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ASSESSMENT OF THE RISKS OF CROSS-INFECTION BY COVID-19 USING DIFFERENT OUTDOOR VENTILATION RATES IN A CLASSROOM CONDITIONED WITH SPLIT SYSTEM.

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Abstract.*This study aimed to estimate the risks of cross-infection by COVID-19 in a classroom conditioned with split system using different ventilation rates of outdoor air. The Wells-Riley model was used to predict the risks of COVID-19 infection and the different ventilation rates were measured using the equilibrium technique, with the CO_2 as a tracer gas. The minimum outdoor ventilation rate tested was 32 m^3/h, which represents the real ventilation rate provided when only is used split system and the maximum was 891 m^3/h, required to maintain the indoor CO_2 concentration within acceptable levels (1000 ppm). The results showed that the CO_2 concentration increased above acceptable levels when only was used the split-type system, reaching approximately 3500 ppm. It was also found that the risks of cross-infection by COVID-19 increase considerably with decreasing ventilation rate and does not change when the split system was turned on or turned off. The infection risk when only is used split system was 32.0% and decreased to 4.6% when was provided a ventilated 891 m^3/h of outdoor air together with split air conditioning. This suggests that inefficient ventilation provided by the split system in a classroom is a significant problem, resulting in impaired air quality and high health risks to occupants, including increased risk of infections such as COVID-19.*

Keywords*: ventilation, air quality, infection risk, classroom, split system*

1. INTRODUCTION

Building ventilation is designed to provide healthy air by both diluting and removing pollutants originating in the building (Etheridge et al., 1996; Awbi, 2003). Ventilation is a combination of processes resulting in the supply and removal of air from inside a building. It typically involves introducing outdoor air, conditioning and mixing the outdoor air with a fraction of indoor air, distributing this mixed air throughout the building, and exhausting a fraction of the indoor air to the outside.

Ventilation rate plays a significant role in preventing the airborne transmission of diseases in indoor spaces. Researchers suggest that, in an environment with a low per person ventilation rate, endemic airborne infectious diseases can potentially be transmitted (Wells, 1955; Richardson, 2014; Issarowa et al., 2015). Conversely, a higher ventilation rate permits a higher dilution capability and can reduce the risk of airborne infections (Pereira et al., 2015), particularly where many people share air space, such as in a classroom. School classrooms are a considerable challenge during the COVID-19 pandemic because of large occupancy density and mainly poor ventilation conditions. Classrooms present a much higher occupancy rate as compared to many other buildings environments. For example, Santamouris et al. (2008), found that there are four times as many occupants per unit area in a classroom as compared to an office building. Thus, ensuring high air quality is of fundamental importance in such environments. Research has linked the occurrence of respiratory problems and infectious diseases in schools with insufficient ventilation; leading to increased absentees and poor learning outcomes (Seppänen et al., 2002). Moreover, improving classroom ventilation to the minimum recommended levels has been found to decrease illness-related absences and provide an economic benefit (Mendell et al., 2013; Batterman, 2017). Therefore, classrooms and other school or university spaces must be ventilated to remove particles, odors, CO_2, and other pollutants.

Most schools in Brazil have natural ventilation in the classroom and the schools with air conditioning most have split systems. Split systems provide cooling by cycling refrigerant between an outdoor condensing unit and one or more indoor fan coil units that circulate the room-air directly over an evaporator coil in the room. The use of split systems has become popular in various environments, due to their low cost, simple installation, ease of operation, flexibility, acoustic performance, and unobtrusive installation to buildings without the need for ductwork.

There aremany advantages of using a split system. However, split systems only recirculate the air inside the room, and do not normally provide ventilation as indicated by the carbon dioxide (CO_2) levels that reach fairly high levels in a short period of time. The popularity of split-type air conditioning equipment for use in various environmentsindicates the need to study in detail the impact of this equipment on the indoor air quality and thermal comfort of the occupants. Very little is known about the impact of the use of split systems as a ventilation strategy in a classroom, in terms of the air changes per hour,reduction of CO_2 and particle concentrations, and infection risks involved (Jones et al., 2008).

