

REHVA COVID-19 Multi-room and Recirculation Calculator - User Guide

A tool for HVAC systems operational strategy assessment for reducing infection risk in existing and newly designed buildings

Introduction

As reported in [REHVA COVID-19 Guidance v. 4 - “How to operate HVAC and other building service systems to prevent the spread of the coronavirus \(SARS-CoV-2\) disease \(COVID-19\) in workplaces”](#), there are several ways for reducing the infection risk:

- increasing ventilation rates as much as compatible with comfort and energy issue;
- avoiding recirculation of indoor air;
- avoiding that individuals are staying directly in the flow of air from another person;
- minimizing the number of people sharing the same indoor environment,
- protective facial masks wearing for people sharing the same common space.

To allow identifying the effectiveness of such potential measures, a simplified tool has been developed to assess comparatively different options potential in reducing the infection risk.

The tool is based on the standard airborne disease transmission Wells-Riley model, i.e. quanta based and full mix hypothesis as described in Appendix 1 of [1]-. It extends the single room model to a Multi-rooms Model with possible air recirculation among rooms, through centralised HVAC system and via air transfer to common service area (corridor, toilettes and staircases) where air extraction to outside is performed via dedicated exhaust air ductwork.

It is possible to partially remove the full-mix hypothesis using the ventilation Contaminant Removal Effectiveness, ϵ_r , which depends on the chosen air distribution system. It is possible to modify the air recirculation ratio from 1 to 0 and eventually to add an HEPA filter or equivalent virus removal/inactivation equipment (UV-C, etc.) on the return air to lower as much as possible the virus spread via air recirculation. The model also accounts for “virus losses” in the HVAC system (deposition in ducts, in AHU and natural decay when moving through such components), using the same approach used for rooms but in a steady state approximation, i.e. using virus removal coefficients as done for general-use spaces.

The number of rooms is limited to 100 but it can be extended, by just modifying a parameter in the code, while only one corridor, one toilet-space and staircase compartment can be simulated. This happens in order to avoid complex building description and simplify data input. Details on the used models and numerical solution are available in ref. [2].

Building layout and limitations

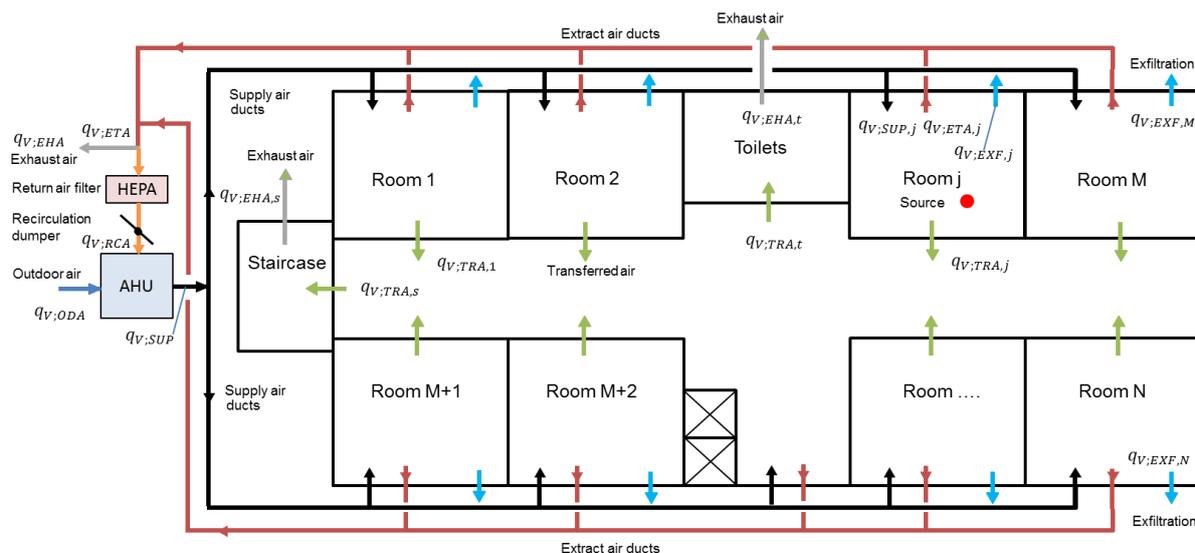


Figure 1 Floor plan and system layout

The tool is designed to simulate a fixed floor plan configuration, as depicted in Figure 1. All rooms are connected to one corridor, which connects to the toilets and a staircase compartment. An HVAC air system distributes treated air from the AHU to each room (and eventually to the corridor) and back, mixing outdoor air (ventilation air) with return air according to the chosen recirculation fraction.

To have a relatively easy and fast use of the tool some limitations have been applied, such as:

- supply and return air flow rates have to be specified for each room and, eventually for the corridor;
- constant ventilation air flow rate during the whole day;
- extraction-only system is possible in toilets and staircase only;
- transferred air through the corridor is automatically calculated, if any exists due to extraction in toilets and/or in staircase compartments;
- the building is pressurised and no infiltrations are allowed: the excess air (difference between supply and return flow) can move only from room to the corridor or just exfiltrate.

Tool organization and input data

The tool is an MS Excel based workbook organised in 6 sheets:

1. **sheet INFO:**
it contains general information on the tools, like developers, version, licensing, disclaimer and colophon;
2. **sheet Inputs:**
in this sheets a dropdown "database" with some special input data gives the possibility to select some of them to use after in sheet Multi-cal; for each data references are reported together with same note.
3. **sheet Filters:**
in this sheet some information is given on air filter efficiency in respect to SARS-COV2 virus;

4. **sheet Multi-calc:**
it is the main sheet where data have to be input, run the macro and obtain the main results;
5. **sheet Concentrations:**
it reports the virus concentration time-history over 24 hours for each considered space
6. **sheet Deposition:**
it reports the virus on-surfaces deposition time-history over 24 hours for each considered space.

INFO Sheet

COVID-19 Multi-rooms Calculator: Estimation of ventilation effect on COVID-19 airborne infection in a HVAC multizone air system

Developed by: Prof. Livio Mazzarella, Dept. of Energy, Politecnico di Milano, Italy
under AicARR and REHVA COVID-19 Task Forces commitments

Using input from: [Jimenez and all his references \(available at https://tinyurl.com/covid-estimator\)](https://tinyurl.com/covid-estimator)

Feedback from: Prof. Manuel Ruiz de Adana

Model description available at: [REHVA Journal 05/2020](#)

Version & date: 1.3.0 27-Oct-20

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Inputs

Filters

Main Menu

Multi-calc

Concentrations

Depositions

What we are trying to estimate

The propagation of COVID-19 by airborne transmission ONLY, when air recirculation among close space is in place due to a HVAC air system

The model is based on a standard model of airborne disease transmission, the Wells-Riley model. It is calibrated to COVID-19 per recent literature on quanta emission rate

This is NOT an epidemiological model and it does not takes into account average rate of infection for a given location and time period

This model does NOT include droplet or contact / fomite transmission, and assumes that 1 to 2 m social distancing is respected. Otherwise higher transmission will result due to other transmission paths

This model aims to estimate transmission to the people present, when they are in locations other than the one the infected person stays

Key parameters, sources, and uncertainties

Same key parameters are provided through drop-down lists, taken from the Jimenez work users can refer to for updates and source references

Several parameters are uncertain, and have been estimated based on current knowledge. Alternative estimates can be entered to explore their effect in the results.

