Technical note: The Max Planck Institute for Chemistry mechanical extract ventilation (MPIC-MEV) system against aerosol transmission of COVID-19

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13 May 2022

1. Introduction and overview

Extensive experimental studies, measurement data, numerical calculations, and practical experience show that window ventilation supported by extract fans (i.e. mechanical extract ventilation) is a simple, highly effective and low-cost means of increasing air quality in classrooms. This approach can be used to reduce indirect infections through aerosol transmission of SARS-CoV-2 (Helleis et al. 2022; Lelieveld et al. 2020; Morawska et al. 2021; Su et al. 2021). Mechanical extract ventilation (MEV) is very well suited not only for combating the COVID-19 pandemic but also for sustainably ventilating schools in an energy-saving, resource-efficient, and climate-friendly manner (Helleis et al. 2021, 2022; Klimach and Helleis 2021; Pöschl et al. 2021) (www.ventilation-mainz.de).

The ventilation concept presented here is part of a multi-layered risk reduction strategy. As such it is not intended to replace, but rather to complement, other preventive public health measures - including vaccinations, masks and social distancing (Bodenschatz 2021; Cheng et al. 2021; Drewnick et al. 2021; Foitik et al. 2022; Moriske et al. 2021; Pöschl and Witt 2021; Su et al. 2021).

After the COVID-19 pandemic, the MPIC-MEV system can still be used to maintain high levels of indoor air quality (IAQ) in classrooms, especially in poorly ventilated spaces, lowering the risks from harmful indoor pollutants (McLeod et al. 2021) as well as helping to reduce the spread of seasonal viruses such as colds and flu. Distributed extract ducts or hoods can be flexibly removed, stored and reused, or combined with other devices (e.g. CO_2 sensors), which is easy due to the modular concept.

Table 1 provides an overview of different variants of decentralized mechanical extract ventilation (MEV) systems that make use of fans. Specific information and recommendations on the dimensioning and operation of such systems can be found in the following sections of this fact sheet.

Table 1: Different variants of mechanical extract ventilation (MEV) systems for classrooms

Variant	Explanation
1. Simple extract fan	Can be used continuously or intermittently (e.g., with increased air flow rates for intense purge ventilation periods during breaks).
2. Extract fan with central extract duct (Figure 3)	Can be used either continuously or intermittently, promotes displacement ventilation effects, and prevents or minimises potential disturbances from the direct intake of warm convection currents via radiators under windows (to prevent "short-circuit" air flows).
3. Extract fan with distributed extract duct terminals	Enhances displacement effects and ensures that potentially infectious aerosols are uniformly removed from the entire room (to prevent cross-contamination and the decoupling of remote areas).
4. Extract fan with distributed extract hoods (Figure 4)	Enhances the direct extraction of potentially infectious respiratory aerosols before they are mixed into the room air. Extract hoods assist in pandemic containment (reducing the likelihood of infection) and can be flexibly dispensed with thereafter (helpful but not required for maintaining good indoor air quality according to normal hygiene and occupational health and safety guidelines).

We recommend regulating the room air quality using CO_2 sensors, whether this be for the control of window openings or for regulating the MPIC mechanical extract ventilation system. In this way, the proportion of exhaled air in the room (approx. 400 ppm CO_2 per 1% breathing air proportion) and the corresponding risk of infection can be estimated (Helleis et al. 2022; Peng and Jimenez 2021) where the exceedance of CO_2 concentrations above 1000 ppm should be avoided (DGUV e.V 2021; Umweltbundesamt 2020). We recommend the use of CO_2 sensors with a digital display, preferably incorporating a pre-calibrated traffic light warning system, in order to facilitate the management of the ventilation strategy in response to the transmission risks (Helleis et al. 2022).

