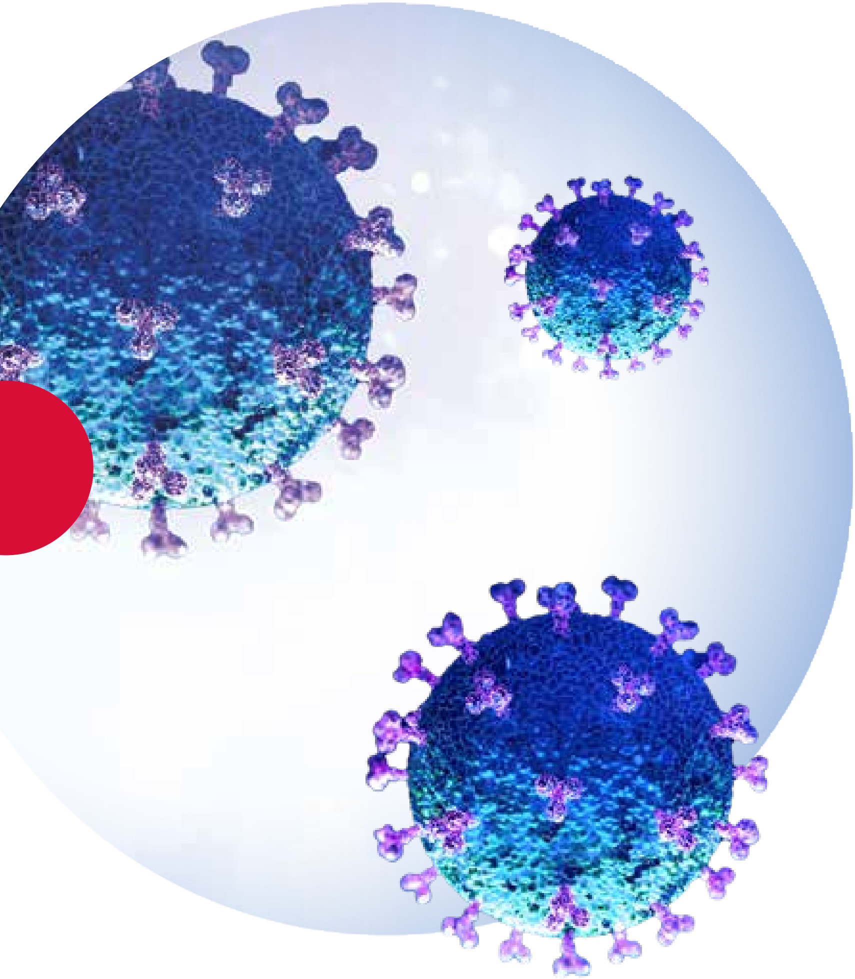
COVID-19 and indoor air quality



New air filtration systems for SARS-CoV-2 abatement

RHOSS

NIBE GROUP MEMBER

1. Introduction

Covid-19 pandemic

The COVID-19 pandemic put HVAC systems to the test, highlighting the shortcomings of existing air treatment technologies and system management.

Pros and cons of the pandemic.

Increased attention on occupants' health conditions in buildings

It showed the ineffectiveness of HVAC systems to meet this challenge

Starting conditions.

Under **normal conditions** , HVAC systems are operated to ensure **adequate indoor conditions while minimising the energy and environmental impacts of buildings**.

Under **emergency conditions**, the focus was entirely on ensuring adequate indoor conditions so as **not** to **compromise the health of the occupants**.

Recommendations during the pandemic

During the pandemic, several **recommendations were defined for the management of air systems** to limit the spread of the SARS-CoV-2 virus (and its variants) and to ensure the maintenance of good air quality in confined spaces.

Actions

Air handling unit (AHUs) operation entailed:

- **Almost continuous operation of the system** (up to 24 hours a day);
- **Elimination of the recirculation function of the return air** (to avoid the transport of chemical/biological agents);
- **Deactivation of heat recovery units** (to avoid contamination between return air and outdoor air flows).

Improved indoor air quality

Higher energy consumption

Objectives of design

With the aim of gradually returning HVAC systems to normal operation, the design of AHU configurations will depend on innovative solutions and technologies, the adoption of which can return systems management to standard operations, ensuring a good compromise between **energy consumption, indoor air quality and occupant health**.