Disclaimer

This model is our best scientific estimate, based on the information currently available. It is provided in the hope that it will be useful to others in providing and applying more efficient virus removal options during this pandemic.

It must be used **ONLY** for comparative infection risk analysis related to possible improvements on both ventilation solutions for new buildings/systems and retrofit and operational strategies for existing buildings/systems under pandemic condition.

The model result strongly depends on the input parameters and their uncertainty reflect on the result itself. Thus this tool is intended to be used by expert only, who know the meaning of each input and their implication on the results.

It is not a finished work and may therefore contain defects or "bugs" inherent to this type of software development. Please let us know if you discover any.

The developers will in no event be liable for any direct or indirect, material or moral, damages of any kind, arising out of the use of this tool.

How to use the tool

The tool is composed of 5 sheets:

- sheet Inputs: in this sheets a "database" with some special input data gives the possibility to select some of them to use after in sheet Multi-cal; references are reported too.
- sheet Filters: in this sheet some information is given on air filter efficiency in respect to SARS-COV2 virus
- sheet Multi-calc: it is the main sheet where data have to be input, run the macro and obtain the main results
- sheet Concentrations: it reports the virus concentration time-history over 24 hours for each considered space
- sheet Deposition: it reports the virus on-surfaces deposition time-history over 24 hours for each considered space

Figure 2 INFO Sheet.

On top-right a "navigation menu" with arrows is available to "navigate" through the tools without using the excel tabs.

Inputs Sheet

In sheet Inputs there are four main blocks of data referring to:

- main input parameters related to COVID-19 disease as:
 - Virus emission rate
 - Breathing rate susceptible people
 - Decay rate of the virus infectivity in aerosols
 - Deposition of virus-containing aerosol to surfaces
 - Virus removal rate of other control measures
 - Mask efficiencies in reducing virus emission
 - Mask efficiencies in reducing virus inhalation;

- REMARK FOR ROOM AIR PURIFIERS:
how derives from manufacturers data the equivalent virus removal rate to use in the tool;

Main Menu
Reload data
Filters
Multi-calc

| INPUT PARAMETERS | VALUES | UNITS | REFERENCES | NOTES | |
|--|---|-------|-------------------|---|--|
| Virus emission rate | Professor delivering a lecture: breathing | 4.4 | q/h | Buonanno et al. (2020), Env.Int. 141, doi.org/10.1016/j.envint.2020.105794 | High uncertainty, probably at factor of 5 or 10 |
| Breathing rate susceptible people | Normal | 0.54 | m ³ /h | Binazzi et al. (2006), Acta Physiologica doi 10.1111/j.1748-1716.2006.01529.x, | Used for office and classroom |
| Decay rate of the virus infectivity in aerosols | Mostly used | 0.63 | h ⁻¹ | van Doremalen et al (2020) New Engl J Med , doi.org/10.1056/NEJMc2004973 | Based on 3 hours experiments |
| Deposition of virus-containing aerosol to surfaces | Average (Buonanno) | 0.24 | h ⁻¹ | Chatoutsidou S.E. (2019) Journal of Cultural Heritage, doi.org/10.1016/j.culher.2019.02.017 | as interpreted by Buonanno et al. (2020), Env.Int. 141, doi.org/10.1016/j.envint.2020.105794 |
| Virus removal rate of other control measures | Portable HEPA filter unit efficiency (SEE REMARK) | 0.95 | - | Mousavi et al (2020) Build Environ., doi.org/10.1016/j.buildenv.2020.107186 | 0.95 is proposed instead of 0.99 HEPA filter efficiency to account for not proper positioning. |
| Mask efficiencies in reducing virus emission | Average default value | 0.5 | - | Davies et al. (2013) Disaster Med Public Health Prep, doi.org/10.1017/dmp.2013.43 | Default value for the general population, with a variety of types of masks (cloth, surgical) and also variation on how well they are worn. |
| Mask efficiencies in reducing virus inhalation | Cloth masks | 0.3 | - | Davies et al (2013) Disaster Med Public Health Prep., doi.org/10.1017/dmp.2013.43 | Davies reported 0.5 efficiency if well worn, to account for imperfect wearing 0.3-0.5 is a reasonable number. |

REMARK FOR ROOM AIR PURIFIERS
Virus removal rate of room air cleaners (any type) can be calculated as $\lambda_{Rad} = \frac{Q_{cleaner}}{V_{room}} \eta_{cleaner}$ [h⁻¹]
where
- air cleaner volume flow rate $Q_{cleaner}$ [m³/h]
- volume of the room where it is placed V_{room} [m³]
- virus removal efficiency $\eta_{cleaner}$ [-]

| HVAC - AHU | VALUES | REFERENCES | NOTES |
|--|--|------------|---|
| Decay rate of the virus infectivity in aerosols | This parameter does not depend on the considered space, room, equipment, ect.: use upper selected value. | 0.63 | |
| Deposition of virus-containing aerosol to surfaces | It depends on the specific Surface to Volume Ratio of the AHU, its composition, and so on. No experimental values available: estimation. | 0.24 | Horve et al. (2020), medRxiv preprint doi.org/10.1101/2020.06.26.20141085 |
| Virus removal rate of other control measures | Not used. The effect of filtration/virus deactivation in considered in the Recirculation filter virus removal efficiency | 0 | |

| HVAC - AHU | VALUES | REFERENCES | NOTES |
|--|--|------------|---|
| Decay rate of the virus infectivity in aerosols | This parameter does not depend on the considered space, room, equipment, ect.: use upper selected value. | 0.63 | |
| Deposition of virus-containing aerosol to surfaces | It depends on the specific Surface to Volume Ratio of the AHU, its composition, and so on. No experimental values available: estimation. | 0.24 | Horve et al. (2020), medRxiv preprint doi.org/10.1101/2020.06.26.20141085 |
| Virus removal rate of other control measures | Not used. The effect of filtration/virus deactivation in considered in the Recirculation filter virus removal efficiency | 0 | |

| HVAC - Ductwork | VALUES | REFERENCES | NOTES |
|--|--|------------|----------------------------|
| Decay rate of the virus infectivity in aerosols | This parameter does not depend on the considered space, room, equipment, ect.: use upper selected value. | 0.63 | |
| Deposition of virus-containing aerosol to surfaces | Duct have the same geometrical configuration of a room but higher S/V ratio and air is moving much faster through: conservative estimation | 0.24 | |
| Virus removal rate of other control measures | Not used. The effect of filtration/virus deactivation in considered in the Recirculation filter virus removal efficiency | 0 | No available specific data |

| | |
|--|---|
| Supply Ductwork Average Cross-Section Area | Average cross-section area of the whole supply ductwork |
| Supply Ductwork Max Branch Length | Max duct length from UTA to farrest room |
| Return Ductwork Average Cross-Section Area | Average cross-section area of the whole return ductwork |
| Return Ductwork Max Branch Length | Max duct length from farrest room to UTA |

| HVAC - Rooms, Corridor | VALUES |
|--|--|
| Supply air volume flow rate | Supply flow rate to this space in m ³ /h |
| Extraction fraction | Ratio of extracted to supply flow rate (extracted flow rate as function of supply flow rate) |
| Supply Ductwork Volume Fraction | using an average cross-section area it is just the ratio of the ductwork length serving the considere room to the max length |
| Return Ductwork Volume Fraction | using an average cross-section area it is just the ratio of the ductwork length serving the considere room to the max length |
| Ventilation Contaminat Removal Effectiveness | to account for no perfect mixing in relation to specific air distribution systems in the rooms |