In this context, the aim of this study is to analyze the impact of the split systems on CO_2 concentrations and therisk of cross-infection by COVID-19 using different ventilation rates of outdoor air in an university classroom. The Wells-Riley model was used to predict the risks of COVID-19 infection and the different ventilation rates were measured using the equilibrium technique, with the CO_2 as a tracer gas.

2. MATERIALS AND METHODS

This study aimed to estimate the risks of cross-infection by COVID-19 in a classroom conditioned with split system using different ventilation rates of outdoor air. The risks of cross-infection were estimated for five conditions of ventilation with outdoor air. In the first case, only the split system remained on without outdoor ventilation (case 1); in this case, the ventilation grill located above the doorway was kept closed; in the second case, only the split system remained on with outdoor ventilation through a ventilation grill (case 2); In the third case, the split system and an exhaustfan (378 m^3/h)remained on (case 3); in the fourth case, the split system and an exhaustfan (653 m^3/h) remained on (case 4); and in the fifth case, the split system and an exhaustfan (891 m^3/h) remained on (case 5).

2.1 Sampling Site

Samples were collected in an university classroom with an area of 162 m^3 (9 × 6 × 3 m). A single split system unit with a capacity of 36.000 BTU/h, installed at a height of 2.8 m at the rear of the classroom, was responsible for air recirculation. Furthermore, one mechanical exhaust fanwas installed above the doorway for realization of the test. The room also has a ventilation grill (0.8 x 0.5 m) located above the doorway.

The number of students in the room was 32 plus 1 teacher. The activity in the room was typical of an university classroom; students were seated and took notes during lectures, and a lecturer presented information using a chalkboard, overhead projector, and/or computer projector. The duration of each lecture was 1 h and 20 min.

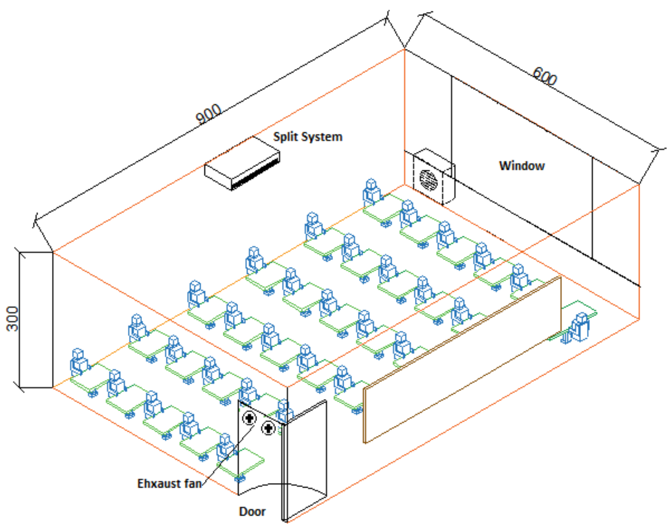

Figure 1. Classroom geometry

2.2 Estimated ventilation rate based on CO_2 generation

The indoor CO_2 concentration is strictly dependent on the number of people in a building and the efficiency of the ventilation system in diluting occupant generated CO_2. Thus, the estimated ventilation rate for each case was based on CO_2 generation using the constant injection method. This method is well established in the literature and the procedure is fully described in ASTM E 741 (2017),

In this method CO_2 was released in the room at a rate corresponding to 33 people generating. Thus, the CO2 concentration increased with time until reaching a stable value (equilibrium concentration), which depends on the outdoor ventilation. The ventilation rate can then be calculated based on CO_2 generation, outdoor CO_2 concentration and CO_2 equilibrium concentration. That is, if the CO_2 generation rate inside of the room and the outdoor airflow rate are both constant, then the indoor concentration builds up to an equilibrium concentration $C_{eq\,(i)}$. Then, the ventilation rate can be calculated from steady state carbon dioxide concentration as follows:

$$\mathrm{ACH} = \frac{N.G.10^6}{\left(C_{\mathrm{eq.}(i)} - C_{(c)}\right).V} \tag{1}$$

