISEASES





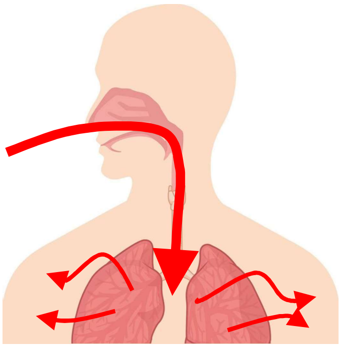
RESPIRATORY VIRUSES AND OTHER VIRUSES

"IN & STAY" RESPIRATORY VIRUS



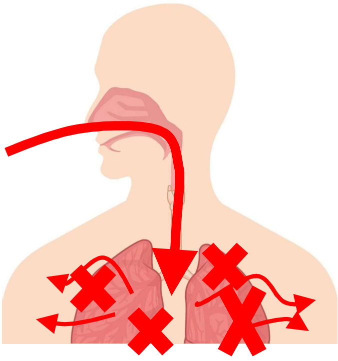
This is a virus whose entry point and target is the respiratory tract. This corresponds to viruses transmitted via the respiratory tract and essentially targeting the respiratory system: flu, parainfluenza, RSV, ...

"IN & RUN" RESPIRATORY VIRUS



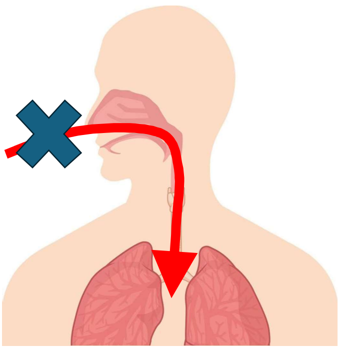
This a virus with a respiratory entry point but which do not primarily target the respiratory system: chickenpox, measles,...

"IN & SPREAD" RESPIRATORY VIRUS



This a virus with a respiratory entry point then spreads to several organs: COVID-19

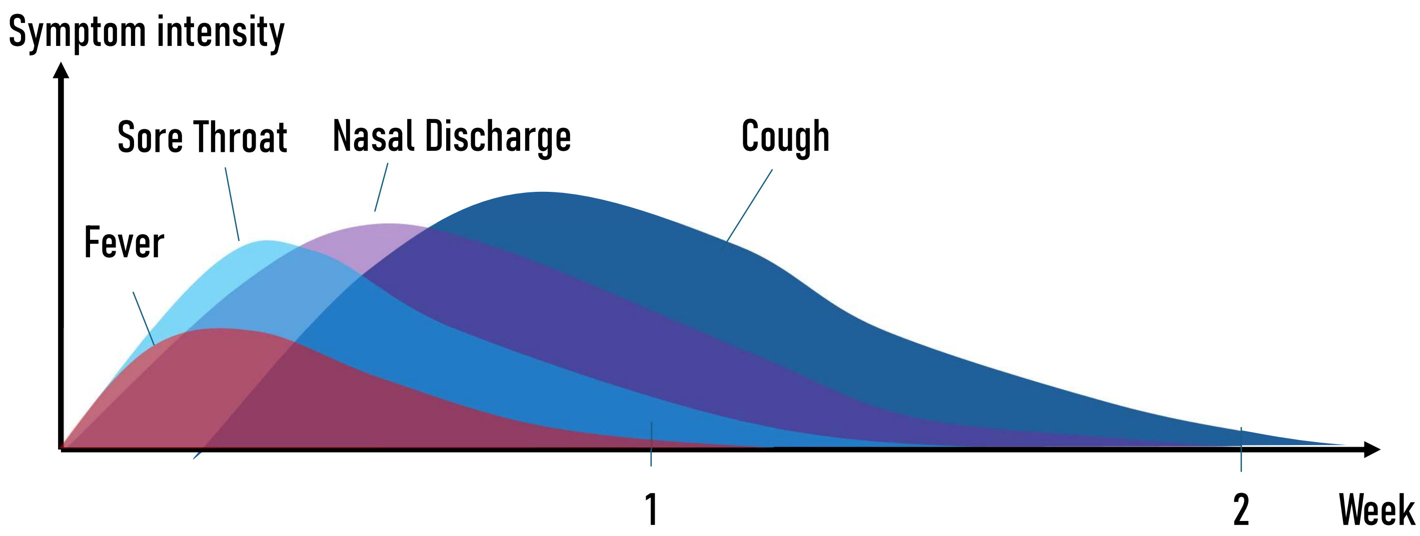
NON-RESPIRATORY VIRUS



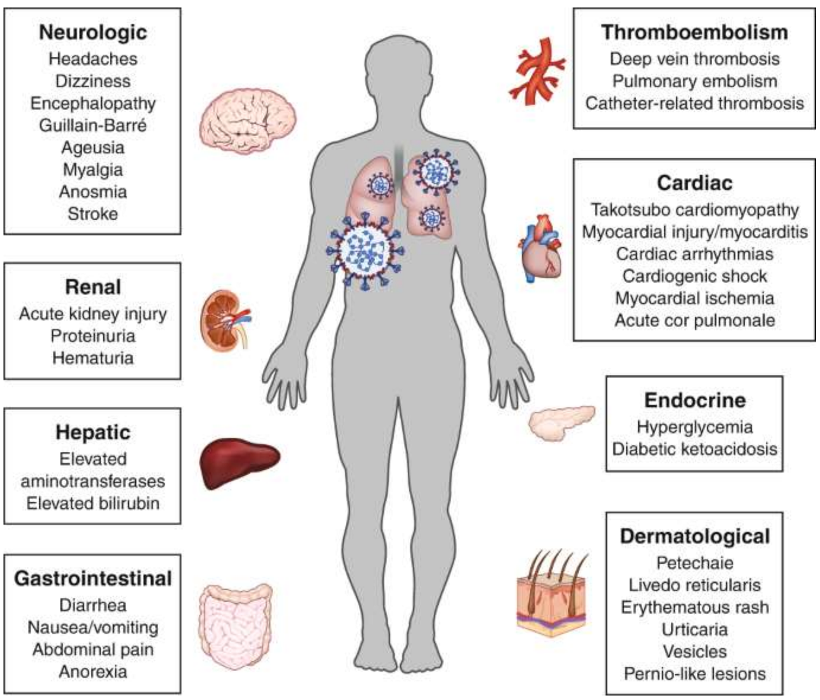
There are viruses that are clearly not respiratory and whose entry point and target are not respiratory: HIV, HBV, ...

NATURE AND EVOLUTION OF SYMPTOMS

When infected by a pathogen, several symptoms may appear at different times during the illness. The number and intensity of symptoms can vary from person to person. This graph below is for illustrative purposes only.

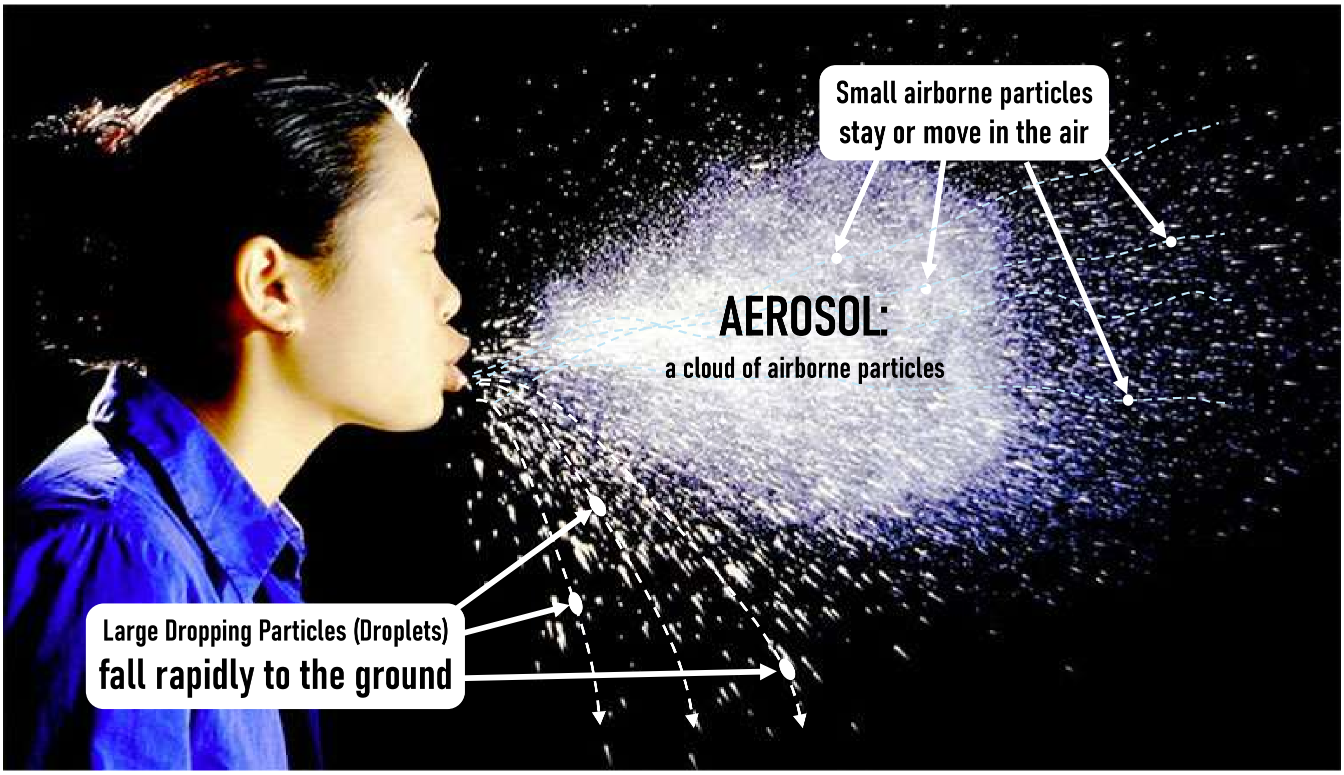


In the case of COVID-19, a wide range of organs can be affected.