Figure 3 Inputs Sheet

- HVAC - AHU COVID-19 disease related data as:
 - o Decay rate of the virus infectivity in aerosols
 - o Deposition of virus-containing aerosol to surfaces
 - o Virus removal rate of other control measures
- HCVAC - Ductwork COVID-19 disease related data as:
 - o Decay rate of the virus infectivity in aerosols
 - o Deposition of virus-containing aerosol to surfaces
 - o Virus removal rate of other control measures

In each block a drop-down menu is available for each item allowing the selection of its input parameters among several options; for almost each option the REFERENCE column indicates where the data was taken from, and under the column NOTES some more information on the data quality.

The values, in column VALUES, can be just copied and pasted to the respective cells in the "Multi-calc" tab.

NOTE: if the drop-down menus or the VALUE column appear empty just push button “Reload Data” on top of the sheet.

Filters Sheet

About filters
Main Menu
Inputs
Multi-calc

Filters selection is a very important task, because the filter efficiency depends both on the filter typology and the particle size distribution (i.e. the virus characteristic sizes)

EN ISO 16890-1 2016 Definitions for air filters in HVAC systems

efficiency fraction or percentage of a challenge contaminant that is removed by a filter
fractional efficiency ability of an air cleaning device to remove particles of a specific size or size range
 NOTE: The efficiency plotted as a function of particle size gives the **particle size efficiency spectrum**.
particulate matter efficiency, ePMx efficiency of an air cleaning device to reduce the mass concentration of particles with an optical diameter between 0,3 μm and x μm

Looking at particle size efficiency spectra of different filters it is evident that their filtration capability is minimum nearby the declared particle size (i.e. PM1, PM2.5, PM10). For larger particles, the filter acts like a net as we would expect; for smaller particle size other mechanisms act in capturing particles. The declared particulate matter efficiency, ePMx, is the ratio of the particulate mass captured by the mass challenging the filter, when tested with a defined PMx size spectrum.

Thus, to give an efficiency related to SARS-CoV2 virus capturing capability we need to know the fractional distribution of infectious particles and their virus concentration.

Some information are available from ref.1 showing different size spectrum between highly infected and low infected zones. Thus, ePM1 ≥70% efficiency filter could be effective in cleaning low infected areas with low virus load, while HEPA filter is needed to capture infected particles in the lowest range (< 0.25 μm)

taken from REHVA GuideBook 11 - AIR FILTRATION IN HVAC SYSTEMS (2019)

more information right => taken from REHVA GuideBook 11 - AIR FILTRATION IN HVAC SYSTEMS (2019)

This graph shows how different filters (from A to H) have different efficiencies for different particle sizes.

Efficiency of air filters vs. particle size. This graph shows how different filters (from A to H) have different efficiencies for different particle sizes.

This table, referred to the graph, shows how many different classification are possible for the same filter if referred to a specific particulate size efficiency.

| Filter | eP5.0 | ISO eP10 | eP2.5 | ISO eP2.5 | eP1.0 | ISO eP100 |
|--------|-------|----------|-------|-----------|-------|-----------|
| A | 89% | 85 | 93% | 90 | 98% | 95 |
| B | 84% | 80 | 89% | 85 | 97% | 95 |
| C | 72% | 70 | 80% | 80 | 94% | 90 |
| D | 58% | 55 | 70% | 70 | 91% | 90 |
| E | 53% | 50 | 66% | 65 | 89% | 85 |
| F | 42% | 40 | 58% | 55 | 87% | 85 |
| G | 27% | - | 40% | - | 78% | 75 |
| H | 11% | - | 27% | - | 71% | 70 |
| I | 3% | - | 14% | - | 61% | 60 |

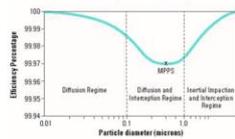
Ref.1: Liu, Y., Ning, Z., Chen, Y. et al. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. Nature 582, 557–560 (2020). <https://doi.org/10.1038/s41586-020-2271-3>

HEPA Filters (EN 1822-1:2019)

High-Efficiency Particulate Air or HEPA air filters is a special class of filters used when contaminant control is the utmost importance as in airborne infectious isolation rooms. They have an efficiency rating of >99.95% at 0.3μm, but as for the other filters they are able to filter also smaller particles with higher efficiency (see picture below). Reference standards: EN 1822-1:2019; ISO 29463:2017

| EN Classification | ISO equivalence |
|--|---------------------|
| EPA Filter (efficient particulate air filter): Ex | ISO 15 E - ISO 30 E |
| HEPA Filter (high efficiency particulate air filter): Hx | ISO 35 H - ISO 45 H |
| ULPA Filter (ultra low penetration air filter): Ux | ISO 50 U - ISO 75 U |

| EN Filter Class | Collection Efficiency % |
|-----------------|-------------------------|
| E10 | 85 |
| E11 | 95 |
| E12 | 99,5 |
| H13 | 99,95 |
| H14 | 99,995 |
| U15 | 99,9995 |
| U16 | 99,99995 |
| U17 | 99,999995 |



MPSS = most penetrating particle size
 Picture from <https://blog.pricelindustries.com/hepa-filters-versus-particle-size>

Figure 4 Filters Sheet

In this sheet some information is given on air filter efficiency in respect to SARS-COV-2 virus, to allow a conscious selection of filter units.

Multi-calc Sheet

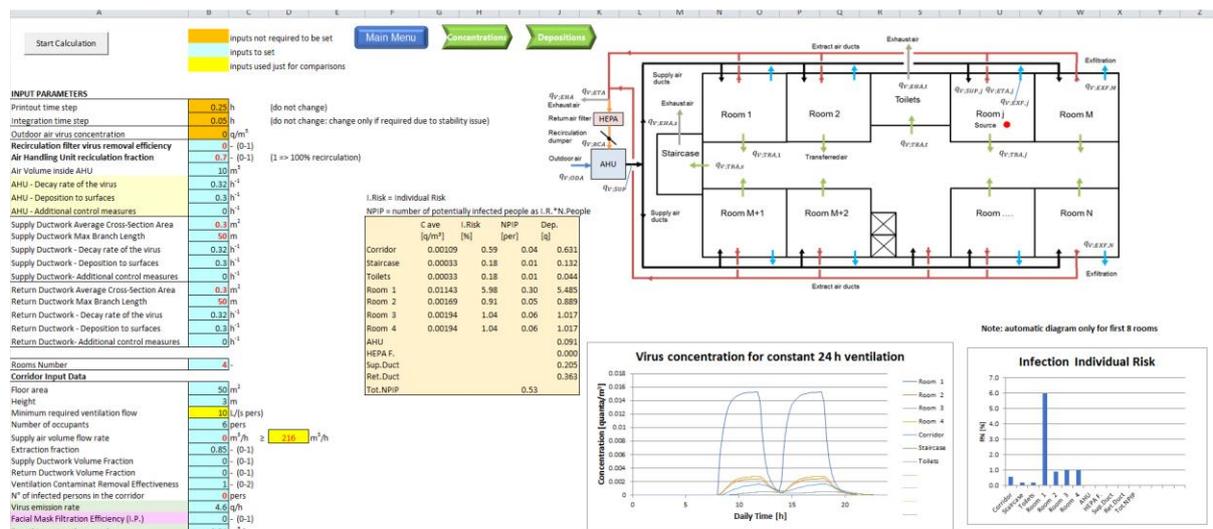


Figure 5 Multi-calc Sheet

This is the main sheet, where the input data have to be inserted and the calculation is started. Also, the main results are presented here, numerically (in the light orange box) and graphically (both daily time history and histograms).