Actions

To reduce energy costs related to air handling system management, it is necessary:

- To re-introduce return air recirculation;
- To re-introduce the use of heat recovery units;
- Adopt **innovative technological solutions** to reduce the transport of chemical/biological agents in the return air.

Improved indoor air quality

Lower energy consumption

How to evaluate investment projects in the energy sector?

Energy performance

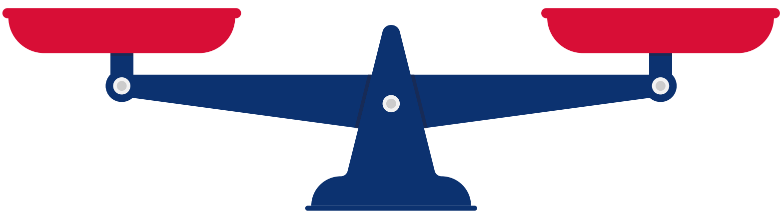
Financial evaluation

Social-economic impacts

Cost-benefit analysis

Benefits

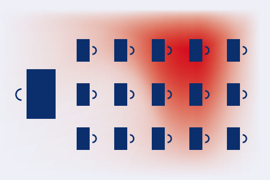
Costs



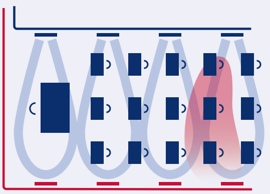
Critical issues of classrooms

Schools are recognised as critical points for the transmission of the SARS-CoV-2 virus. The elements that make classrooms particularly **critical** for risks of direct contagion are:

- The high **density** of people;
- The seating **arrangement** inside the classrooms;
- The prolonged **amount of time spent indoors** (required by the lessons).

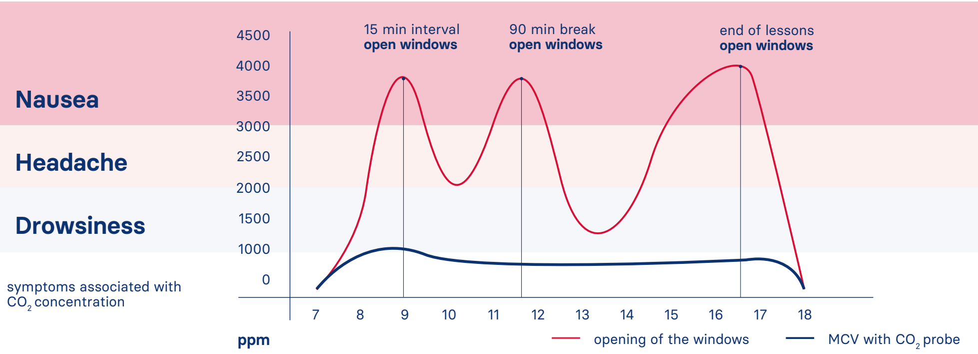


Dynamics of contamination in the presence of an infectious subject without ventilation



Dynamics of contamination in the presence of an infectious subject with ventilation

CO_2 rate on a school day
(Reference standards for air quality EN 13 779)



2.
Research project

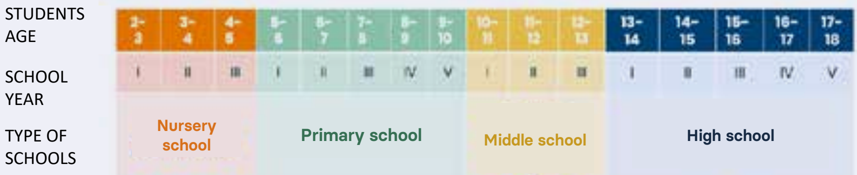
Objective of the research

The research aims to compare different configurations of AHUs, taking into account management differences in the **pre-COVID**, **COVID** and **post-COVID** phases.

Post-COVID configuration

In post-COVID configurations, the analysis compares the use of two filter systems: absolute filter H13 and filter PONENTE 1000 on the return.