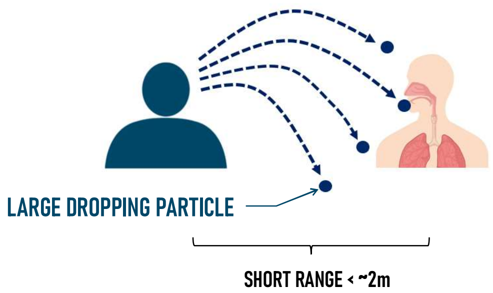


See reference [5]

HOW ARE AIRBORNE DISEASES TRANSMITTED?
THE ROLE OF INFECTIOUS RESPIRATORY PARTICLES

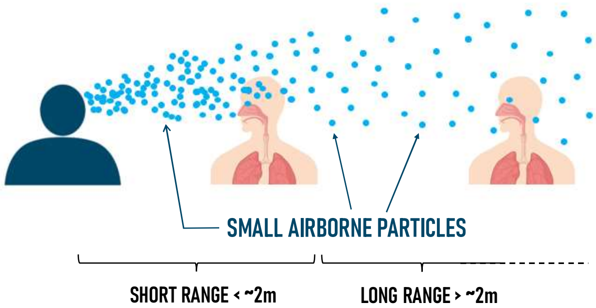


DEPOSITION OF PARTICLES
ON THE MUCOUS MEMBRANES OF THE MOUTH, NOSE, EYES



- transmission by semi-ballistic particles (also known as “droplets”)
- trajectories are governed by gravity
- fall quickly after travelling a few meters
- do not travel long distances

INHALATION & DEPOSITION
OF PARTICLES IN THE UPPER RESPIRATORY TRACT



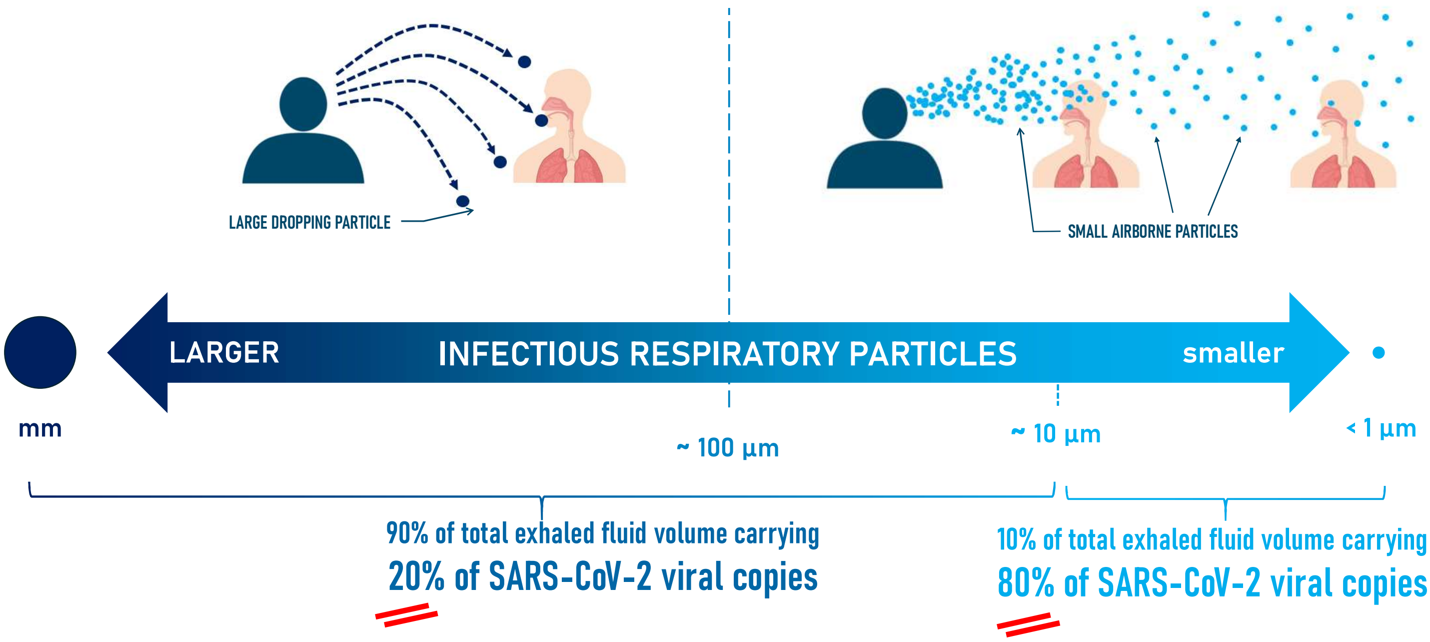
- transmission by airborne particles (also known as “aerosols”)
- trajectories are influenced by airflow
- suspended in the air, sometimes for hours
- can travel long distances

HOW ARE AIRBORNE DISEASES TRANSMITTED? THE ROLE OF INFECTIOUS RESPIRATORY PARTICLES

Infectious Respiratory Particles exist on a continuous spectrum of sizes (from sub-microns to millimeters in diameter) and their behavior and trajectories in the air depend on several parameters : ambient air temperature, velocity, humidity, sunlight (ultraviolet radiation), airflow distribution within a space...

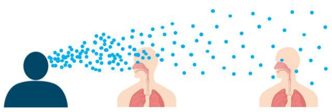
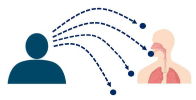
The two diagrams below are a simplified representation, showing the behavior of physical particles from the smallest (right) and largest (left) in size. The transition from one behavior to another is continuous, with hybrid and often complex overlap. The two routes correspond to « Inhalation » and « Direct deposition » modes of transmission, as defined by the WHO.

The limits of 10µm and 100µm and percentages are approximate and serve as an indication.

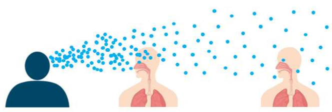
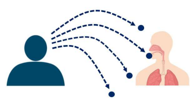


TERMINOLOGIES FOR DISEASES THAT TRANSMIT THROUGH THE AIR

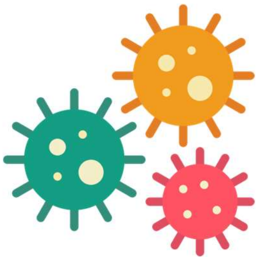
Numerous terminologies have been used in the past to describe the two routes of contamination: inhalation and direct deposition. These terminologies have evolved over time and vary according to the disciplines concerned (physics, health, etc.). Here are a few examples of terminology found in articles or reports:

Mode of contamination: Inhalation		Mode of contamination: Direct deposition
		
SHORT & LONG RANGES AIRBORNE PARTICLES		SHORT RANGE SEMI-BALLISTIC PARTICLES
AIRBORNE PARTICLES		BALLISTIC PARTICLES
World Health Organization	INFECTIOUS RESPIRATORY PARTICLES	
AEROSOLS	DROPOSOLS	DROPLETS
AEROSOL PARTICLES		LARGER DROPLETS
BIOAEROSOLS / VIROSOLS		DROPLETS
AIRBORNE DROPLETS		BALLISTIC DROPLETS
AIRBORNE DROPLET NUCLEI		DROPLETS

To make it easier for non-specialists to discover the subject, we recommend using the following terms:

	
SMALL AIRBORNE PARTICLES	LARGE DROPPING PARTICLES

9

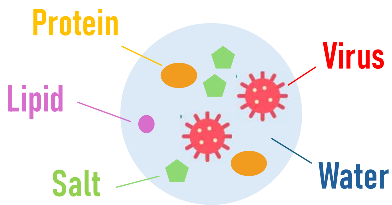


WHAT IS AN AEROSOL ?