The input data are split in several functional boxes.

| INPUT PARAMETERS | | |
|---|----------------------|---------------------------|
| Printout time step | 0.25 h | (do not change) |
| Integration time step | 0.05 h | (do not change: change c |
| Outdoor air virus concentration | 0 q/m ³ | |
| Recirculation filter virus removal efficiency | 0 - (0-1) | |
| Air Handling Unit recirculation fraction | 0.7 - (0-1) | (1 => 100% recirculation) |
| Air Volume inside AHU | 10 m ³ | |
| AHU - Decay rate of the virus | 0.32 h ⁻¹ | |
| AHU - Deposition to surfaces | 0.3 h ⁻¹ | |
| AHU - Additional control measures | 0 h ⁻¹ | |
| Supply Ductwork Average Cross-Section Area | 0.3 m ² | |
| Supply Ductwork Max Branch Length | 50 m | |
| Supply Ductwork - Decay rate of the virus | 0.32 h ⁻¹ | |
| Supply Ductwork - Deposition to surfaces | 0.3 h ⁻¹ | |
| Supply Ductwork- Additional control measures | 0 h ⁻¹ | |
| Return Ductwork Average Cross-Section Area | 0.3 m ² | |
| Return Ductwork Max Branch Length | 50 m | |
| Return Ductwork - Decay rate of the virus | 0.32 h ⁻¹ | |
| Return Ductwork - Deposition to surfaces | 0.3 h ⁻¹ | |
| Return Ductwork- Additional control measures | 0 h ⁻¹ | |

Figure 6 Sheet Multi-calc: input parameters

In the **input parameters box**, the orange cells are inputs not required to be set (the printout time step => integration time step, which has been tuned against analytical solution to have the best resolution in the lowest calculation time, and the outdoor air virus concentration is set to zero).

It could happen that a requirement is pulled up by the tool to lower the integration time-step, due to instability related to too high flow rate in a small space: only in that case lower the integration

time-step.

Below these parameters, the **Air Handling Unit parameters** are as input to be defined by the user:

- Recirculation filter virus removal efficiency, if any, or other equivalent virus removal/inactivation equipment;
- Air Handling Unit recirculation fraction,
- AHU - Decay rate of the virus, in [h⁻¹] (values from sheet Inputs)
- AHU - Deposition to surfaces, in [h⁻¹] (values from sheet Inputs)
- AHU - Additional control measures, in [h⁻¹] (values from sheet Inputs)

In the following two boxes the parameters for the air supply ductwork and the air return ductwork have to be provided. For each of them the following data are required (if you leave the value at 0, the system is just ductless and the model will run anyhow):

- Supply or Return Ductwork Average Cross-Section Area
(for ductwork with different cross-section area the length-weighted cross-sectional area)
- Supply or Return Ductwork Max Branch Length
(it is the max length of a ductwork branch among all from the AHU and the farthest room)
- Supply or Return Ductwork - Decay rate of the virus, in [h⁻¹] (values from sheet Inputs)
- Supply or Return Ductwork - Deposition to surfaces, in [h⁻¹] (values from sheet Inputs)
- Supply or Return Ductwork- Additional control measures, in [h⁻¹] (values from sheet Inputs)

Before the Corridor Input data box, the rooms number has to be specified (four in the example below)

| | |
|--------------|---|
| Rooms Number | 4 |
|--------------|---|

This number can be up to 100. If the user prefers to simulate a large number of rooms, the source code must be opened (under developer menu) and change some arrays size from 100 and 103 to a larger value.

| Corridor Input Data | |
|--|---------------------------|
| Floor area | 50 m ² |
| Height | 3 m |
| Minimum required ventilation flow | 10 L/(s pers) |
| Number of occupants | 6 pers |
| Supply air volume flow rate | 0 m ³ /h ≥ 216 |
| Extraction fraction | 0.85 - (0-1) |
| Supply Ductwork Volume Fraction | 0 - (0-1) |
| Return Ductwork Volume Fraction | 0 - (0-1) |
| Ventilation Contaminat Removal Effectiveness | 1 - (0-2) |
| N° of infected persons in the corridor | 0 pers |
| Virus emission rate | 4.6 q/h |
| Facial Mask Filtration Efficiency (I.P.) | 0 - (0-1) |
| Breathing rate other people | 0.54 m ³ /h |
| Facial Mask Filtration Efficiency (others) | 0 - (0-1) |
| Initial virus concentration | 0 q/m ³ |
| Decay rate of the virus | 0.32 h ⁻¹ |
| Deposition to surfaces | 0.3 h ⁻¹ |
| Additional control measures | 0 h ⁻¹ |
| Occupancy starting time | 8 h |
| Occupancy ending time | 18 h |
| Infected person incoming time 1 | 8 h |
| Infected person outcoming time 1 | 18 h |
| Infected person incoming time 2 | 0 h |
| Infected person outcoming time 2 | 0 h |

Figure 7 Multi-calc Sheet : Corridor Input Data

The **Corridor Input data box** contains all needed input for the corridor:

- Floor area, in [m²]
- Height, in [m];
- Minimum required ventilation flow, in [L/(s pers)]
not needed for the calculation, it will be used just for comparison with the supply air flow rate (which is NOT only ventilation flow: it depends on the recirculation fraction)
- Number of occupants:
it will be used to calculate the number of potentially infected people;
- Supply air volume flow rate, in [m³/h]
- Extraction fraction, [-]:
it is the ratio between the return flow rate and the supply flow rate;
- Supply Ductwork Volume Fraction, [-]:
it is the relative length of the supply ductwork branch serving the corridor to the Ductwork Max Branch Length specified in the supply ductwork box;
- Return Ductwork Volume Fraction, [-]:
it is the relative length of the return ductwork branch serving the corridor to the Ductwork Max Branch Length specified in the return ductwork box;
- Ventilation Contaminant Removal Effectiveness, [-];
it allows, if known, to partially remove the full mix hypothesis;
- N° of infected persons in the corridor, [-]
- Virus emission rate, in [q/h];
values from sheet Inputs;
- Facial Mask Filtration Efficiency (I.P.) for the infected person/s, [-]
values from sheet Inputs;
- Breathing rate other people, in [m³/h]
values from sheet Inputs;
- Facial Mask Filtration Efficiency (others) for susceptible people, [-]:
values from sheet Inputs;
- Initial virus concentration, in [q/m³]:
usually 0, but it can be used to run for a second day the tools a check the night cleaning effect of ventilation;
- Decay rate of the virus, in [h⁻¹] (values from sheet Inputs)
- Deposition to surfaces, in [h⁻¹] (values from sheet Inputs)
- Additional control measures, in [h⁻¹]
values from sheet Inputs;
NOTE: this input can be used to simulate a local air cleaner according to the rules reported in Inputs sheet.
- Occupancy starting time, in clock [h]
- Occupancy ending time, in clock [h]
NOTE: Occupancy ending time - Occupancy starting time: occupancy time window for susceptible people;
- Infected person incoming time 1, in clock [h]
- Infected person outcoming time 1, in clock [h]
- Infected person incoming time 2, in clock [h]
- Infected person outcoming time 2, in clock [h]
NOTE: two steps-time window for the infected person

