Strojniški vestnik - Journal of Mechanical Engineering 68(2022)4, 233-239
© 2022 The Authors. CC BY 4.0 Int. Licensee: SV-JME
DOI:10.5545/sv-jme.2022.68
Original Scientific Paper, Special Issue: SARS-CoV-2
Received for review: 2022-02-15
Received revised form: 2022-04-05
Accepted for publication: 2022-04-07

Analysis of Educational Building's Ventilation Suitability to Prevent the Spread of Coronavirus (SARS-CoV-2)

Eneja Osterman[1,*] – Mateja Dovjak[2] – Janja Vaupotič[3] – Tomaž Verbajs[1] – Urška Mlakar[1] – Eva Zavrl[1] – Uroš Stritih[1]

[1] University of Ljubljana, Faculty of Mechanical Engineering, Slovenia
[2] University of Ljubljana, Faculty of Civil and Geodetic Engineering, Slovenia
[3] Jožef Stefan Institute, Department of Environmental Sciences, Slovenia

In a larger educational building in Slovenia, we examined the efficiency of ventilation systems by analysing the operation of the heating, ventilation, and air conditioning (HVAC) system in several classrooms. Using the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) COVID-19 ventilation calculator, the probability of infection due to the spread of coronavirus through aerosol particles and the reproduction number were calculated based on the classroom occupancy, ventilation rates, and other parameters (i.e., classroom characteristics, preventive measures). Firstly, different levels of ventilation capacity (50 % and 80 %) were applied. Considering the distance between occupants 1.5 m and wearing the masks of all participants, the probability of infection during lectures was always lower than 1 %. Secondly, the maximum number of students that can attend lectures is about 30 %, as calculated according to the legal requirements, recommendations, and given conditions.

Keywords: classroom ventilation, REHVA calculator, probability of infection, reproduction number, HVAC system

Highlights

- *A mixed-mode ventilation in the examined large classrooms is not appropriate for effective control and prevention of transmission risks in the educational environment.*
- *Considering the ventilation efficiency increase from 50 % to 80 %, in a larger size classroom, the probability of infection is reduced from 0.40 % to 0.27 %.*
- *Considering the ventilation efficiency increase from 50 % to 80 %, in a larger size classroom, the reproduction number decreases from 0.11 to an acceptable level of 0.07.*
- *During the restrictions against the spread of coronavirus, maximum occupancy of the classrooms is not recommended.*

0 INTRODUCTION

It is well known how important the design of heating, ventilation, air conditioning (HVAC) systems is to achieve adequate air quality, while not deteriorating thermal comfort [1]. Since the Coronavirus disease COVID-19 outbreak, preventive measures have been taken to mitigate transmission risks (i.e., airborne, contacts) in buildings. Ventilation solutions present the main engineering controls described in the traditional infection control hierarchy [2] to reduce environmental risks of airborne transmission [3] to [5].

Expelled respiratory droplets that are airborne range from less than 1 μm to more than 100 μm in diameter. Airborne transmission depends on the droplet size and includes i) short-range region for close contact (i.e., large droplets up to 2 mm that fall within 1.5 m) and ii) long-range region (i.e., small droplets less than 50 μm fall beyond 1.5 m distance) [6] and [7]. In indoor air, coronavirus SARS-CoV-2 can remain active for up to 3 hours and up to 2 to 3 days on room surfaces in common indoor conditions [8]. Therefore, the main role of efficient ventilation is to ensure a sufficient amount of fresh air per occupant while simultaneously removing the harmful airborne microbes. A study by Nishiura et al. [9] highlighted that the odds that a primary case transmitted COVID-19 in a closed environment was 18.7 times greater compared to an open-air environment.

Poorly designed and/or not properly maintained HVAC systems enable the airborne droplets to be easily transported around the spaces in buildings, and therefore, such a method of transmission is becoming increasingly important [10] and [11].

