Health based IAQ design: comparison among different approaches

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Abstract. In designing any system that must achieve and maintain a certain indoor air quality (IAQ), a ventilation system or an air cleaning system, it is necessary to know the required clean air flow rate they must provide, where clean air means free of pollutants. Herewith a methodology is provided for defining the minimum clean air flow rate able to keep the infection probability due to a pathogen presence below a target value. A program has been developed to calculate such target values for any available pathogen infectious capacity, expressed in quanta, which allows us to specify all boundary conditions, such as the activity and activity level of both infectious and susceptible individuals, their numbers, the room size, etc. At the same time several others standardised air quality design method as described in EN 16798-1, ASHARE 62.1, ASHARE 241 have been employed to check the difference in the required clean air flow rate between them and the health-based approach. What emerges from a preliminary analysis carried out using such tool is that if we constrain the comparison to the most common and frequently spread virus, seasonal influenza, the design flow rate required by the perceived IAQ method is enough in several cases.

1 The model for health-based clean air flow rate

Herewith a methodology is provided for defining a minimum clean air flow rate to be used as design target for keeping the infection probability at a defined level respect to a specific virus. This methodology is not based on the usual steady state approach to define the most severe conditions for system sizing, i.e. design conditions. Under the unsteady state and the fully mixing hypothesis, the generic pollutant concentration in air is given by equation:

$$\frac{dC(t)}{dt} = \left[\frac{G(t)}{V} + \lambda_V^*(t) \cdot C_{SUP}(t)\right] - \lambda(t) \cdot C(t) \quad (1)$$

C_{SUP} supply air pollutant concentration, [mg/m^3]
G pollutant source, [mg/h]
λ total removal rate, [1/h]
λ^*_V useful supply air volume flow rate per room volume, [1/h]
V room net volume, [m^3]

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which can be easily integrated over the time if the pollutant source (G=const), the total removal rate (λ =const and λ^*_V=const) and the pollutant concentration in the supply air (C_{SUP}=const) are constant:

$$C(t) = C_0 e^{-\lambda t} + \frac{1}{\lambda}\left[\frac{G}{V} + \lambda_V^* \cdot C_{SUP}\right]\left(1 - e^{-\lambda t}\right) \quad (2)$$

where

C_0 pollutant indoor uniform concentration at t=0, [mg/m^3]

1.1 Airborne disease transmission

The model of airborne disease transmission is based on a conceptual model that represents the concentration of virus-laden small droplets as a plume, where expired viral content is diluted immediately upon expiration and as it travels in the air carried by the air flow. As a result, the concentration of the virus does not increase uniformly in the interior environment of the enclosed space but is found at higher concentrations closer to the infectious subject.

1.1.1 Full-mixed homogenous model

Due to the difficulty of solving the associated complex fluid dynamics, it is usual to assume that the emission of virus-laden small droplets is instantaneous and completely mixed into the indoor environment (full mix hypothesis or homogenous model). This simplified model is referred as "airborne long-range transmission": inhalation of airborne droplet nuclei, or aerosols, at separation distances that can be greater than 2 meters away from an infectious emission, where we can assume that the homogeneity hypothesis is enough true.

1.1.2 From particles to mixture

These airborne droplet nuclei containing the virus or bacteria are very small and then can be treated as pollutant particles or molecules and the classic fluid mixture concentration balance equations can be used with a certain confidence. The accuracy of this homogenous model also depends on the considered space: the smaller the enclosed space and the more completely mixed the air, the more the results will approximate reality. While it is difficult to set an upper limit to the appropriate room size, model application to spaces of about 500 square meters or less [1], with a height not greater than 3 metres, is more likely to produce good results. For larger spaces a zoning procedure can be a workaround, applying the model to several smaller spaces

1.1.3 Steady state as usual condition for system sizing

Thus, if the pollutant is constituted by airborne droplet nuclei and if we assume that the supply air flow rate is completely clean of them (C_{SUP} = 0), their concentration in steady state (C_{ss}) condition is given by equation (2) as modified in the following:

$$C_{SS} = \frac{G}{\lambda V} \quad (3)$$

where total removal rate λ is given by

$$\lambda = \lambda_V^* + \lambda_d + \kappa + \eta_{AC}\lambda_{AC} \quad (4)$$

with

λ_d virus deposition rate, [1/h]
κ virus decay coefficient, [1/h]
λ_{AC} flow rate through the air cleaner per room volume, [1/h]
η_{AC} air cleaner effectiveness, [-]

1.1.4 Introduction of quanta

The next step in the model is switching from a droplet nuclei concentration to its infective strength. In 1955 Wells [2] not knowing for sure how many airborne infectious particles (conceivably containing more than one infectious microorganism), used quantum or quanta (q) to describe whatever that unknown number was. He also understood that inhalation and infection was an inherently statistical process involving low probabilities due to dilution and other factors, and he introduced the Poisson distribution in his definition of quanta: a quantum is the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons.

