RISK OF BIOAEROSOLS IN SMALL AND POORLY VENTILATED INDOOR PLACES WITH LOW CONCURRENT USE

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ABSTRACT:

Currently, the risk of aerosol transmission of respiratory viruses such as SARS-Cov-2 indoors is recognised. Therefore, the objective of this work is focused on the study of small and poorly ventilated indoor spaces with low concurrent use, to find out if it is possible in a simple way to obtain at least an orientation of the potential risk for users at each moment of use. The methodology is based on the study of the existing bibliography, analysing models, equations, and calculations to find out if it is possible to use any of them to the case and that at the same time does not present excessive complexity. The results and conclusions indicate that there are clear limitations (fluid dynamics- aerodynamic, influence by temperature, light and humidity, or situations in which the user speaks, sings, shouts, coughs, or sneezes), but useful approximations can be offered regarding the risk of use.

Keywords: Indoors; risks; ventilation; human bioaerosols

RESUMEN:

Actualmente, se reconoce el riesgo de transmisión por aerosol de virus respiratorios como el SARS-Cov-2 en interiores. Por tanto, el objetivo de este trabajo se centra en el estudio de espacios interiores pequeños y mal ventilados con bajo uso concurrente, para averiguar si es posible de una forma sencilla obtener al menos una orientación del riesgo potencial para los usuarios en cada momento de uso. La metodología se basa en el estudio de la bibliografía existente, analizando modelos, ecuaciones y cálculos para saber si es posible aplicar alguno de ellos al caso y que a la vez no presente una excesiva complejidad. Los resultados y conclusiones indican que existen claras limitaciones (fluidodinámica-aerodinámica, influencia de la temperatura, la luz y la humedad, o situaciones en las que el usuario habla, canta, grita, tose o estornuda), pero se pueden ofrecer aproximaciones útiles en cuanto al riesgo de uso.

Palabras clave: Interiores; riesgos; ventilación; bioaerosoles humanos

1. INTRODUCTION

In the field of buildings, environmental risks in interior spaces have always been a topic of interest, especially in spaces designed for the stay of more than one person at a time. However, this study focusses on the environmental risk of infectious viral aerosols in confined spaces, understood as those designed almost exclusively for successive, nonsimultaneous use and with a low ventilation rate. But before developing this objective, we provide some preliminary points about the state of the matter.

1.1 STATE OF THE ART

The risk of transmission of respiratory viruses such as SARS-Cov-2 has been linked to aerosols, which are generally more dangerous in closed spaces where the virus dissipates or degrades more slowly [1], especially in dwellings [2].

These and other authors have also detected the different factors that influence the risk of contagion in these indoor spaces [3].

Regarding quantitative methodologies for estimating the risk of indoor aerosols, since the appearance of COVID-19, various researches and reviews have been carried out.

Peng et al. [1] propose two indicators of infection risk, relative risk (Hr) and risk (H), and their calculation is carried out by combining key factors such as the rate of the generation of aerosols containing viruses, the rate of respiration flow, masking and its quality, ventilation and aerosol removal rates, the number of occupants and the duration of exposure. However, it focusses on shared spaces, which is not exactly the case study.

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Pag. 1 / 12

RESEARCH ARTICLE

David Marín-García, Ubaldo Espino, David Bienvenido-Huertas, Pedro Fernández-Valderrama

Parhizkar et al. [4] provide a model that calculates the concentration of virus-laden aerosol particles in well-mixed indoor air using a mechanistic approach that takes into account particle emission dynamics, particle deposition on indoor surfaces, ventilation rate, and filtration of a single zone, relating in a novel way the concept of "inhaled and deposited dose" in the respiratory system of receptors linked to a dose-response curve.

However, these are calculations in shared scenarios and to carry out its verifications, it uses cases of COVID-19 outbreaks in spaces that are not as reduced as those that are the object of this investigation and in which infected people of different infectious behaviour are mixed (with more or less cough) with uninfected.