Quite a few studies have been done analysing HVAC systems and the impact of natural ventilation (opening of windows) [4], [12] and [13]. It was found that with appropriate measures regarding ventilation, the probability of infection is relatively low (less than 1 %) [14].

Similarly, our study aimed to verify the ventilation efficiency in the selected educational building in Slovenia and to calculate the transmission risks for COVID-19. The main question was whether the existing ventilation system meets the requirements of standards to prevent the spread of SARS-CoV-2

*Corr. Author's Address: University of Ljubljana, Faculty of Mechanical Engineering, Askerceva 6, 1000 Ljubljana, Slovenia, eneja.osterman@fs.uni-lj.si

during normal occupancy of classrooms and how the probability of infection could be quantified.

1 METHODS

To be able to assess the current state of the probability of infection in the selected building and to be able to propose appropriate measures, the REHVA COVID-19 ventilation calculator was used [15]. The calculation is based on the Wells-Riley model [16], which determines the probability of infection for the selected space and human activity. The probability of infection (p) is defined by Eq (1):

$$p = 1 - e^{-n}, \quad (1)$$

where n is the number of quanta inhaled.

Quantum represents the number of airborne droplet nuclei that cause infection in 63 % of susceptible individuals. This depends on the origin of the viruses, which is defined with quanta emission rate, E, [quanta/h]. The quanta inhaled (n, quanta) depends on the time-average quanta concentration, C_{avg}, [quanta/m^3], the volumetric breathing rate of an occupant, Q_b, [m^3/h] and the duration of the occupancy, t, [h] as shown in Eq. (2):

$$n = C_{avg} Q_b t. \quad (2)$$

C_{avg} is defined in Eq. (3), where V represents the volume of the room [m^3], λ is a first-order loss rate coefficient for quanta/h due to the summed effects of ventilation, deposition onto surfaces and virus decay. Values for λ are taken from studies [17] to [19]. Estimated values for E and Q_b are based on the studies of the Skagit Valley Chorale event [5] and quanta generation rates for SARS-CoV-2 [6] and are given in Table 1.

$$C_{avg} = \frac{E}{\lambda V}\left[1 - \frac{1}{\lambda t}\left(1 - e^{-\lambda t}\right)\right]. \quad (3)$$

Table 1. *66th percentile SARS-CoV-2 quanta emission rates for different activities* [20]

Human activity	Quanta emission rate, E, [quanta/h/occupant]
Resting, oral breathing	0.72
Heavy activity, oral breathing	4.9
Light activity, speaking	9.7
Light activity, singing (or loudly speaking)	62

In addition to the calculation of the probability of infection, it was also necessary to define its acceptable value. For this, several studies propose to define the event reproduction number R. It is defined as the number of new disease cases divided by the number of infectors and its value should be below 0.1 [15].

Table 2. *Volumetric breathing rates* [21] *and* [22]

Human activity	Breathing rate, Q_b, [m^3/h]
Standing (office, classroom)	0.54
Talking (meeting room, restaurant)	1.10
Light exercise (shopping)	1.38
Heavy exercise (sports)	3.30

Mentioned should also be the assumptions made in this model. It is assumed that quanta are emitted at a constant rate throughout the event; the infected occupant is present in the room throughout all occupancy time; an infectious respiratory aerosol is evenly distributed throughout the well-mixed room air; infectious quanta are removed by ventilation, filtration, deposition, and airborne virus decay.

2 EXPERIMENTAL AND CALCULATIONS

2.1 Experimental

An inspection of ventilation systems with a description of mechanical installations of the selected educational building was made as part of the energy audit in 2012. Mechanical installation systems have not changed much since then, as only service and maintenance works have been carried out in the meantime. We also reviewed some parameters (type of recuperation, surface area, height and volume of the classrooms, air flow rate of air-conditioning (AC) unit, type of air inlet, the maximum number of occupants, number of seats, etc.) and measured them based on the obtained data. The results are given in Table 3. Validation of their Supervisory control and data acquisition (SCADA) system was performed using the reference measuring equipment Testo 400 (Universal IAQ instrument), according to the standard EN ISO 12599 requirements [23]. The cross-checking of temperature, CO_2 and air inlet velocity showed that their system deviates by less than 6 % from the reference. It should be noted that the CO_2 sensors from their SCADA system detect a higher value than the reference one, which in turn means that the ventilation turns on at lower CO_2 concentrations and consequently the ventilation is better. At the time of our measurement, the SCADA was set to increase the power of the ventilation system at elevated CO_2 concentrations (>1000 ppm) in the air of classrooms.

