

The impact of different air distribution and exhaust strategies on the risk of airborne infections in classroom environments

KEY WORDS: AIR DISTRIBUTION, LOCAL EXHAUST, INFECTION RISK, CFD, CLASSROOM



RISTO KOSONEN
Professor, Department of
Mechanical Engineering, Aalto
University, Espoo, Finland
risto.kosonen@aalto.fi



MUHAMED FARHAN EJAZ
Department of Mechanical
Engineering, Aalto University,
Espoo, Finland



SIMO KILPELÄINEN
Department of Mechanical
Engineering, Aalto University,
Espoo, Finland

In crowded classrooms, students are easily exposed to airborne pathogens. Mixing ventilation is typically not efficient and needs a lot of energy to run. Advanced air distribution and local exhaust can prevent the spread of pollutants more efficiently than mixing ventilation.

Children spend a significant portion of their daily time at school. Classroom environments are often characterized by limited space per student, in some cases as little as 1.4 m² per child (Sadriyadeh et al., 2022). In these situations, students are easily exposed to airborne pathogens. This increases the risk of infection for students and teachers, especially in poorly ventilated spaces (Becerra et al., 2020).

The purpose of the currently commonly used mixing ventilation is to dilute pollutants and mix the air volume of the entire room as efficiently as possible so that the entire room has the same pollutant concentration. Advanced ventilation, on the other hand, can prevent the spread of pollutants. This can be achieved by ventilation strategies in which the air distribution method and the location of the exhaust are chosen so that pollutants are removed in the immediate vicinity of the source before they spread throughout the room, while at the same time bringing clean supply air directly to the breathing zone (Izadyar and Miller, 2022).

This study analyzed the impact of different air distribution solutions and exhaust locations on the risk of airborne infection. CFD simulations were used to compare mixing, wall attachment and displacement air distribution and different exhaust solutions in a classroom setting where there were three possible locations for an infected person.

Methods

The effectiveness of different air distribution and exhaust strategies was investigated in a typical classroom with 17 students and one teacher, where an infected person can be located in three different locations. The dimensions of the room were 5.60 m long, 7.50 m wide and 3.00 m high. The 3D model of the classroom, the three possible locations of the infected person and the ventilation principles chosen for this study are presented in **Figure 1**.

The classroom supply air flow was 170 l/s (4.1 l/s/m²) in all cases other than M-case 4, where the air flow was 213 l/s (+25%). The supply air solutions studied

were mixed ventilation, wall attachment and displacement ventilation (case-specific floor molding blowing from 3 walls). Depending on the solutions, there were 1–4 exhaust valves in the room. In addition, the importance of local exhaust was studied when it was installed above the students at a height of 2.0 m from the floor. The target room air temperature was 22°C and the supply air temperature was 18°C in all cases.

Table 1 shows the different cases studied. In this study, the modified Wells-Riley equation was used to estimate the local probability of infection at different points in the classroom breathing zone (Su et al, 2022). The breathing air flow used in the model was 6 l/min and the exposure time was 45 min. The value used as the Quanta value in this study is 20.

Results

Figures 2, 3 and **4** show the probability distributions of infection risk at the respiratory level after 45 minutes of exposure at infection source locations 1, 2 and 3.

The colour scale depicts the distribution of infection risk in a classroom. Blue shades (0.0–0.5%) indicate low risk, while green shades (0.5–1.0%) represent medium risk. Yellow (1.0–1.3%) marks the beginning of the high-risk zones, and orange to red (1.3% and above) correspond to the areas of highest risk. The colours classify the relative exposure and highlight local differences in infection risk in the occupied area. In addition to ventilation solutions, the location of the infected person in the classroom and, above all, the location in relation to the exhaust significantly affects the risk of infection.

Table 1. The supply and exhaust methods.

