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RISK ASSESSMENT FOR AIRBORNE INFECTIOUS DISEASES BETWEEN NATURAL VENTILATION AND A SPLIT-SYSTEM AIR CONDITIONER IN A UNIVERSITY CLASSROOM

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ABSTRACT
Indoor air quality is a critical factor in the classroom due to high people concentration in a unique space. Indoor air pollutant might increase the chance of both long and short-term health problems among students and staff, reduce the productivity of teachers and degrade the student's learning environment and comfort. Adequate air distribution strategies may reduce risk of infection in classroom. So, the purpose of air distribution systems in a classroom is not only to maximize conditions for thermal comfort, but also to remove indoor contaminants. Natural ventilation has the potential to play a significant role in achieving improvements in IAQ. The present study compares the risk of airborne infection between Natural Ventilation (opening windows and doors) and a Split-System Air Conditioner in a university classroom. The Wells-Riley model was used to predict the risk of indoor airborne transmission of infectious diseases such as influenza, measles and tuberculosis. For each case, the air exchange rate was measured using a CO_2 *tracer gas technique. It was found that opening windows and doors provided an air exchange rate of 2.3 air changes/hour (ACH), while with the Split System it was 0.6 ACH. The risk of airborne infection ranged between 4.24 to 30.86 % when using the Natural Ventilation and between 8.99 to 43.19% when using the Split System. The difference of airborne infection risk between the Split System and the Natural Ventilation ranged from 47 to 56%. Opening windows and doors maximize Natural Ventilation so that the risk of airborne contagion is much lower than with Split System.*

Keywords*: Indoor air quality, Airborne infection, Natural Ventilation, Split system, Air changes/hour*

INTRODUCTION

The general purpose of ventilation in buildings is to provide healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it. A higher ventilation rate can provide a higher dilution capability and consequently potentially reduce the risk of airborne infections (WHO, 2009).

Dilution ventilation with fresh air becomes critical for airborne infection control whenever people share air space, such as a classroom. Schools present a much higher occupancy than many other buildings, for example, there are four times as many occupants per unit of area than in office buildings (Santamouris et all, 2008).

Classrooms and other school spaces must be ventilated to remove odors and other pollutants. Investigations at schools often use the CO2 concentration in classrooms as a measure of ventilation (Jones at al, 2008). Quantitative links between carbon dioxide, ventilation and occupant performance have been established (Seppänen and Fisk, 2002). Carbon dioxide, which in itself may not be a direct cause of poor indoor air quality, but is recognized as a surrogate indicator of indoor air quality and ventilation rates (Seppänen and Fisk, 2002; Jones at al, 2008). In general, a larger peak difference between indoor and outdoor CO2 concentration indicates a small ventilation rate per person. In urban areas, outside concentrations have been in the 375 to 450 ppm range (Schell and Int-Hout, 2001). Indoor concentrations above 1000 ppm are generally considered unacceptable (Apte et al, 2000)).

Most schools in Brazil have natural ventilation in classroom and most of the schools with air conditioning have split system. Normally this type of system only recirculates the air inside the room without filtration and the appropriate quantity of outside air. Besides, this kind of equipment produces an enormous turbulence inside the room. In addition, the use of split-systems in classrooms may result in the spread of infectious diseases, instead of being an important tool for infection control. It is also important to highlight that, although split system ventilation is often used, there are few published studies that examines the impact of the split system on indoor contamination concentration and distribution in classrooms and other school spaces (Pereira et all, 2009).

The use of outdoor air for natural ventilation can be an interesting alternative, but natural ventilation is variable and depends on outside climatic conditions relative to the indoor environment. Furthermore, natural ventilation may be difficult to control, with airflow being uncomfortably high in some locations and stagnant in others (WHO, 2009).

In this context, the aim of this work is to compare the risk of cross-infection between natural ventilation and split-systems used in university classroom. The risk of airborne infection (percent of susceptible persons infected) was estimated for each ventilation experiment using the Wells-Riley model.