Thus, instead of particles (airborne droplet nuclei) concentration, its infective effects have been introduced in the steady state mass balance equation, which is the homogeneous quanta concentration assuming that no pathogens are present in the supply air flow. Equation (3) then becomes:

$$n_{SS} = \frac{ER_q}{\lambda V} \tag{5}$$

where

n_{ss} quanta concentration in steady-state condition, [q/m^3]
ER_q total quanta emissions rate, [q/h]

1.1.5 Individual infection risk probability: deterministic approach

Later, in the 1970s, Richard L. Riley and others [3] built on Wells's work to create the Wells-Riley model (WR), which uses the quanta unit to predict infection risk in enclosed spaces. That model deals with the probability of a person, among *S* susceptible people, breathing a randomly distributed quantum of airborne infection, to get infected by *I* infectious people, and this probability is given by a Poisson distribution function as a ration between the number of exposed individuals (been infected but are not yet infectious) *E* over the number of susceptible people *S*:

$$P_I = \frac{E}{S} = 1 - e^{-D_q} \tag{6}$$

where D_q is the inhaled dose in quanta, which in its extended form is given by

$$D_q = (1 - \eta_{SPFM}) \cdot n_{SS} \cdot q_{V;b,in} \cdot t_{ex} \tag{7}$$

with

η_{SPFM} facial mask efficiency for susceptible people ,[-]
$q_{V;b,in}$ susceptible people breathing inhalation rate, [m^3/h]
t_{ex} exposure time (given space occupancy time interval) in the given space, [h]

Gammaitoni and Nucci (GN) [4] removed the steady state hypothesis keeping constant the total removal rate and total quanta emission rate. Thus, they substituted in equation (7)

the steady state quanta concentration, n_{SS}, for the average quanta concentration over the exposure time n_{avg} obtained integrating equation (2) over t_{ex}:

$$n_{avg} = \frac{1}{t_{ex}} \int_0^{t_{ex}} n(t)\, dt = \frac{n_0}{\lambda\, t_{ex}} \left[1 - e^{-\lambda \cdot t_{ex}}\right] + \frac{ER_q}{\lambda\, V} \cdot \left[1 - \frac{1 - e^{-\lambda \cdot t_{ex}}}{\lambda \cdot t_{ex}}\right] \tag{8}$$

where
n_{avg} average quanta concentration in the given space over the occupancy time interval, [q/m^3].

Assuming no virus in the space at initial condition, $n_0 = 0$, and no facial mask wearing, the quanta inhaled dose becomes

$$D_q = \frac{ER_q}{\lambda\, V} \cdot \left[1 - \frac{1 - e^{-\lambda \cdot t_{ex}}}{\lambda \cdot t_{ex}}\right] \cdot\ q_{V;b,in} \cdot t_{ex} \tag{9}$$

Equation (6) with equation (9) provide the tool to evaluate the Poisson probability that one person can become infected by S infectious persons. This is a straightforward deterministic approach that relay on the quality of the assumed data, mainly the total quanta emission rate.

1.2 Individual infection risk probability: stochastic dose-response approach

To overcome the difficulty to derive the quanta emission rate directly from epidemiological studies (large uncertainty), a similar but different approach is followed as proposed by Buonanno et al. [5, 6] a stochastic dose-response model.

Even if using quanta to express the effect of inhaled infectious airborne droplet nuclei, the inhaled infectious dose D_q is not determined from epidemiological studies, as

$$D_q = -\ln(1 - P_I) = \ln\left(\frac{S}{S - E}\right) \tag{10}$$

from which the total emission rate can be directly derived using equation (5), in in steady state, or (9) in transient state, but linking the people infectious emission rate to the basic phenomena of respiratory aerosol emission and viral load. According to Mikszewski et al [7], the individual emission rate in quanta, q_{ER}, can be expressed as:

$$q_{ER} = c_v \cdot c_i \cdot V_d \cdot q_{V;b,ex} \tag{11}$$

with

c_v viral load in sputum, [RNA copies/mL]
c_i conversion factor defined as the ratio between one quantum and the infectious dose expressed in viral RNA copies, [q/RNA copies]
V_d droplet volume concentration expelled by the infectious person, [mL/m^3]
$q_{V;b,ex}$ pulmonary exhalation rate, [m^3/h]

where c_v and c_i depend on the virus type, while V_d and $q_{V;b,ex}$ on the activity and activity level of the infectious person [1].

It should be noted that the statistic variable to be determined is now the viral load in sputum, c_v, which is easier to determine than the infection effect on a population, using in lab well controlled experiments. Also, if the base-10 logarithm c_v is used for building the statistic, a close to normal distribution is usually found that allows us to consider $\log10(c_v)$ and thus $\log_{10}(q_{ER})$ a stochastic variable.

