The role of ventilation on aerosolized virus in multizone buildings

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ABSTRACT

Topic. Ventilation of buildings is a good way of preventing transmission of some virus in aerosolized form as the SARS-CoV-2. In many buildings, prevention strategies as window opening and sealing door have to be considered with a multizone approach. **Approach.** We modelled a residence equipped with a exhaust-only ventilation system where a family is isolating in a pandemic context, with one infected person. We modelled and analysed the impact of opening the window and sealing the door in the quarantine room on exposures. We tested several window- and door-opening strategies. **Results.** We illustrate the importance of moving from a single zone approach to a multizone approach for quantifying ventilation and airing impacts in multizone buildings as residences in order to prevent epidemics of viruses like SARS-CoV-2.

KEYWORDS

indoor air quality, aerosolized virus, airflow distribution, residences, window opening

1 INTRODUCTION

If aerosol transmission of SARS-CoV-2 was underestimated at the beginning of the pandemic, this way of transmission has been recognized by WHO (WHO, 2020) and the American and European centres for disease prevention and control CDC (CDC, 2020; ECDC, 2020), and several countries implemented airing in the list of barrier gestures or actions on building ventilation systems, or in national protocols, in order to prevent the Covid-19 transmission (ECDC, 2020; HCSP, 2020; SAGE-EMG, 2020; Task force ventilation Belgium, 2021).

If several authors have identified poor ventilation as a particular factor favouring transmission of the SARS-CoV-2 (Correia et al., 2020; Dai and Zhao, 2020; Jones et al., 2020), there is still a need to push work forward from theory to prevention practices, particularly regarding which ventilation conditions have a strong impact on the environmental contexts that favour (or hamper) the survival and transport of infectious aerosols (Fernstrom and Goldblatt, 2013).

Technical guidelines for building ventilation were provided by two international associations : the Federation of European of Heating, Ventilation, and Air-conditioning Associations (REHVA), and the American Society of Heating, Refrigeration, and Air-

Conditioning Engineers (ASHRAE) (ASHRAE, 2020; Guo et al., 2021; REHVA, 2021). In contrast to REHVA, ASHRAE does not recommend maximum airing but rather the minimum necessary, they warn of the risk of creating thermal discomfort which would reduce the resistance of individuals to infection.
With the exception of one measure proposed by the REHVA: avoid opening windows in toilets), published literature and technical guidelines on ventilation rarely take into account the risk of contamination within zones of the same building. However, a few rarer published examples also demonstrate the possibility of transmission of the virus between different rooms in a building in New Zealand (Eichler et al., n.d.) and in Seoul (Hwang et al., 2021).
We observe that ventilation is mainly considered from a single-zone point of view, and not from a multizone point-of-view. Therefore, it is considered that the higher the air change rate (through ventilation and/or airing), the lower the risk of infection. However, from a multizone perspective, we should ensure that the higher the air change rate in one zone, the lower the risk of infection in that zone, but also in all connected zones, which is not obvious.

2 METHODS

1. Case study presentation

We study a multi-family building with houses rental accommodation, spread over 8 floors. We study particularly one of the flats, named the "reference apartment" (or app. R). It is a 3-BR flat on the fifth floor. Its neighbourhood consists of four other flats arranged as in Figure 1: two identical flats below (app. D) and above (app. U), as well as two flats on the same floor, a 3BR flat to the south (app. S), and a 3BR flat to the east (app. E). We assume that two inhabitants live in the master bedroom (BR2 in the flat) and one inhabitant in each other bedroom. All occupants are isolating in their homes in a pandemic context such as the first wave of Covid-19 in 2020.