Table 3. *Characteristics of AC units, classrooms and analysed ventilation scenarios*

Classroom	Air-conditioning unit	The airflow rate [m³/h]	Surface area of classroom [m²]	Classroom height [m]	Max number of occupants (with 1.5 m distance)
LCR 1_G	NP1: IMP KNMD 9/6 D25	4500	197	2.9	28
LCR 2_G	NP2: IMP KNMD 9/6 D25	4500	198	2.9	25
LCR 3_G	NP3: IMP KNMD 12/6 D25	5800	245	4.5	32
LCR 4_G	NP4: IMP KNMD 12/6 D25	5800	267	3.95	39
LCR 5_G	NP5: IMP KNMD 12/6 D25	9400	307	4.5	35
LCR 6_G	NP6: IMP KNMD 12/6 D25	9400	624	4.5	42
SCR 1_B – SCR 6_B	N1: IMP KNMD 9/9 D25	7505	509	2.9	73

The inspection followed the Methodology for Regular Inspections of Air-conditioning Systems [24].

6 AC units supplied air for 6 large classrooms (LCR) on the ground floor (LCR 1_G – LCR 6_G) and 1 AC unit for small classrooms (SCR) in the basement (SCR 1_B – SCR 6_B).

2.2 Calculations: the Probability of Infection and Reproduction Number

The following assumptions had to be made when calculating the probability of infection and the reproduction number using the REHVA COVID-19 ventilation calculator [15]:

- Proper wearing of the masks of all occupants was envisaged; the value for mask efficiency for susceptible occupant is 0.3, and the value for mask efficiency for the infectious occupant is 0.5.
- The virus decay was the default from the study by van Doremalen et al. [8], and its value is 0.63 h^{-1}.
- Deposition to surfaces was defaulted from the studies by Buonnano et al. [20] and Miller et al. [25], where the value could vary between 0.24 and 1.5 h^{-1}, depending on the aerosol particle size range. For the study, the value taken was 0.24 h^{-1}.
- Additional control measures (such as a removal rate of UV disinfection) were 0 h^{-1}.
- Quanta emission rate was 5 quanta/h.
- Breathing rate was 0.54 m^3/h.
- Classroom occupancy was 12 h/day.
- The distance between the occupants is at least 1.5 m.
- There is only one infected occupant in the classroom.

3 RESULTS AND DISCUSSION

As presented in the previous chapter, we analysed the ventilation systems in the educational building and came to the following conclusions:

- All larger ventilation devices have rotary heat exchangers, which means that there is a possibility of the virus being transferred back into the classroom in the event of a leak.
- There is mixed-mode ventilation in large classrooms, which is not suitable for keeping the sufficient quality of air in the classroom. Small classrooms have a displacement mode of ventilation, which is more suitable from the air exchange point of view.
- The windows were opened after each lecture so that a large number of windows were completely opened for several minutes. Windows were also opened if the CO_2 sensor showed values above 1000 ppm.
- Ventilation ducts are not being cleaned.
- Large classrooms have ventilation efficiency controlled by CO_2 sensors, while small classrooms do not.

The results obtained from the computations are shown in Figs. 1 to 4 and Table 4. For LCR 1_G – LCR 6_G, the ventilation capacity was set at 50 % and 80 % (Figs. 1 and 2), and for SCR 1_B – SCR 6_B was assumed the ventilation with the same share of airflow (Figs. 3 and 4). Note: in some figures, the lines overlap.