When more than one infectious person is present in the same space where the susceptible people are, the total emission rate ER_q has been usually calculated as expressed in the WR original model, i.e. as a product of the infectious people number I and the individual emission rate q_{ER}. This is not the case even if each infectious person has the same activity and activity level, because they will never release the same q_{ER} at the same time. To account for the diversity a stochastic approach has been employed as in [1] to obtain for each infectious person his individual emission as a random value from the inverse of the cumulative normal distribution, $\Phi^{-1}(p_i, \mu, \sigma)$, as

$$q_{ER,i} = 10^{\log_{10} q_{ER,i}} = 10^{\Phi^{-1}(p_i,\mu,\sigma)} \tag{12}$$

where $\mu=(\log_{10} q_{ER})_{av}$, $\sigma=(\log_{10} q_{ER})_{SD}$, are respectively the average and the standard deviation of the base-10 logarithm of individual emission values for the specific virus considered, while p_i is a randomly extracted percentile for the i-th infectious person. Then, the total emission rate is calculated for each extraction set j summing the single contribution as

$$\log_{10} ER_{q,j} = \log_{10} \left\{ \sum_{i=1}^{I} q_{ER,i} \right\}_j \tag{13}$$

Finally, a lognormal statistic is built over M=10.000 extraction sets as

$$\log_{10} ER_{q,av} = \frac{1}{M} \sum_{j=1}^{M} \log_{10} ER_{q,j} \tag{14}$$

$$\log_{10} ER_{q,SD} = \sqrt{\frac{1}{M} \sum_{j=1}^{M} \left[\log_{10} ER_{q,j} - \log_{10} ER_{q,av} \right]^2} \tag{15}$$

from which $ER_{q,av}$ and $ER_{q,SD}$ are derived and represent the average and the standard deviation of the total emission rate. The lognormal total emission rate distribution function for a given virus, a specific number I of infectious persons and their specific activity is then given by $f(\log_{10} ER_q) = N(\log_{10} ER_q ; \log_{10} ER_{q,av}, \log_{10} ER_{q,SD})$.

To find the ER_q value as function of a percentile p the cumulative distribution function $\Phi(\log_{10} ER_q; \mu. \sigma)$ is used throughout its inverse,

$$\log_{10} ER_q (p) = \Phi^{-1}(p; \mu, \sigma) \tag{16}$$

where $\mu = \log_{10} ER_{q,av}$, $\sigma = \log_{10} ER_{q,SD}$.

Thus, the quanta inhaled dose given by equation (9) can be rewritten in terms of probability distribution as

$$n_{avg}(p_i) = \frac{10^{\Phi^{-1}(p_i;\mu,\sigma)}}{\lambda V} \cdot \left[1 - \frac{1 - e^{-\lambda \cdot t_{ex}}}{\lambda \cdot t_{ex}} \right] \tag{17}$$

where p_i is the i-th percentile in the lognormal inverse cumulative distribution of the total emission rate, $\mu = \log_{10} ER_{q,av}$ and $\sigma = \log_{10} ER_{q,SD}$.

Thus, the individual probability of infection, given by equation (6) becomes a stochastic function when all the other terms are fixed:

$$P_{I,i} = P_I(p_i) = 1 - e^{-\frac{10^{\Phi^{-1}(p_i,\mu,\sigma)}}{\lambda V}\cdot\left[1-\frac{1-e^{-\lambda\cdot t_{ex}}}{\lambda\cdot t_{ex}}\right]\cdot q_{V;b,in}\cdot t_{ex}} \tag{18}$$

A Montecarlo simulation is then performed calculating with equation (18) the individual infection probability for a set of percentiles p_i, ranging from 0,001 to 0,995, $P_{I,i}$ and its occurrence probability $P_{ERq,i}$ given by

$$P_{ER_{q,i}} = N(\log_{10} ER_{q,i}\,;\mu,\sigma)\cdot\left(\log_{10} ER_{q,i} - \log_{10} ER_{q,i-1}\right) \tag{19}$$

and, finally, the stochastic individual infection risk probability R_I is obtained summing over the percentile range (1 to N_p) the compound probability, that is

$$R_I\left(ER_{q,av}, ER_{q,SD}\right) = \sum_{i=1}^{N_p} R_I\left(ER_{q,i}\right) = \sum_{i=1}^{N_p} P_{I,i}\cdot P_{ER_{q,i}} \tag{20}$$

1.3 Health-based design clean air flow rate

Because of the use of the stochastic model based on Montecarlo simulation it is no possible to calculate the required clean air flow rate as usually done with the deterministic approach, for which from equations (4), (5), (7) and (10) it is, if the steady state approach is followed (WR):

$$q_V = V\cdot\lambda_V = \frac{ER_q\cdot q_{V;b,in}\cdot t_{ex}}{\ln\frac{S}{S-E}} - V\cdot(\lambda_d + \kappa) \tag{21}$$

or, if the transient approach (GN) is used applying equation (9) instead of equation (7):

$$q_V = V\cdot\lambda_V = \frac{ER_q\cdot q_{V;b,in}\cdot t_{ex}}{\ln\frac{S}{S-E}}\cdot\left[1-\frac{1-e^{-\lambda\cdot t_{ex}}}{\lambda\cdot t_{ex}}\right] - V\cdot(\lambda_d + \kappa) \tag{22}$$

It should be noted that in equation (21) the total removal rate term λ contains the unknown λ_V (see equation (4)); thus, it can be solved only numerically, or some approximation must be employed.