Cases	Supply and exhaust air flow rates (l/s)	Air distribution	Exhaust
M-case 1	170	Mixing	1 x exhaust valve
M-case 2	170		2x exhaust valves
M-case 3	170		4x exhaust valves
M-case 4	213		1x exhaust valve
W-case 1	170	Wall attachment	1x exhaust valve
W-case 2	170		2x exhaust valves
W-case 3	170		4x exhaust valves
W-case 4	170		local exhaust + 1x exhaust valve
D-case 1	170	Displacement	exhaust valve
D-case 2	170		local exhaust + 1x exhaust valve

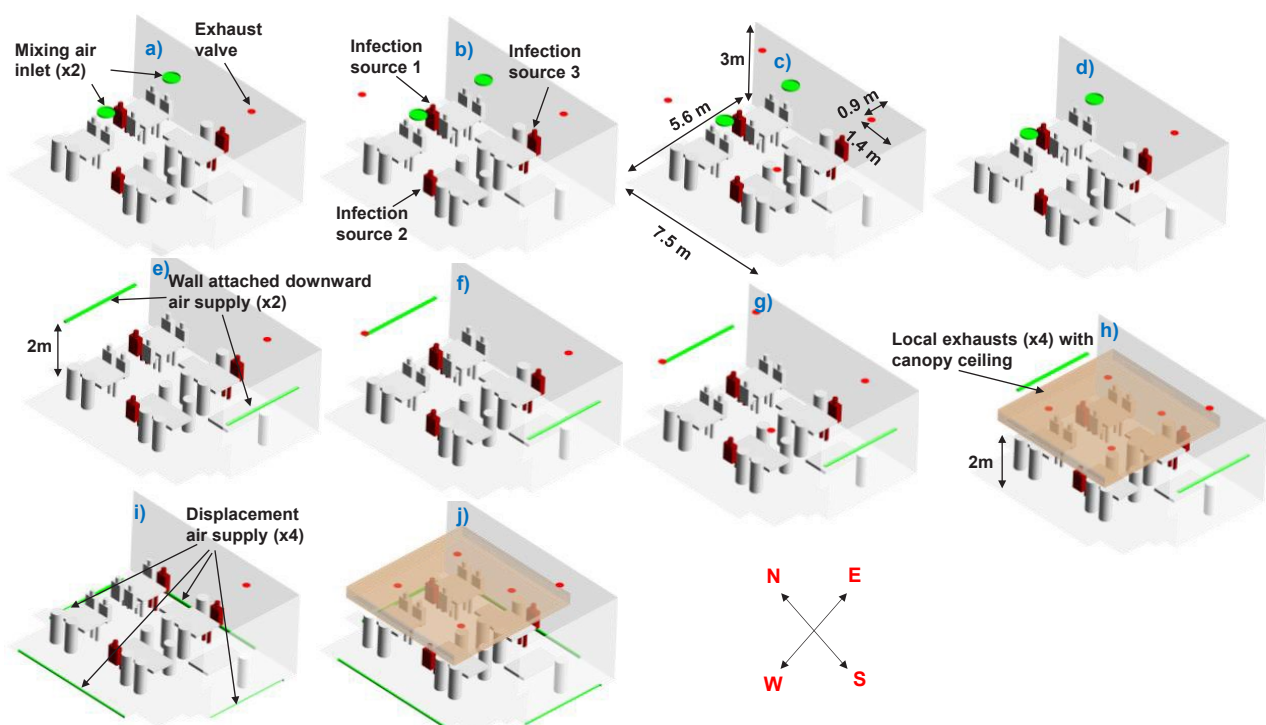


Figure 1. Classroom layout and the analysed ventilation solutions: a) M-case 1, b) M-case 2, c) M-case 3, d) M-case 4 (increased air flow rate), e) W-case 1, f) W-case 2, g) W-case 3, h) W-case 4 (local exhaust), i) D-case 1, j) D-case 2 (local exhaust).

Table 2 shows the high, medium and low risk students according to the infection probability curves shown in **Figures 2, 3** and **4**. Mixed ventilation with a single exhaust valve (M-case 1) has the highest number of students in the high and medium risk categories. Adding more exhaust points (M-case 2 and 3) or increasing the airflow by 25% (M-case 4) did not significantly reduce the number of students in the high and medium risk categories.

In the wall attachment cases (W-case 1-4), the infection risk was lower than in mixed ventilation. Similarly, displacement ventilation horizontally supplied from three walls, which was installed in the floor skirting, significantly reduced the number of students at high infection risk. Combining targeted exhaust with wall attachment (W-case 4) significantly improved the removal efficiency of pollutants. Instead, combined local exhaust of displacement air (D-case 2) only slightly improved efficiency compared to general exhaust (W-case 2).

Table 2. The supply and exhaust methods.