Application case: school building



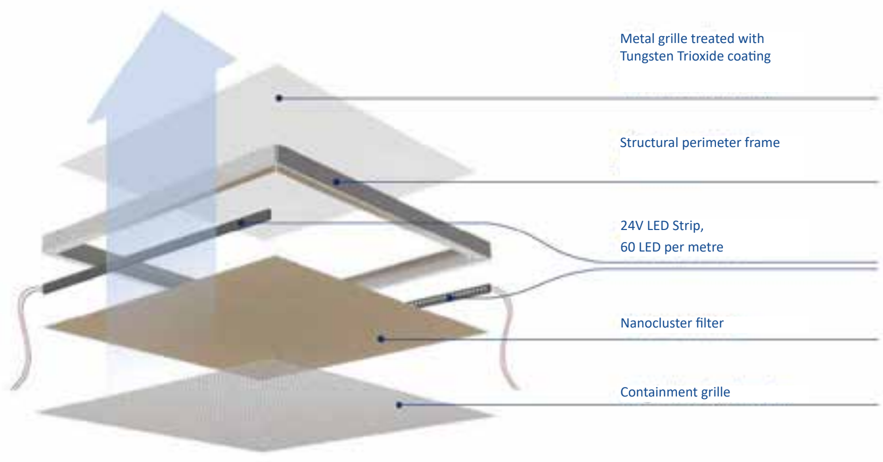
Number of classrooms served by an AHU	7
Number of students per classroom (total)	24 (168)
Number of teachers per classroom (total)	1 (7)
Minimum air flow per classroom (m^3/h)	714,3
Air flow rate per person (l/s per person)	7,9

Ponente 1000: how it works

Most of the technologies used to abate SARS-CoV-2 use photocatalysts based on titanium dioxide (TiO2), a substance that needs to be exposed to UV light to be activated.

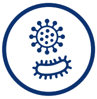
New

The development of a **new photocatalyst based on tungsten trioxide (WO3)** has increased the effectiveness of photocatalysis and eliminated the problem of UV light being activated by LED lamps.

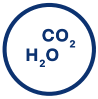


Light source with visible LED light

Activation of the WO_3 Tungsten trioxide photocatalyst



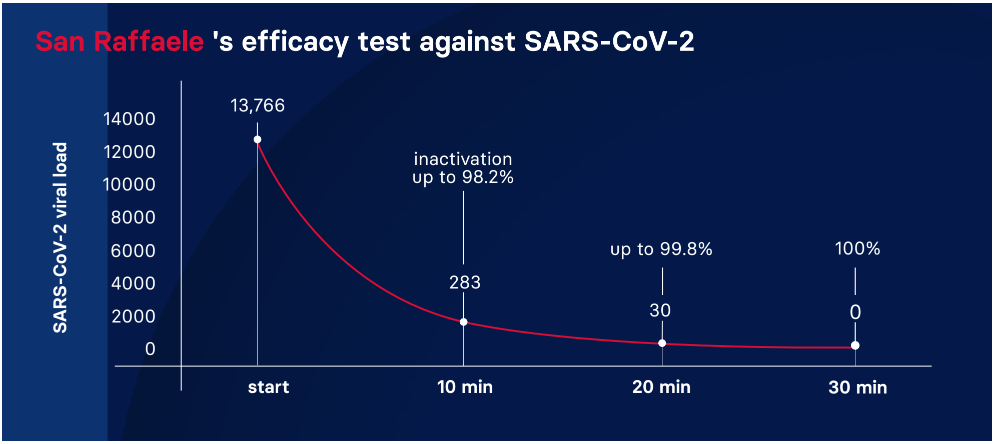
Destruction and decomposition of pathogenic microorganisms



Formation of water vapour and carbon dioxide

The San Raffaele test

The efficacy of the PONENTE 1000 filter to inactivate SARS-CoV-2 was tested in the laboratory of the San Raffaele Hospital in Milan by Dr. Elisa Vicenzi, head of the Viral Pathogenesis and Biosecurity Unit, also known for having isolated and studied the SARS coronavirus from 2003 to 2008.



Inactivation of the infectious charge

The device is able to inactivate the infectious charge of SARS-CoV-2 quickly:

10 minutes
after-treatment
reducing the infectious load by
98.2%

30 minutes
after-treatment
reducing the infectious load by
100%

The abatement capacity

The analysis of the results obtained revealed the effectiveness of the use of the photocatalytic system as an improvement of the environmental conditions with respect to contaminated airborne particles. The reduction in the percentages of the airborne particles, in fact, is quite significant in the case of application of the photocatalytic system for air treatment even after only one hour of activation, with almost a total reduction after 24 hours of operation.