With the stochastic approach fixed the target value of R_I, an iterative procedure is employed that is calculating for different clean air flow rates the individual infection risk (RI) using equation (20) till the required R_I is found. That is

$$\begin{aligned}\forall\,\lambda = 0.0001 \div MaxReal;\, variable\ \Delta\lambda\ step\\ \rightarrow\quad R_I\left[ER_{q,av}(\lambda), ER_{q,SD}(\lambda)\right]\ \rightarrow\ \ till\ \ R_I \le R_{I,req}\end{aligned} \tag{23}$$

Then a linear interpolation is carried out using the last R (λ_i) value and the previous one R (λ_{i-1}) for both the removal rate and the total average emission rate:

$$\lambda\left(R_{I,req}\right) = \lambda(\,R_{I.i-1}) + \frac{\lambda(\,R_{I.1}) - \lambda(\,R_{I.i-1})}{R_{I.i} - R_{I.i-1}}\left(R_{I,req} - R_{I.i-1}\right) \tag{24}$$

$$ER_{q,av}(R_{I,req}) = ER_{q,av}(R_{I.i-1}) + \frac{ER_{q,av}(R_{I.1}) - ER_{q,av}(R_{I.i-1})}{R_{I.i} - R_{I.i-1}}(R_{I,req} - R_{I.i-1}) \quad (25)$$

and, finally, the required clean air flow rate is given by

$$q_{V,HB} = V \cdot [\lambda(R_{I,req}) - \lambda_d - \kappa] \quad (26)$$

2 The health-based IAQ design calculator

A simple program has been developed to calculate such target values for any available virus infectious capacity, expressed in quanta, which allows us to specify all boundary conditions, such as the activity and activity level of both infectious and susceptible individuals, their numbers, the room size, etc. At the same time several others standardized air quality design method as described in EN 16798-1 [8], ASHRAE 62.1 [9], ASHRAE 241 [10] have been employed to be able to check the difference in volume flow rate between the health-based and the perceived quality-based approach.

These are mainly prescriptive method that directly provide the required clean air flow rate as function of some general parameters as the number of people in the space, the building category, the final use, and in some cases the perceived quality.

2.1 EN 16798-1 Standard

EN 16798-1 [8] provides a prescriptive method based on perceived air quality where the design ventilation air (just outdoor air supposed to be enough clean) is calculated as:

$$q_V = N_p \cdot q_p + A_R \cdot q_B \quad (27)$$

where

q_V total ventilation rate for the breathing zone, [L/s]
N_p design value for the number of the persons in the room, [persons]
q_p ventilation rate for occupancy per person, [L/(s person)]
A_R floor area, [m^2]
q_B ventilation rate for emissions from building, [L/(s m^2)]

The ventilation rate for occupancy per person and ventilation rate for emissions from building default values are reported in Annex B of EN 16798-1 and can be overridden by the values defined in Annex A by national standardization bodies. For instance, the program implements these default values but also the Italian National values, both as a function of the quality category (ranging from I to IV) and of the building type (very low, low non low polluting building). The Italian implementation also includes a dependency on the final use of the building/space.

EN 16798-1 also provides a performance method applicable to any pollutant, but only CO_2 is directly taken into consideration (Annex B provide threshold concentration values only for CO_2). Thus, the program also calculates the outdoor air flow rate needed to maintain the given threshold CO_2 concentration for each quality category using the following steady-state mass balance equation:

$$q_{V,CO2} = \lambda_V V = \frac{(C_{SS} - C_{SUP})_{CO2}}{G_{CO_2}} \quad (28)$$

where $(C_{SS} - C_{SUP})_{CO2}$ is the relative to outdoor concentration threshold value reported in Annex B of EN 16798-1, and G_{CO2} is the indoor CO_2 production due to only the human breathing.

2.2 ASHRAE 62.1

The ASHARE Standard 62.1 [9] proposes a prescriptive approach, called ventilation rate procedure, which is using the same approach of EN 16798-1 (same equation of (25)); they differ only for the tables that are mode detailed respect to occupancy categories, but do not have quality categories.

2.3 ASHRAE 241

The ASHRAE Standard 241 [10] establishes minimum requirements for control of infectious aerosols to reduce risk of disease transmission in the occupiable space. That is achieved through the definition of the minimum equivalent clean airflow rate required in the breathing zone for each occupiable space to mitigate long-range transmission risk in Infection Risk Management Mode (IRMM), $V_{ECA,i}$, shall be determined as

$$V_{ECA_i} = ECA_i \cdot P_{Z,IRMM} \quad (29)$$

V_{ECA_i} minimum equivalent clean airflow rate required in the breathing zone to mitigate long-range transmission risk in IRMM, [L/s]
ECA_i equivalent clean airflow rate required per person in IRMM, [L/(s person)]
$P_{Z,IRMM}$ number of people in the breathing zone in IRMM. PZ,IRMM shall default to the number of occupants used to calculate the ventilation rate per the applicable standard or design occupancy or lower number of occupants during IRMM accepted by the owner.