Cases	Infected 1			Infected 2			Infected 3		
	$P \geq 1$	$0.5 \leq P < 1$	$P < 0.5$	$P \geq 1$	$0.5 \leq P < 1$	$P < 0.5$	$P \geq 1$	$0.5 \leq P < 1$	$P < 0.5$
M-case 1	11	5	0	5	11	0	6	10	0
M-case 2	7	9	0	3	13	0	3	13	0
M-case 3	2	9	5	4	12	0	5	11	0
M-case 4	4	7	5	2	5	9	2	0	14
W-case 1	5	11	0	3	13	0	0	2	14
W-case 2	4	12	0	2	8	6	1	4	11
W-case 3	4	12	0	2	4	8	2	4	10
W-case 4	2	4	10	0	5	11	1	2	13
D-case 1	1	1	14	1	2	13	2	2	12
D-case 2	0	2	15	1	2	13	2	2	12

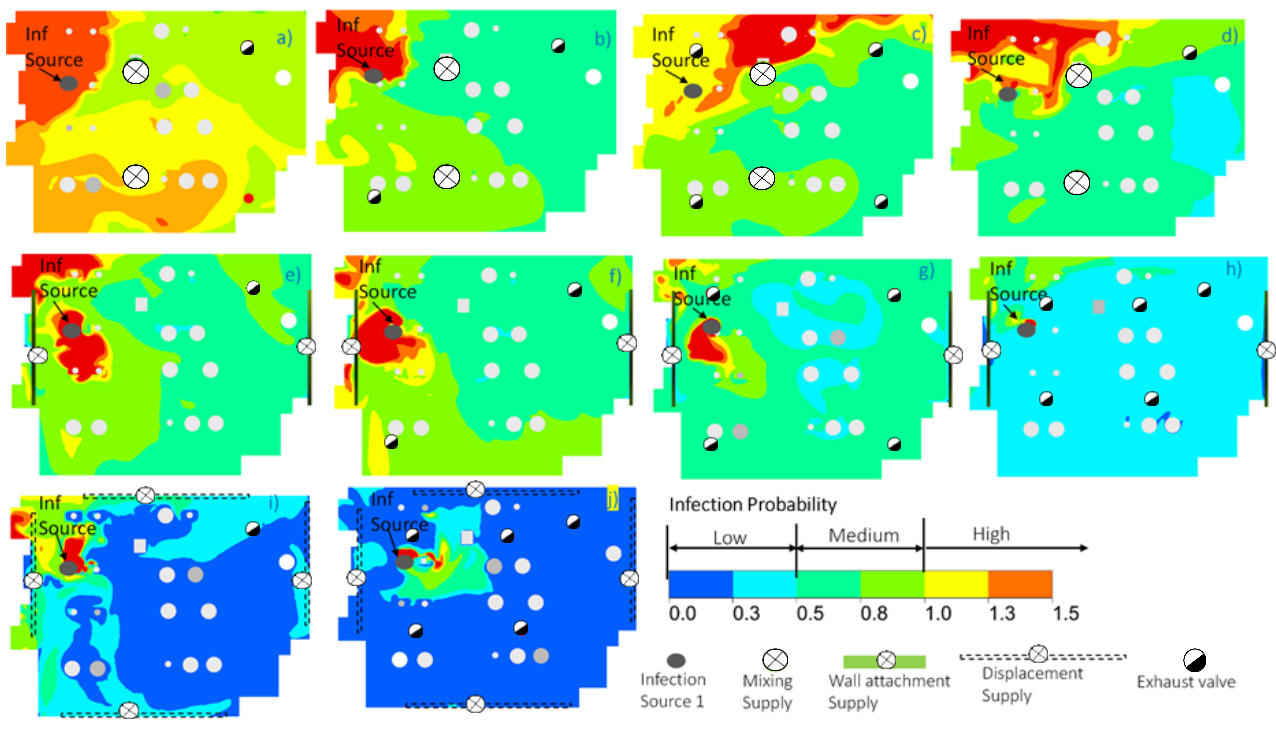


Figure 2. Risk of infection at different points in the classroom: the infected person is at point 1: a) M-case 1, b) M-case 2, c) M-case 3, d) M-case 4 (increased air flow rate), e) W-case 1, f) W-case 2, g) W-case 3, h) W-case 4 (local exhaust), i) D-case 1, j) D-case 2 (local exhaust).