Where:

N = Number of room occupant;
G = CO_2 generation rate (m^3/s per person);
10^6 = Conversation factor to ppm;
$C_{eq.(i)}$ = CO_2 equilibrium concentration inside the room (ppm);
$C_{.(c)}$ = CO_2 concentration in the outdoor air (ppm);
V = Room volume (m^3).

Considerations: the value of G depends on person's age and activity level. In this study was considered a value of 5.3 x 10^{-6} m^3/s per person; CO_2 concentration in the outdoor air was considered 400 ppm; and special attention was paid to guarantee the correct mixing of the CO_2 concentration in the room.

2.3 Estimated risk of airborne infection

The Wells–Riley model was used to estimate airborne transmission risk. This model assumes that an infected person constantly generates a number of infectious quanta over time, with a quantum defined as the dose of airborne droplet nuclei required to cause infection in $1/e^{-1}$, or 63%, of susceptible persons. In other words, when an infected person coughs or sneezes, a percentage of the ejected aerosol contains microbes that have the potential to cause disease. Thus, the Wells–Riley model predicts the risk of acquiring an infection by inhalation an infectious particle. It is described as follows (Riley et al., 1978):

$$P(t) = C/S = 1 - e^{(-I.q.p.t/Q)} \tag{2}$$

Where:

P(t) = probability of infection risk (%), at time t;
C = number of infection cases;
S = number of susceptible individuals exposed;
I = number of infectors;
p = pulmonary ventilation rate, (m^3/h);
q = quanta generation rate, (quanta/h);
t = exposure time, (h);
Q = air supplied into a room, (m^3/h).

The following premises are assumes in the Wells–Riley equation: (1) particles are evenly distributed in the space, which means that the infection risk predicted by this equation is uniform within the space and (2) the equation neglects the viability and infectivity of the pathogen quanta.

2.4 Measuring equipment

Sampling equipment was positioned centrally in the room at a height of 1.10 m, corresponding to the approximate breathing height of a seated person. The data collection methodology and reference standards for classroom air quality were based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers - ASHRAE standard 62-2007.

A CO_2 concentration meter (Testo 440 - CO_2 meter) with a non-dispersive infrared sensor, feeding 20–30 V direct current, was used to determine CO_2 concentration. The apparatus was calibrated by the manufacturers and had a reported accuracy of ± 1 ppm.

2.5 Experimental Scenarios

Scenarios using different quantum generation for the Covid-19 were considered for each case. For each scenario, it was assumed that one asymptomatic individual in the classroom was infected at the beginning of a lecture and exposed others for a defined number of hours (1.33 h). Subsequently, knowing the number of occupants in the classroom (33), the ventilation rate and other parameters relating to the Wells–Riley model, the risk of airborne infection can be predicted. Table 1 shows the input parameters used in the Wells–Riley model.

In this study, quantum generation values were obtained from the literature (REHVA, 2020; Pavilonis et al., 2021; Burridge et al., 2022), for two scenarios: a silent class where most occupants are sitting breathing and sometimes emit small vocalizations. The other scenario was considered a noisy class with the students talking many times aloud (Table 1).

Table 1. Input parameters used in the Wells–Riley model

PARAMETER	INFECTIOUS AGENTS- COVID-19		
	Silent class	Noisy class	Teacher
- Number of students/teacher	32	32	1
- Volume of shared airspace (m^3)	162	162	162
- Total exposure time (h)	1.2	1.2	1.2
- Pulmonary ventilation rate (m^3/h)*	0.54	0.54	1.1
- Number of infectors	1.0	1.0	1.0
- Quantum generation rate (q/h)**	1.0	1.0	5.0

* REHVA , 2020, ** Burridge et al, 2022.