Virus reduction

	Reduction %
	8 hours
Feline calicivirus	35.7
Adenovirus (Type 3)	33.3

Bacteria reduction

	Reduction %
	8 hours
Staphylococcus aureus	>99%
MRSA	>99%
	24 hours
Escherichia coli	>99%
Enterohemorrhagic E. coli	>99%
Klebsiella pneumoniae	>99%
Pseudomonas aeruginosa	>99%

VOC reduction

	Reduction %		
	25′	50′	100′
Toluene	45	65	99
Formaldehyde	55	77.5	99

Analysis **scenarios**

Pre-Covid situation

1. System with recirculation
with functioning heat recovery unit

1. Pre-filter on outdoor air
2. Pre-filter on return
3. F7 STANDARD filter

Covid situation

2. All-outdoor air system
with heat recovery unit NOT working

1. Pre-filter on outdoor air
2. Pre-filter on return
3. F7 STANDARD filter

Post-Covid situation

3. System with recirculation
with functioning heat recovery unit

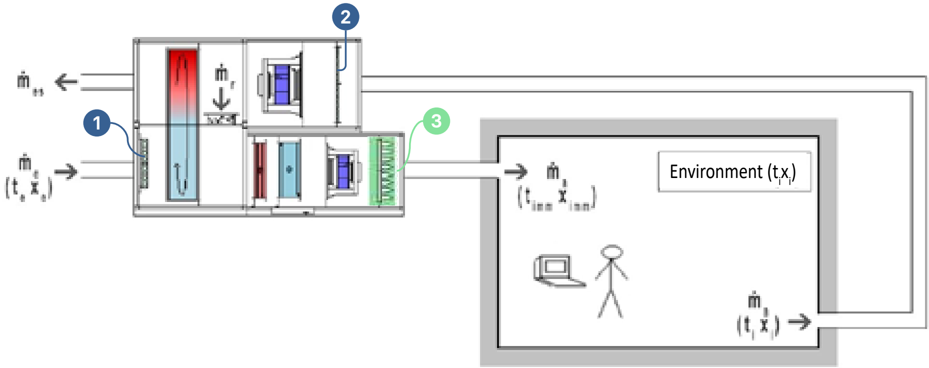
1. Pre-filter on outdoor air
2. Pre-filter on return
3. AIR'SUITE F7 filter
4. PONENTE 1000 filter

4. System with recirculation
with functioning heat recovery unit

1. Pre-filter on outdoor air
2. Pre-filter on return
3. AIR'SUITE F7 filter
4. ABSOLUTE Filter

Pre-COVID situation

Recirculation system with working heat recovery unit.



Key

1. PRE-FILTER on outdoor air
2. PRE-FILTER on return
3. STANDARD F7 FILTER

$\dot{m}_a$ Room air flow rate

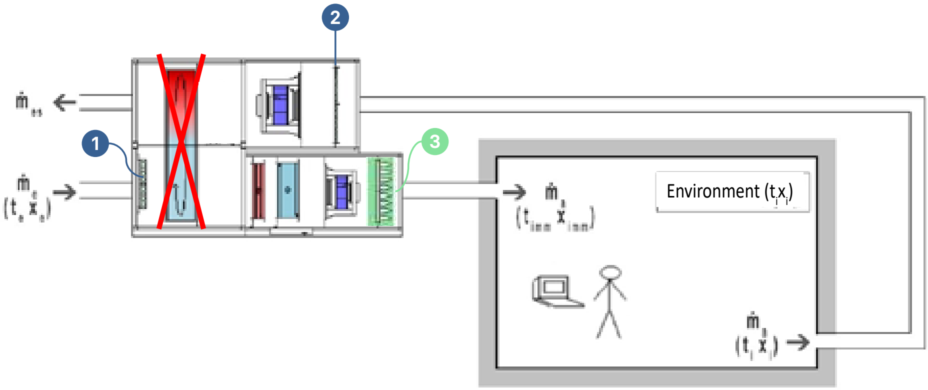
$\dot{m}_e$ Outdoor air flow rate

$\dot{m}_{es}$ Expelled air flow rate

$\dot{m}_r$ Recirculation air flow rate

COVID situation

All-outdoor air system with non-functioning heat recovery unit.