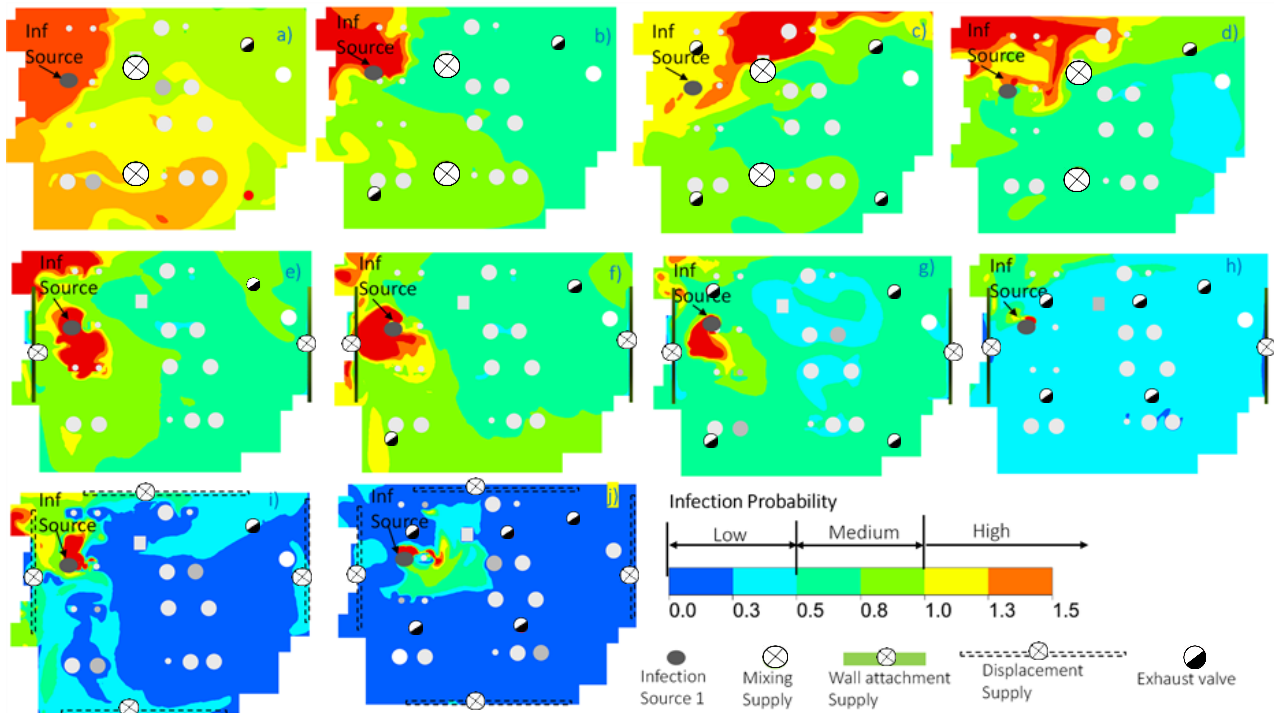


Figure 3. Risk of infection at different points in the classroom: the infected person is at point 2: a) M-case 1, b) M-case 2, c) M-case 3, d) M-case 4 (increased air flow rate), e) W-case 1, f) W-case 2, g) W-case 3, h) W-case 4 (local exhaust), i) D-case 1, j) D-case 2 (local exhaust).