The minimum equivalent clean airflow rate required per person, ECA_i, is given in table only as a function of the space occupancy category, without any info and specifications about virus type, activity, etc.

2.4 prEN 16798-1-3 Standard revision

The EN 16798-1 [8] is currently under review and has been split in five parts (general, thermal comfort, indoor air quality, lighting and acoustic performance). prEN 16798-1-3 is dealing with indoor air quality; in its draft version of May 2025 it proposes a new method, named Design for airborne transmission among the others that are unchanged. This method calculates the ventilation rate reducing the expected number of secondary infections from an infected person to one over the sequence of interactions the infected person has with susceptible persons during the whole pre-symptomatic infectious period. The model applies for the long-range transmission and assumes that a close contact is avoided.

Infection risk-based ventilation rate for the breathing zone is found by combining the ventilation to dilute the viral load and removal by other mechanisms than ventilation calculated as

$$q_V = q_q \cdot (N_p - 1) - V \cdot q_r \tag{30}$$

where
q_V target ventilation rate for the breathing zone, L/s
q_q quanta emission specific ventilation rate for occupancy per person, [L/(s person)]
q_r removal rate of virus decay, deposition, air filtration and disinfection, [L/(s m^3)]
N_p design value for the number of persons in the room with the distancing >1.0 m to avoid close proximity, [-]
V room volume, [m^3]

The parameters in Formula (30), the quanta emission specific ventilation rate q_q and the removal rate of virus decay, deposition, air filtration and disinfection q_r can be calculated from equation (31) and equation (32)

$$q_q = q_{ER} \cdot q_{V;b,in}/R_0 \tag{31}$$

$$q_r = \lambda_d + \kappa + \eta_{AC}\lambda_{AC} + \kappa_{UV} \tag{32}$$

where the new terms are:
R_0 basic reproduction number, R_0=1, [-]
κ_{UV} disinfection by upper room ultraviolet germicidal irradiation UVGI, [1/h]

Because the goal is to set threshold ventilation values, the required clean flow rate must be calculated without the contribution of any technical apparatus, i.e. air cleaner and ultraviolet germicidal irradiation. That means that for our purpose equation (32) reduces to

$$q_r = \lambda_d + \kappa \tag{33}$$

No suggestions or values are reported for q_{ER}, $q_{V;b,in}$, λ_d and κ in the body of the text, while default values for q_q and q_r are given in Annex B for different space category without any specification about what type of virus, activity, etc., they have been derived. Such default values are reported in table 1.

Table 1. Design ventilation rates for diluting emissions from different types of buildings.

Space category	q_q L/(s person)	q_r L/(s m^3)[a)]
Classroom	10	0,24 + $\eta_{AC}\lambda_{AC}$/3,6
Office	23	0,24 + $\eta_{AC}\lambda_{AC}$/3,6
Assembly hall	30	0,24 + $\eta_{AC}\lambda_{AC}$/3,6
Meeting room	40	0,24 + $\eta_{AC}\lambda_{AC}$/3,6
Restaurant	40	0,24 + $\eta_{AC}\lambda_{AC}$/3,6
Gym, fitness	70	0,24 + $\eta_{AC}\lambda_{AC}$/3,6
[a)] in the case of no room air cleaner, λ_{AC}=0		

The use and the setting to 1 of the basic reproduction number R_0 is an unclear point in the revision of standard, because it applies to large events than one room event. But more explanations about its use and the derivation of the values reported in Table 1 can be found

in reference [12]. To calculate such default values for q_q and q_r, occupancy duration of 2,6, and 9 h in meeting rooms, classrooms, and offices, and interaction time of an infectious individual in the vicinity of susceptible persons, including traveling, lunches, and other out-of-home activities, of 16 h in schools and 22,5 h in other spaces over 2,5 days of the pre-symptomatic infectious period have been used. These result in R_0 values of 0,4 in offices, 0.375 in classrooms and 0,089 in meeting rooms, restaurants and gyms. For quanta emission rates time average values of the of q_{ER} = 4 quanta/(h pers) in classrooms, 6 quanta/(h pers) in offices and gyms, and 10 quanta/(h pers) in meeting rooms and restaurants are used.

2.5 The calculator interface

The computer program, titled "Health-Based Design Air Quality Calculator", is implementing all features reported in the previous sections and is performing all calculation in real time: when an input variable is changed, the related flow rates are immediately recalculated. Figure 1 shows the interface where in the same window both the input variables, the intermediate calculated values, the outputs and a graph are reported, where the different colours refer to the different calculation methods.

The program has been developed for Windows, and an installable version and a portable version are available.