As seen from Fig. 1, the probability of infection after 12 h is the highest in LCR 2_G, when it reaches 0.4 % with 50 % ventilation capacity. If ventilation capacity is increased to 80 %, the probability of infection is reduced to 0.27 %. This means a 28 % lower probability of infection. The lowest probability of infection is in LCR 6_G and LCR 5_G.

The same is true when comparing the reproduction number (Fig. 2). At 50 % ventilation capacity, the maximum value is 0.11 in LCR 2_G, and at 80 %, it is reduced to 0.07. The recommended value of the reproduction number is 0.5, and to control the epidemic, it should be kept below 1 [1].

It was envisaged that the fresh air is distributed equally among SCR 1_B – SCR 6_B. We can see that the probability of infection is still below 1.5 % (Fig. 3). The reproduction number is the highest in SCR 5_B (0.21 – Fig. 4), which is also the most problematic classroom because it has no windows. In Figs. 1 to 4, the values only consider the transmission of the virus by air in aerosols, i.e., assuming a distance of 1.5 m between occupants. Transmission with contact or droplets is not taken into account.

The evaluation of the adequacy of the value of ventilation was carried out with the legally required [24] and recommended values [26], where large classrooms (LCR 1_G – LCR 6_G) require 30 m^3/h air per occupant. 4 loads of classrooms were inspected (scenarios S1 – S4) according to the number of occupants present, which were determined for each classroom separately:

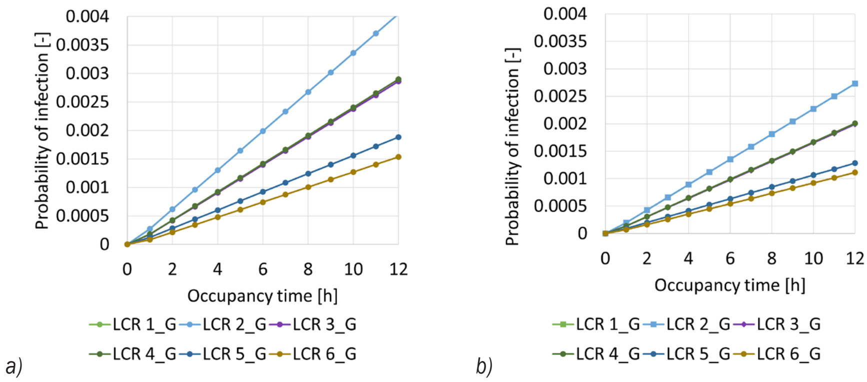

Fig. 1. *Probability of infection for the ground floor and the ventilation of a maximum value of; a) 50 %, and b) 80 %*

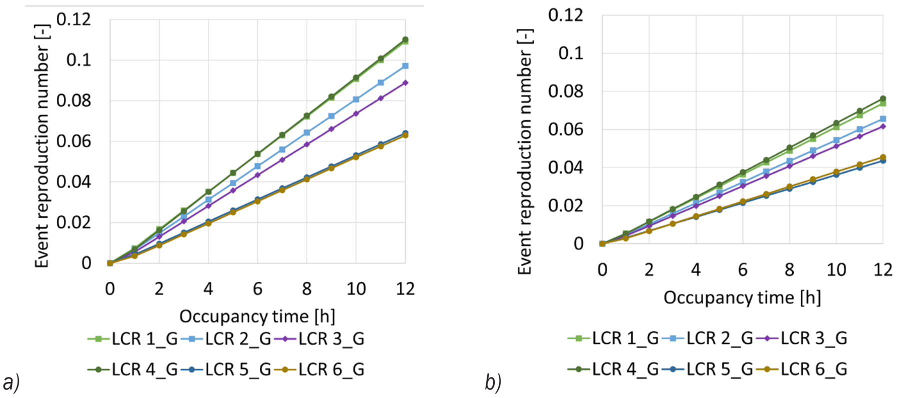

Fig. 2. *Event reproduction number for the ground floor and the ventilation of a maximum value of; a) 50 %, and b) 80 %*