 Jones et al. [5] develop a mass balance model for the number of ARN copies inhaled over a period of time by occupants of a well-mixed indoor space. For the objective pursued in this research, this approximation is not possible, due to reasons similar to those of previous cases, and because the actual experimentation is very complex.

Lelieveld et al. [6] provide an algorithm that automatically calculates the probability of transmission if a person in the room is highly infectious, being able to choose between different options (learning classroom, office, choir, etc.). In addition, it provides information of interest such as the infectious dose, the virus load of the infected person, and the survival time of the virus in the air.

However, it needs to introduce parameters with the air exchange rate, in this case the efficiency of the filters of the face masks. For the objective pursued in this research, it is once again a partial approach since it focusses on shared spaces, and therefore it is not fully applicable, although it is of great interest.

Sze To GN et al. [7], concerned about not having a perfectly mixed environment, to estimate the concentration of infectious "units" in the air and thus calculate the exposure to viruses in such environments, develop a methodology using the spatial distribution of expiratory aerosols and the virus viability characteristics.

Therefore, this methodology combines a virus viability function with aerosol distribution data to estimate exposure levels in different locations. Thus, the volumetric density of expiratory aerosols is determined at different points using an aerosol spectrometer. This could be done using cultures and biological sampling, but with the spectrometer the times for collecting samples and obtaining results are greatly reduced.

This is an interesting approach but one that is difficult to apply to the case under study since an aerosol spectrometer is needed to perform constant measurements at various points and if it is to be reliable, it must be of high quality and this implies a high cost since, although there are low-cost particle metres, there are also discrepancies regarding their reliability [8].

At this point, it must be said that it is common in epidemiological studies to assume that the indoor environment is perfectly mixed when estimating the concentration of infectious 'units' in the air, such as for example the well-known Well-Riley equation [9] and it must also be said that this has been controversial [10], [11] since it depends on existing air flow at all times [12], [13], which has been evidenced in various ways, such as for example using contaminants in the gas phase to simulate aerosols [14], [15] or considering aerosols like discrete polydisperse matter using experimental and numerical methods in different types of ventilation systems [16], [17].

However, estimating exposures to airborne pathogens in different locations, circumstances, particle sizes, and airflows existing at each moment would require constant biological sampling and count at numerous points. This can be an expensive, tedious, and very complex process.

Therefore, our study will continue to use the assumption of a more or less homogeneous mixture, applying a safety margin or coefficient that obeys the results offered by the aforementioned authors.

Taking all of the above into account, this study focusses on finding out it is possible to analyse the risks in spaces not normally used simultaneously, special circumstances not being the object of this study (super spreaders, talking, coughing, sneezing, abnormal environmental parameters, etc.).

2. MATERIALS AND METHODS

The methodology is based on the study of the existing bibliography and the application of the models, equations and calculations that allow the corresponding risk to be ascertained in similar situations.

Once the appropriate equations have been detected, data are taken from a room with ventilation and reduced dimensions, in order to apply said models, calculations and equations, with them and draw the corresponding conclusions with the results.