Key

1 PRE-FILTER on outdoor air

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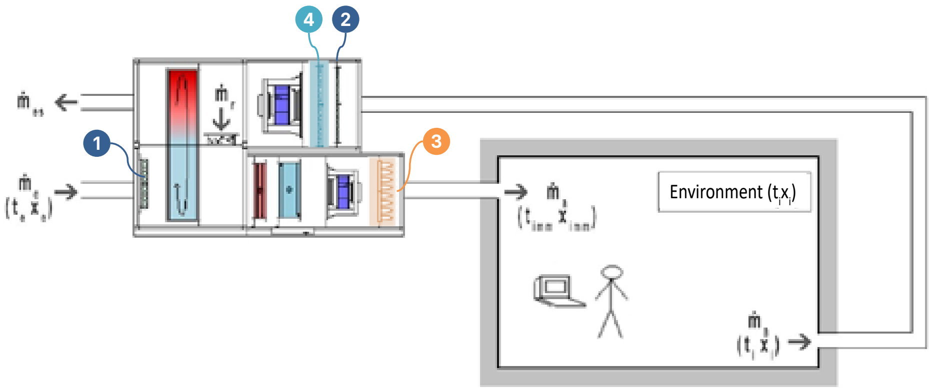
Post-COVID situation (1)

Recirculation system with working heat recovery unit with Ponente 1000 filter.



Key

1 PRE-FILTER on outdoor air

2 PRE-FILTER on return

3 AIR'SUITE FILTER F7

4 PONENTE 1000 FILTER

$\dot{m}_a$ Room air flow rate

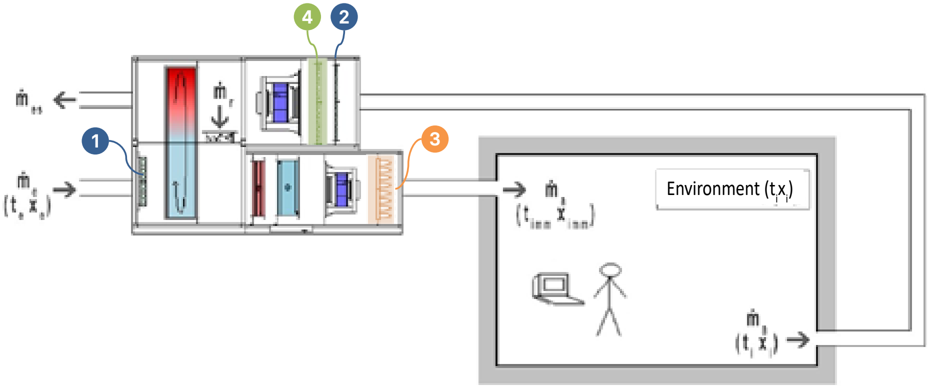
$\dot{m}_e$ Outdoor air flow rate

$\dot{m}_{es}$ Expelled air flow rate

$\dot{m}_r$ Recirculation air flow rate

Post-COVID situation (2)

Recirculation system with working heat recovery unit with Absolute H13 filter.



Key

1. PRE-FILTER on outdoor air
2. PRE-FILTER on return
3. AIR'SUITE FILTER F7
4. ABSOLUTE FILTER H13

$\dot{m}_a$ Room air flow rate

$\dot{m}_e$ Outdoor air flow rate

$\dot{m}_{es}$ Expelled air flow rate

$\dot{m}_r$ Recirculation air flow rate

Costs

Avoided costs = Benefits

AHU configuration costs

Student and teacher health

Student performance

Cost-Benefit Analysis

Incremental Analysis

$$\Delta BCR = \frac{\sum_i B(i)_{PostCovid} - \sum_i B(i)_{PreCovid}}{\sum_i C(i)_{PostCovid} - \sum_i C(i)_{PreCovid}}$$