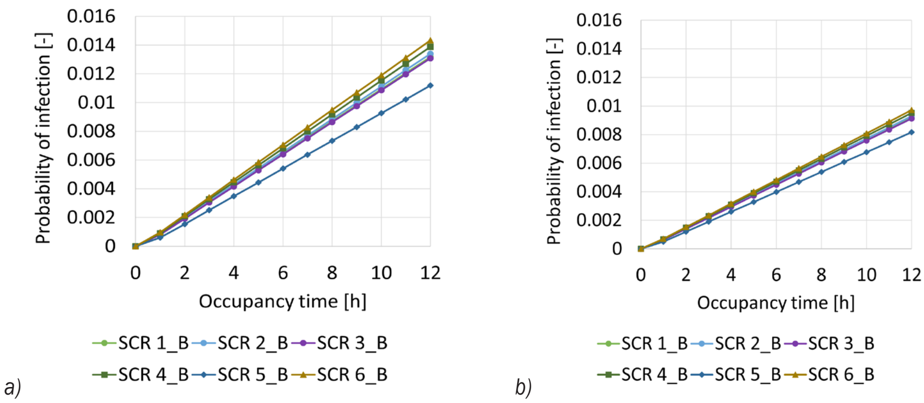

Fig. 3. *Probability of infection for the basement and the ventilation of a maximum value of; a) 50 %, and b) 80 %*

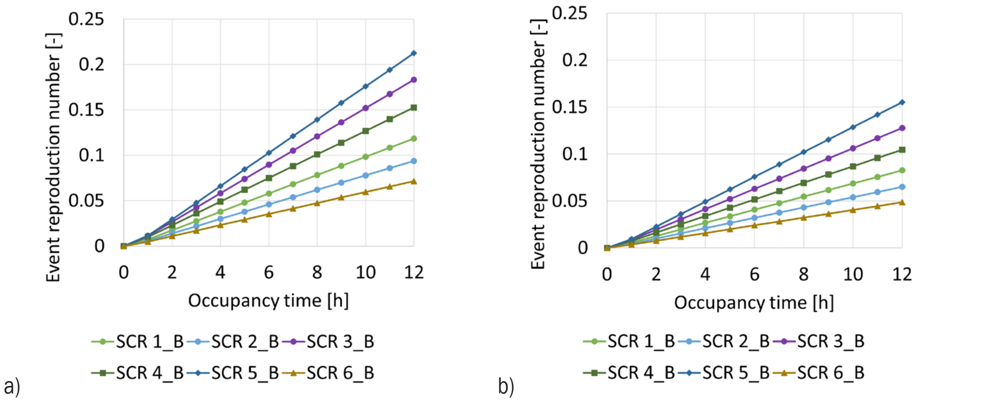

Fig. 4. *Event reproduction number for the basement and the ventilation of a maximum value of; a) 50 %, and b) 80 %*

Table 4. *Set of scenarios on occupational load, airflow and AC capability*

Classroom	Number of seats [-]	AC capability at 100 % [m³/h]	S1: Covid - needed airflow [m³/h]	S2: 50 % occupancy - needed airflow [m³/h]	S3: max occupancy – needed airflow [m³/h]	S4: max number of occupants at 100 % capability [-]
LCR 1_G	210	4500	840	3150	6300	150
LCR 2_G	196	4500	750	2940	5880	150
LCR 3_G	270	5800	960	4050	8100	193
LCR 4_G	330	5800	1170	4950	9900	193
LCR 5_G	304	9400	1050	4560	9120	313
LCR 6_G	200	9400	1260	6000	6000	313
SCR 1_B	63	1250	300	945	1890	41
SCR 2_B	56	1250	240	840	1680	41
SCR 3_B	56	1250	450	840	1680	41
SCR 4_B	42	1250	360	630	1260	41
SCR 5_B	70	1250	600	1050	2100	41
SCR 6_B	12	4500	180	180	360	41

S1: Subject to minimal required airflow and COVID-19 recommendations, safety distance between persons 1.5 m.
S2: Half occupancy of classrooms.
S3: Maximum load after the epidemic (full occupancy of classrooms with occupants).
S4: Sufficient air volume (30 m³/h/person), 1.5 m distance between persons not taken into account.