The considered room has a reduced volume (9m3) and a renewal of air of 0.8 renewals per hour. Regarding ventilation, it was calculated using the CONTAM® simulation software [18]. Figure 1 shows the steps followed in the research.
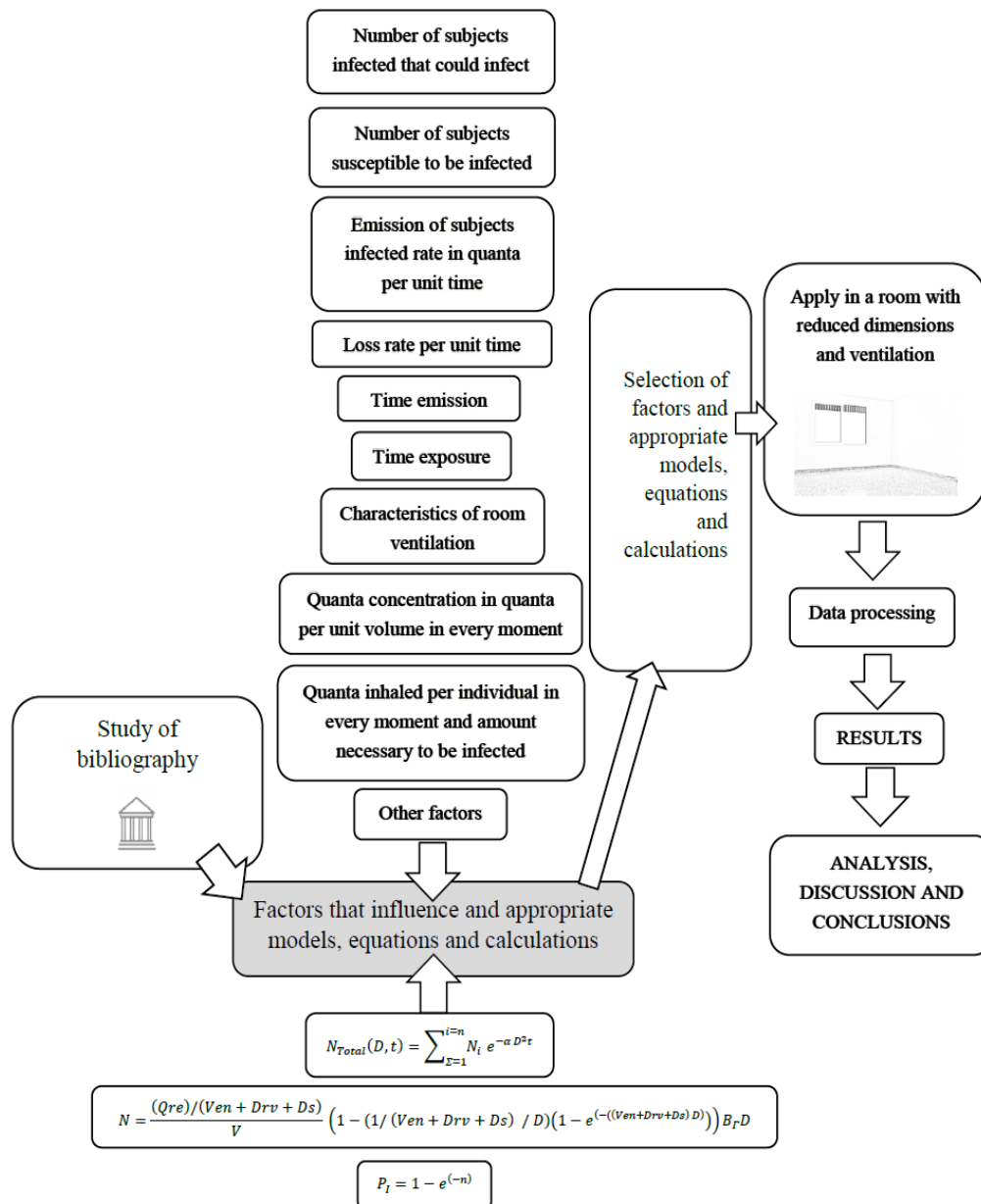

Figure 1. Flowchart of steps followed in the research.

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Pag. 3 / 12

2.1 FACTORS, MODELS, AND EQUATIONS

The classical concept of the probability of becoming infected is a simple relationship between infected cases and the number of susceptible cases, whose equation would be the following (1):

$$P_I = C/S \qquad (1)$$

where C is the number of cases that will be infected and S the number of subjects susceptible to infection. The difficulty lies in how to calculate or predict the number of subjects who would become infected. In this sense, this probability would be conditioned by the amount of infectious dose of virus inhaled at each moment by an individual susceptible to being infected. This variable is often called (n), and the Wells-Riley model [9] has been used for decades to calculate the probability of infection using Equation (2):

$$P_I = 1 - e^{(-n)} \qquad (2)$$

There are several models [19] [20] [21] [22] [23] that quantify the risk of aerosol transmission in various scenarios. These models are called quantitative microbiological risk assessment (QMRA) and calculate the probability infection risk according to the Wells-Riley model; the (n) should be determined for each specific case as, in indoor spaces, this (n) depends on many factors or variables:

- Number of individuals infected that could infect;
- Quanta or rate of generation produced by an infector (infectious units produced / time / infector) [24].
- The rate of pulmonary ventilation of each susceptible individual, that is, their respiratory frequency (m3/time).
- Exposure time
- The ventilation rate of the room (m3/time).

