Leaflet on the dimensioning of fan-assisted window ventilation systems for classrooms developed at the Max Planck Institute for Chemistry in Mainz (Mainz Model)

Version 2.0, October 7, 2021, Max Planck Institute for Chemistry, Hahn-Meitner-Weg 1, 55128 Mainz, Germany

1. Overview

Since summer 2020, various fan-assisted window ventilation systems have been developed, tested, and successfully applied in several hundred classrooms at the Max Planck Institute for Chemistry in cooperation with the IGS Bretzenheim and other schools in Mainz (Helleis / Klimach 2021; Klimach / Helleis 2021; ventilation-mainz.de 2021).

Extensive experimental studies, measurement data, model calculations, and practical experience show that window ventilation supported by exhaust fans is a simple and highly effective measure to increase air quality in classrooms and can be used against the aerosol transmission of COVID-19. Fan-assisted window ventilation is ideal not only for combating the COVID-19 pandemic but for sustainable ventilation in schools. That's because it's energy-saving, resource-saving, and climate-friendly (Helleis et al. 2021; Pöschl / Witt 2021).

Even after the pandemic, exhaust fans can continue to be used to keep air quality high in classrooms, especially in poorly ventilated spaces. They can also help to minimize the spread of colds and flu. Distributed extraction systems can be flexibly reused, removed, and combined with other systems as needed. This is feasible thanks to their modularity and low cost.

Table 1 provides an overview of different variants of fan-assisted window ventilation systems. Specific information and recommendations on the dimensioning and operation of such systems can be found in the following sections of this leaflet.

Table 1: Different variants of fan-assisted window ventilation systems for classrooms

Variants	Explanations
Simple extractor fan	Can be used continuously or discontinuously (e.g., with increased air flow rate for intense ventilation periods during breaks).
Extractor fan with exhaust air duct (Mainz model – basic version)	Can be used either continuously or discontinuously, promotes displacement- and cross-ventilation effects, and prevents or minimizes potential disturbances from a direct intake of uplift currents via radiators under windows (to prevent "short-circuit currents").
Extractor fan with distributed exhaust ducts	Enhances displacement effects and ensures that potentially infectious aerosols are uniformly removed from the entire room (to prevent decoupling of remote areas).
Extractor fan with distributed exhaust hoods (Mainz model – hood version)	Enhances the direct exhaust ventilation of potentially infectious respiratory aerosols before they are mixed into the room air. Exhaust hoods assist in pandemic containment (reducing the likelihood of infection) and can be flexibly dispensed with thereafter (helpful but not required for maintaining good air quality according to normal hygiene and occupational health and safety guidelines).

2. Extractor fan and supply air duct (for all variants)

- We recommend slowly rotating fans with diameters of at least 30 cm – better 35 cm – in order to minimize noise pollution. Axial fans are most suitable because centrifugal fans can cause high negative pressures in the room (> 50 Pa) when the supply air window is closed.
- When blowing freely, the fans should produce volume flows of 1600–2000 m³/h. When installed, the volume flow per person should be around 25–40 m³/h (i.e., around 800–1200 m³/h for typical classrooms with a room volume of around 200 m³ and up to 30 people). For larger rooms and higher occupancy rates, we recommend increasing the number of fans with an exhaust duct and distributing them as evenly as possible in order to ensure adequate ventilation and prevent the formation of disconnected areas.
- The fans should be adjustable in terms of speed or volume flow in order to achieve comfortable conditions with standard-compliant volume flows (approx. 800 m³/h) in winter and the highest possible flow rates in summer. Electronically commutated (EC) fans with built-in speed control (e.g., Papst EBM-W3-G300-CK13-32 or similar) or AC fans with upstream inverter (e.g., Dalap RAB TURBO 350 ECO or similar) are suitable for this purpose.
- In order to prevent potential problems with dimming, historic preservation, heat loss, or structural modifications, the fan should be installed in a box that encloses one or more laterally pivoted windows within the classroom (Figure 1). The windows should be equipped with OL90 hand levers so they can be closed at night. By using transparent materials (e.g., PC double web panels), the room is hardly darkened. Alternatively, the fan can be placed in a wall opening, in a window pane, or in an insulating panel. In this case, appropriate measures for sealing should be taken outside the hours of use.
- Fresh air should flow in through an open window near the floor so that concentration differences form between the floor and ceiling (displacement air effect). When outside temperatures are low, the cold outside air flows to the floor by itself. For this purpose, it is enough to have a window open about 10–12 cm – ideally facing a corner of the room. If possible, the rotation function rather than the tilt function of the window should be used – for the most direct flow to the floor.
- If possible, the outside air should be directed towards the floor through a curtain or projection that is as transparent as possible (Figure 2). In this way, comfort can be decisively improved in winter – also compared with free window ventilation or impact ventilation. In summer, this promotes the displacement air effect and further increases ventilation efficiency.
- CO_2 sensors are suitable for monitoring and, if necessary, regulating the ventilation (Helleis et al. 2021).
- For use as a simple extraction fan without exhaust ducts, researchers at the Max Planck Institute for Dynamics and Self-Organization in Göttingen and their partners recommended (Bodenschatz 2021) using stronger axial fans with volume flows up to 4000 m³/h without exhaust ducts (Göttingen model; e.g., Ziehl-Abegg FN040-4IH.ZC.V3P6 controlled by potentiometer 10K/IP54 or similar). In continuous operation at approx. 1000 m³/h, such