Aerosol refers to the suspension, in a gaseous medium (air, in most cases), of liquid or solid particles, or both, with negligible limit falling velocity. In air, under normal conditions, this corresponds to particles between a few fractions of a nanometer and 100µm in size. The aerosol is therefore a two-phase system formed by particles and the carrier gas. Nevertheless, the term aerosol is often used in practice to refer only to particles in the air.

in "Les aérosols physique et métrologie", Boulaud, D. and A. Renoux, Paris, Tec Doc Lavoisier(1998)

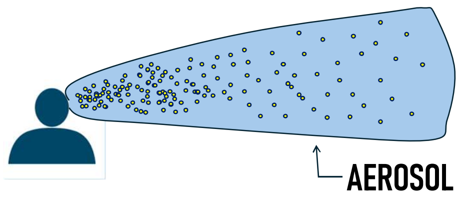
Bioaerosols (short for biological aerosols) are aerosols whose airborne particles contain living microorganisms (viruses, bacteria, molds and protozoa) and substances or by-products derived from these organisms. In the case of a virus, the composition of an airborne infectious particle will be as follows:



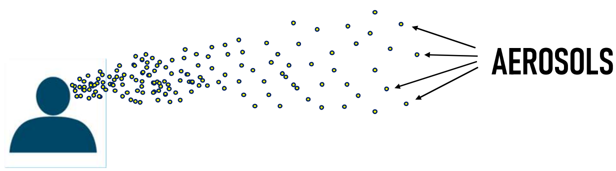
Components of an airborne infectious particle

In scientific literature, aerosol (or bioaerosol) describes a group of particles or cloud, but also designates each particle or "aerosol (bioaerosol) particle"; this can lead to confusion and inaccuracy :

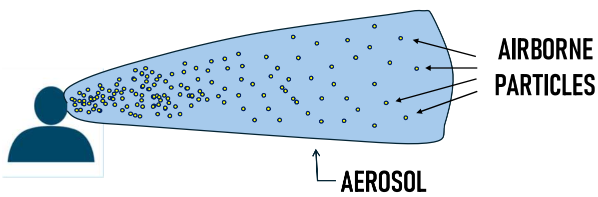
AEROSOL SEEN AS A CLOUD OF PARTICLES



AEROSOLS SEEN AS AIRBORNE PARTICLES



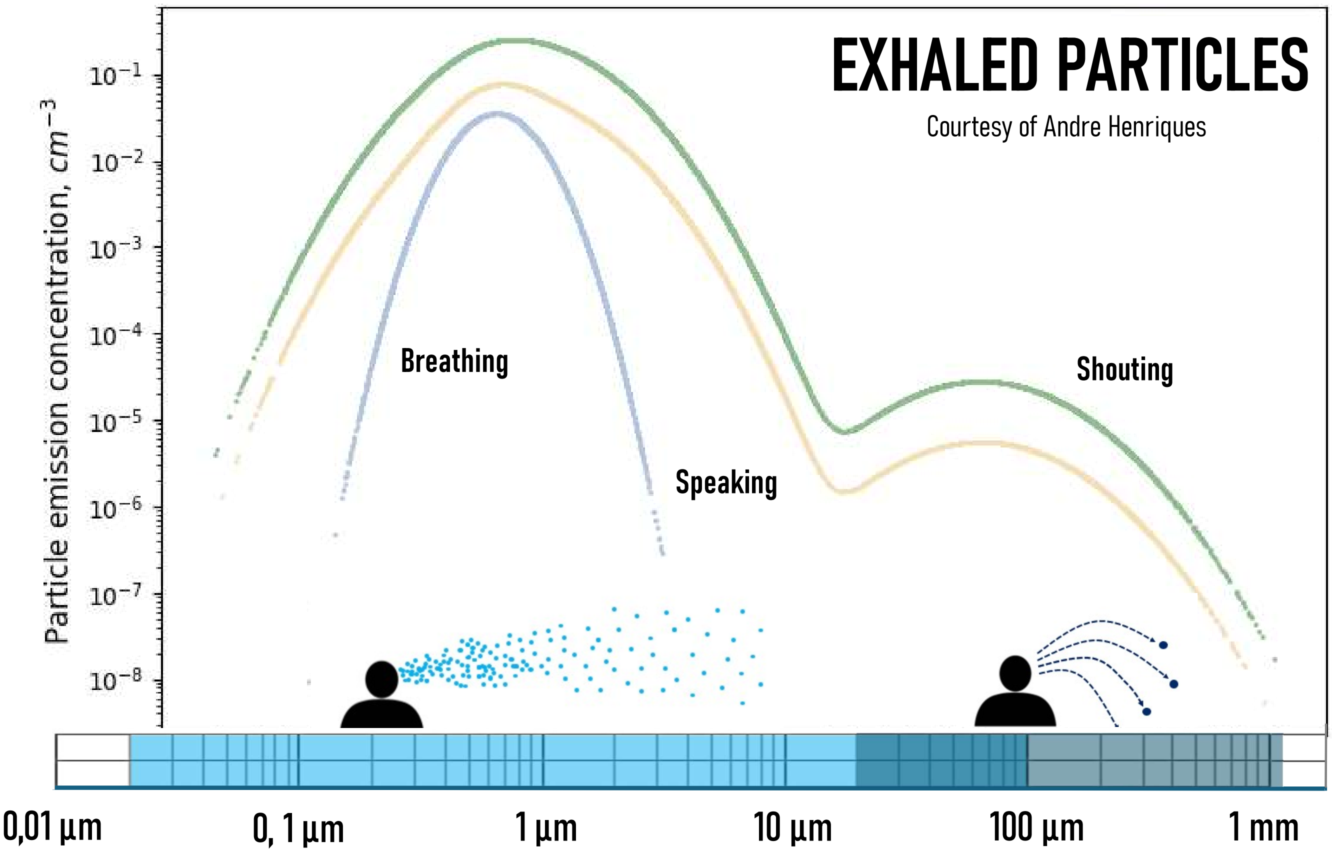
Our recommendation: it is preferable to use the term 'aerosol' ('bioaerosol') to designate the cloud of particles suspended in the air, and to refer to the constituents of this aerosol (bioaerosol) cloud as "Particles". We can then specify that these are "airborne particles".



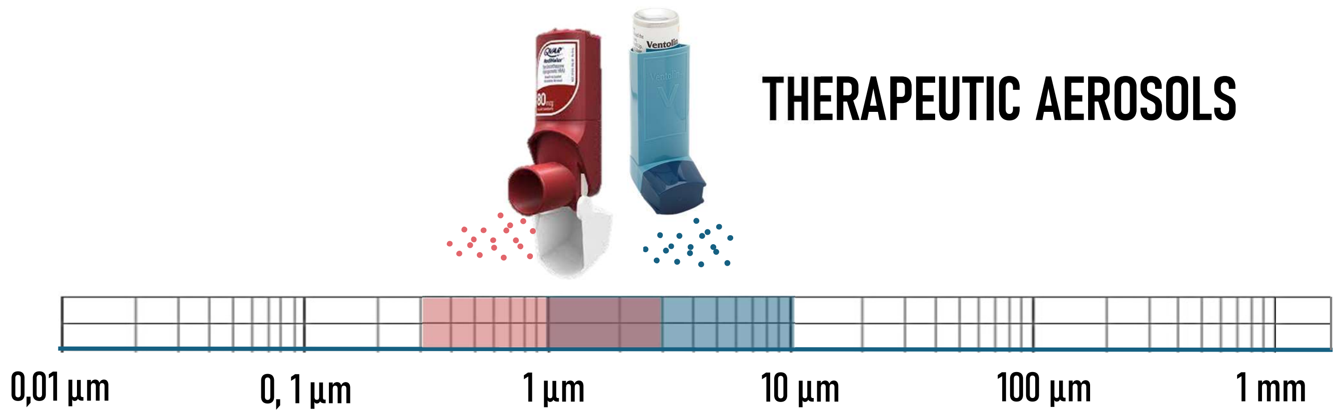
An aerosol is made up of airborne particles.

EXHALED PARTICLE SIZE

The number of particles exhaled by a human depends on the size considered. These particles are generated in different parts of our anatomy, which explains the variations in size. Their distribution and number depend on the activity performed: breathing, speaking, shouting.