The original Wells-Riley model considered the rate of ventilation as the only factor affecting the risk of infection, assuming that the space is well mixed.

The study by Sun and Zhai [25] introduced two other indexes: the probability of social distance (Pd) and the effectiveness of ventilation (Ez). Reagarding Ez, references from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), indicated by Sun and Zhai [25], could be used.

Studies by Peng and Jimenez [26] also included "1-min" in the equation, i.e., the filtration effectiveness of the face mask by inhalation, and "1-Pim", the infectious units inhaled by a non-infected and immune individual.

On the other hand, Peng and Jiménez [26] indicated that if an individual who does speak and is infected and another who is susceptible to being infected, is considered (n) would be as follows (Eqs. (3)-(6)):

$$(n) = AvgQc \, B_r \, D \, (1 - Maski) \qquad (3)$$

being

$$AvgQc = \left(Ner/Lr/V \left(1 - \left(\frac{1/Lr}{D} \right) \left(1 - e^{(-Lr\,D)} \right) \right) \right) \qquad (4)$$

where

$$N_{er} = \left(Q_{er}(1 - Maskee) \right) \qquad (5)$$

$$L_{\Gamma} = V_{en} + D_{rv} + Ds + \text{Acm} \qquad (6)$$

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Pag. 4 / 12

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where

n is the inhaled quanta per individual;

AvgQc is the Avg quanta concentration in quanta per m3;

Br is the breathing rate of an individual in m3/h (1.1 talking a lot, 0,8 talking little, or no talking) Miller 2020 [27];

D is the duration;

Maski is the mask efficiency for intake %;

Ner is the net emission rate in quanta per hour;

Lr is the total first order loss rate per hour;

V is the volume;

Qer is the quanta emission rate in quanta per hour (individual who does not talk): 16 per hour estimated by Miller (2020) [27] and Buonnano et al. [28], [29];

Maskee is the mask efficiency for emission;

Ven is the ventilation w/outdoor air=air changes per hour in the room;

Drv is the virus decay rate of the virus per hour (0.32 Covid19);

Ds is the deposition on surfaces per hour (average of literature values (0 and 0.62), Miller et al. (2020) [27]);

Acm is the additional control measures (including disinfection with UV and HEPA filters);

Applying to this equation the parameters corresponding to the room under study, if two individuals enter it at the same time without any kind of protection (Maski =0; Maskee =0; Acm =0) and one of them is infected, Equation (7) would be as follows:

$$N = \frac{(Qre)/(Ven+Drv+Ds)}{V} \left(1 - (1/ (Ven + Drv + Ds) \ / D)\left(1 - e^{(-((Ven+Drv+Ds)\,D))}\right)\right) B_\Gamma D \qquad (7)$$

On the other hand, Scott H. Smith et al. [30], which focused on aerosol persistence in relation to the SARs-COv-2 transmission, studied the dynamics of respiratory droplets. The risk of infection is estimated according to the experimental results of the persistence of the infectious droplets in the air, thus deducing that the number of droplets in suspension significantly decreases, so if the original number of droplets in suspension No and their diameters D are known, the decrease N of the droplets would be as follows (8):

$$N(D,t) = \text{N}oe^{-\alpha D^2 t} \qquad (8)$$

Being α an empirical constant dependent on the height h of typical sedimentation.

According to these authors [30] $\alpha \cong \rho g/18\eta h$.