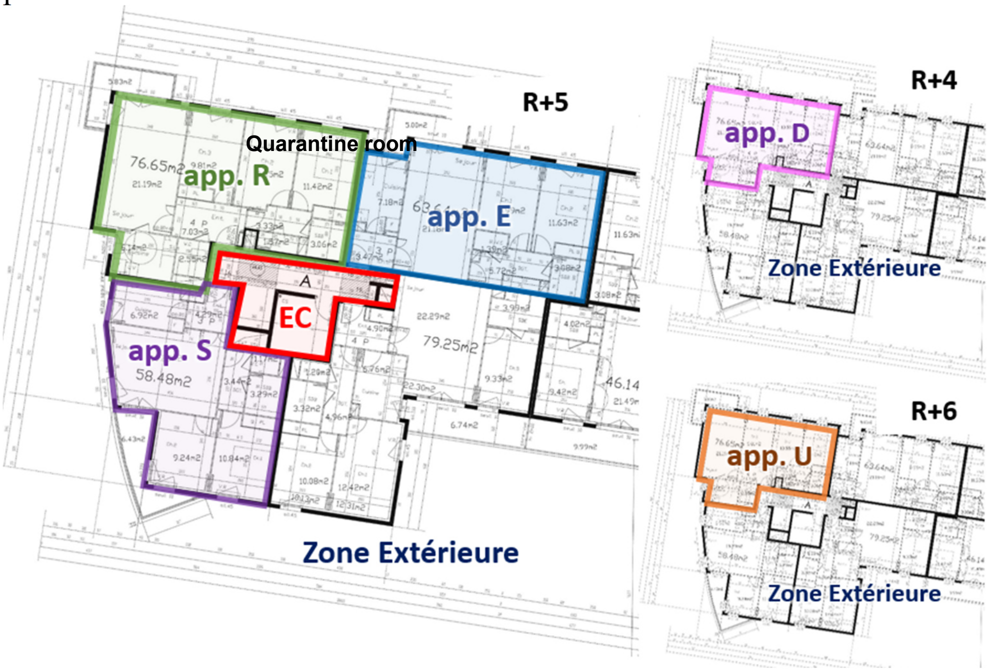


Figure 1. Plan of the studied building

In App. R, one of the occupants is infected and is quarantined in his bedroom, BR1. He stays in this room all day long, except for 40 minutes in the bathroom (Bath1) in the evening.

For the time spent in the various rooms by the other occupants, we use detailed data from the IAQ French national campaign (Zeghnoun et al., 2010). According to these data, each day people spend on average around 2 h 40 min in the kitchen, 2 h 50 min in the living room, and 40 min in bathrooms. In the particular context of lockdown, we suppose that the rest of the time is spent in the bedrooms, with people either working, studying or sleeping.

2. Modelling

We investigate airflows and particle concentrations using numerical modelling with CONTAM software (Emmerich and Dols, 2016; Lorenzetti et al., 2013; Walton and Emmerich, 1994). Each room in the house is modelled as one air zone (making a total of 11 zones). The air mass balance equation is considered for each zone. Once the airflow rates are known, the concentrations of pollutants are obtained by calculating a) the pollutant transport due to airflows, and b) the mass balance for each zone.

We use typical dynamic meteorological data for two winter weeks in Paris, France, on a 10-minute time step (ASHRAE IWEC Weather file, 2001), from 00:00 am on January 1st until 00:00 am on January 16th.

For the airleakage distribution, we use for external walls, data from on-site measurements. For leakage between the walls separating the different flats, our data are calculated from the proportions of q_{50} proposed by (Lozinsky and Touchie, 2021) and the value of the overall measured air leakage of the building. Thus, the values of the model are as follows: q_{50}=0,504 $m^3.h^{-1}.m^{-2}$ for ceilings and floors; q_{50} = 0,07 $m^3.h^{-1}.m^{-2}$ for vertical walls between two neighbouring flats; and q_{50} = 4,01 $m^3.h^{-1}.m^{-2}$ for walls facing the common corridor of the building. It should be noted that these values are quite low, so our study tends to minimise virus circulation through permeability defects between dwellings.

We model an exhaust-only ventilation system, which provides extract units in wet rooms and trickle vent to allow fresh air into living and bedrooms. The values of the exhaust airflows in wet rooms in the model are those provided by the French regulation (J.O., 1983), given in Table 1.