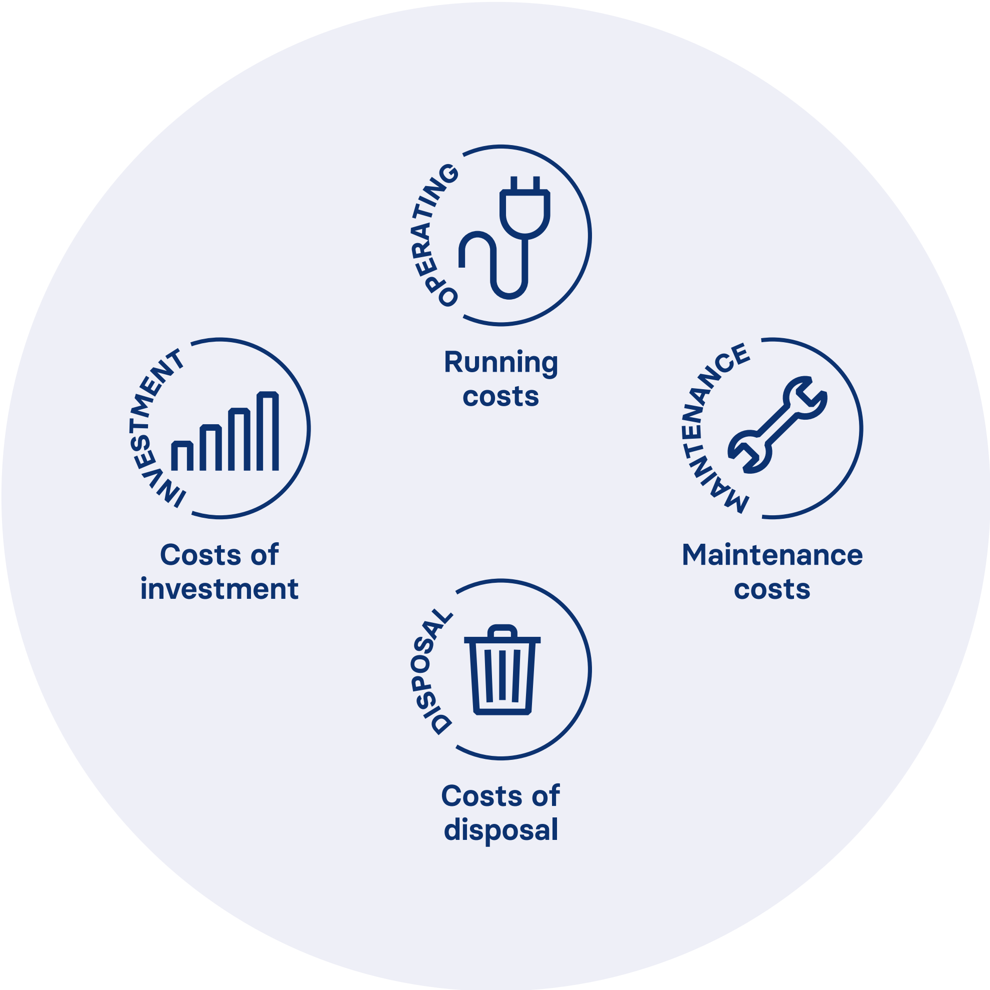
$$B(i)_{PostCovid/\ PreCovid} = \text{Benefits}$$

$$C(i)_{PostCovid/\ PreCovid} = \text{Costs}$$

ΔBCR > 1

$_{PostCovid}$ Benefits > $_{PreCovid}$ Benefits

Evaluation of **costs**



Assessment of benefits: Health

The **Cost Of Illness** method makes it possible to assess the **BENEFITS** of the filter as **AVOIDED COSTS**: direct costs and indirect costs (via **Human Capital Approach**).

Direct Costs =
Medical Care Costs

Home Management
Cost of drugs borne by the patient

Hospitalisation/ Intensive care
Cost of therapy borne by the National Health Service

Indirect Costs =
Unused educational resource costs

Lost school days
Share of educational service that remains an unused resource.
It is monetised through the average annual per capita income from employment in the public administration