2.6 Statistical Analysis

The Statistical Software Package for Social Sciences (SPSS) version 20.0 was used to conduct descriptive statistical analysis and comparisons of the means. The Friedman test with Dunn Post Hoc was used to compare mean differences between the cases regarding CO_2 and particle concentrations. This is a nonparametric test that is used to compare more than two means from non-normal distributions. Tests were considered significant at $p<0.05$.

3. RESULTS

3.1 CO_2 concentrations measured for the different cases

Figure 2 shows the variation over time for CO_2 concentrations measured for the different cases. Curves have a minimum of approximately 450 ppm and vary according to the case. The highest CO_2 concentration was when the split system air conditioner was used without outdoor ventilation (Case 1), increasing from 450– 3561 ppm. The lowest CO_2 concentration was when the split system and an exhaustfan with 891 m^3/hremained on (Case 5; 452–1003 ppm). When the split system and an exhaustfan with 891 m^3/hremained on (Case 2), CO_2 concentrations ranged from 455–2506 ppm. When the split system remained on with outdoor ventilation through a ventilation grill (case 2), CO_2 concentrations ranged from 455–2506 ppm.When the split system and an exhaustfan with 378 m^3/hremained on (Case 3), CO_2 concentrations ranged from 455–2050 ppm and when the split system and an exhaustfan with 653 m^3/hremained on (Case 4), CO_2 concentrations ranged from 455–1270 ppm. It is also apparent that concentrations in Case 1 increased faster as compared to Case 5; it took 9 min for CO_2 concentrations in Case 1 to exceed 1000 ppm and 20 min in Case 5.

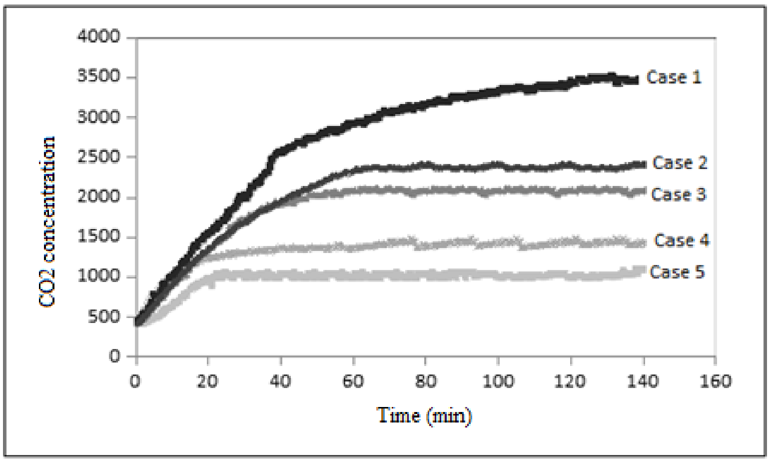

Figure 2 – Time series of CO_2 concentration for each case

3.2 Estimated ventilation rate based on CO_2 generation

Figure 3 shows the estimated air change ratefor each case. As was expected, the highest ventilation rate was obtained for case 5 (6.5/h), which is the ventilation required to maintain the indoor CO_2 concentration within acceptable levels (1000 ppm). The lowest was for case 1 (1.2/h), obtained when only the split system remained on without outdoor ventilation. When the split system remained on with outdoor ventilation through a ventilation grill (case 2), the ventilation rate was 1.8. It is apparent that the ventilation grill increased 66% theventilation rate in the room. In the cases 3 and 4, the ventilation rate was 2.3 and 4.5, respectively.

