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Ventilation strategies of school classrooms against cross-infection of COVID-19: A review

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SUMMARY

Under current pandemic of COVID-19, children are still spending long hours in school classrooms every day. A literature study is therefore conducted to investigate the current ventilation strategies used in schools and assess their performance of controlling contagious respiratory diseases in the indoor environment, and also to seek for future solutions. Research papers, reports and standards relevant to school ventilation, airborne transmission and complementary air distribution methods are reviewed. It is concluded that schools usually have natural ventilation (NV) or mechanical ventilation (MV), however the overall indoor air quality is not ideal. Both NV and MV can reduce the airborne transmission of respiratory droplets efficiently when designed, operated, and maintained properly, yet schools are in shortage of informative standards and guidance. Personalized ventilation (PV) has a promising potential in protecting occupants from local indoor air contaminants, yet further studies are needed before PV can be applied to children in classrooms.

INTRODUCTION

Ever since the early stage of the global pandemic of COVID-19, researchers have been investigating the epidemiological features of pediatric patients, and it is suggested that children in general have milder symptoms than adults (Qiu et al., 2020). However, existing evidence cannot determine whether children are less frequently infected or infectious (Li et al., 2020). In fact, the large proportion of asymptomatic cases among them may become overlooked threats to susceptible individuals when sharing indoor space (Merckx et al., 2020), especially in densely occupied school classrooms. According to a recent report by European Centre for Disease Prevention and Control (ECDC, 2020), the proportion of infected children aged 12-18 to the total confirmed cases has slightly exceeded the population distribution of this age group among 11 EU/EEA countries. Considering the long hours students spend in their classrooms every day, it is therefore in urgent need to determine whether schools can provide a safe indoor environment.

Since airborne transmission (aerosols) has now been widely recognized as one of the major transmission routes of SARS-CoV-2, ventilation is hence stressed again to be an important means for cross-infection control between indoor occupants (Morawska et al., 2020). However, for most school buildings, their ventilation strategies are not initially designed for such purpose, but rather based on a balance between comfort and energy. Therefore, this literature review is aimed to (1) identify the common ventilation strategies currently in use by school buildings, (2) evaluate their efficiency of reducing infectious aerosols in the indoor environment, and (3) propose potential solutions for the future. To highlight, a full version of this literature review is in preparation and it is intended to be published later as a journal article. Hereby, only key references are presented in this short paper.

METHODS

The concepts included in the literature search of this study are listed in **Table 1**. Research papers are mainly acquired from databases including Google Scholar, ScienceDirect, Scopus, SpringerLink and PubMed, etc. In general, the scope of the journal, the research background of the author(s), and the publication recency are the main criteria for assessing the quality and relevance of the papers. The official websites of WHO, ISO, CEN, REHVA and ASHRAE are used for access to relevant standards and guidelines. The articles are examined and summarized into three sub-topics:

- Current knowledge of the features and indoor air quality control measures of airborne transmission of respiratory droplets.
- Patterns of ventilation strategies in schools and relevant requirements.
- Potential of personalized ventilation systems for reducing cross-infection indoors.

Table 1. Literature search concepts.

	Concepts: combine with **AND**		
Synonyms and/or related terms: combine with **OR**	*concept 1:* **airborne transmission**	*concept 2:* **school**	*concept 3:* **ventilation**
	aerosol	classroom	air distribution
	respiratory droplets	children	air change rate
	droplet nuclei	student	airflow

AIRBORNE TRANSMISSION OF RESPIRATORY DROPLETS: FEATURES AND CONTROL

Normally, the cross-infection of contagious respiratory diseases like COVID-19 between indoor occupants consists of three stages: first, an infected person generates pathogen-containing droplets by respiration activities such as breathing, sneezing, coughing, and talking; then the infectious droplets spread indoors; once a susceptible person is exposed to a certain concentration of pathogens, infection may take place. (Ai & Melikov, 2018). Preliminary guidance on prevention of COVID-19 mainly stressed three transmission routes which are distinguished as close contact, fomites and long-range airborne (i.e., aerosols) (Zhang & Li, 2018). Recently experiment and simulation studies have also indicated that airborne transmission of respiratory droplets can occur both at short and long-range (Chen et al., 2020). Since the dispersion of aerosols can be easily affected by all kinds of indoor airflows, ventilation is thus widely adopted to minimize the airborne transmission (Ai & Melikov, 2018).