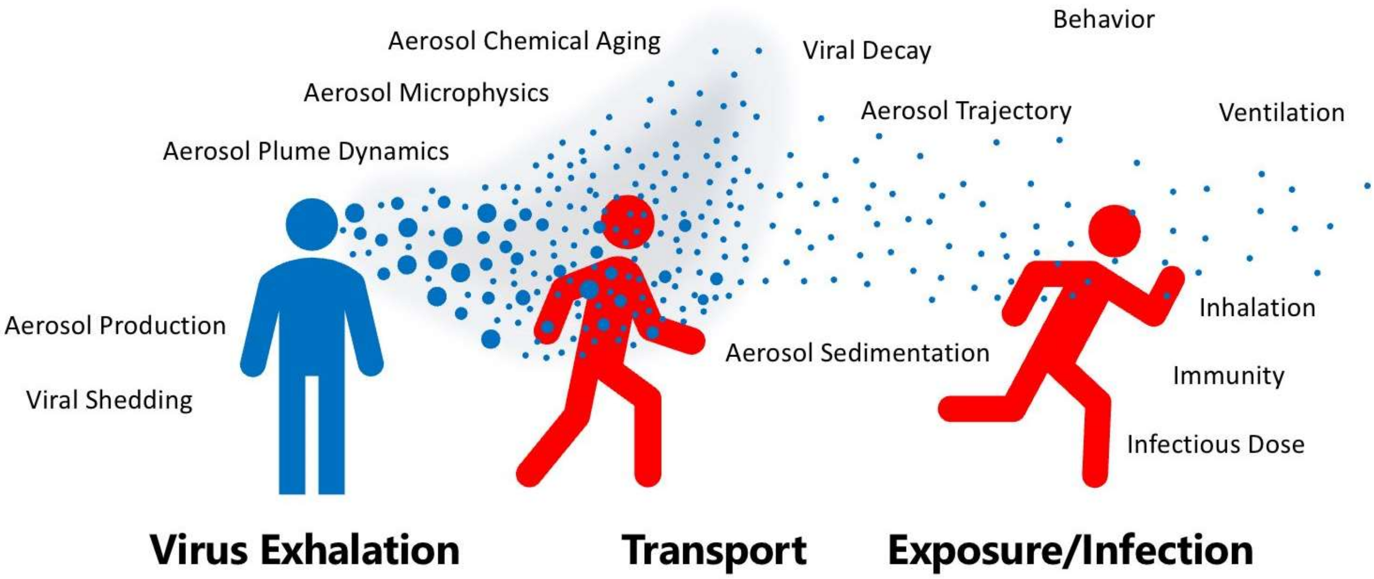


Airborne infectious particles are well suited to being inhaled into our lungs. Some of these particles are the same size as those making up the therapeutic aerosols generated by inhalers, designed to target certain parts of the lungs.



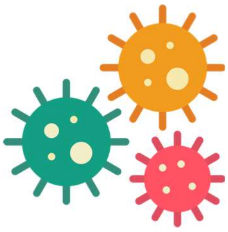
KEY PHENOMENA TO CONSIDER
IN THE STUDY OF AIRBORNE TRANSMISSION

Airborne disease transmission is an extremely complex process, involving fundamentally different scientific fields. A comprehensive understanding of the transmission phenomenon and its influencing factors requires expertise from many disciplines, as shown in the figure below [Courtesy of Al Haddrell]



The corresponding field of research is therefore highly multidisciplinary, drawing on numerous disciplinary expertise. Establishing a methodological framework that promotes collaboration between all these disciplines is one of the major challenges for teams working in this field. Several initiatives have emerged in recent years that move in this direction

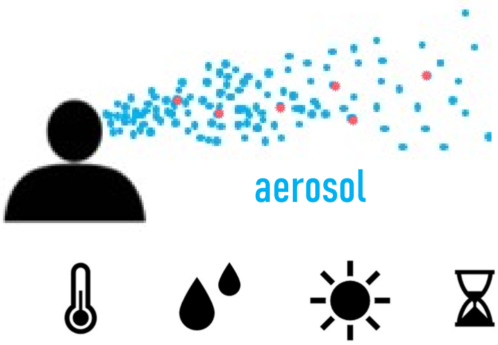
It is also worth noting the importance of engineering, which could provide concepts, tools, and methodologies from systems engineering to address these challenges of multi-disciplinary collaboration and integration. A "systems" view of Airborne Disease Transmission seems to us an interesting avenue to follow.



INFECTIONS & RISKS

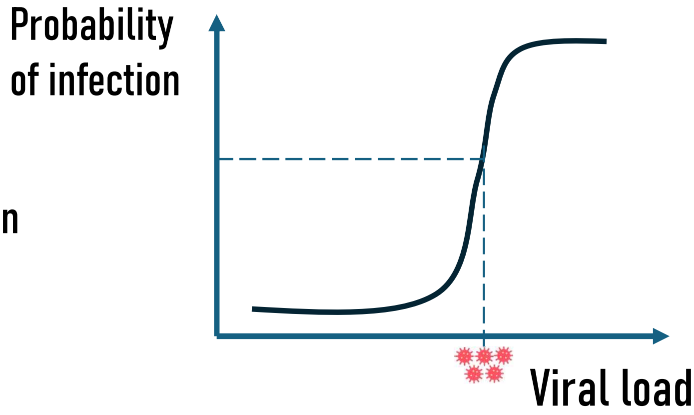
VIRAL LOADS

- Carried by airborne infectious particles.
- A virus may be more present in small particles.
- Load depends on particle size, time, temperature, humidity, UV exposure, …



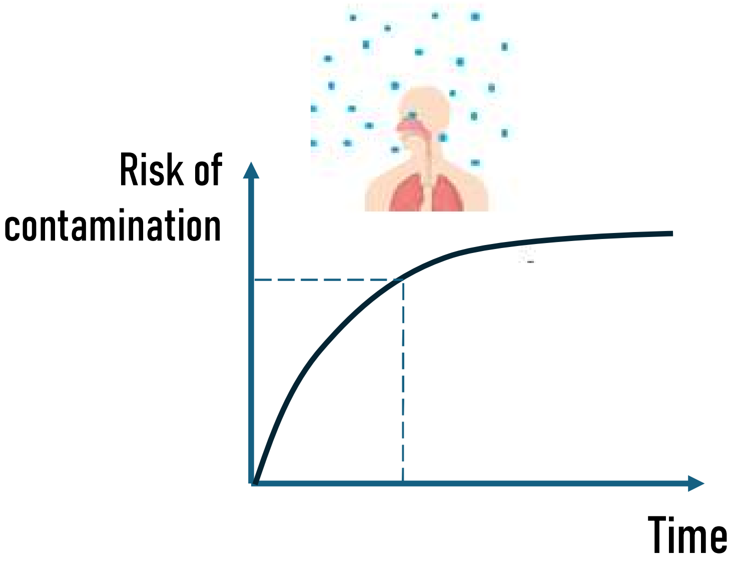
INFECTIOUS DOSE

- Depends on virus type/variant,
- Depends on receptor type and localization
- For a given viral load, we rather define a probability of infection



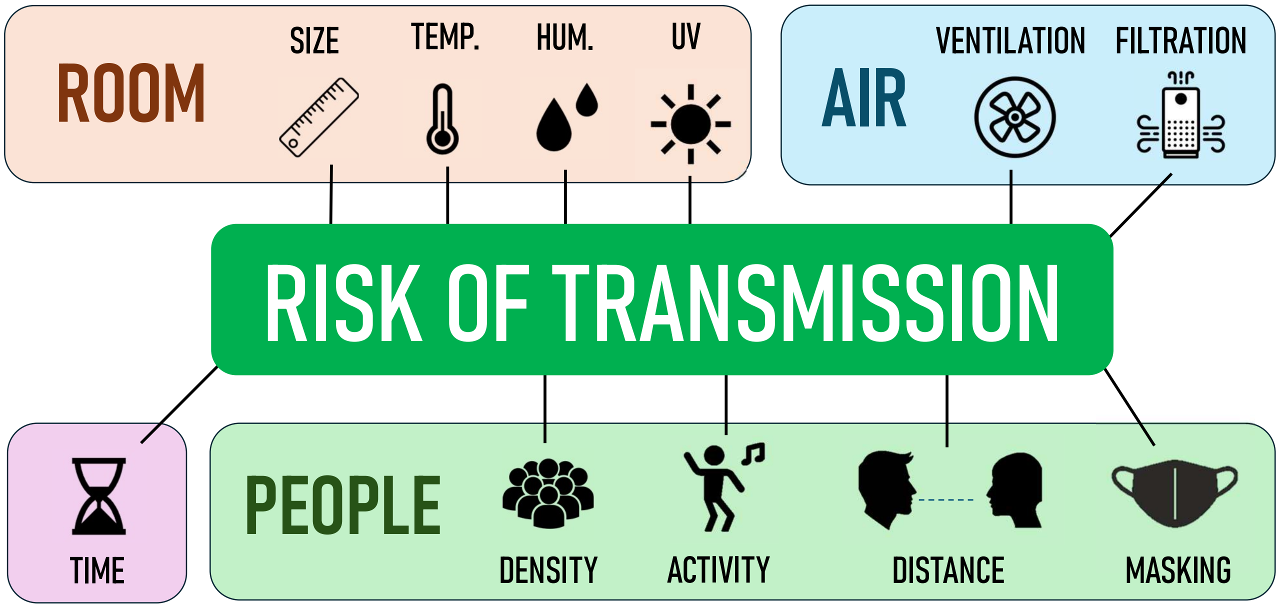
RISK ASSESSMENT

- Depends on the person
- Depends on exposure conditions
- Depends on exposure time
- …