2. Extract fan and fresh supply air (for all variants)

- We recommend slowly rotating fans with diameters of at least 30 cm (or preferably 35 cm) in order to minimize noise pollution. Axial fans are most suitable because centrifugal (i.e. radial) fans can cause high negative pressures in the room (> 50 Pa) if the supply air window is inadvertently closed.
- When running freely, the fans should produce volume flows of 1600–2000 m^3/h (see manufacturers' free inlet/discharge data). When installed in a ducted system, the volume flow per person should be around 25–40 m^3/h, i.e., around 800–1200 m^3/h for typical classrooms with a room volume of around 200 m^3 and up to 30 people. For larger rooms and higher occupancy rates, we recommend increasing the number of fans, each with its own dedicated extract 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 thermally comfortable conditions with standard-compliant volume flows (of approx. 800 m^3/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 an upstream inverter (e.g.,

Dalap RAB TURBO 350 ECO or similar) are suitable for this purpose. When purchasing extract fans, one should only consider models that allow a sufficiently high-volume flow with a low noise level. Practical experience with such systems has shown that fans should not emit more than 45 dB(A) at 3m (at the maximum fan speed required) for acceptable use in classrooms. For operation in schools there are legal requirements with regard to noise development (BAUA ASR A3.7 2021)

- In order to avoid potential problems with issues such as: loss of daylight, historic façade preservation, unwanted heat loss, or structural modifications, the fan can be installed in a transparent (polycarbonate) window-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 easily closed at night or alternatively an airtight openable hatch should be inserted into the side of the window box. By using transparent materials (e.g., polycarbonate single sheet or double web panels), the room remains well lit. Alternatively, the fan can be placed in a wall opening, in a window-pane, or in an insulated panel (within the window frame). In this case, appropriate measures should be made to close the main duct, against the ingress of cold air, outside the hours of use (e.g. through the installation of a back-damper or shutters).
- Fresh "make-up" air should flow in through an open window in the room where the MPIC-MEV system is located. Ideally this "make-up" air should enter at floor level (to minimise mixing), so that air density differences form between the floor and ceiling (buoyancy effect). When outside temperatures are low, the cold outside air flows to the floor of its own accord. For this purpose, it is enough to have a window slightly open (about 10–12 cm – ideally) facing a corner of the room. If possible, the rotation (i.e. turn) function, rather than the tilt function, of the window should be used (with the window latched in position) – for unimpeded flow downward to the floor.
- If possible, the outside air should be redirected towards the floor using a curtain or projection that is as transparent as possible (Figure 2) to reduce cold draughts, near to the open window(s), and the loss of daylight. In this way, thermal comfort can be decisively improved in winter – also compared with typical window ventilation or purge ventilation strategies.
- CO_2 sensors are suitable for monitoring and, if necessary, regulating the ventilation (Bhagat et al. 2020; Helleis et al. 2022). It is recommended to install CO_2 sensors at the level of the seated breathing zone (i.e. nose-height) circa 1.2m above the finished floor level (FFL). CO_2 sensors should be wall mounted in a classroom and located not too near the open window.
- Appropriate CO_2 levels can be achieved, for example, by intermittent ventilation when the concentration exceeds approx. 1000 ppm CO_2 until it falls below approx. 800 ppm. The lower the CO_2 concentration in the classroom is above the outside air value (approx. 420-450 ppm), the lower the associated risk of long range aerosolised viral infection.
- For use as a simple MEV extract fan (without extract ducts), researchers at the Max Planck Institute for Dynamics and Self-Organization in Göttingen and their partners recommend using larger (e.g. 400mm dia) axial fans with volume flows up to 4000 m³/h (Bodenschatz 2021)(e.g., Ziehl-Abegg FN040-4IH.ZC.V3P6 controlled by a potentiometer 10K/IP54 or similar). In continuous operation at approx. 1000 m³/h, such extract fans will work similarly to the fan-assisted window ventilation systems we recommend with relatively low noise levels. Under intermittent operation at up to 4000 m³/h, they can have a similar effect to purge ventilation through wide-open windows. However, with the "Göttingen model" (using extraction fans without extract ducts) local imbalances can also occur as a result of the direct extraction of thermal plumes from radiators under the windows (short-circuit air flows) leading to reduced displacement and cross-ventilation effects (as well as thermal discomfort). We therefore recommend the operation of extract fans

with extract ducts as described in Table 1 and below (MPIC-MEV base version, distributed duct version, or hood version).