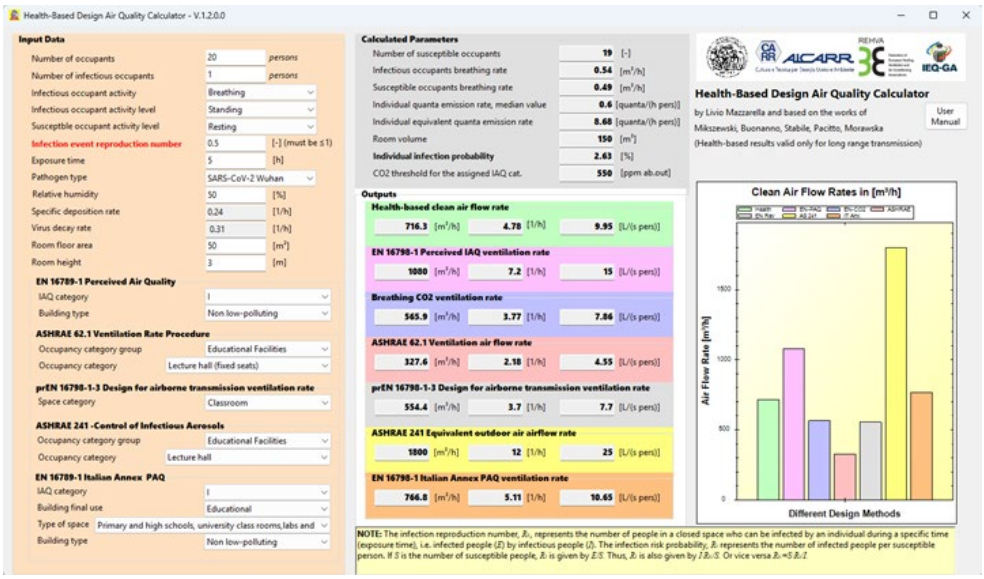

Fig. 1. Program interface: input and output with graphics in the same unique window.

3 Application to a lecture room

An example of the information that the calculation program can provide to the designer is reported in the following for the case of a lecture hall of room floor area of 50 m^2 and hight of 3 m (150 m^3). The number of persons in the room is fixed to 20 and the infectious person is always only one, except the last influenza case when is has been set to five. For all cases, except influenza virus, the infectious person activity is "loudly speaking" and the activity level "standing", while for the other susceptible people the activity level is "resting". Relative humidity is always equal to 50%.

For the other methods, which depend only on the occupants' number and the susceptible people the activity level (only breathing CO_2), other than they specific parameters, these parameters have been taken the same in all considered cases in a way to provide their maximum flow rate; respectively:

- EN 16789-1 Perceived Air Quality
  - IAQ Category: First
  - Building Type: Non-low polluting building
- ASHRAE 62.1 Ventilation Rate Procedure
  - Occupancy Category Group: Educational Facilities
  - Occupancy Category: Lecture Hall (fixed seats)
- prEN 16798-1-3 Design for airborne transmission ventilation rate
  - Space : Classroom
- ASHRAE 241 -Control of Infectious Aerosols
  - Occupancy Category Group: Educational Facilities
  - Occupancy Category: Lecture Hall
- EN 16789-1 Italian National Annex PAQ
  - IAQ Category: First
  - Building final use: Educational
  - Type of space: Primary and high schools, university classroom, labs and teachers' room
  - Building Type: Non-low polluting building

Thus, three different types of viruses have been considered, Wuhan SARS-CoV-2, its Delta variant and Measles (the most infective), and the exposure time, t_{ex}, the infection event reproduction number, R_e, have been changed, respectively form 5 h to 1 h and from 1 to 0,5. The results are reported in Figure 2, Figure 3, Figure 4and Figure 5.

The specific cases for influenza virus are instead reported in Figure 6.