S1: Subject to all regulations and COVID-19 recommendations, safety distance between occupants 1.5 m.

S2: Half occupancy of classrooms.

S3: Maximum load after the epidemic (full occupancy of classrooms with occupants).

S4: Sufficient air volume (30 m³/h/occupant), 1.5 m distance between occupants not considered.

Table 4 lists the number of seats in each classroom, the maximum airflow that AC units can supply (100 % capability), required airflow rate according to S1 and S2. The amounts of air determined by the REHVA calculator for one-third load of classrooms with users (S1) represent a minimal risk of infection and at the same time meet the requirements of the regulations and recommendations of the standard. The quantities for the anticipated half-load in scenario S2 are sufficient and meet the requirements of the rules and recommendations of the standard, except for LCR 4_G and SCR 5_B. It should be noted that the quantities in S2 are valid only for the time after COVID-19 as minimum distance of 1.5 m is not achieved.

The quantities set for the estimated maximum load in scenario S3 do not meet the requirements. The S4 scenario includes the maximum number of students in each classroom to meet the requirements. This scenario is taken into account only in the period after the end of the COVID-19 pandemic, as it does not take into account the distance of 1.5 m between space users.

5 CONCLUSIONS

Using the REHVA calculator, the probability of infection due to the spread of coronavirus through aerosol particles and the reproduction number for each classroom at the selected educational building were calculated. Considering the distance between occupants 1.5 m and wearing the masks of all participants, the probability of infection was always lower than 1 %. The acceptable reproduction number is less than 0.1 which was achieved in most of the cases. The most critical are cases with 50 % capability and when the occupancy time approaches 12 h. In reality, such a case is highly unlikely therefore spread of the virus should not be an issue.

In the calculations for the maximum allowed number of people in each classroom assuming all corona measures, i.e. 1.5 m distance and wearing the mask of all participants, about a third of the number of seats could be occupied.

The AC system was analysed also according to the required amount of fresh air to define how many people can be in individual classrooms with four specific scenarios (S1 to S4). It should be noted that scenarios S2, S3 and S4 are not appropriate during the COVID-19 situation and do not take into account the distance of 1.5 m, but the prescribed value of the fresh air is guaranteed according to the rules (ventilation rate of 30 m^3/h/occupant). Due to the construction of the ventilation system at the educational building before 2002, when the Rules on ventilation and air conditioning of buildings [27] were amended, we concluded that the occupancy of large classrooms could be 70 % if the ventilation system is operating at full power. In the case of full-day occupancy of large classrooms the ventilation system operating with at least 80 % power is recommended. In the case of 80 % ventilation capacity, a sufficient amount of fresh air is provided for the half occupancy of classrooms.

6 REFERENCES

[1] Elsaid, A.M., Mohamed, H.A., Abdelaziz, G.B., Ahmed, M.S.(2021). A critical review of heating, ventilation, and air conditioning (HVAC) systems within the context of a global SARS-CoV-2 epidemic. *Process Safety and Environmental Protection*, vol. 155, p. 230-261, **DOI:10.1016/j.psep.2021.09.021**.

[2] CDC: Infection Control Guidance, Centers for Disease Control and Prevention (2022). from *https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html*, accessed on 2022-02-14.