The **Staircase Input data box** contains all needed input for the toilet compartment:

| Staircase Input Data | |
|--|---|
| Floor area | 30 m ² |
| Height | 3 m |
| Minimum required ventilation flow | 10 L/(s pers) |
| Number of occupants | 6 pers |
| Exhaust air volume flow rate | 30 m³/hv ≥ 14.4 m³/h |
| N° of infected persons in staircase | 0 pers |
| Virus emission rate | 4.6 q/h |
| Facial Mask Filtration Efficiency (I.P.) | 0 - (0-1) |
| Breathing rate other people | 0.54 m ³ /h |
| Facial Mask Filtration Efficiency (others) | 0 - (0-1) |
| Initial virus concentration | 0 q/m ³ |
| Decay rate of the virus | 0.32 h ⁻¹ |
| Deposition to surfaces | 0.3 h ⁻¹ |
| Additional control measures | 0 h ⁻¹ |
| Occupancy starting time | 8 h |
| Occupancy ending time | 18 h |
| Infected person incoming time 1 | 8 h |
| Infected person outgoing time 1 | 18 h |
| Infected person incoming time 2 | 0 h |
| Infected person outgoing time 2 | 0 h |

Figure 8 Multi-calc Sheet : Staircase Input Data

- Floor area, in [m²]
- Height, in [m];
- Minimum required ventilation flow, in [L/(s pers)]
not needed for the calculation, it will be used just for comparison with the supply air flow rate (which is NOT only ventilation flow: it depends on the recirculation fraction)
- Number of occupants:
it will be used to calculate the number of potentially infected people;
- Exhaust air volume flow rate, in [m³/h]
- N° of infected persons in the staircase compartment, [-]
- Virus emission rate, in [q/h];
values from sheet Inputs;
- Facial Mask Filtration Efficiency (I.P.) for the infected person/s:, [-]
values from sheet Inputs;
- Breathing rate other people, in [m³/h]
values from sheet Inputs;
- Facial Mask Filtration Efficiency (others) for susceptible people, [-]:
values from sheet Inputs;
- Initial virus concentration, in [q/m³]:
usually 0, but it can be used to run for a second day the tools a check the night cleaning effect of ventilation;
- Decay rate of the virus, in [h⁻¹] (values from sheet Inputs)
- Deposition to surfaces, in [h⁻¹] (values from sheet Inputs)
- Additional control measures, in [h⁻¹]
values from sheet Inputs;
NOTE: this input can be used to simulate a local air cleaner according to the rules reported in sheet Inputs.
- Occupancy starting time, in clock [h]
- Occupancy ending time, in clock [h]
NOTE: Occupancy ending time - Occupancy starting time: occupancy time window for susceptible people;
- Infected person incoming time 1, in clock [h]
- Infected person outgoing time 1, in clock [h]

- Infected person incoming time 2, in clock [h]
 - Infected person outgoing time 2, in clock [h]
- NOTE: two steps-time window for the infected person**

The **Toilet Input data box** contains all needed input for the toilet compartment:

| Toilets Input Data | |
|--|---|
| Floor area | 10 m ² |
| Height | 3 m |
| Minimum required ventilation flow | 10 L/(s pers) |
| Number of occupants | 3 pers |
| Exhaust air volume flow rate | 10 m³/h ≥ 14.4 m³/h |
| N° of infected persons in toilets | 0 pers |
| Virus emission rate | 4.6 q/h |
| Facial Mask Filtration Efficiency (I.P.) | 0 - (0-1) |
| Breathing rate other people | 0.54 m ³ /h |
| Facial Mask Filtration Efficiency (others) | 0 - (0-1) |
| Initial virus concentration | 0 q/m ³ |
| Decay rate of the virus | 0.32 h ⁻¹ |
| Deposition to surfaces | 0.3 h ⁻¹ |
| Additional control measures | 0 h ⁻¹ |
| Occupancy starting time | 8 h |
| Occupancy ending time | 18 h |
| Infected person incoming time 1 | 8 h |
| Infected person outgoing time 1 | 12 h |
| Infected person incoming time 2 | 14 h |
| Infected person outgoing time 2 | 18 h |

Figure 9 Multi-calc Sheet: Toilets Input Data

It requires exactly the same type of data as the staircase compartment (see above).

The **Room X Input data box** contains all needed input for the toilet compartment: this input box is exactly the same as the Corridor Input Data box; therefore, please advise the respective section.

NOTE: What is important is that the tool needs to have as many Room Input boxes as the specified room numbers. As provided, there are 8 room boxes. To add more boxes just select one box as shown in the following picture, copy and paste just on the first free cell below the last Room box. Then you may update the progressive Room X value, just to know what the data are referring to.

| | | | |
|---|--|--------|---|
| 9 | Infected person outcoming time 2 | 18 | h |
| 0 | Repeat the following block for each room | Room 2 | |
| 1 | Floor area | 50 | m ² |
| 2 | Height | 3 | m |
| 3 | Minimum required ventilation flow | 10 | L/(s pers) |
| 4 | Number of occupants | 6 | pers |
| 5 | Supply air volume flow rate | 270 | m ³ /h ≥ 216 m ³ /h |
| 6 | Extraction fraction | 0.85 | -(0-1) |
| 7 | Supply Ductwork Volume Fraction | 1 | -(0-1) |
| 8 | Return Ductwork Volume Fraction | 1 | -(0-1) |
| 9 | Ventilation Contaminat Removal Effectiveness | 1 | -(0-2) |
| 0 | N° of infected persons in the room | 0 | pers |
| 1 | Virus emission rate | 4.6 | q/h |
| 2 | Facial Mask Filtration Efficiency (I.P.) | 1 | -(0-1) |
| 3 | Breathing rate other people | 0.54 | m ³ /h |
| 4 | Facial Mask Filtration Efficiency (others) | 0 | -(0-1) |
| 5 | Initial virus concentration | 0 | q/m ³ |
| 6 | Decay rate of the virus | 0.32 | h ⁻¹ |
| 7 | Deposition to surfaces | 0.3 | h ⁻¹ |
| 8 | Additional control measures | 0 | h ⁻¹ |
| 9 | Occupancy starting time | 8 | h |
| 0 | Occupancy ending time | 18 | h |
| 1 | Infected person incoming time 1 | 8 | h |
| 2 | Infected person outcoming time 1 | 12 | h |
| 3 | Infected person incoming time 2 | 14 | h |
| 4 | Infected person outcoming time 2 | 18 | h |

Figure 10 Multi-calc Sheet: Room Input Data box selection for copying

The virus source (infected person) can be placed at any space and it can be more than one, each of them with its specific virus strength.