Table 1. Extracted airflows by the ventilation system

Case study	**Zone**	**Q ($m^3 \cdot h^{-1}$)**	**Qpeak ($m^3 \cdot h^{-1}$)** - 12:00–13:00 19:00–20:00
App R (3BR) **App D (3BR)** **App U (3BR)**	Kitchen	45	120
	WC	30	
	Bathroom 1 &2	30	
App E (2BR) **App S (2BR)**	Kitchen	45	105
	WC	15	
	Bathroom	30	

Airflows through the open windows are modelled using a two-way flow model, with a neutral height (air can enter and exit at the same time), and a discharge coefficient of 0.78 as proposed by Weber and Kearney (1980) (Weber and Kearney, 1980), for an opening measuring 1.2 m x 1.35 m.

The aerosolized virus is considered as a pollutant, in precisely the same way as contaminated particles transferred through the air. As (“REHVA_COVID-19_Ventilation_Calculator_user_guide.pdf,” n.d.), we assume that the infected occupant is at rest throughout the modelling, emitting contaminated particles at a constant rate, which corresponds to the 90ème percentile of Buonnano (Buonanno et al., 2020) : **3,1 quanta.h^{-1}**. We take into account a decay rate of the virus of : **λ=0,32 h^{-1}** (Miller et al.,

2020) ("REHVA_COVID-19_Ventilation_Calculator_user_guide.pdf," n.d.), a deposition rate of **0,3 h^{-1}** ("REHVA_COVID-19_Ventilation_Calculator_user_guide.pdf," n.d.), and a penetration factor of 1 (Liu and Nazaroff, 2003), (Chen and Zhao, 2011).

3. Reference case and studied scenarios

In the reference case all the internal doors and all the windows of the house are closed. We will also follow the recommendation of the French high council for public health (HCSP) (HCSP, 2020) of opening the window and seal the door of the quarantine room, in all our scenarios, with windows being opened three times a day for fifteen minutes at the following times: at 8:00 am, at 12:00 pm and at 6:00 pm. The neighbouring flats all have, in all scenarios, all doors and windows closed.
To study the sensitivity of our results, we studied six mitigation scenarios, Table 2.

Table 2. Definition of the studied mitigation scenarios based on different window- and internal door-opening scenarios and assessment strategies.

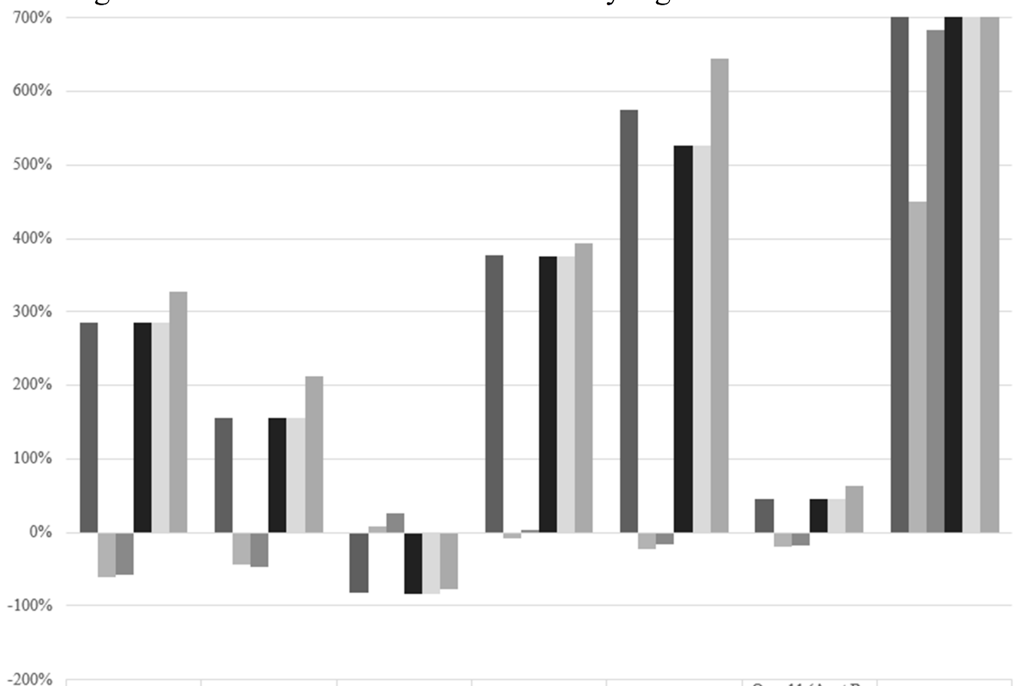
	Quarantine room window	Quarantine room door	Other internal doors	3 other windows - same facade	3 other windows - opposite facade
Reference case	***Closed***	***Sealed***	***Closed***	***Closed***	***Closed***
Scenario 1-HCSP	Open	Sealed	Closed	Closed	Closed
Scenario 2- low diluting strategy	Open	Open	Closed	Closed	Closed
Scenario 3- high diluting strategy	Open	Open	Open	Closed	Closed
Scenario 4-balanced strategy	Open	Sealed	Closed	Open	Closed
Scenario 5-balanced strategy	Open	Sealed	Closed	Closed	Open
Scenario 6- entering airflow limiting strategy	Half-open	Sealed	Closed	Closed	Closed