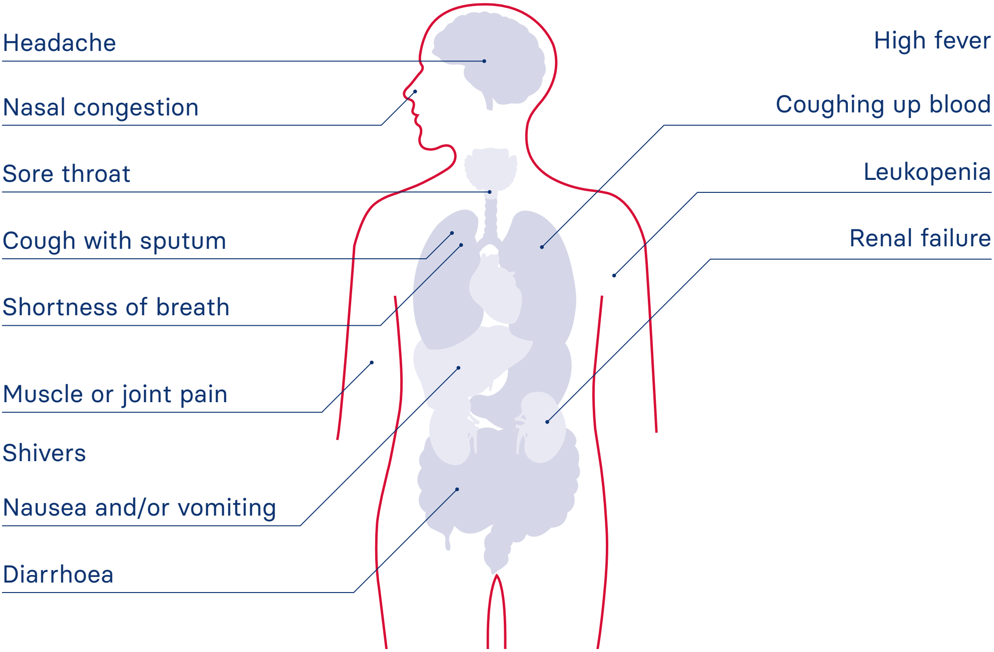
COVID-19: Clinical manifestation

Common symptoms

Fever, dry cough, fatigue.

Rare symptoms

In serious cases



COVID-19: Clinical manifestation

Symptoms vary according to the severity of the disease:

1.

No symptoms

(asymptomatic);

2.

Flu-like symptoms

Such as fever (in more than 90% of cases), dry cough (more than 80% of cases), tiredness, shortness of breath (about 20% of cases) and difficulty breathing (about 15% of cases);

3.

Serious symptoms

The most severe cases of infection can cause pneumonia, acute renal failure, and even death. Patients also present with leucopenia (white blood cell deficiency) and lymphocytopenia (lymphocyte deficiency).

Asymptomatic infection

Individuals who test positive in the virological test for SARS-CoV-2, but do not have symptoms compatible with COVID-19.

Home management

Mild illness

Individuals who have one of the various symptoms of COVID-19 (fever, cough, headache, ...) but do not have shortness of breath, dyspnoea or abnormal chest images. They can be managed in an outpatient setting or at home. No imaging or specific laboratory evaluations.

Moderate illness

Individuals showing evidence of lower respiratory disease during clinical assessment and having oxygen saturation (SpO2 > 94%). As lung disease can progress rapidly, patients with moderate disease must be monitored.

Hospitalisation

Severe/serious illness

Individuals who have SpO2 = 30 breaths/min. These patients may undergo rapid clinical deterioration. Oxygen therapy must be administered immediately.

Hospitalisation (ICU)

Critical illness

Individuals with respiratory failure, septic shock and multiple organ dysfunctions. These patients need treatment in an intensive care unit (ICU).

Summing up...