extraction fans work similarly to the fan-assisted window ventilation systems we recommend (including displacement or displacement air effect). In discontinuous operation at up to 4000 m^3/h, they can have a similar effect to impact ventilation through wide-open windows. However, in the "Göttingen model" with extraction fans without exhaust ducts, disturbances can also occur as a result of a direct extraction of uplift currents via radiators under the windows (short-circuit currents) and to lower displacement and cross-ventilation effects. We therefore recommend the operation of extraction fans with exhaust ducts as described in Table 1 and below (Mainz model in basic version, distributed exhaust, or hood version).

3. Extractor fan with exhaust duct (Mainz model – basic version)

- A central exhaust duct leads from the extractor fan to the opposite side of the room. The inlet vent should be at least a few meters – preferably over 2/3 to 3/4 of the width of the room from the fan window (Figure 1). Extracting the exhaust air from the area of the room near the ceiling opposite the fan window should prevent the warm air flow from radiators under the windows from being directly captured by the exhaust fan (prevention of short-circuit currents). In addition, displacement and cross-ventilation effects are promoted.
- The diameter of the central exhaust duct must be at least 30 cm and is ideally matched to the diameter of the fan.
- A suitably dimensioned central exhaust duct can be flexibly and modularly supplemented with further distributed exhaust ducts as required – as described in the next section (upgrading the basic version to the distributed exhaust air version of the Mainz model).
- Exhaust ducts can be made of tubular film and support grid (www.ventilation-mainz.de) or purchased as commercially available ventilation components.

4. Extractor fan with distributed extraction ducts

- Distributed exhaust ducts lead from the central exhaust duct to inlet vents in all room areas or above classroom seating. This counteracts the formation of areas that are disconnected from ventilation and where locally elevated respiratory air aerosol concentrations can occur.
- The diameter of the distribution lines must be at least 9 cm if no tee connectors are used and the lines lead to only one inlet vent at a time (no branches to multiple inlet vents). If tee connectors or branches to multiple inlet vents are installed, the diameter of the distribution lines should be increased to at least 11 cm and the branches should be pneumatically balanced in order to allow for uniform distribution of the volume flows.

5. Extractor fan with distributed extraction hoods (Mainz model – hood version)

- Extraction hoods are installed at the inlet vents of the distributed extraction ducts above the classroom seating (Figure 4). This results in a direct extraction or hood effect in addition to displacement- and cross-ventilation effects: Potentially infectious respiratory aerosols are specifically captured and extracted before they can disperse throughout the room, thereby further increasing the infection control effect of the fan-assisted window ventilation system (Helleis et al. 2021).

- The hoods should be placed as close as possible to the seating areas in order to allow direct extraction of as much of the respiratory aerosol as possible. According to previous experience, the positioning of one extraction hood each with a diameter of about half a meter at about 2.1 m room height centrally above the edge of the table between the two seats is recommended (www.ventilation-mainz.de).
- Hoods should open downward in a funnel shape in order to direct rising exhaust air to the extraction vent (www.ventilation-mainz.de). They should be as transparent as possible, lightweight, and easy to assemble so that they can be flexibly attached and removed as needed to protect against infection (COVID-19 pandemic, cold and flu waves).

6. Materials and assembly

In the city of Mainz, fan-assisted window ventilation systems as described above (hood model or basic version) have been installed and successfully commissioned in over 600 classrooms of primary and secondary schools. The work was carried out in cooperation with parents, teachers, and Gebäudewirtschaft Mainz. Across Germany, the number of classrooms equipped with this system is estimated to be over 1000 (www.ventilation-mainz.de).