- Irrespective of the type of ventilation system used the rows of desks should not be placed closer than 1.5m apart (measured from the centreline) so as to maintain social distancing which provides substantial benefit in further reducing viral transmission (Sun and Zhai 2020).

3. Extract fan with central extract duct (MPIC-MEV base version) (Variant #2)

- A central extract duct leads from the extract fan to the opposite side of the room. The inlet vent (or window providing the “make-up” air) should be at least a few meters – preferably over 2/3 to 3/4 of the width of the room away from the fan window (Figure 1) to avoid the possibility of short-circuiting air flows causing cross-contamination between the fresh and stale airstreams.
- Avoid placing extract terminals directly above radiators (to prevent the warm air flow from radiators under the windows being directly captured by the extract fan) to prevent short-circuit air flows. In addition, displacement effects are enhanced when the room air is able to stratify.
- The diameter of the central extract duct must be at least 30 cm and is ideally matched to the diameter of the fan. By using “V” direction axial fan (as opposed to an “A” direction fan) the internal flange on the fan can be used to provide a secure connection for the main duct.
- A suitably dimensioned central extract duct can be flexibly and modularly supplemented with further distributed extract ducts as required – as described in the next section (upgrading the base case version to the distributed extract air version of the MPIC-MEV).
- Extract ducts can be made of transparent polythene sheeting (available pre-formed as a tubular roll) and a plastic internal supporting mesh (www.ventilation-mainz.de) or purchased as commercially available ventilation components (e.g. Schepp, etc) for self-assembly.

4. Extract fan with distributed extract ducts (MPIC-MEV distributed duct version) (Variant #3)

- Distributed extract ducts are smaller in diameter and lead from the central extract duct to inlet vents (i.e. terminals) located above classroom seating. This distributed design counteracts the formation of areas that are disconnected from the ventilation system where locally elevated respiratory aerosol concentrations would otherwise occur.
- The diameter of the distribution branches must be at least 9 cm (if no intermediate T-connectors are used). Ideally the individual branches should only connect one inlet terminal to the main duct (i.e. no branches connecting multiple inlet vents). If T-connectors or branches to multiple inlet vents are installed, the diameter of the distribution ducts should be increased to at least 11 cm and the branches should be aerodynamically balanced (i.e. using a volume control damper or an air valve) in order to allow for uniform distribution of the volumetric air flows. Otherwise, reduced flow rates will occur at the distal terminals.

5. Extract fan with distributed extract hoods (MPIC-MEV hood version) (Variant #4)

- Extract hoods are installed at the extract terminals of the distributed extract ducts above the classroom seating (Figure 4). This results in direct extraction, or hood effect, in addition to the displacement effects: Potentially infectious respiratory aerosols are specifically captured and extracted before they can disperse throughout the room, thereby further increasing the infection control efficacy of the fan-assisted window ventilation system (Helleis et al. 2022).

- The hoods should be placed as close as possible to the seating areas in order to allow direct extraction of as much of the expired respiratory aerosol as possible. Where desks are typically shared by two students (in central Europe) previous experience shows that, the positioning of one extract hood each with a diameter of about 0.5-1 m at about 2.1 m height centrally above the edge of the desk, between the two seats, is recommended (www.ventilation-mainz.de).
- Desks should be arranged in rows, in order to maintain a grid arrangement, which will simplify the installation of the branch ducts and hoods, perpendicular to the main duct. The rows of desks should not be placed closer than 1.5m apart (measured from the centreline) (see Section 2).
- Hoods should open downward in a shallow funnel shape in order to direct rising extract air to the extraction terminal (www.ventilation-mainz.de). They should be as transparent as possible, lightweight, and easy to assemble so that they can be flexibly attached (e.g. using a plastic cable-tie) and removed, as needed, to protect against infection cycles (COVID-19 pandemic, cold and flu waves).