[3] Federation of European Heating, Ventilation and Air Conditioning Associations: REHVA COVID19 GUIDANCE version 4.12021 (2021). from *https://www.rehva.eu/activities/covid-19-guidance*, accessed od 2022-02-14

[4] Magnavita, N., Chirico, F. (2020). Headaches, personal protective equipment, and psychosocial factors associated with COVID-19 pandemic. Headache. *The Journal of Head and Face Pain*, vol. 60 , no. 7, p. 1444-1445, **DOI:10.1111/head.13882**.

[5] William, M.A., Suárez-López, M.J., Soutullo, S., Hanafy, A.A. (2021). Evaluating heating, ventilation, and air-conditioning systems toward minimizing the airborne transmission risk of Mucormycosis and COVID-19 infections in built environment. *Case Studies in Thermal Engineering*, vol. 28, p. 101567, **DOI:10.1016/j.csite.2021.101567**.

[6] Asadi, S., Bouvier, N., Wexler, A.S., Ristenpart, W.D. (2020). The coronavirus pandemic and aerosols: Does COVID-19 transmit via expiratory particles?. *Aerosol Science and Technology*, vol. 54, no. 6, p. 635-638, **DOI:10.1080/02786826.2020.1749229**.

[7] Lipinski, T., Ahmad, D., Serey, N., Jouhara, H. (2020). Review of ventilation strategies to reduce the risk of disease transmission in high occupancy buildings. *International Journal of Thermofluids*, vol. 7-8,, p. 100045, **DOI:10.1016/j.ijft.2020.100045**.

[8] van Doremalen, N., Bushmaker, T., Morris, D.H., Holbrook, M.G., Gamble, A., Williamson, B.N., Tamin, A., Harcourt, J.L., Thornburg, N.J., Gerber, S.I., Lloyd-Smith, J.O., de Wit, E., Munster, V.J. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *New England Journal of Medicine*, vol. 382, no. 16, p. 1564-1567, **DOI:10.1056/NEJMc2004973**.

[9] Nishiura, H., Oshitani, H., Kobayashi, T., Saito, T., Sunagawa, T., Matsui, T., Wakita, T., MHLW COVID-19 Response Team, Suzuki, M. (2020). Closed environments facilitate secondary transmission of coronavirus disease 2019 (COVID-19), *MedRxiv*, **DOI:10.1101/2020.02.28.20029272**.

[10] Malhotra, N., Bajwa, S.J.S., Joshi, M., Mehdiratta, L., Trikha, A. (2020). COVID Operation theatre- advisory and position statement of Indian Society of Anaesthesiologists (ISA National). *Indian Journal of Anaesthesia*, vol. 64, no. 5, p. 355-362, **DOI:10.4103/ija.IJA_454_20**.

[11] Ascione, F., De Masi, R.F., Mastellone, M., Vanoli, G.P. (2021). The design of safe classrooms of educational buildings for facing contagions and transmission of diseases: A novel approach combining audits, calibrated energy models, building performance (BPS) and computational fluid dynamic (CFD) simulations. *Energy and Buildings*, vol. 230, p. 110533, **DOI:10.1016/j.enbuild.2020.110533**.

[12] D Souza, P., Biswas, D., Deshmukh, S.P. (2020). Air side performance of tube bank of an evaporator in a window air-conditioner by CFD simulation with different circular tubes with uniform transverse pitch variation. *International Journal of Thermofluids*, vol. 3-4, p. 100028, **DOI:10.1016/j.ijft.2020.100028**.

[13] Mouchtouri, V.A., Koureas, M., Kyritsi, M., Vontas, A., Kourentis, L., Sapounas, S., Rigakos, G., Petinaki, E., Tsiodras, S., Hadjichristodoulou, C. (2020). Environmental contamination of SARS-CoV-2 on surfaces, air-conditioner and ventilation systems. *International Journal of Hygiene and Environmental Health*, vol. 230, p. 113599, **DOI:10.1016/j.ijheh.2020.113599**.

[14] Park, S., Choi, Y., Song, D., Kim, E.K. (2021). Natural ventilation strategy and related issues to prevent coronavirus disease 2019 (COVID-19) airborne transmission in a school

building. *Science of the Total Environment*, vol. 789, p. 147764, **DOI:10.1016/j.ijheh.2020.113599**.