Fan-assisted window ventilation system materials can be purchased from home improvement stores, online stores, and other commercial suppliers. Installation can be DIY or done by ventilation companies, metering companies, or other professional contractors.

7. Notice and disclaimer

The variants of fan-assisted window ventilation systems presented here were developed for DIY and replication. The Max Planck Institute for Chemistry has no financial interest in this project. All information and content can be used free of charge via a Creative Commons license.

The contents of this document and the website www.ventilation-mainz.de have been prepared with due diligence. However, we do not guarantee the accuracy, completeness, and timeliness of the content provided. In particular, no guarantee is given that the exhaust air system described here fulfills the functions shown and is suitable for the use shown or intended. The use of the contents is at the user's own risk.

With the provision of the website and documents and through its use, no contractual relationship or other legal relationship is established. The contents of this website and the documents are licensed under the Creative Commons license CC BY-SA 4.0 (see https://creativecommons.org/licenses/by-sa/4.0/deed.de). The Max Planck Institute for Chemistry is to be cited as the source.

References

Bodenschatz, Eberhard (2021). “How does a classroom become Corona safe with little cost and maintenance concerns?”.

Helleis, Frank / Klimach, Thomas (2021). “Lüftung von Schulräumen -ein ‘frischer’ Blick von draußen” [Ventilation of school rooms – a ‘fresh’ view from outside]. https://ventilation-mainz.de/lowcostVent_MPIC_german.pdf (Zugriff am 18.05.2021).

Helleis, Frank / Klimach, Thomas / Pöschl, Ulrich (2021). *Vergleich von Fensterlüftungssystemen und anderen Lüftungs- bzw. Luftreinigungsansätzen gegen die Aerosolübertragung von COVID-19 und für erhöhte Luftqualität in Klassenräumen [Comparison of window ventilation systems and other ventilation/air purification approaches against aerosol transmission of COVID-19 and for increased air quality in classrooms]*. Zenodo, DOI: 10.5281/zenodo.5070422.

Klimach, Thomas / Helleis, Frank (2021). “Vorläufige Dokumentation Abluftanlage für Klassenräume.” [Preliminary documentation: air extraction system for classrooms] In:, p. 27.

Pöschl, Ulrich / Witt, Christian (2021). “Stellungnahme zur Wirksamkeit und Nutzung von Gesichtsmasken gegen COVID-19.” [Statement on the effectiveness and use of face masks against COVID-19.] https://www.mpic.de/4972415/stellungnahme (Accessed on July 30, 2021).

ventilation-mainz.de (2021). “Umsetzung der Low-Cost-Abluftanlage” [Implementation of the low-cost air extraction system] https://ventilation-mainz.de/implementation.html (accessed October 7, 2021).

Figure 1: *CAD model of a ventilator box built from polycarbonate double web panels and aluminum corner profiles for monument-protection- and thermal-insulation-compatible connection of the extractor fan to a laterally pivoted window. The window remains fully functional and can be closed via the existing OL90 remote control outside of class time so that there is no additional heat loss.*

Figure 2: *CAD model of a movable (rollable) projection built of polycarbonate double-webbed sheets, aluminum corner profiles, and furniture casters for monument-protection-, heat-protection-, and comfort-compatible introduction of fresh air from a window to the floor (fully or partially opened turn-only window or laterally pivoted window). The window remains fully functional and can be closed outside lesson time so that no additional heat loss occurs.*