6. Materials and assembly

Since summer 2020, fan-assisted window ventilation systems as described above (MPIC-MEV hood version or base version) have been installed, tested, commissioned, and applied successfully in over 650 classrooms in primary and secondary schools (beginning at the IGS Bretzenheim) in the city of Mainz, Germany (Helleis and Klimach 2021; Klimach and Helleis 2021). The work was carried out in cooperation with parents, teachers, and building management (Gebäudewirtschaft) Mainz. Across Germany, the number of classrooms equipped with this or similar systems is currently estimated to be over 2000 (www.ventilation-mainz.de). The system is now being adopted in Austria and further afield (www.coved.tugraz.at). Fan-assisted window ventilation system materials can be purchased from home improvement stores, online DIY stores, and other commercial suppliers. Installation can be either DIY or carried out by ventilation/HVAC companies, electricians, facility managers or other professional contractors. Further information on the type of fans (e.g. “V” versus “A” direction axial fans) will be available shortly on www.coved.tugraz.at.

Notice and disclaimer

The variants of fan-assisted window ventilation systems presented here were developed for DIY use in the spirit of open science and knowledge sharing. The Max Planck Institute for Chemistry (MPIC) has no financial interest in promoting this system. 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 MPIC-MEV systems described here fulfil the functions described and are suitable for the use shown or intended. The use of the content is entirely at the user’s own risk.

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Figure 1: *CAD model of a ventilator box built from polycarbonate double web panels and aluminium corner profiles suitable for conservation-protection and the thermally-insulated connection of the extractor fan to a bottom-hung window. The window remains fully functional and can be closed via the existing OL90 control system outside of class time so that there is no additional heat loss.*