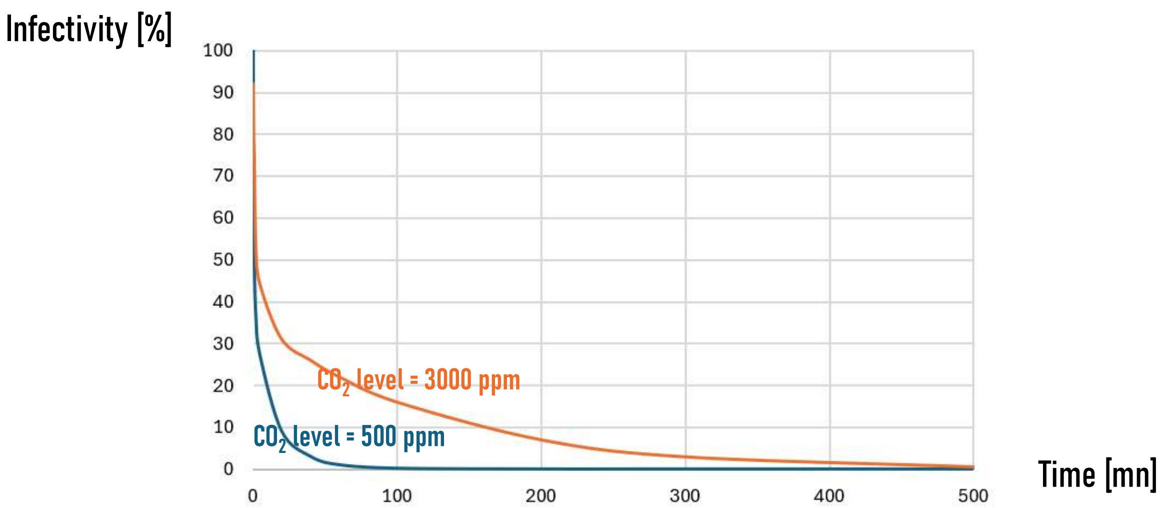


PARAMETERS INFLUENCING THE RISK OF TRANSMISSION

For a given pathogen, the risk of interpersonal transmission therefore depends on a very large number of factors:

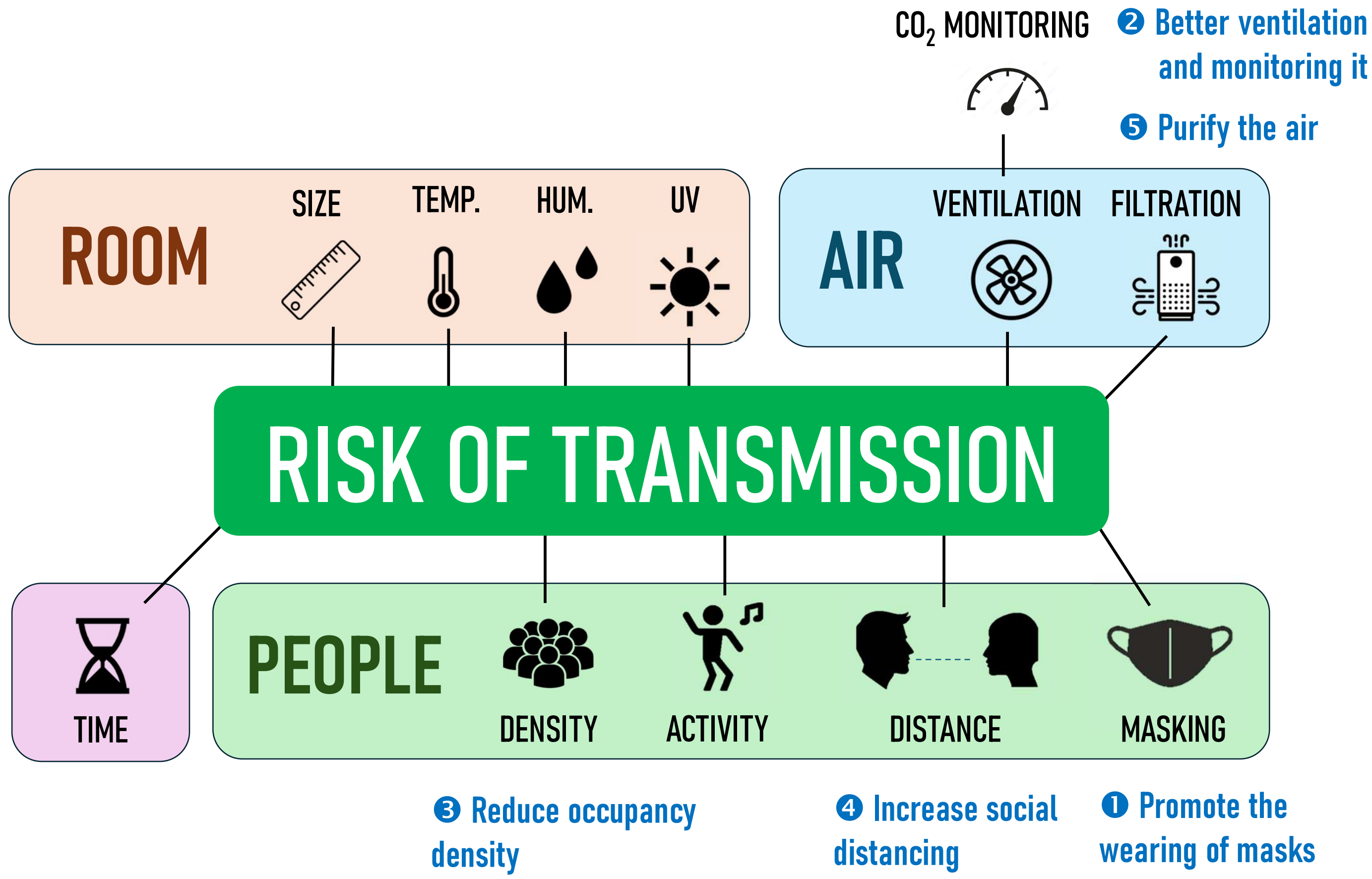


These factors are the subject of research, and many studies published in recent years have allowed us to study the influence of certain parameters. Much research, very multidisciplinary, remains to be carried out to progress in our understanding and many elements remain to be consolidated. Among this research work, we can cite an article[1] published in 2024 studying the influence of time and CO_2 levels on the infectivity of SARS-CoV-2 in an airborne particle (the graph is a free adaptation of the data from the article):



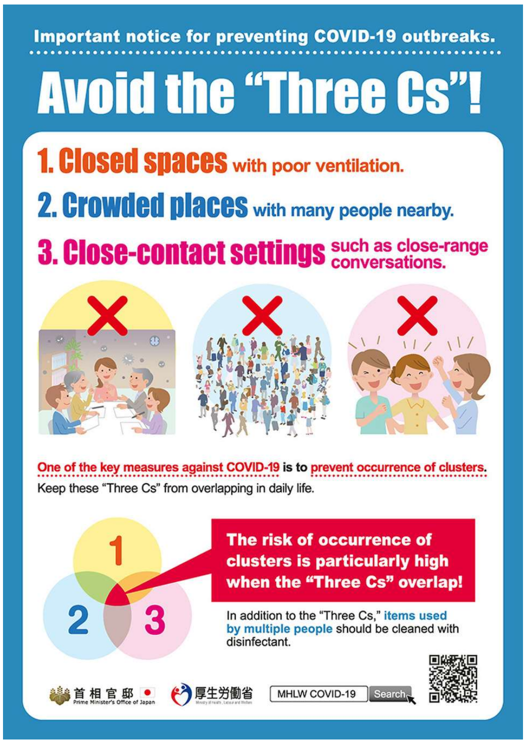
WAYS TO MITIGATE THE RISKS OF AIRBORNE DISEASES

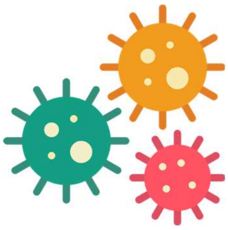
To mitigate transmission of airborne diseases, several means are available:



In some countries, airborne transmission of pathogens is well understood and integrated into individual and collective social practices. Several measures can then be mobilized and recommended simultaneously, depending on the context and the intensity of the risk. This is what the Japanese government did in 2020 with the "Three Cs," see opposite.