ESTIMATED RISK OF AIRBORNE INFECTION

The Wells-Riley equation has been extensively used as a tool to predict infection risk of respiratory infectious diseases in indoor environments. Wells-Riley model can give useful indications of expected transmission in a wide range of circumstances and numerous researchers have carried out risk-analysis studies based on this model. Wells–Riley model requires knowledge of the air ventilation rate and some studies has modified this model incorporating other loss terms, including filtration by personal respirators, UV degradation, particle deposition, and HVAC filtration (Rudnick and Milton, 2003; Stephens, 2012). The Wells-Riley equation is described as follows (Riley, et al., 1978):

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

Where: P(t) is the probability of infection risk at time t, (%); C is the number of infection cases; S is the number of susceptible individuals exposed; I is the number of infectors; p is the pulmonary ventilation rate, (m^3/h); q is the quanta generation rate, (quanta/h); t is the exposure time, (h) and Q is the ventilation rate, (m^3/h).

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

EXPERIMENTAL METHOD

The classroom studied has 162 m^3 (9x6x3m, see figure 1) with one air-conditioning unit capacity of 24,000 BTU/h, installed 2,8 meters from the ground at the back of the classroom, responsible for the recirculation of the air and with no qualified filter.

The number of student in the room was approximately 32 and the activity in the room was typical of a college 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 periods was 1 hour and 20 minutes.

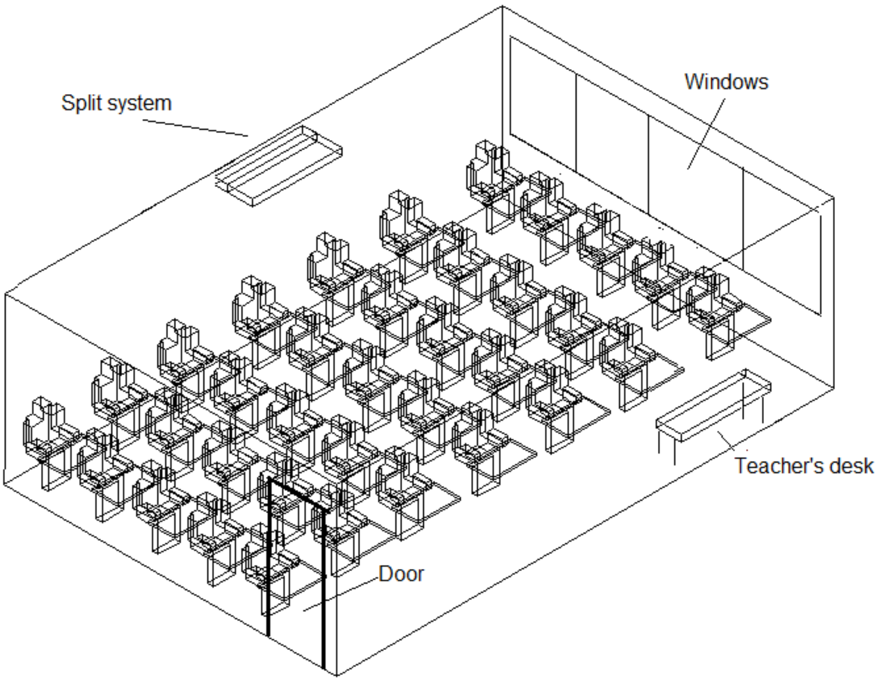

Figure 1. Classroom geometry

For each experiment with empty room, the air exchange rate (ACH) was measured using a CO_2 tracer gas technique. Initially, for both cases, with all windows and doors closed, CO_2 was released and mixed well with room air using fans to create a spatially uniform CO_2 concentration in the room. After the air reaches the appropriate uniformity and concentration, fans were then switched off. For natural ventilation analyses, all windows and doors were opened and for split-system analyses all windows and doors remained closed and with equipment turned on. Measurements were considered from peak concentrations after reaching 2250 ppm until the concentration fell to within 450 ppm. The air exchange rate was calculated as the gradient of the straight line through the natural logarithm of CO_2 concentration plotted against time in hours.