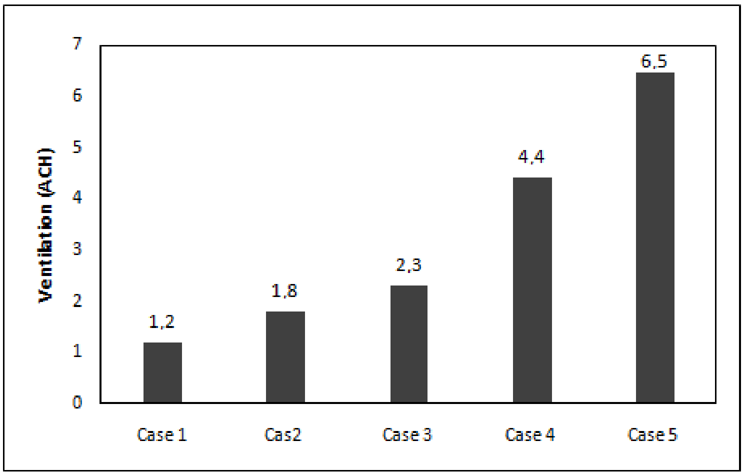

Figure 3 – Ventilation rate measured for each case

3.3 Estimated risk of infection

Figure 4 shows the risk of infection from COVID-19 for students inside the classroom, according to the Wells–Riley airborne infection model, considering different scenarios. It can be seen that, for all cases, the infection risk decreases with the increase of the outdoor ventilation. Case 1 has the highest risk of infection, at 32.6% for teacher, 2.6% for noisy class,and 0.5% for silent class. The lowestrisk of infection was obtained for case 5, at 18.6% for teacher, 0.5% for noisy class, and 0.1% for silent class. It can also be observed, thatthe risk of infection increased with the increase of the intensity of the occupants' respiratory activity.

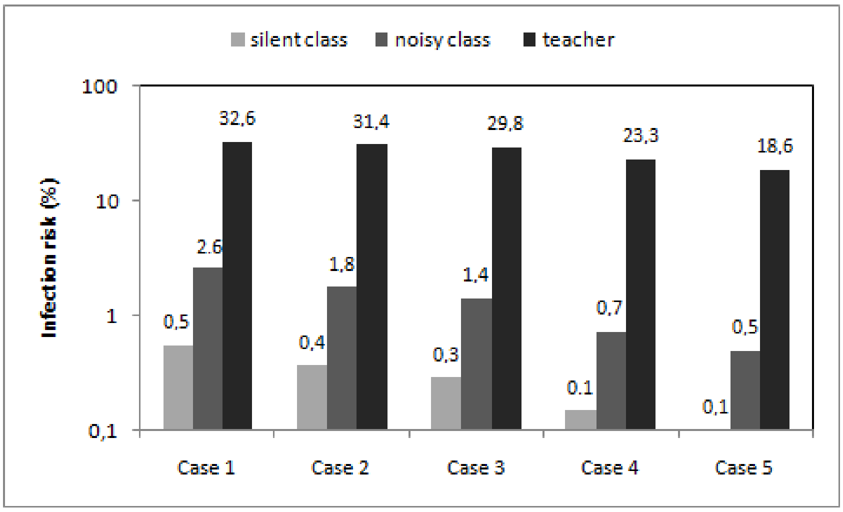

Figure 4 – Risk of infection from COVID-19 for the people inside the room

4. DISCUSSION

4.1 Ventilation Rate and CO_2 concentration

Figure 2 shows that only the Case 5 did not exceeded the recommended CO_2 level of 1000 ppm. When using only the split system for ventilation, CO_2 levels reached 3561 ppm, demonstrating the ineffectiveness of the split system in terms of ventilation. When ventilation with outside air was incorporated, the CO2 levels inside the room began to decrease. CO_2 concentrations using only the split system were approximately 3.5 times higher as compared to case 5, where the split system worked with an exhaust fan with ventilation rate of 891 m^3/h ($p<0.05$). When was opening the ventilating grill, case 2, CO_2 concentration decreased1.5 times in comparison to case 1 ($p<0.05$). The ventilation rate provided by the exhaust fan in the case 3 and 4 was not sufficient to keep the indoor CO_2 concentration within acceptable levels (1000 ppm). Comparing the cases 3 and 4 with case 1, CO_2 concentration were 1.4 and 2.7 times higher, respectively ($p<0.05$) .