If the droplets are of different size, Equation (9) would be as follows:

$$N_{Total}(D,t) = \sum_{\Sigma=1}^{i=n} N_i \ e^{-\alpha D^2 t} \qquad (9)$$

This model focusses on the calculation of the amount of virus inhaled by an individual who enters and stays in the same room where an infected individual generated aerosol. For this purpose, it is assumed that the number of infectious droplets required to infect an individual N inf is comparable to that of other coronaviruses, including SARS-CoV-1 and the influenza virus, i.e., N inf = 100–1000, adopting the most conservative position and assuming the value of N inf = 100 droplets. It is also assumed that subjects have a normal respiratory frequency (16 inhalations/min, each with 0.0005 m3 of air volume). In this case, and supposing a uniform mix, if it is known at each moment how many infectious droplets per m3 of air of the room are in suspension, it could theoretically be established at each moment whether the susceptible subject inhales enough droplets to become infected and therefore the time from which the risk is high could be predicted.

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Pag. 5 / 12

Since more than 80-90% of aerosols are very small and an average of more than 500 are generated per litre of exhaled air (about 3000 droplets are generated when coughing and about 40000 are when sneezing) [31]–[33], the initial infectious droplets could be calculated and that number could be included in the exponential formula (9) of the decrease of these droplets (by degradation) to which the decrease by proportional ventilation should be added to air renovations, thus knowing at each moment how many accumulated droplets are inhaled by the susceptible subject and when the risk of infection starts.

2.2 CHARACTERISTICS OF THE ROOM

As indicated later in the limitations section, based on the predetermined objective, it has been chosen to simulate the calculations sustained by data from a real space that is considered small because it is of a typical design for a single-use room with characteristics that favour it be poorly ventilated. This makes it possible to study an unfavourable case that serves as a reference, since it would be the subject of another future study to be able to carry out combinations of dimensions and various ventilations.

Thus, the room chosen does not have a window or extractor fan and during the time of use of the room, it is considered that the door remains closed, which, as already mentioned, is considered the most unfavourable case.

Regarding the dimensions of the room, it is 2.00x2.00x2.25 m (9 m3). The one entrance door is 1.26 m2, with a 30 cm2 ventilation opening at the bottom and a 140 cm2 ventilation duct outside in the upper part of one of its walls.

3. RESULTS AND DISCUSSION.

3.1 GENERAL BEHAVIOUR ASPECTS

First, if we only take into account Wells-Riley models [19]–[23], with the adjustments introduced by other authors mentioned [25], [26], applying this to the data obtained from the chosen room would give us the probability of aerosol infection according to the residence time of two individuals simultaneously. Taking into account that the room considered has a reduced volume (9m3) and an air renewal of 0.8 renewals per hour, the results are those shown in Figure 2.
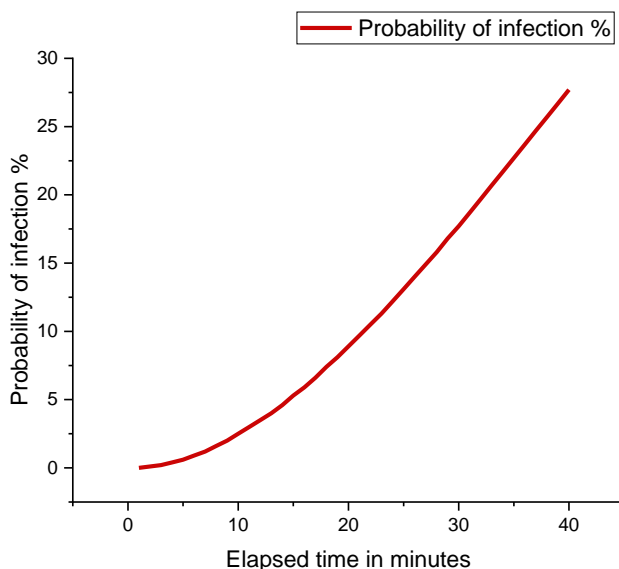

Figure 2. Probability of infection obtained by applying the Wells-Riley equation to the simulation room, using the data of the minimum ventilation of 0.8 changes per hour and two individuals who remain in said room simultaneously without talking, singing, shouting, coughing, or sneezing, and separated at least 1.5 metres.