Some scenarios were considered for each ventilation system, including infectious agents such as measles, TB and influenza. For each scenario, it was assumed that one individual is infected since the beginning of a lecture and exposed others for a defined number of hours (1,20hs). Then, knowing the number of occupants in the classroom, the ACH and the other parameters relating to the model of Wells-Riley, can predicted the risk of airborne infection. Table 1 show the input parameters used in the Wells–Riley model.

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

PARAMETER	**INFECTIOUS AGENTS**		
	Influenza	**Measles**	**TB**
- Number of students	32	32	32
- Volume of shared airspace (m^3)	162	162	162
- Total exposure time (h)	1.20	1.20	1.20
- Breathing rate (m^3/h)*	0.6	0.6	0.6
- Number of infectors	1	1	1
- Quantum generation rate (q/h)	76.18**	108.16**	12.70*

*Nardell et all, 1991, **Liao et all, 2008

RESULTS AND COMMENTS

Figure 2 shows the time series of CO_2 for each experiment. It illustrates that opening windows and doors provide a ventilation rate of 2.3 ACH and 0.6 ACH is provided with Split System.

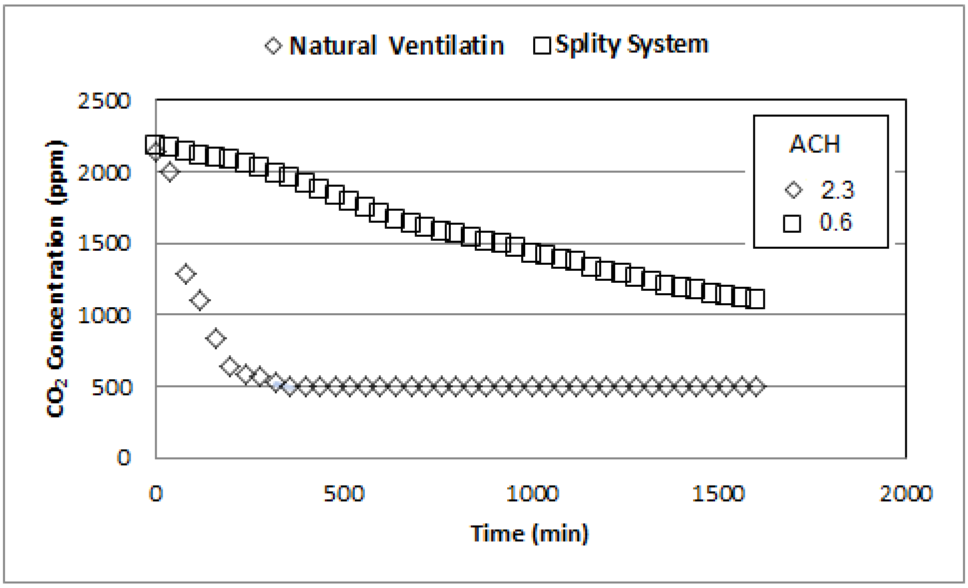

Figure 2. Time series of CO_2 for each experiment

Table 3 summarizes the infection risk for each configuration and scenario studied. According to the type of infectious agent the risk of airborne infection ranged between 8.99 % and 43.19% when using the Split System and between 4.24 to 30.86 % when using the natural ventilation. The difference of infection risk between the Split System and the Natural Ventilation ranged from 47% to 56%.

Table 3. Infection risk for each configuration and scenario studied

VENTILATION	**INFECTIOUS AGENTS**		
	Influenza	**Measles**	**TB**
Ventilation Natural	22.89	30.86	4.24
Split System	43.19	55.19	8.99
Difference (%)	53	56	47

CONCLUSIONS

The present study compares the risk of cross-infection between natural ventilation and split-system used in a university classroom using the Wells-Riley airborne infection model.

Results showed that opening windows and doors provided a higher air exchange rate than split-Systems, therefore providing a smaller risk of airborne infection. These findings suggest that split system should not be used in large densely occupied rooms with long term exposure as occur in classrooms. This is due to the fact that split systems only recirculate the indoor air, without a fresh supply of outdoor air, thus causing an increase of contamination over time. This lead to an increasing of the air contamination inside the room representing a risk to the students.

This approach allows rapid mathematical prediction, proving to be a powerful tool for analyzing and predicting the infection risk of airborne transmission diseases.

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