Tool output

As result of the tool calculation the following data are available in the main sheet of the Excel workbook (Multi-calc):

- average virus concentration in each room, corridor, toilettes and staircase, over the working day
- individual infection risk over the day in each of those spaces calculated with the Wells-Riley model;
- average number of potentially infected people in each room, corridor, toilettes and staircase, over the working day;
- virus air to surface deposition over the day in each space, on AHU surfaces, on HEPA or equivalent virus removal/inactivation equipment (V-C, etc.), on supply and return ductworks.

The virus concentration time evolution in each space is reported (using a printout time interval, which can be greater than the integration time interval) in a second sheet called “Concentrations”, while air to surface virus deposition time history is available in a third sheet called “Depositions”.

In the main sheet diagrams are available for:

- virus concentration time history in each space;
- virus air to surface deposition time history in each space;
- individual infection risk in each space histogram;
- average number of potentially infected people in each room histogram.

For the example reported in the excel file when downloaded, which assumes 1 infected person in room1 , four rooms of 50 m² and a supply for rate of 270 m³/h each, a corridor of 50 m² without direct ventilation, a staircase compartment of 30 m² with an exhaust flow rate of 30 m³/h and a toilet compartment of 10 m² with an exhaust flow rate of 10 m³/h, assuming a virus emission rate of 4.6 quanta/h for the infected person and a breathing rate of 0.54 m³/h for the other people, the results with 70% of air recirculation without any virus “filtering” on the return air are those reported in figure 11, 12, 13, 14 and 15.

I.Risk = Individual Risk

NPIP = number of potentially infected people as I.R.*N.Peop

| | C ave [q/m ³] | I.Risk [%] | NPIP [per] | Dep. [q] |
|-----------|------------------------------|---------------|---------------|-------------|
| Corridor | 0.00109 | 0.59 | 0.04 | 0.631 |
| Staircase | 0.00033 | 0.18 | 0.01 | 0.132 |
| Toilets | 0.00033 | 0.18 | 0.01 | 0.044 |
| Room 1 | 0.01143 | 5.98 | 0.30 | 5.485 |
| Room 2 | 0.00169 | 0.91 | 0.05 | 0.889 |
| Room 3 | 0.00194 | 1.04 | 0.06 | 1.017 |
| Room 4 | 0.00194 | 1.04 | 0.06 | 1.017 |
| AHU | | | | 0.091 |
| HEPA F. | | | | 0.000 |
| Sup.Duct | | | | 0.205 |
| Ret.Duct | | | | 0.363 |
| Tot.NPIP | | | 0.53 | |

Figure 11 Multi-calc Sheet: general output

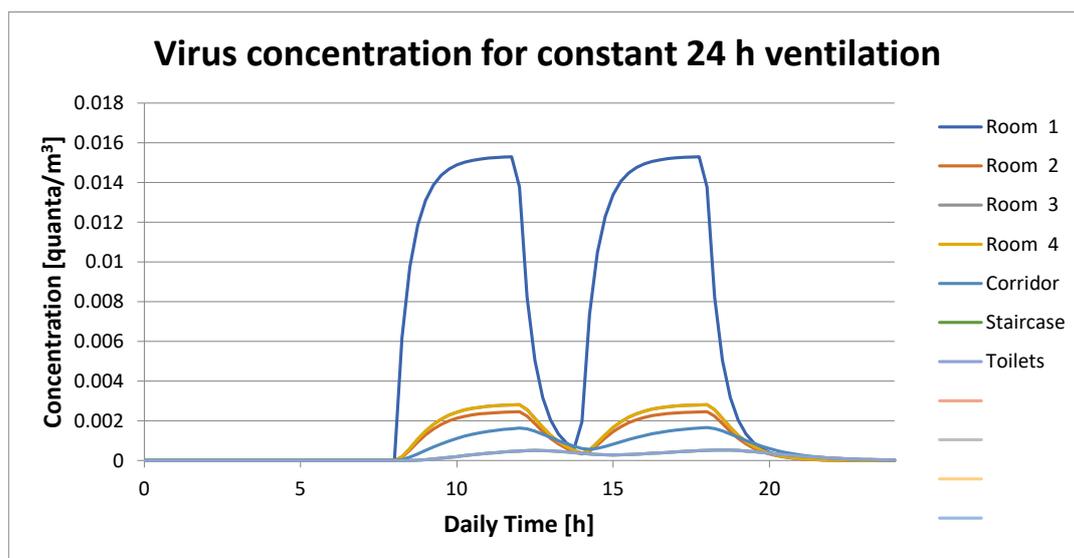


Figure 12 Sheet Multi-calc: virus concentration time history (detailed data from sheet Concentrations)

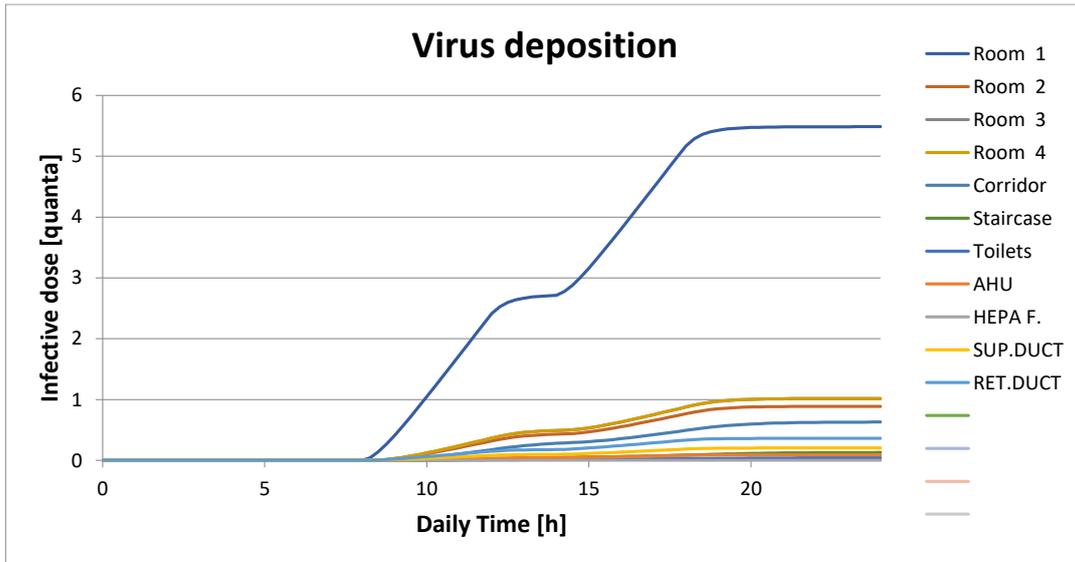


Figure 13 - Multi-calc Sheet: virus deposition time history (detailed data from sheet Depositions)