These results show that split systems do not provide effective ventilation as indicated by CO_2 concentrations that were elevated to harmful levels to the occupants (ASHRAE, 2010). According to Pereira et al. (2015), split systems should not be used in densely occupied environments with long exposure times, such as classrooms. This is because the split system only recirculates indoor air and lacks a fresh supply of outdoor air causing an increase in contamination over time, surpassing 1,000 ppm within few minutes and reaches as high as several thousand within a few hours. Hence, the use of split systems in classrooms are a cause for concern.

Research on classrooms has suggested that high CO_2 concentrations in normal indoor settings are associated with poor air quality, increased prevalence of acute health symptoms (e.g., headache, mucosal irritation), slower work performance, and increased absence (Milton et al., 2000; Erdmann and Apte, 2004; Federspiel et al., 2004). Research has also shown that high CO_2 concentrations cause drowsiness, lethargy, and a general perception that the air is stale (Siskos et al., 2001; Daisey et al., 2003). Moreover, they are associated with an increase in student absenteeism and a decrease in learning performance and staff productivity (Mendell et al., 2013). Twardella et al. (2012) carried out a study with 417 students in 20 classrooms at primary schools in Germany using mechanical ventilation and found that student accuracy markedly decreased in “worse” environments (median CO_2 level of 2115 ppm) as compared to “better” environments (median CO_2 level of 1045 ppm).

The use of an exhaust fan with adequate ventilation flow, together with the split, maximized the ventilation rate and, consequently, CO_2 concentrations remained below those recommended by the standard (Riley et al., 1978; Nardell et al., 1991; ASHRAE, 2007). Our finding is supported by Ismail et al. (2010),who reported that an extractor fan turned on for five minutes every half hour could also solve the problem of excess CO_2 accumulation indoors. According to these authors, indoor air needs to be ventilated with sufficient outdoor air to dilute contaminants and provide students with enough oxygen (O_2) for breathing.

4.3 Infection Risk

In this study, the Wells–Riley equation was used to predict the infection risk of respiratory infectious diseases (COVID-19) using different outdoor ventilation rates in a classroom conditioned with split system. The model requires knowledge of the air ventilation rate as an input parameter for calculating the risk of infection, i.e., the probability of infection through infectious droplet nuclei is inversely correlated to the ventilation rate. Our results, Figure 4, showed that a higher ventilation rate, provided by an exhaust fan with adequate flow together with the split system, results in faster dilution of contaminated air inside a space more rapidly than a lower rate, and at the same time, can also decrease the risk of transmission of infectious droplet nuclei to students in the classroom. For example, when the teacher was the transmission agent, the infection risk was 32.6% for an ACH of 1.6/h when only the split system was used. The infection risk decreased to 18.6% for an ACH of 6.5/h when an exhaust fan with adequate ventilation flow was used together with the split system. According to these results, it is apparent that in the current pandemic scenario, the use of split systems can be dangerous because of the number and density of people in the classroom, due to their low ventilation rate. Split systems can increase the risk of inhaling particles that are contaminated by microbiological contaminants, and consequently increasing the risk of infection. As suggested by Salo et al. (2009), indoor environments such as schools with high occupancy density have high indoor biological concentrations.Therefore, the practice of adequate ventilation is of fundamental importance.

According to Chatzidiakou (2014), lower ventilation rates have been linked to increased infection risk in a range of environments, including schools, usingthe Wells–Riley equation since the 1970s (Riley, 1978). The work of Menzies et al. (2000), found that the tuberculin conversion among clinical personnel was significantly more rapid and frequent among those working in environments with ventilation lower than 2 ACH.