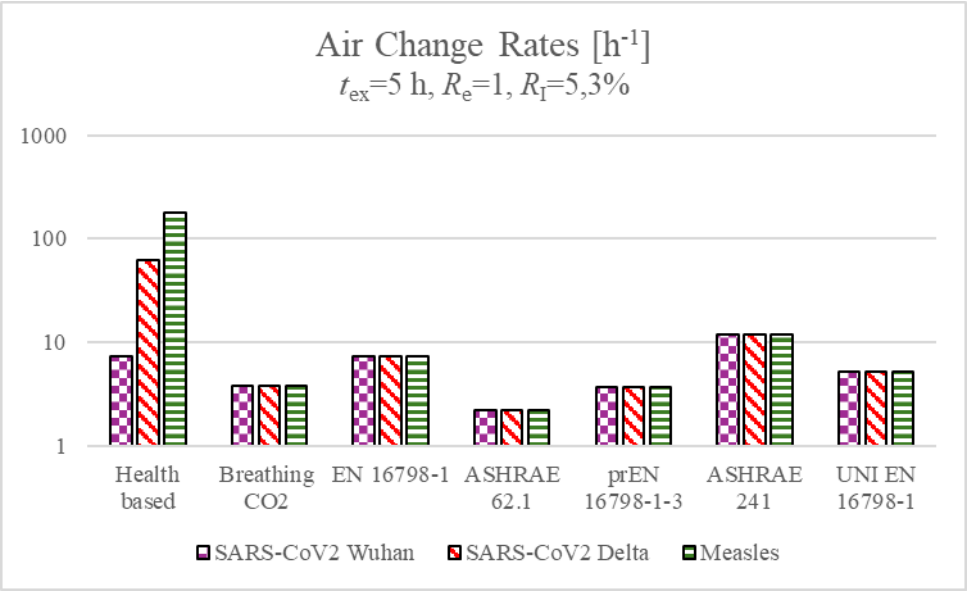

Fig. 2. Air change rate for t_{ex}=5 h, R_e=1.

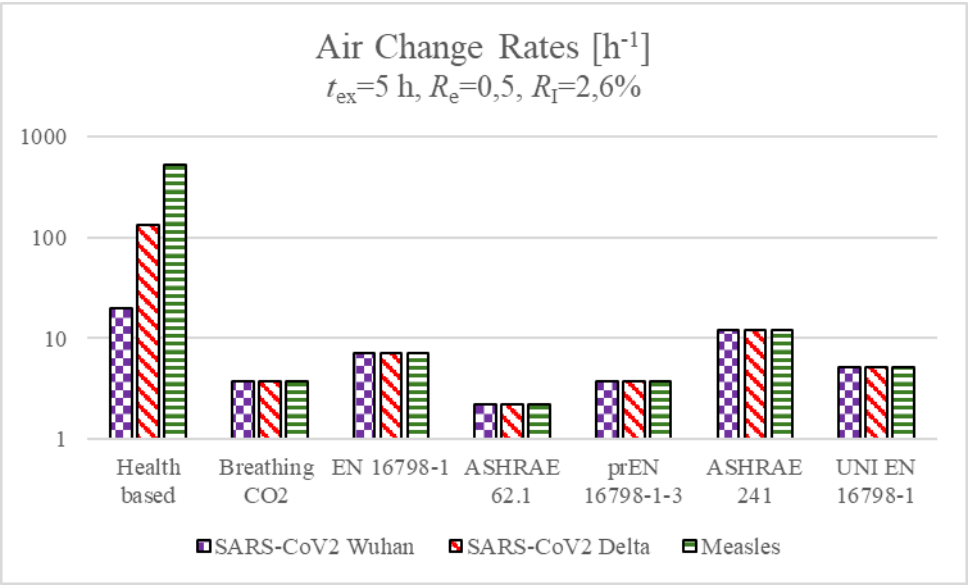

Fig. 3. Air change rate for t_{ex}=5 h, R_e=0,5.

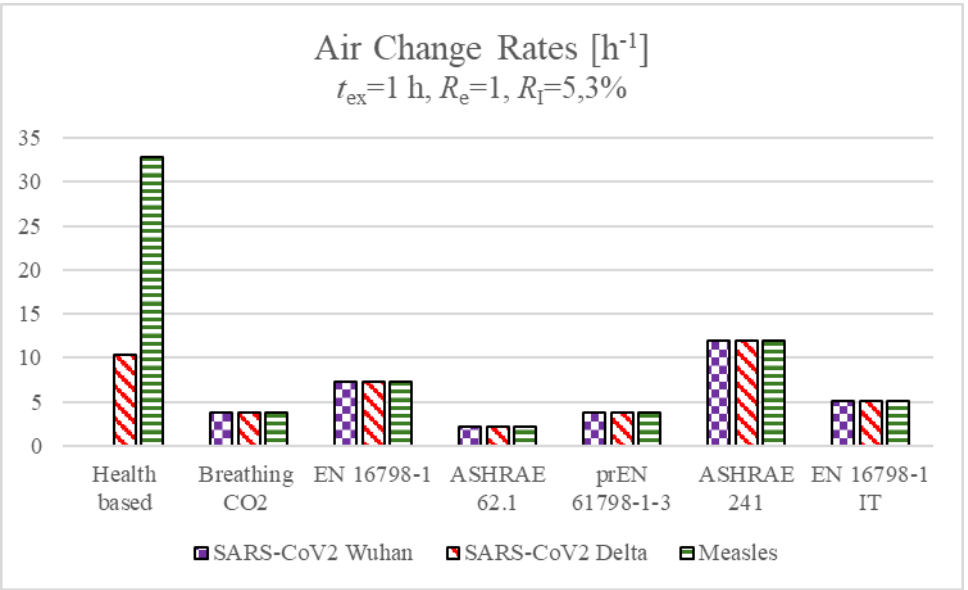

Fig. 4. Air change rate for t_{ex}=1 h, R_e=1.