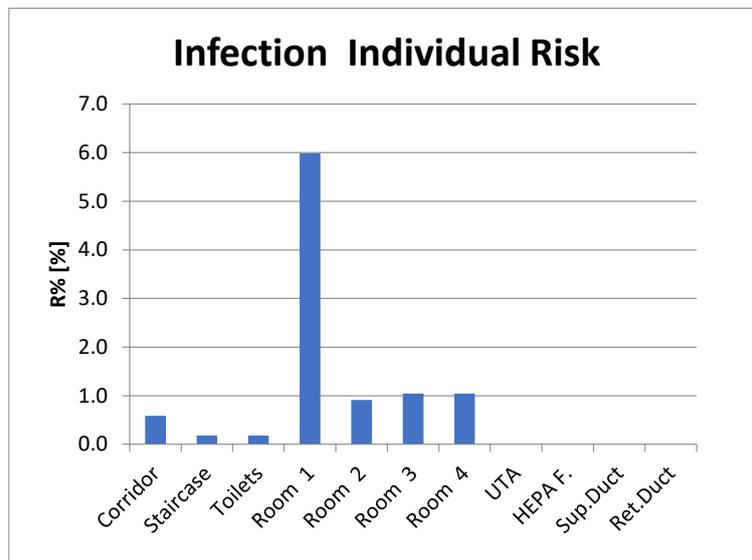


Figure 14 Multi-calc Sheet: individual risk of infection

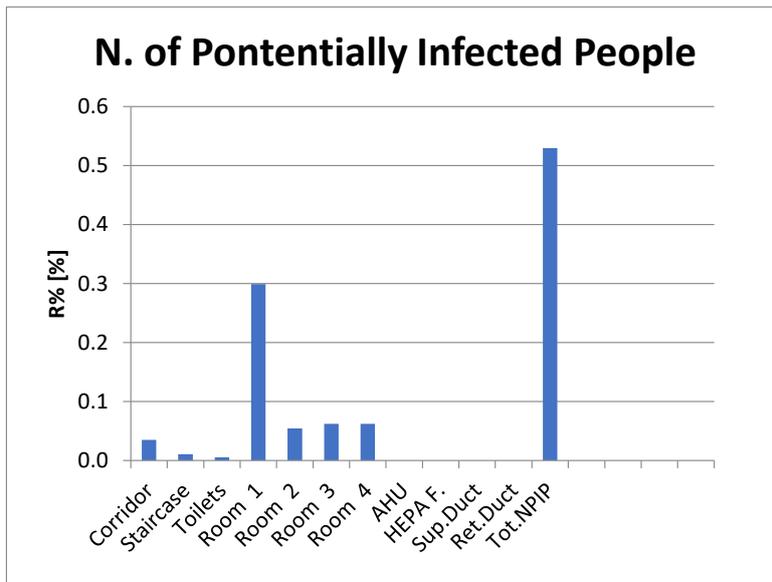


Figure 15 Multi-calc Sheet: potential number of infected people

Use, Limitations and Uncertainties

The tool was developed with the Sars-CoV-2 virus in mind and the underlying estimates for source strengths (quanta values) are based on studies that solely examined the 2019 version of the virus and not any latest, more contagious SARS-CoV-2 variants (i.e. in the UK, South-Africa, Brazil etc.). Therefore, any subsequent research on the topic has not been considered for its development and update. Its application and calculation results should be interpreted considering this limitation.

Currently, the tool is using the infection risk probability function from Wells-Riley model to assess the infection risk, but it is physically based (i.e. mass balance based) and can easily be updated with different infection risk probability functions or just by using virus particles concentration instead of quanta values to give a relative picture of different proposed actions.

The tool is developed under MS Excel using VBA (Visual Basic for Applications) programming language. It is simple enough to use and fast to execute for a comparative COVID-19 infection risk analysis for a standard building floor and the most common air distribution layouts - something that compromises its flexibility as it can't be used for any type of application.

Input values and assumptions

Although SARS-CoV-2 quanta/h emission values include some uncertainties, it is already possible to calculate infection risk estimates and conduct comparisons on the effect of ventilation and room parameters. These limitations and uncertainties mean that rather than predicting an absolute infection risk, the calculation is capable of comparing the relative effectiveness of solutions and ventilation strategies to support the most appropriate choice. Therefore, the tool provides just an indication of risk.

The model results strongly depend on the input parameters and their uncertainty reflect on the result itself. Thus, this tool is intended to be used by experts only, who know the meaning of each input value and their impact on the results.

Some very sensible and specific COVID-19 input parameters are provided in drop-down lists, such as the virus emission rate per person, susceptible people breathing rates, etc. Even though these parameters have been taken from the most updated scientific sources (as reported in the disclaimer), their selection is under the user's responsibility.

Full mixing hypothesis creates another uncertainty because, in large and high-ceiling rooms, the virus concentration is not necessarily equal all over the room volume.

Results

The generated results are sensitive to quanta emission rates which can vary over a large range. The uncertainty of these values is high. Also, there are likely to be super spreaders that are less frequent but may have higher emission rates. This makes absolute probabilities of infection uncertain, and it is better to look at the order-of-magnitude. The relative effect of control measures may be better understood from this calculation, given the current state of knowledge.

Calculated probability of infection is a statistical value that applies for a large group of individuals, but differences in individual risk may be significant depending upon the individual's personal health situation and susceptibility.

These limitations and uncertainties mean that rather than predicting an absolute infection risk, the calculation is capable of comparing the relative effectiveness of solutions and ventilation strategies to support the most appropriate choice. The calculation model can show which strategy offers the lowest load for non-infected persons and provides just an indication of risk. The model can be

applied to show low and high-risk rooms in existing buildings, which is very useful in the risk assessment of how buildings should be used during the outbreak.

Example

In the following table, there is an example of a comparative analysis (based on the previous example) - with varying recirculation fraction from 100% to 0% (full outdoor air).