In many countries, progress remains to be made in this area.



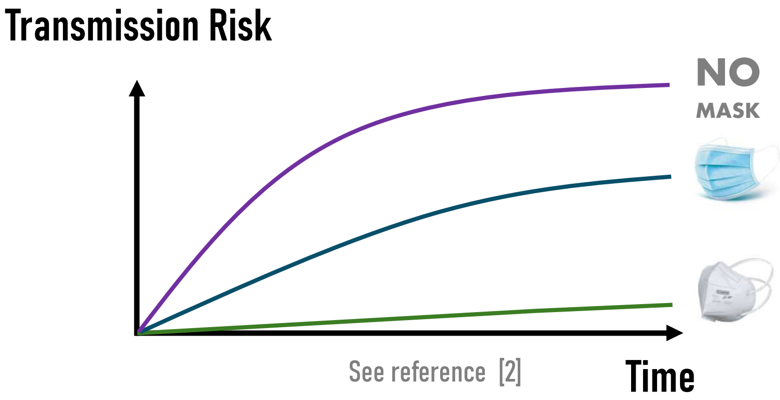


QUANTIFY THE RISK REDUCTION BASED ON MITIGATION MEANS

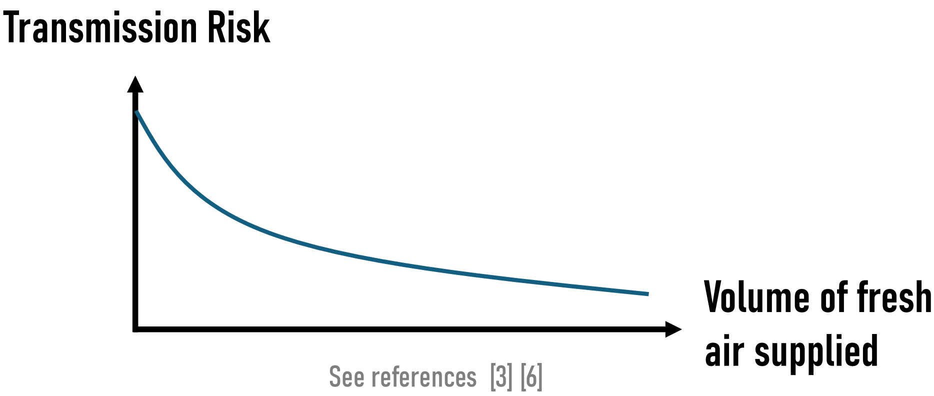
For a given situation, the 3 main ways to reduce the risk of airborne contamination are masking, ventilation and filtration. Quantifying the risk for each of these means is still the subject of much research, modeling and studies.

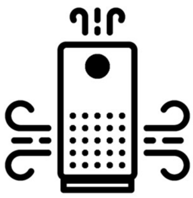
Below you will find trends from recent research findings. The figures are adapted from research data and freely represented to illustrate observed trends.

MASKING

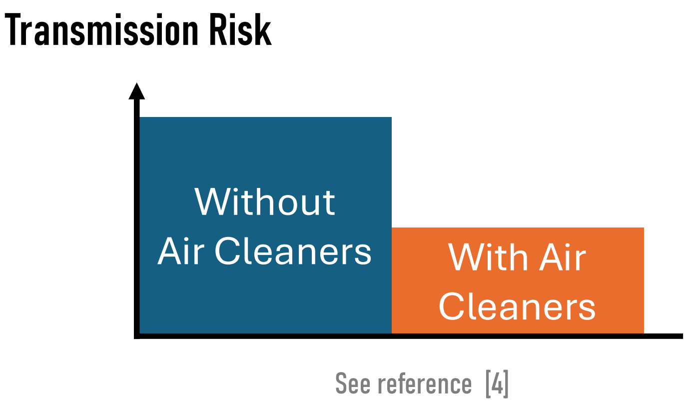


VENTILATION





FILTRATION



QUANTIFICATION OF INDOOR AIR RENEWAL

To measure or to specify the quality of air renewal in a room, and therefore assess the risk of airborne transmission, three metrics can be used: CO_2 level, Air Change per Hour, or Airflow per Person.

CO_2 LEVEL

Measuring the CO_2 level in a room is a simple way of determining the level of containment. The higher the CO_2 level, the greater the containment. The value that is usually recommended not to exceed is 800ppm. (Parts Per Million is the usual unit). Reliable, inexpensive detectors are now available, and anyone can use them to check that the air is properly renewed.

AIR CHANGE PER HOUR

To ensure good air renewal in a room, you can specify the number of times the air in the room is renewed each hour. This number is known as ACH (Air Change per Hour). A widely recommended value for most general-purpose premises is 6: the air is renewed 6 times an hour. The room's ventilation system enables this renewal to take place.

AIRFLOW PER PERSON

To take account of the actual use of a room, you can specify the volume of fresh air to be supplied for each person in the room. In this case, we specify a volume per hour and per person (m3/h/p or CFM per person or liters/s/person). The higher the value, the better the air renewal. For example, 30 m3/h/p or 8 l/s/p or 18 CFM/p can be a good value for a classroom.

CLASSROOM EXAMPLE

Surface = 60 m^2 / 646 ft^2

Ceiling heigh = 2.5 m / 82 ft

Number of children = 30

MAXIMUM CO_2 LEVEL = 800ppm
You can simply measure it with a CO_2 monitor and adapt the ventilation to the measurement.

AIR CHANGE PER HOUR = 6
The ventilation must be able to provide 60 * 2.5 * 6 = 900 m3/h or 530 CFM.

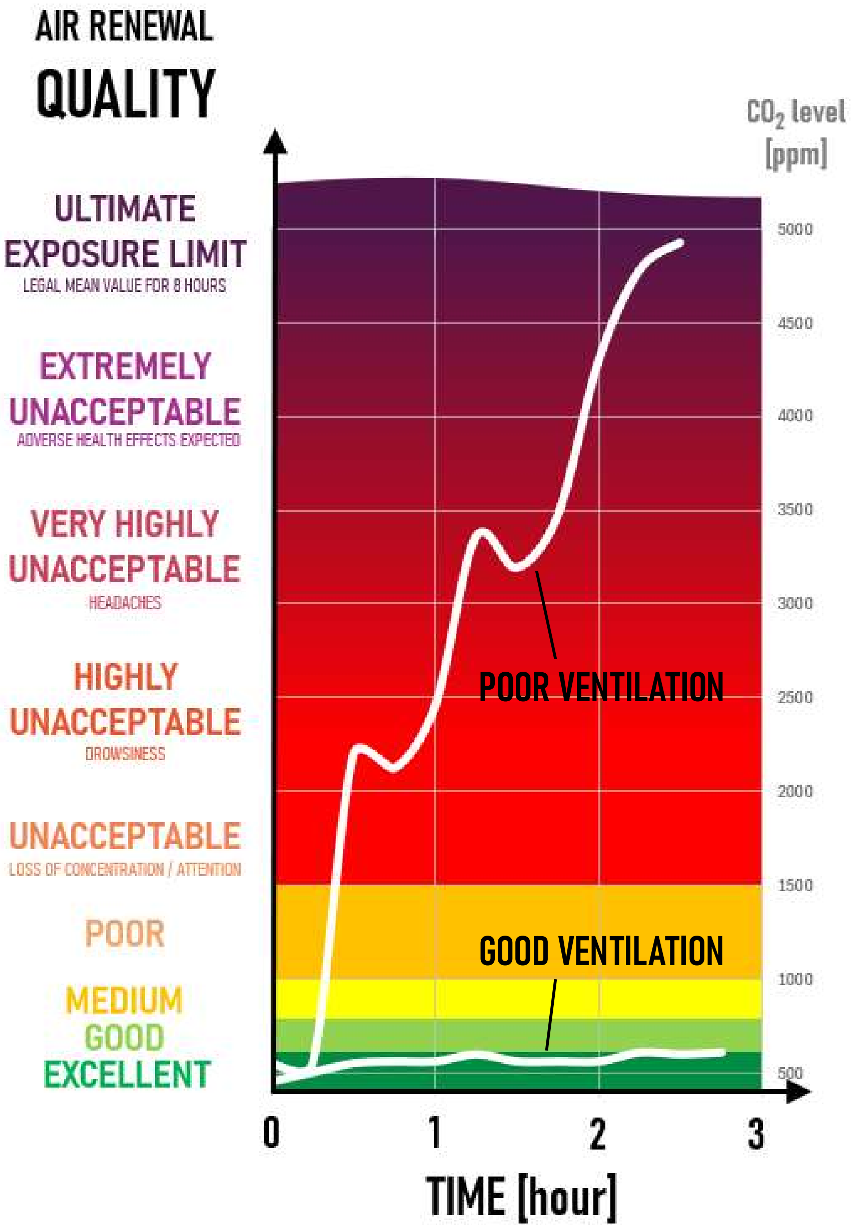
AIRFLOW PER PERSON = 30 m3/h/p or 18 CFM/p
The ventilation must be able to provide 30 * 30 = 900 m3/h or 530 CFM.