The risk of transmission varied widely depending on whom (student or teacher) was infected (student or teacher) and on the activity levels inside of room. Lower infection risk was associated in the silent class where most occupants are sitting breathing and sometimes emitting small vocalizations. However, the infection risk increases strongly to the case where the infected was the teacher,who was talking aloud all times. The infection risk increased approximately three to four times for teacher-to-student transmission scenarios. It is important to highlight that these differences are associated with emission rates which can vary over a large range, depending on the activity level. Our finding is supported by Pavilonisa et al. (2021), who reported that the infection associated to the teacher is a result of larger inhalation and quanta generation rates.

5. CONCLUSIONS

This study aimed to estimate the risks of cross-infection by COVID-19 in a classroom conditioned with split system using different ventilation rates of outdoor air. Infection risk was calculated for different respiratory activitiesusing the Wells-Riley model.

The results showed thatthe used of split systemdo not provide effective ventilation as indicated by CO_2 concentrations that were elevated to harmful levels to the occupants. Equipment such as split systemshould not be used for ventilation in densely occupied rooms with long-term exposure, such as the kind which occurs in classroom environments. This is because split systems only recirculate indoor air, without a fresh supply of outdoor air, thus causing an increase in contamination over time and increasing the risk to the occupants.

The incorporation of an exhaust fan to supply outdoor air to the room significantly reduced the concentration of CO_2, as well as the risks of infection.With the use of an exhaust fan to supply outdoor air to the room the CO_2 concentration was reduced around 3.5 times and the risk of infection to occupants between 1.7 and 5.0 times, depending on the respiratory activity. Further investigation is necessary for this potential solution, because increased ventilation with outdoor air can also increase the indoor concentration of outdoor-generated pollutants and during the summer it can increase the indoor thermal load, consequently, increasing energy consumption.

The results showed that the transmission varied widely depending on whom was infected and depending on the activity levels inside of room. These differences are associated with emission rates which can vary over a large range, depending on the activity level.

Few studies have undertaken a quantitative determination of indoor CO_2, concentrations and the risk of infection using split system in classrooms. Thus, this study is important for future work related to health in such environments and will serve as a basis for corrective actions.

6. REFERENCES

ASHRAE, 2007. Ventilation for acceptable indoor air quality, standard 62-2007, *American Society for Heating, Refrigerating and Air Conditioning Engineers*, Atlanta, GA.

ASHRAE Environmental Health Committee (EHC), 2010.The Ventilation, Humidity Control and Health Effects in Buildings using Split System Air Conditioning Equipment.*Emerging Issue Report*.

ASTM E741-11, 2017. Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution.*American Society for Testing and Materials.*

Awbi HB. *Ventilation of buildings*, 2nd ed. New York:Taylor& Francis; 2003.

Batterman S., 2017. Review and Extension of CO2-Based Methods to Determine Ventilation Rates with Application to School Classrooms. *Int J Environ Res Public Health*;14:145.

Burridge H C, Fan S, Jones R L, Noakes C J, Linden P F, 2022. Predictive and retrospective modelling of airborne infection risk using monitored carbon dioxide. *Indoor and Built Environment*.;31(5):1363-1380. doi:10.1177/1420326X211043564.

Chatzidiakou E, 2014. Is CO2 a good proxy for Indoor Air Quality in school classrooms? *Doctor Thesis*. UCL Institute for Environmental Design and Engineering.The Bartlett University College London.

Daisey JM, Angell WJ, Apte MG, 2003. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air*;13:53-64.

Erdmann CA, Apte MG, 2004. Mucous membrane and lower respiratory building related symptoms in relation to indoor carbon dioxide concentrations in the 100-building BASE dataset. *Indoor Air*; 14:127-134.

Etheridge D, Sandberg M, 1996. *Building ventilation — theory and measurement*. Chichester, UK: John Wiley & Sons.

Federspiel CC, Fisk WJ, Price PN, Liu G, Faulkner D, Dibartolomeo DL, Fisk WJ , Price PN , Sullivan DP, 2004. Worker performance and ventilation in a call center: analyses of work performance data for registered nurses. *Indoor Air*; 14:41-50.