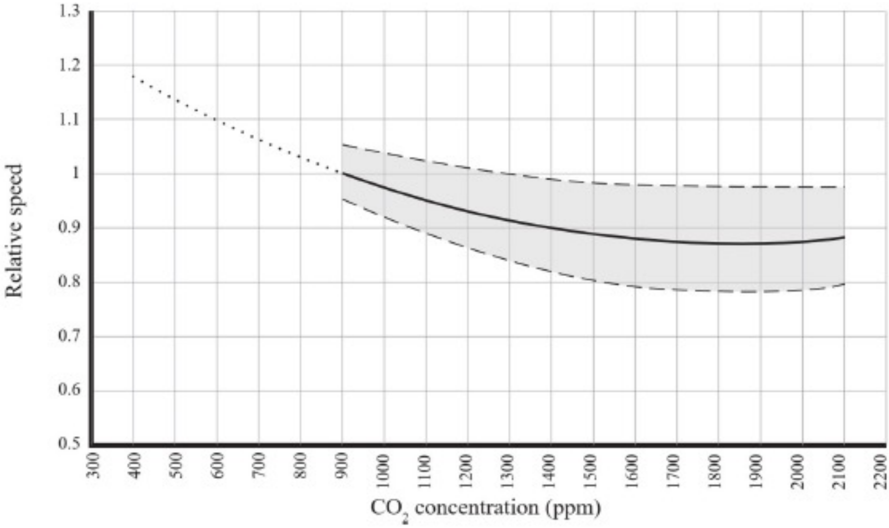
Disease	Viruses		Bacterium	
	SARS-CoV-2	Adenovirus	Staphylococcus Aureus	Escherichia Coli
COVID-19	●			
Pneumonia		●	●	●
Meningitis			●	●

Disease	Air Suite Filter	Ponente 1000 Filter	Absolute H13 Filter
Filter abatement capacity (in 24h) SARS-CoV-2	-	100%	100%
Filter abatement capacity (in 8h) Adenovirus	-	33.3%	30%
Filter abatement capacity (in 24h) Staphylococcus Aureus	98%	99%	99%
Filter abatement capacity (in 24h) Escherichia Coli	90%	99%	99%

Assessment of benefits: Performance

The performance of students in classrooms is influenced by the **concentration** of$_{CO2}$ (used as an **indicator of air quality**) in the room, with the same air flow rate from the different configurations considered.

The$_{CO2}$ concentration in the environment varies (decreases) due to different filter technologies with different abatement capacities.



Comparison with Pre-Covid configuration

Post-Covid (1) vs. Pre-Covid

(Ponente filter 1000 + Air'Suite vs. market filter F7)

	ΔCosts	ΔBenefits	ΔB/ΔC	
Nursery School (2-3 years)	5,646.2	4,126.3	**0.73**	Health
Nursery School (6-10 years)	5,610.4	46,030.4	**8.20**	Health + Productivity
Middle school (11-13 years)	5,643.6	48,038.5	**8.53**	
High school (14-19 years)	5,634.6	48,375.8	**8.59**	

Post-Covid (2) vs. Pre-Covid

(Absolute filter H13 + Air'Suite vs. market filter F7)

	ΔCosts	ΔBenefits	ΔB/ΔC	
Nursery School (2-3 years)	11,032.4	4,126.3	**0.37**	Health
Nursery School (6-10 years)	10,736.1	5,739.4	**0.53**	Health + Productivity
Middle school (11-13 years)	10,936.5	7,747.5	**0.71**	
High school (14-19 years)	10,936.5	8,084.8	**0.74**	

Comparison with Covid configuration

Post-Covid (1) vs. Covid

(Ponente filter 1000 + Air'Suite vs. market filter F7)

	∆Costs	∆Benefits	∆B/∆C
Nursery School (6-10 years)	5,524.9	184,427.8	**33.38**
High school (14-19 years)	5,524.9	181,953.4	**32.93**

The analysis underlines the unsustainability of energy-intensive HVAC system countermeasures undertaken during the pandemic emergency and supports the need to identify solutions able to provide healthy indoor spaces, whilst reducing the air handling energy impact.

New air
for the future.

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RHOSS S.P.A.
Via Oltre Ferrovia, 32
33033 Codroipo (UD) - Italy
tel. +39 0432 911611
rhoss@rhoss.com

RHOSS France
Bat. Cap Ouest - 19 Chemin de la Plaine
69390 Vourles - France
tel. +33 (0)4 81 65 14 06
rhossfr@rhoss.com

RHOSS Deutschland GmbH
Hölzlestraße 23, D
72336 Balingen, OT Engstlatt - Germany
tel. +49 (0)7433 260270
rhossde@rhoss.com

RHOSS Iberica Climatizacion, S.L.
Frederic Mompou, 3 - Pta. 6ª Dpcho. B 1
08960 Sant Just Desvern – Barcelona
tel. +34 691 498 827
rhossiberica@rhossiberica.com

rhoss.com

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