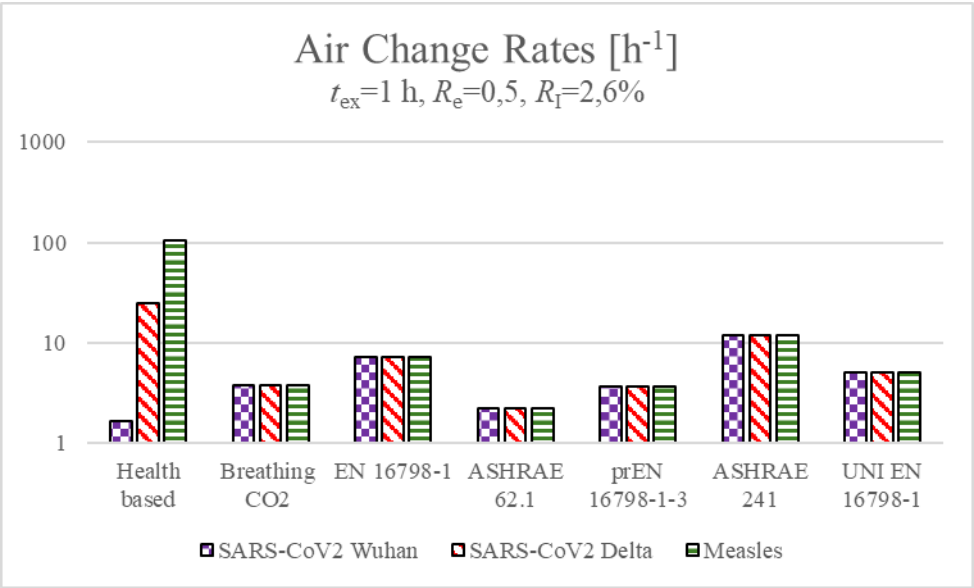

Fig. 5 Air change rate for t_{ex}=1 h, R_e=0,5.

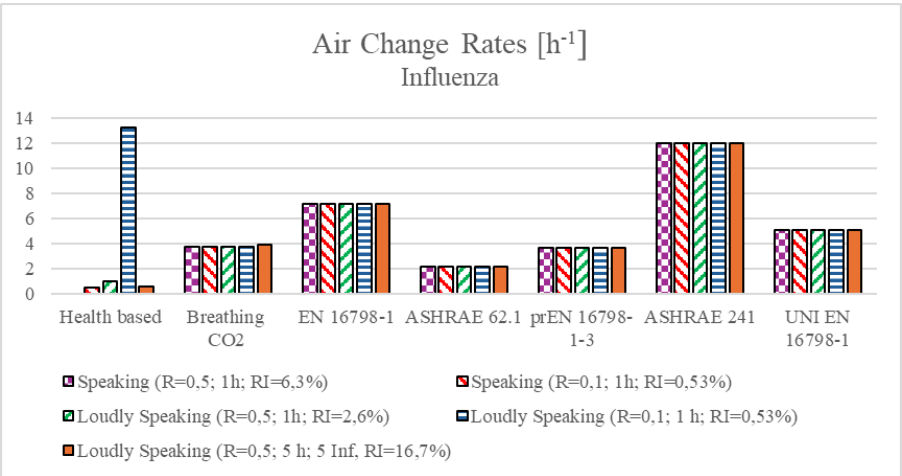

Fig. 6 Air change rate for Influenza virus in different emission conditions.

4 Results and conclusions

Analysing the results it is possible to see how the required clean flow rates for the three viruses considered are always higher than any design flow rates calculated with the other methods, when 5 hours permanence time is considered regardless the imposed event reproduction number (R_e =1 or 0,5, which means individual infection probability of 5,3% or 2,6%) (Figure 2 and Figure 3). If this time is lowered to 1 hour, then the required clean flow rates are still higher only for R_e =0,5 (Figure 5) and only for SARS-CoV-2 Delta variant and Measles. For R_e =1 only Measles required air flow is higher (Figure 4). The other flow rates are always the same in any case.

Looking at Figure 6, which represents the required clean air change rate for Influenza virus under different emission conditions and permanence time, it is possible to see that this flow rate is in almost all the cases lower than the other design flow rates. Only when loudly speaking with R_e =0,1 (R_I=0,53%) is considered, then the required clean air flow is the highest. Even if we increase the number of infectious people to 5 but keeping R_e =0,5 (R_I =16,7%) the required clean air flow rate remains lower than all the others. This is explained by the fact that the individual infection probability increases from 0,53% to 16,7% requiring much less clean air flow rate pro-capita.

As conclusions, we can point out that:

- the health-based clean air flow rate depends on several variables, which cannot be all incorporated in a table-based method as the ASHRAE 241 or the prEN 16798-1-3; high flow rate sensitivity on variables changes does not allow such kind of approach;
- the most common virus, influence, due to its low infectivity, can be effectively controlled in most cases by the usual design flow rate define by the Perceived Indoor Air quality methods;
- it should be noted that the proposed method for the health-based design relays un the full mix hypothesis and thus is valid for what is called “long range transmission of an infection”, i.e. from 1,5 or 2 meters from the source.

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