4. Relative exposure as a performance indicator

As a very common indicator by (Brinke et al., 1998; BSR/ASHRAE, 2016; Laverge et al., 2013; Morawska et al., 2017; Weschler, 2009) and as proposed by (Jones et al., 2020), in this study, we examine the cumulative exposure to the contaminated particles for each occupant. We compare it to the reference case exposure, in order to assess the relative performances of different strategies.
This cumulative exposure is calculated considering the occupancy schedules over the 2-week simulated period (360 h). The use of the Wells Riley equation to calculate the probability of infection has also been investigated in (Guyot et al., 2022).

5. Results and discussion

The results include the occupants' exposure for different strategies of windows and doors opening, presented in comparison to the reference case. The relative exposures of the seven most exposed occupants of the multi-family building (in the reference flat and in the adjacent flats) compared to the reference case are given in Figure 2. As this type of ventilation system extracts airflows from high-moisture rooms, it creates a pressure difference with respect to the living room and bedrooms, where fresh air enters through grills placed in the wall or on the windows, thanks to the pressure differences created, plus the wind and stack effects. With this kind of ventilation system, there are higher pressure differences between rooms (than with balanced ones), which causes air to flow from room to room. In this case, we observe that opening the window in the quarantine room always results in increased exposure for at least one other occupant, including in neighbours' dwellings. Some scenarios even cause extremely high relative increases.



	Occ. 4 (Appt U)	Occ. 6 (Appt E)	Occ. 8 (Appt R)	Occ 9 (Appt R)	Occ. 10 (Appt R)	Occ. 11 (Appt R-quarantine)	Occ. 18 (Appt D)
1-Window	286%	155%	-82%	377%	574%	46%	252350%
2-Window+door	-61%	-44%	8%	-8%	-22%	-20%	451%
3-Window+alldoors	-58%	-46%	26%	3%	-16%	-18%	683%
4-3windows	286%	155%	-84%	376%	527%	46%	252454%
5-3windows-sameside	286%	155%	-84%	376%	527%	46%	252458%
6-Window-halfopen	328%	212%	-77%	393%	644%	64%	280450%

Figure 2. Relative exposures for the 6 studied mitigation scenarios

3 CONCLUSION AND PERSPECTIVES

In a virus pandemic context, ventilation of buildings has also been characterised as a risk in some cases (for instance, air recirculation), but overall offers a solution that could curb or even prevent aerosol transmission of a virus.

We observed that with the door of the quarantine room sealed (sc.1,4,5&6), opening the window in the quarantine room always results in increased exposure for at least one other occupant, including in neighbors' apartments, sometimes with extremely high relative increases. For the scenarios with dilution strategies (all internal doors opened (sc. 2&3)), they show moderate impacts, with rather an increase of exposure of the occupants of the same apartments, and a decrease for the occupants located in other apartments.

It shows that with this case study, more the opening of the window, the sealing of the door has a strong negative impact on the occupants' exposure.

In the light of these results, we illustrate the importance of moving from such a single zone approach to a multizone approach for quantifying ventilation and airing impacts in multizone buildings as residences in order to prevent epidemics of viruses like SARS-CoV-2.

More results could be found, with the study of two other ventilation systems, and the estimation of the probability of infection, in (Guyot et al., 2022).

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