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Pag. 6 / 12

As already mentioned, this risk calculation formula does not fit the objective, since the infected and susceptible are in the room at the same time.

However, this is an appropriate reference to verify that if an infected individual is in the room with a susceptible one at the same time, the risk of the first minutes is low, at least in relation to aerosols and provided that the subjects only breathe (no talking, singing, coughing, etc.) and maintain the security distance recommended (from 1.5 to 2 metres), which is a challenge due to the small size of these spaces.

Second, with respect to the model of Scott H. Smith et al. [30], and considering that a subject could expel an average of 500 droplets per litre exhaled (i.e., 16 exhalations per minute and each exhalation is 0.5 litres, which applies 8 litres per minute, which are 4000 droplets per minute), the formula of the decrease of these droplets [30] could be applied with the adaptations mentioned above in relation to the air renovation through ventilation. Thus, the amount of infecting droplets could be approximately obtained (the average per m3) at each moment, thus knowing how many accumulated droplets could be inhaled, even the droplets inhaled by the susceptible subject who enters the room could be accumulatively calculated, thus knowing when the risk of becoming infected starts.

In the case of the room under experimentation, with a dimension of 9 m3, if the most restrictive air renovation of 0.8m3/per hour and a suspension of 4000 droplets generated by a subject staying one minute in the room are considered, these drops would disappear following the curve indicated in Figure 3, assuming a homogeneous mixture.
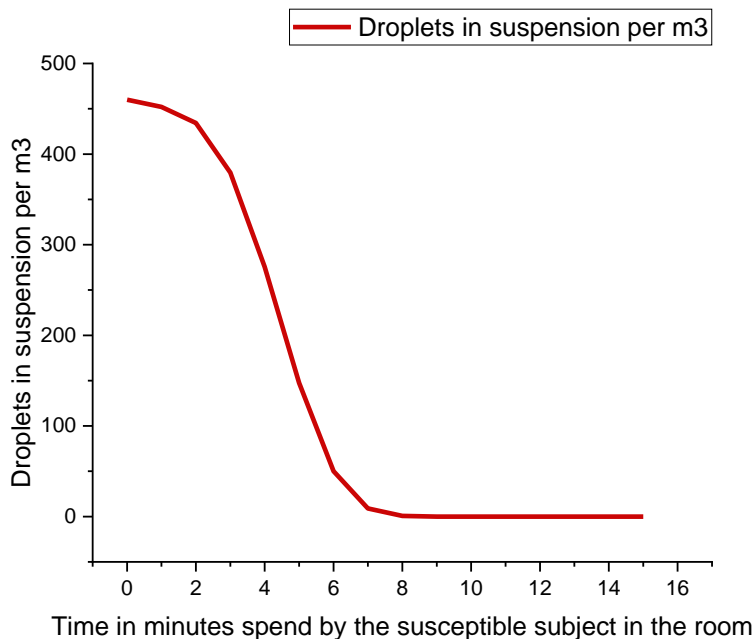

Figure 3. Relationship between time and the number of droplets in suspension per m3 at each moment.

Therefore, if an infected subject uses the simulation room for 1 minute, most droplets in suspension disappear around 5 minutes after leaving. In this case, if at least 100 droplets are required to be infected and the subject breaths 0.008 m3/minute, an approach of how many droplets are inhaled per minute could be accumulatively determined, as Figure 4 shows.