[15] COVID-19 Ventilation Calculator V2.0, REHVA (2022). from *https://www.rehva.eu/covid19-ventilation-calculator*, accessed on 2022-01-31.

[16] Nicas, M., Nazaroff, W.W., Hubbard, A. (2005). Toward understanding the risk of secondary airborne infection: Emission of respirable pathogens. *Journal of Occupational and Environmental Hygiene*, vol. 2, no. 3, p. 143-154, **DOI:10.1080/15459620590918466**.

[17] Fears, A.C., Klimstra, W.B., Duprex, P., Hartman, A., Weaver, S.C., Plante, K.C., Mirchandani, D., Plante, J.A., Aguilar, P.V., Fernández, D., Nalca, A., Totura, A., Dyer, D.,Kearney, B., Lackemeyer, M., Bohannon, J.K., Johnson, R., Garry, R.F., Reed, D.S., Roy, C.J. (2020). Comparative dynamic aerosol efficiencies of three emergent coronaviruses and the unusual persistence of SARS-CoV-2 in aerosol suspensions. *MedRxiv*, **DOI:10.1101/2020.04.13.20063784**.

[18] Thatcher, T.L., Lai, A.C.K., Moreno-Jackson, R., Sextro, R.G., Nazaroff, W.W. (2002). Effects of room furnishings and air speed on particle deposition rates indoors. *Atmospheric Environment*, vol. 36, no. 11, p. 1811-1819, **DOI:10.1016/S1352-2310(02)00157-7**.

[19] Diapouli, E., Chaloulakou, A., Koutrakis, P. (2013). Estimating the concentration of indoor particles of outdoor origin: A review. *Journal of the Air & Waste Management Association*, vol. 63, no. 10, p. 1113-1129, **DOI:10.1080/10962247.2013.791649**.

[20] Buonanno, G., Stabile, L., Morawska, L. (2020). Estimation of airborne viral emission: Quanta emission rate of SARS-CoV-2 for infection risk assessment. *Environment International*, vol. 141,, p. 105794, **DOI:10.1016/j.envint.2020.105794**.

[21] Adams, W.C. (1993). *Measurement of breathing rate and volume in routinely performed daily activities: final report*, contract no. A033-205, California Environmental Protection Agency, Air Resources Board, Research Division, Sacramento.

[22] Binazzi, B., Lanini, B., Bianchi, R., Romagnoli, I., Nerini, M., Gigliotti, F., Duranti, R., Milic-Emili, J., Scano, G. (2006). Breathing pattern and kinematics in normal subjects during speech, singing and loud whispering. *Acta Physiologica*, vol. 186, no. 3, p. 233-246, **DOI:10.1111/j.1748-1716.2006.01529.x**.

[23] Testo 400 universal IAQ instrument | Portable devices - with solid probes | Portable devices | Product type | SI-Site (2022), from *https://www.testo.com/sl-SI/testo-400/p/0560-0400*, accessed on 2022-02-01.

[24] Act on Energy Efficiency (2020). *Official Gazette of the Republic of Slovenia*, No. 158/20, Ljubljana.

[25] Miller, S.L., Nazaroff, W.W., Jimenez, J.L., Boerstra, A., Buonanno, G., Dancer, S.J., Kurnitski, J., Marr, L.C., Morawska, L., Noakes, C. (2021). Transmission of SARS-CoV-2 by inhalation of respiratory aerosol in the Skagit Valley Chorale superspreading event. *Indoor Air*, vol. 31, no. 2, p. 314-323, **DOI:10.1111/ina.12751**.

[26] EN 16798-1:2019. Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6, iTeh Standards Store.

[27] Rules on the ventilation and air-conditioning of building. *Official Gazette of the Republic of Slovenia*, no. 42/02 with changes, Ljubljana.