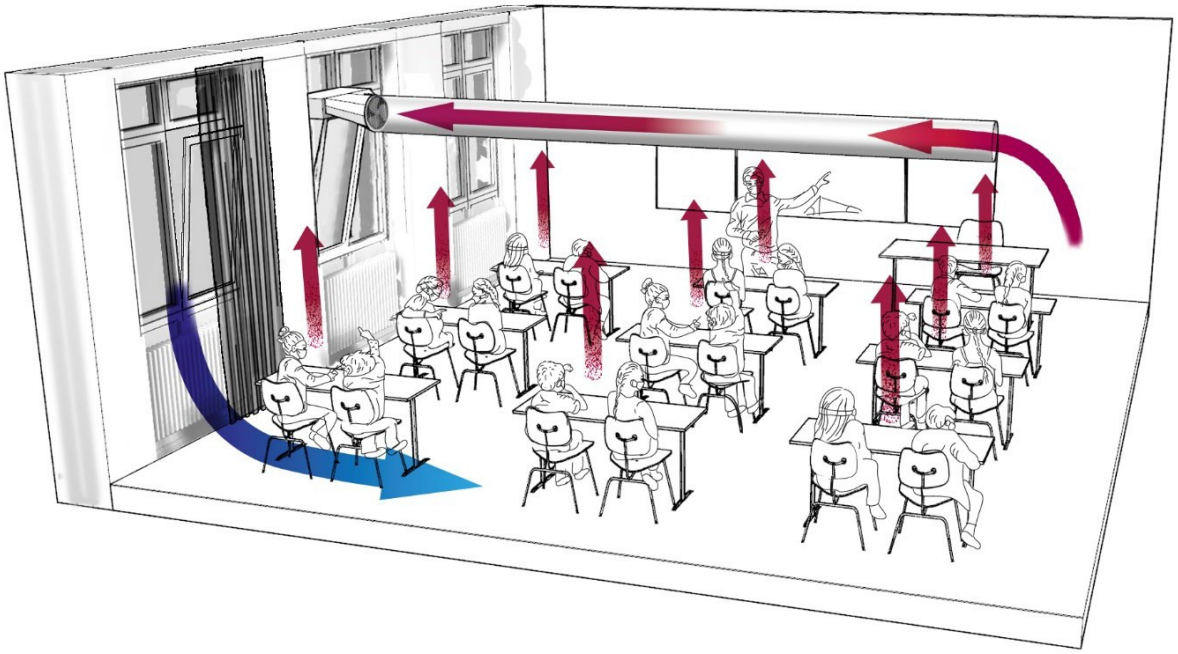

***Figure 3**: Schematic diagram of a fan-assisted window ventilation system with exhaust duct (Mainz model – basic version) (ventilation-mainz.de).*

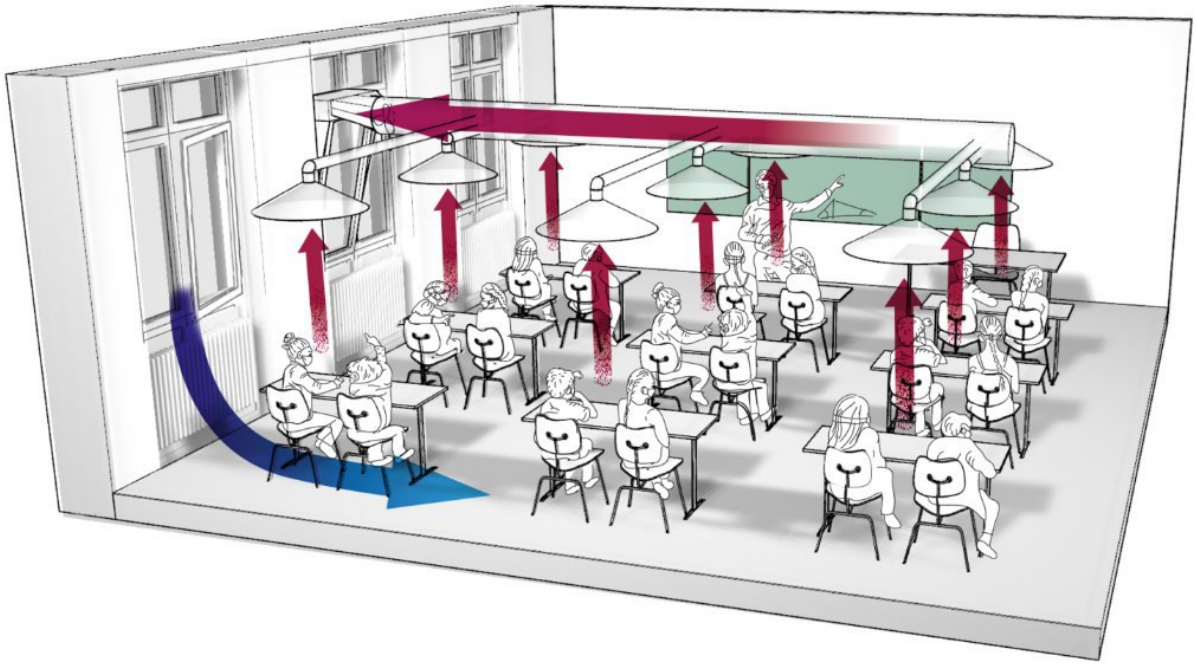

***Figure 4:** Schematic diagram of a fan-assisted window ventilation system with distributed extraction hoods (Mainz model – basic version) (ventilation-mainz.de).*