MEASURING CO_2 LEVEL
TO ASSESS TRANSMISSION RISK

In an occupied room, the CO_2 level is higher when ventilation is poor. By measuring the CO_2 level, we can therefore assess whether the air renewal in a room is excellent, good, poor, insufficient or unacceptable.

Today, the maximum recommended CO_2 level is 800 ppm (parts per million). If we take the example of schools, in many countries the majority of classrooms are not or poorly ventilated and the level of 800 ppm is unfortunately exceeded after only a few minutes. The risk of airborne disease transmission is therefore significant.

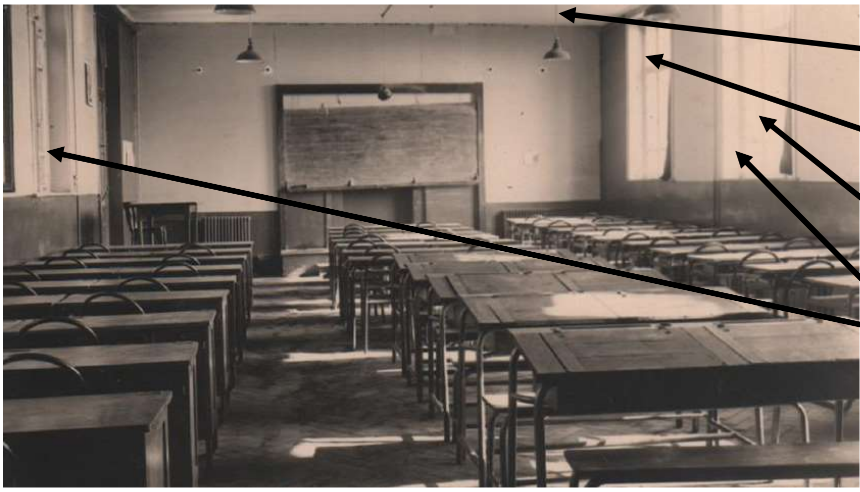
Below are two real-life measurements in a very well-ventilated classroom and a very poorly ventilated classroom.



HISTORY OF INDOOR AIR RENEWAL
FOR THE PREVENTION OF AIRBORNE DISEASES

The importance of good indoor air renewal for the prevention of diseases that transmit through the air has been well known for centuries. And the measurement of CO_2 to assess the quality of air renewal has been known and used since the 19th century. For example, these elements were fully integrated into a course at MIT in 1888 (Heating and Ventilation by S. H. Woodbridge).

In the 19th century, recommendations have been given for designing and constructing buildings that allow for excellent natural or forced ventilation. This is particularly the case for hospitals and schools. Their architecture owes much to these rules, as in the examples below.



High ceilings to increase room volume

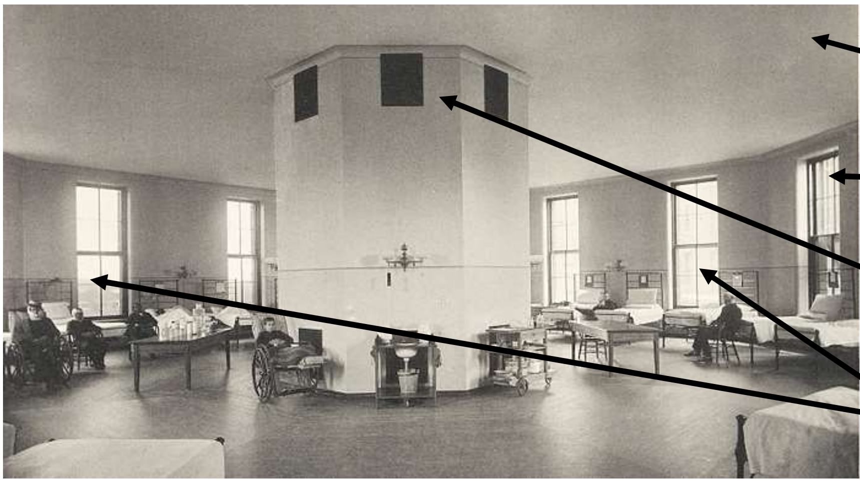
High window for continuous ventilation

Large window opens wide for better ventilation

Opposing openings for through-air flow

All windows face directly outside (rather than into a corridor, for example) to improve ventilation.

Practical School of Agriculture (Wagnonville) - 1896



High ceilings to increase room volume

Large window opens wide for better ventilation

Largely dimensioned natural ventilation system

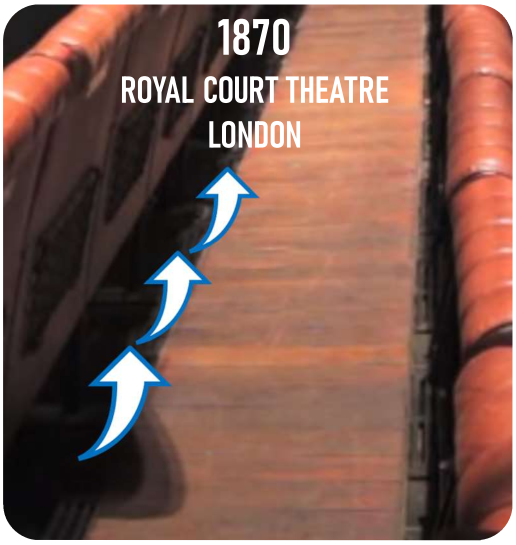
Windows distributed all around the ward to allow through-air flows

Octagon Ward of the John Hopkins Hospital (Baltimore) - 1880

The importance of good indoor air renewal, one of the means of prevention at that time, was gradually lost, particularly with the arrival of vaccines against airborne diseases in the 20th century : tuberculosis, measles, … COVID-19 reminded us of this.

EFFICIENT VENTILATION
IN THEATERS

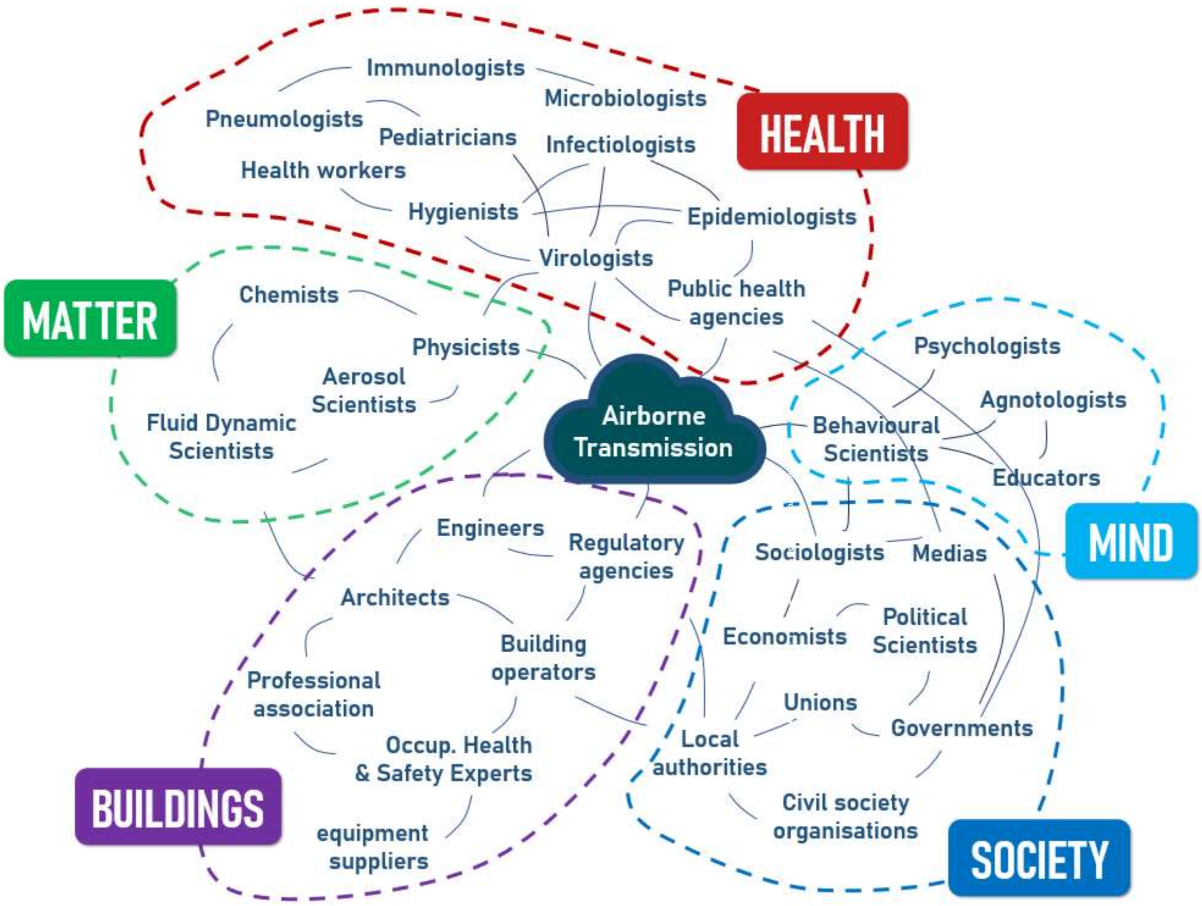
Since the importance of good indoor air renewal has long been recognized, high-density venues have received particular attention in this area. For example, theaters, which, as early as the 19th century, introduced innovative ventilation systems closer to the audience.