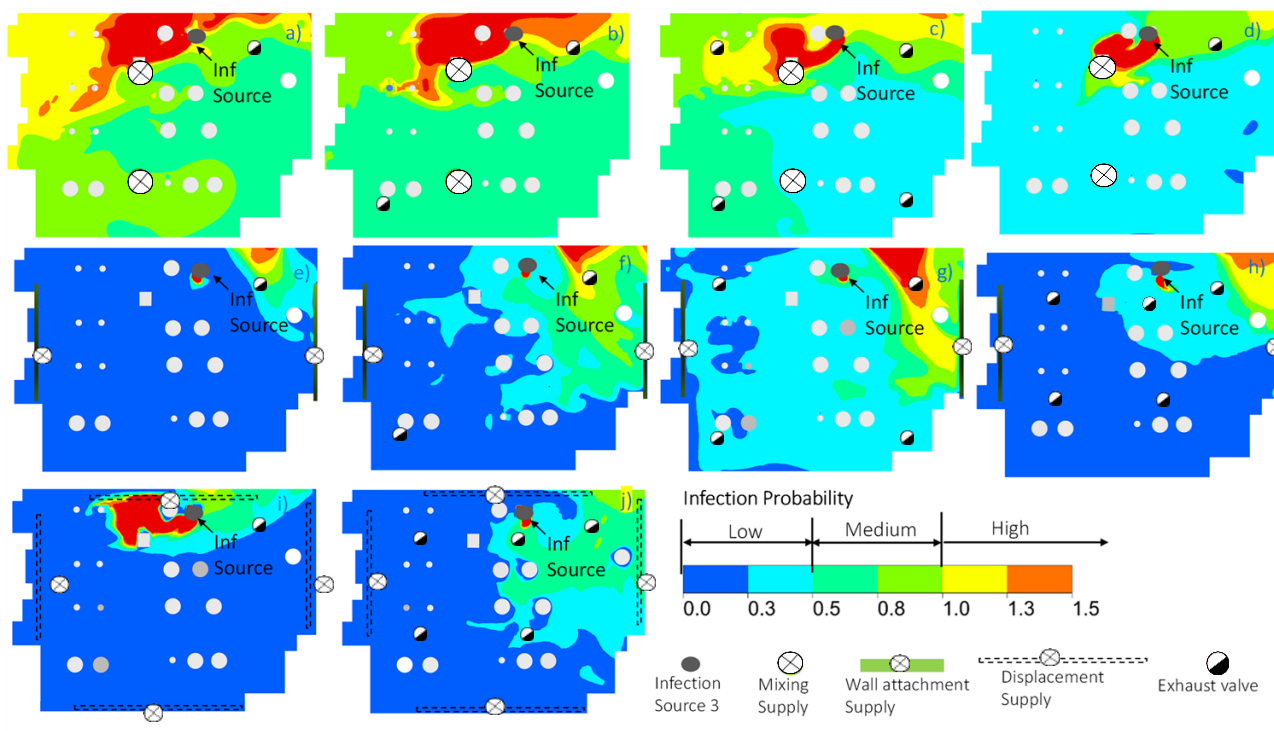


Figure 4. Risk of infection at different points in the classroom: the infected person is at point 3: a) M-case 1, b) M-case 2, c) M-case 3, d) M-case 4 (increased air flow rate), e) W-case 1, f) W-case 2, g) W-case 3, h) W-case 4 (local exhaust), i) D-case 1, j) D-case 2 (local exhaust).

Conclusions

Classrooms have a high density of people and at the same time the risk of airborne infection increases. Effective ventilation can reduce the risk of infection. Currently, mixed ventilation is the most common air distribution method in the classroom. According to the study, solutions that effectively bring clean outdoor air directly to the breathing zone and prevent the spread of contaminants into the room through local and general exhaust can significantly reduce the risk of infection compared to traditional mixed ventilation.

Based on the study, depending on the location of the infected student, in some cases the risk of infection can be reduced by increasing the number of exhaust valves. Of the solutions studied, local exhaust above the people combined with wall attachment supply or displacement ventilation performed best. In this case, the high infection risk of mixed ventilation (1% and 45 min stay) of 5-11 students was reduced to 0-2 students, depending on the different cases.

The comparison shows that local exhaust air systems with wall attachment or displacement ventilation significantly reduce the risk of infection. These solutions also improve the resilience of ventilation in different operating situations.

Acknowledgement

We would like to thank the ILMIRA project (VN/28954/2021) for funding and the City of Helsinki for the test site used in the validation of the CFD simulation.

References

- Becerra J.A, Lizana J., Gil M, Barrios-Padura A., Blondeau P., Chacartegui R. 2020. Identification of potential indoor air pollutants in schools. *Journal of Cleaner Production*, vol. 242, p. 118420. <https://doi.org/10.1016/j.jclepro.2019.118420>
- Izadyar N. and Miller W. 2022. Ventilation strategies and design impacts on indoor airborne transmission: A review. *Building and Environment*, vol. 218, p. 109158. <https://doi.org/10.1016/j.buildenv.2022.109158>
- Sadrizadeh S, Yao R., Yuan F., et al. 2022. Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. *Journal of Building Engineering*, vol. 57, p. 104908. <https://doi.org/10.1016/j.jobe.2022.104908>
- Su W., Yang B., Melikov A., et al. 2022. Infection probability under different air distribution patterns. *Building and Environment*, vol. 207, p. 108555, 2022/01/01/ <https://doi.org/10.1016/j.buildenv.2021.108555> ■