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Pag. 7 / 12

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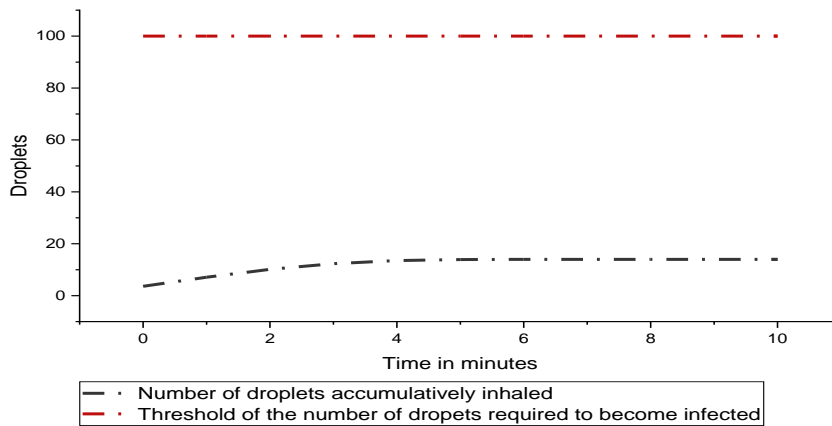
Figure 4. Relationship between the time during which an uninfected subject remains inside the room and the accumulated number of droplets inhaled at each moment.

In this case, the susceptible subject could use the room after it has been used by another subject because, theoretically, the concentration of airborne droplets makes transmission more difficult (although not impossible); moreover, the environment will be clean enough in a short time by air degradation and renovation.

Taking into account this methodology, and as Figure 5 shows, an approach to the relationship between the stay time of an infecting subject who previously has been in the room and the time when the susceptible subject could use the room with medium-low risk, entering the room after the infecting subject.
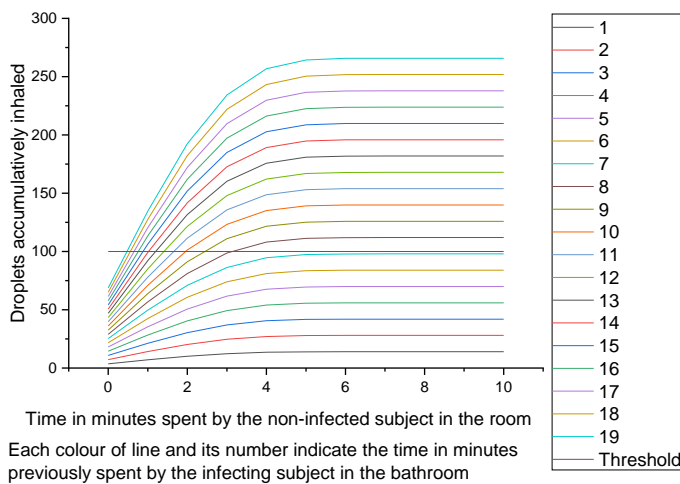

Figure 5. Relationship between the time spent by an uninfected subject in the room and the accumulated number of droplets inhaled at each moment, considering that an infecting subject has previously remained in the room from 1 to 15 minutes.

The minutes during which a susceptible subject could stay in the room could also theoretically be determined on the basis of the minutes during which a potential infecting subject has previously stayed in it.

When looking for functions that adjust to these results, it is detected that equation $y = ax^{-b}$ adjusts very well to these results, obtaining a determination coefficient greater than 0.95 (Figure 6).
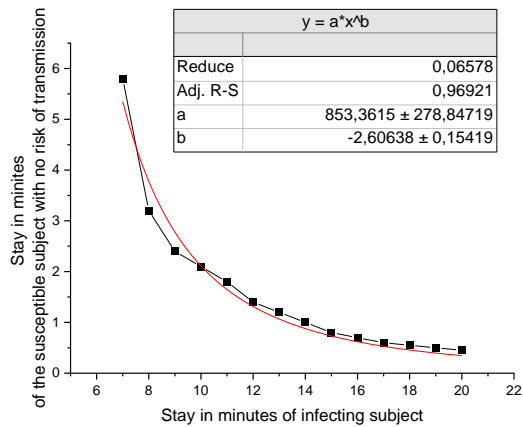
Figure 6. Theoretically relationship between the time during which a potential infecting subject stays in the room and the time that the susceptible subject could stay after using the room immediately after the previous one.

All these results refer to subjects who do not talk, sing, shout, cough or sneeze.