This principle is still used today, for example in the Rousseau Theatre at the CentraleSupélec engineering school. It achieves excellent indoor air renewal and great comfort.

PREVENTION STAKEHOLDERS

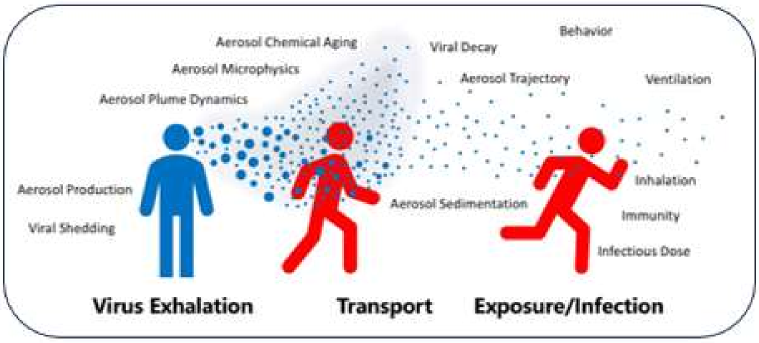
The means of limiting airborne contamination are well known, and in some cases have been for over a century: masks, ventilation of premises, air filtration. The difficulty in implementing these measures, particularly in buildings open to the public, is the large number of stakeholders involved. Below, we have attempted to model the main stakeholders involved in airborne contamination.



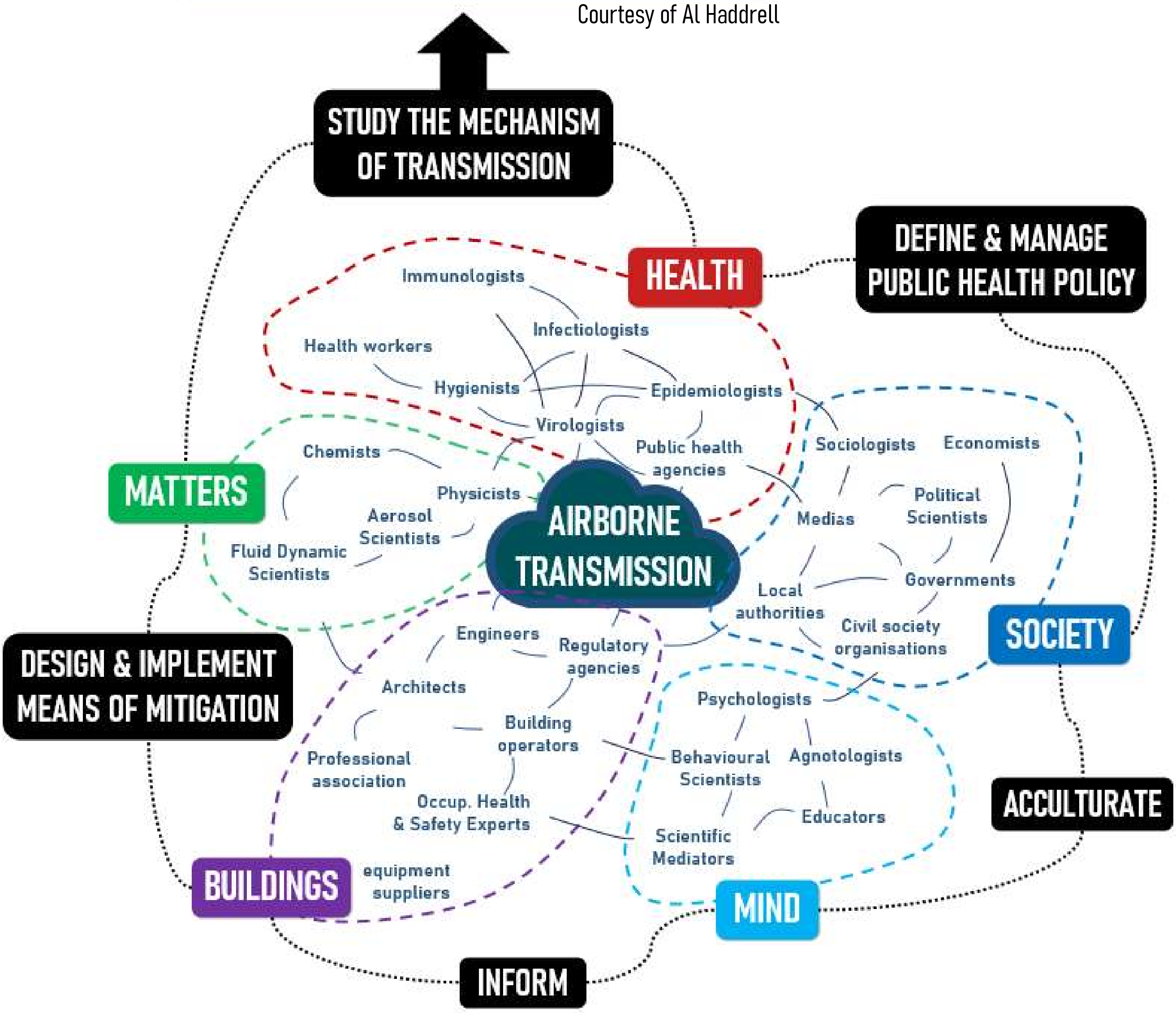
One of the key questions in risk management is: where is an investment most effective at reducing risk and do we have any means of intervening there? This is a massively interdisciplinary question that is still widely debated. Answering this question is critical to guiding public health policies on this topic.

TOWARDS A SYSTEMIC VIEW OF AIRBORNE TRANSMISSION

The study and prevention of airborne diseases is undoubtedly a system of great complexity with a very large number of stakeholders and interactions. A systemic approach seems to us to be definitively essential to frame and structure any action in this area.

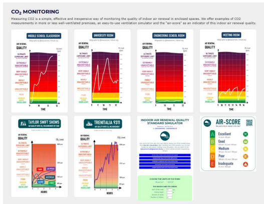


Courtesy of Al Haddrell



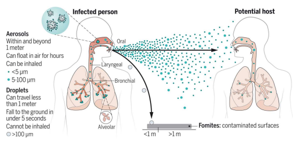
FOR FURTHER INFORMATION

letsair.org



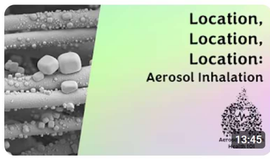
This is our website with information and infographics on CO_2 monitoring, ventilation and air filtration.

Chia C. Wang et al. paper



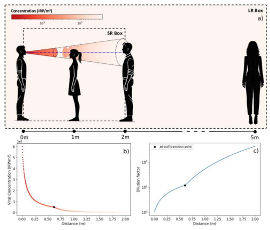
An excellent introduction to airborne transmission of respiratory viruses

Al Haddrell's YouTube Channel



This aerosol scientist offers short, clear and accessible instructional videos to help you understand the many scientific aspects of airborne transmission and aerosol inhalation.

Andre Henriques et al. paper

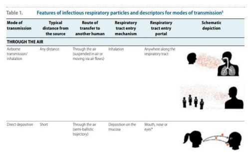


A very clear and didactic article on the risks of airborne contamination. If you want to know more about aerosol science and simulation models, we recommend you start with this article.

Pr Clive Beggs hearing at UK COVID-19 inquiry

During the hearing, Prof. Beggs described the difficulties of having inhalation transmission recognized as the main mode of contamination for COVID-19. He reports on the latest research in this field.

WHO report on proposed terminology



The World Health Organization has published a document proposing a terminology for pathogens that transmit through the air. Our scientific mediation document, which you are now reading, attempts to be compatible with this report.

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