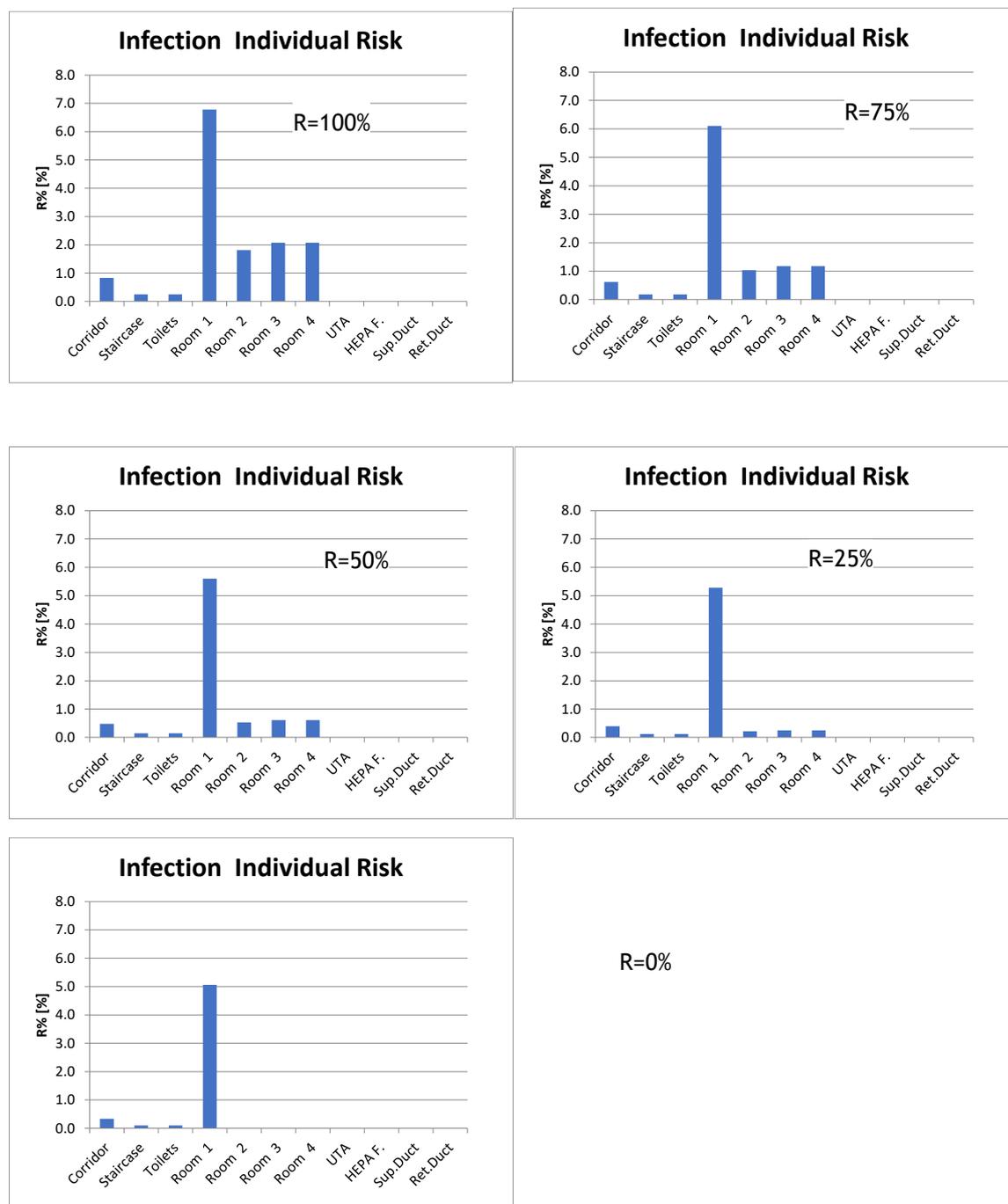


Figure 16 Individual infection risk - without a facial mask.

From the histograms on Figure 16 it is possible to see how the increased ventilation, achieved by reducing the air recirculation with the same supply flow rates. It is reducing close to zero the individual risk in the other rooms, while it is not so effective in the room where the infected person

is.

If instead all people are wearing a facial mask with 50% virus filtration efficiency, it can be estimated from the histograms on Figure 17 what kind of effect this measure would have on the individual infection risk.

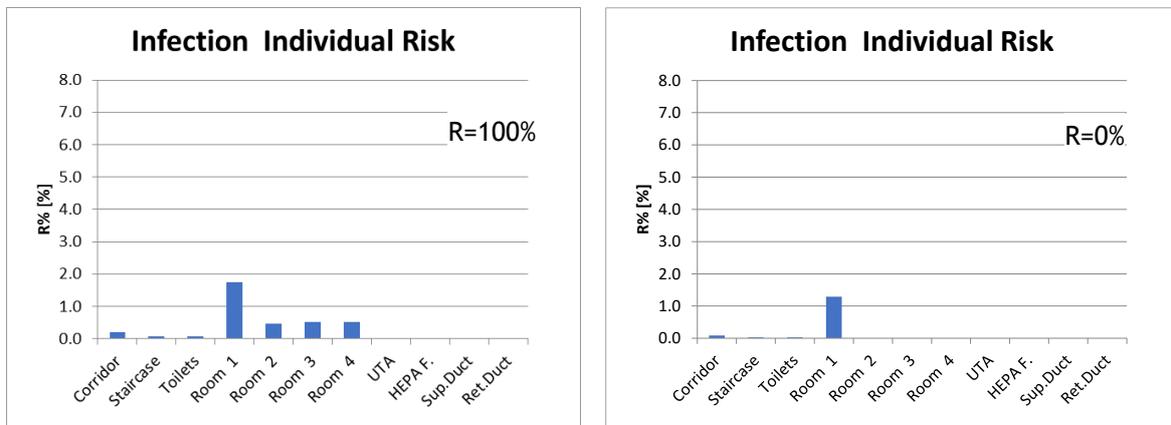


Figure 17 Individual infection risk - wearing a facial mask.

Tool availability

This tool has been produced with the intention to give to any socially responsible HVAC engineer a simple and fast to use engineering “weapon” in fighting against COVID-19 pandemic. For this reason, this tool will be freely available after the evaluation of REHVA COVID-19 Task Force.

Download the REHVA COVID-19 Multi-room and Recirculation Calculator at REHVA’s website:
<https://www.rehva.eu/activities/covid-19-guidance>

Feedback

If you are specialist in the issues addressed in this document and you have remarks or suggestions for improvements, feel free to contact us via livio.mazzarella@polimi.it. Please, mention “Multi-room and Recirculation Calculator” as subject when you email us.

Colophon

This document was prepared by Prof. Livio Mazzarella, Milan Polytechnic University (livio.mazzarella@polimi.it), with the support of the REHVA Covid-19 Task Force. Members of this expert group are:

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This work has been carried out during my mandate as AiCARR expert in the COVID-19 REHVA Task Force, the work of which was stimulus for developing the model. For this reason, I would like to acknowledge all Task Force participants and AiCARR for this opportunity.

Prof. Livio Mazzarella

Disclaimer

This model is our best scientific estimate, based on the information currently available. It is provided in the hope that it will be useful to others in providing and applying more efficient virus removal options during this pandemic.

It must be used ONLY for comparative infection risk analysis related to possible improvements on both ventilation solutions for new buildings/systems and retrofit and operational strategies for existing buildings/systems under pandemic condition.

The model result strongly depends on the input parameters and their uncertainty reflect on the result itself. Thus, this tool is intended to be used by EXPERTS ONLY, who know the meaning of each input and their impact on the results.

It is an ongoing work and may therefore contain defects or “bugs” inherent to this type of software development. In case some mistakes or deficiencies are found, please write to:

livio.mazzarella@polimi.it .

The individual developers and REHVA will in no event be liable for any direct or indirect, material or moral, damages of any kind, arising out of the use of the tool.

References

- [1] [REHVA , 2020, REHVA COVID19 GUIDANCE v. 4 - “How to operate HVAC and other building service systems to prevent the spread of the coronavirus\(SARS-CoV-2\) disease\(COVID-19\) in workplaces”](#)
- [2] [Mazzarella, L. 2020, ”A tool for HVAC systems operational strategy assessment for reducing infection risk in existing and newly designed buildings”, REHVA Journal 05/2020](#)