Although talking is not usual in a room of these features, today some individuals usually talk by phone or sing while having a shower.

In terms of prevention, it is easy to warn people not to carry out these activities inside the room. However, the infecting subject could inevitably cough or sneeze inside the room, thus generating thousands of droplets that should be added to the initial situation. According to the authors mentioned above and considering the droplets emitted by coughing (3,000-4,000) and sneezing (30,000-40,000), a minute of previous stay of the infecting subject per cough and ten minutes per sneeze could be added to the initial time.

On the other hand, these results were obtained considering a relatively steady temperature of 24 ºC and a relative humidity between 40 and 60%, which are the recommended values [34].

However, this is a controversial issue [35]–[37], and some studies have concluded for more than a decade that humidity could affect the spread of this type of virus, so aerosols could reach a greater distance in dry environments; nevertheless, water is previously evaporated and could be the least dangerous droplets, although dryness is not guaranteed.

Although light also affects the virus deactivation [38], it is not considered because the room does not have a window, so it is not naturally ventilated. If it had ventilation and constant natural light, the risk would theoretically be significantly reduced.

4. LIMITATIONS

There are still variables that could affect the results and are not enough determined by the scientific community, at least unanimously (number of droplets required to become infected and suffer from the disease, diverse casuistry, dynamics of aerosols and their complexity, environmental parameters such as temperature, humidity, light, etc.), this study should be understood as an approach or estimate of the risks in a certain environment and conditions, only considering issues related to respiratory aerosols taking place in that environment.

On the other hand, the so-called superspreaders [39] are not considered in this study as many issues should be studied.

As already indicated regarding the possibility of combinations between different dimensions and renewal rates, in the future, it is intended to carry out studies since the current objective was to obtain a reference case.

To finish with the limitations, it must be said that although it is true that the risk of contagion can be influenced by temperature, the incidence of light, and humidity, with respect to the first two factors, this study is designed for interior

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Pag. 9 / 12

spaces with temperature of stable comfort and artificial light for which other studies could continue investigating this issue.

Regarding humidity, a study published by the Journal of the Royal Society Interface[40], and carried out by a team from MIT, found that maintaining a relative humidity between 40-60% is ideal to stabilise the risk of contagion and to prevent the case discussed. However, it is recognised that it would be another factor to control and detect to include it as a possible risk alarm.

5. CONCLUSIONS

It can be concluded that in general small rooms, similar to the one studied, if used for only a few minutes and as indicated in this work, would have little risk.

On the other hand, the risk is considerably increased through activities such as talking, singing, coughing, sneezing, etc. That is why it is of interest to use warning signs so that users do not speak, sing, cough, or sneeze. They could also use the technologies currently available for the detection and classification of certain sounds, such as those indicated, connected to a simple computer programme, which in turn uses, for example, a synthetic voice, to, after the appropriate calculations, alert the Users of the existing risk.

In short, regardless of fluid dynamics, which would be extremely complex to calculate its influence in terms of risk and therefore does not fall within the scope of this study, it can be stated that the risk in the case of use for a few minutes is medium-low, if they are not used simultaneously with other people and if they are not spoken, sing, shout, cough, or sneeze.

However, as may be the case, the existence of warning signs can be a very useful tool to avoid those circumstances that increase the risk or at least the uncertainty of its level. Such notices would also be much more effective if they interacted with timing devices, presence detection, and even sound detectors, in addition to CO2 detectors.

In short, it is a study that aims to make an approach to the risk in a small, poorly ventilated space with nonsimultaneous use, in such a way that, applying the formulation deduced based on existing equations, already verified by previous studies and adapting them to the case study, it can be deduced that the risk can be limited. However, it is necessary to take measures so that in no case do several people use it simultaneously, limiting the time of use based on the calculations of said formulation, and presence devices and detecting, for example, with sound devices, when users they talk, they sing, cough, or sneeze during use to warn that the risk increases significantly in these cases..

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Pag. 11 / 12

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