For natural ventilation (NV), it is confirmed that a good performance of removing aerosols can be achieved, yet its efficiency is largely dependent on specific conditions such as local climate, building design and occupant behaviour (Qian et al., 2010). Consequently, the air change rate of NV can hardly be determined (Hong et al, 2005). For mechanical ventilation (MV), both mixing and displacement air distribution can effectively reduce airborne transmission (Gao et al., 2008). However, their efficiency is not linearly related to the air change rate (ACH), as increasing ACH can sometimes result in local airflow patterns with a higher exposure rate (Pantelic & Tham, 2013). It is also suggested that control measures based on steady-state conditions may not be applicable to airborne transmission during short-term events (or short-range airborne transmission) (Ai et al., 2019).

VENTILATION STRATEGIES IN SCHOOLS: GUIDELINES AND REALITY

The design criteria of required ventilation rate per occupant in school classrooms provided by several international organizations are listed in **Table 2**, including ISO 17772-1:2017 (2017), EN 167981-1:2019 (2019) and ANSI/ASHRAE *Standard* 62.1-2019 (2019).

Table 2. Design criteria of ventilation rate for classrooms.

Standard	Category		
	I (l/s, person)	II (l/s, person)	III/Minimum (l/s, person)
ISO 17772-1:2017	10	7	4
EN 16798-1:2019	10	7	4
ANSI/ASHRAE 62.1-2019	–	–	5

These criteria are in general based on theoretical assumptions, and are only valid for specific indoor environment conditions. Moreover, in most cases CO_2 concentration is used as the sole indicator for assessing indoor air quality and ventilation sufficiency in school buildings (REHVA, 2020).

According to several recent field studies on school buildings located in different countries (**Table 3**), it is observed that both MV and HV can achieve higher ventilation rate, lower CO_2 concentration and better academic performance than NV (Toftum et al., 2015; Canha et al., 2016), and NV is often hampered by other indoor environment control devices (Bluyssen et al., 2018). It is also noticed in some schools that HV and MV were not properly operated and adjustments were needed (Vornanen-Winqvist et al., 2018a; 2018b).

Table 3. Ventilation strategies in school buildings.

Reference	Country	Schools (Classrooms)	Ventilation regime
Toftum et al. (2015)	Denmark	389 (820)	NV: 52% HV*: 17% MV: 31%
Canha et al. (2016)	France	17 (51)	NV: 73% MV: 27%
Bluyssen et al. (2018)	The Netherlands	21 (54)	NV: 48% HV: 19% MV: 33%
Vornanen-Winqvist et al. (2018a; 2018b)	Finland	2 (4)	HV: 50% MV: 50%

*HV: hybrid ventilation

DISCUSSION

Natural ventilation and mechanical ventilation are the major ventilation strategies used in school buildings. Although both of them have shown great potential in reducing airborne transmission of respiratory droplets (Qian et al., 2010), the overall IAQ of school classrooms is not ideal (Bluyssen et al., 2018). Natural ventilation can sometimes achieve higher air change rates, yet it requires a well-thought-out design and constantly proper operation. Mechanical ventilation can perform in a more stable manner, but it also needs careful operation and maintenance. So far, standards and guidelines are mainly based on the control of CO_2 concentration, and thus whether they are sufficient for removing aerosols under various contact scenarios between indoor occupants remains unknown.

With regard to the insufficient ventilation observed in schools, personalized ventilation (PV) can be applied to help minimizing the infectious aerosols. It is well demonstrated that the utilization of PV facilities can compensate the total volume ventilation to improve local IAQ, and thus achieve better protection for occupants exposed to an infected person (Li et al., 2013; Melikov, 2016). Moreover, researchers have proved the ability of PV to efficiently respond to short-range airborne transmission (Pantelic et al., 2009). However, previous studies mainly examined the performance of PV systems in special room settings such as hospital wards or aircraft cabins (Nielsen et al., 2008; Melikov & Dzhartov, 2013). Therefore, further studies are required for adapting PV into school classrooms, since children have specific psychological and physiological demands on IAQ conditions different from adults.

CONCLUSIONS

This literature review is conducted to target the gap between school ventilation measures and the cross-infection control of COVID-19 among children, so as to propose future solutions. The conclusions are drawn as follows:

- School classrooms mainly have natural or mechanical ventilation, where the overall IAQ needs to be improved.
- Both natural and mechanical ventilation can reduce the airborne transmission of infectious respiratory droplets efficiently when designed, operated, and maintained properly, yet relevant standards and guidance are insufficient for school buildings.
- Personalized ventilation (PV) has a promising potential in protecting occupants from local indoor air contaminants, yet systematic studies are needed before PV can be applied to children in classrooms.

REMARK

A full version of this literature review is in preparation and it is intended to be published later as a journal article.

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