Ismail AR, Singh S, Goh CN, 2010. Thermal comfort in a closed air conditional ICT laboratory at Ungku Omar Polytechnic Malaysia. In: *National Conference in Mechanical Engineering Research and Postgraduate Students* (1st NCMER 2010), 26–27, FKM Conference Hall, UMP, Kuantan, Pahang, Malaysia, 555–563; 2010.

Issarowa CM, Mulder N, Wood R, 2015. Modelling the risk of airborne infectious disease using exhaled air.*J Theor Biol*.;372:100-106.

Jones BM, Kirby R, KolokotroniM Payne T. Air quality measured in a classroom served by roof mounted natural ventilation windcatchers. *Proceedings of the 2008 Conference for the Engineering Doctorate in Environmental Technology*. UK.

Mendell MJ, Eliseeva EA, Davies MM, Spears M, Lobscheid A, Fisk WJ, Apte MG. 2013. Association of classroom ventilation with reduced illness absence: A prospective study in California elementary schools. *Indoor Air*.;23:515-528.

Menzies D, Fanning A, Yuan L, FitzGerald JM, 2000. Hospital ventilation and risk for tuberculous infection in Canadian health care workers. *Ann Intern Med.*;133(10):779–789.

Milton DK, Glencross PM, Walters MD, 2000. Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints. *Indoor Air*;10:212-221.

Nardell EA, Keegan J, Cheney SA, Etkind SC, 1991. Airborne infection. Theoretical limits of protection achievable by building ventilation. *Am Rev Respir Dis*.;144:302-306.

Pavilonis B, IerardiAM, Levine L, Mirer F, Kelvin EA, 2021. Estimating aerosol transmission risk of SARS-CoV-2 in New York City public schools during reopening.*Environ Res.;*195:110805.

Pereira ML, Vilain R, Tribess A, Morawska L. Risk assessment for airborne infectious diseases between natural ventilation and split-system air conditioner in a university classroom. *In Proceedings of the 23rd ABCM International Congress of Mechanical Engineering*, COBEM 2015, ABCM, Rio de Janeiro, Brazil, 1-5. 2015.

REHVA, 2020. “COVID-19 ventilation calculator”.https://www.rehva.eu/covid19-ventilation-calculator.

Richardson ET, Morrow CD, Kalil DB, Bekker LG. 2014.Shared air: a renewed focus on ventilation for the prevention of tuberculosis transmission.*PloS One*; 9:e96334.

Riley E, Murphy G, Riley R, 1978. Airborne spread of measles in a suburban elementary school. *Am J Epidemiol*.:421-432.

Salo PM, Sever ML, Zeldin DC, 2009. Indoor allergens in school and day care environments.*J Allergy Clin Immun.*;124:185-192.

Santamouris M, Synnefa A, Asssimakopoulos M, Livada I, Pavlou K, Papaglastra M, Gaitani N, Kolokotsa D, Assimakopoulos V, 2008. Experimental investigation of the air flow and indoor carbon dioxide concentration in classrooms with intermittent natural ventilation.*Energy Build*.;40:1833–1843.

Seppänen O, Fisk WJ, 2002. Association of ventilation system type with SBS symptoms in office workers.*Indoor Air*;12:98-112.

Siskos PA, Bouba KE, Stroubou AP, 2001. Determination of Selected Pollutants and Measurement of Physical Parameters for the Evaluation of Indoor Air Quality in School Buildings in Athens, Greece.*Indoor Built Environ*.;10:185-192.

Twardella D, Matzen W, Lahrz T, Burghardt R, Spegel H, Hendrowarsito L, Frenzeln AC, Fromme H, 2012. Effect of class-room air quality on students’ concentration:Results of a cluster-randomized cross-overexperimental study. *Indoor Air*; 22:378–387.

Wells WF, 1955, *Airborne Contagion and Air Hygiene: An Ecological Study of Droplet Infections*. Boston: Harvard University Press.

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