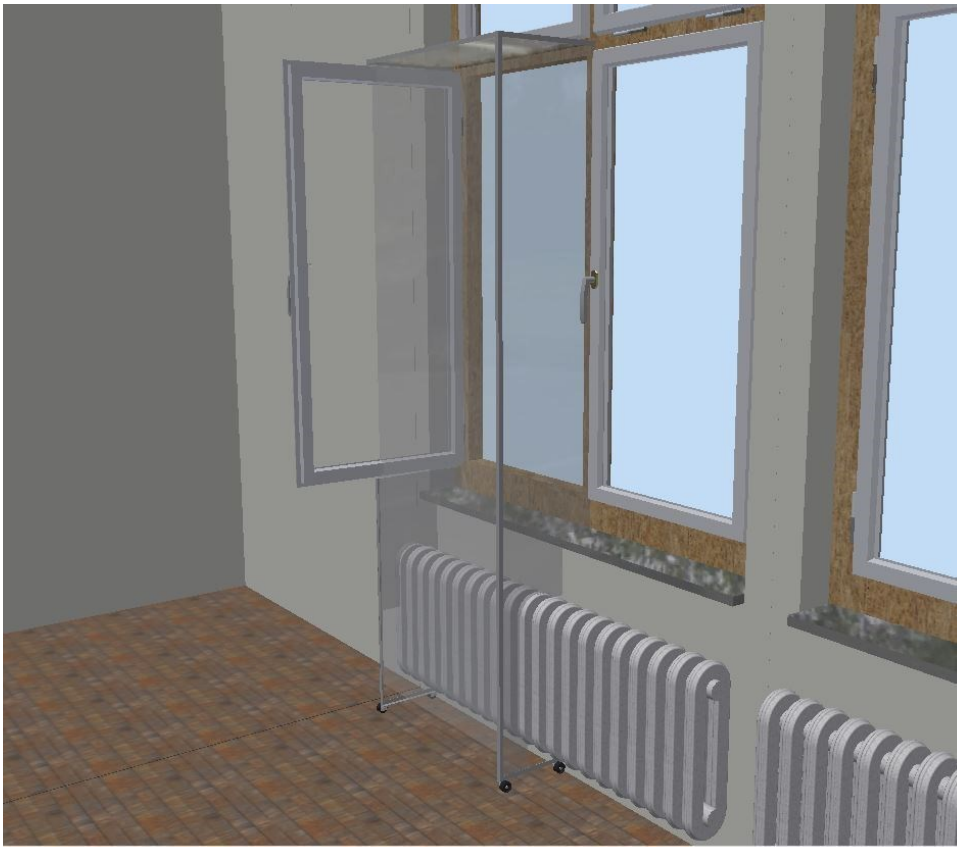

Figure 2: *CAD model of a movable (rollable) draught projection system built of polycarbonate double-webbed sheets, aluminium corner profiles, and furniture casters for historic-building-preservation, draught-reduction and the thermally comfortable introduction of fresh air from a window to the floor (via fully or partially opened turn-only window or laterally tilted window). The window remains fully functional and can be closed outside lesson time so that no additional heat loss occurs.*

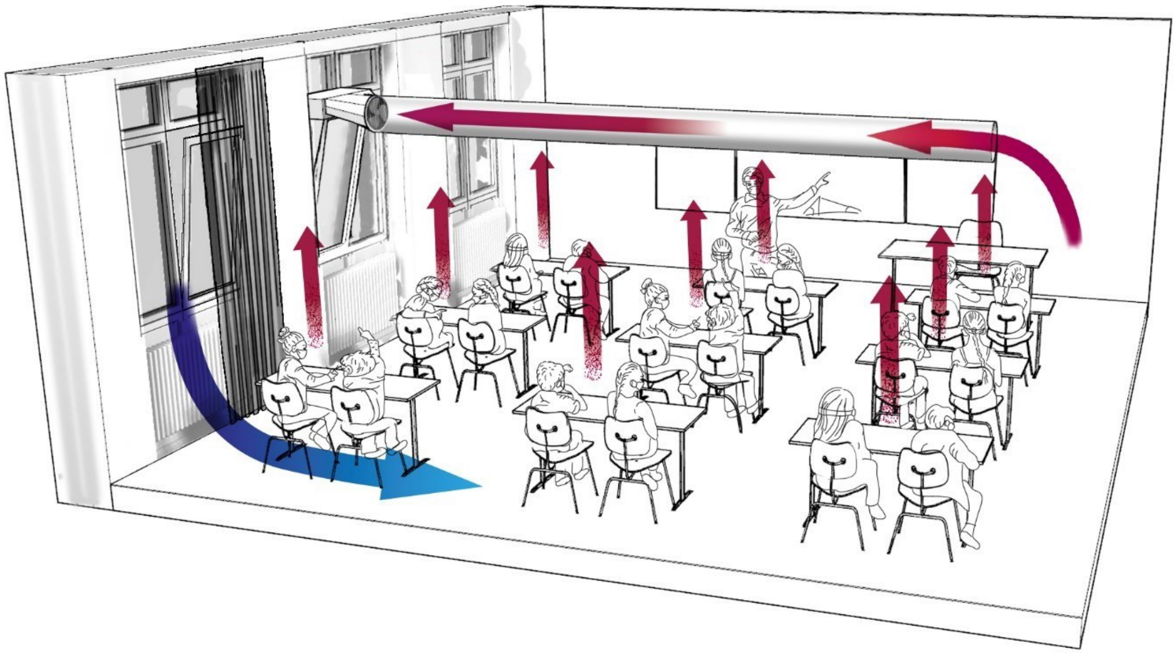

***Figure 3**: Schematic diagram of a mechanical extract ventilation system with central extract duct (MPIC-MEV base version) (ventilation-mainz.de).*

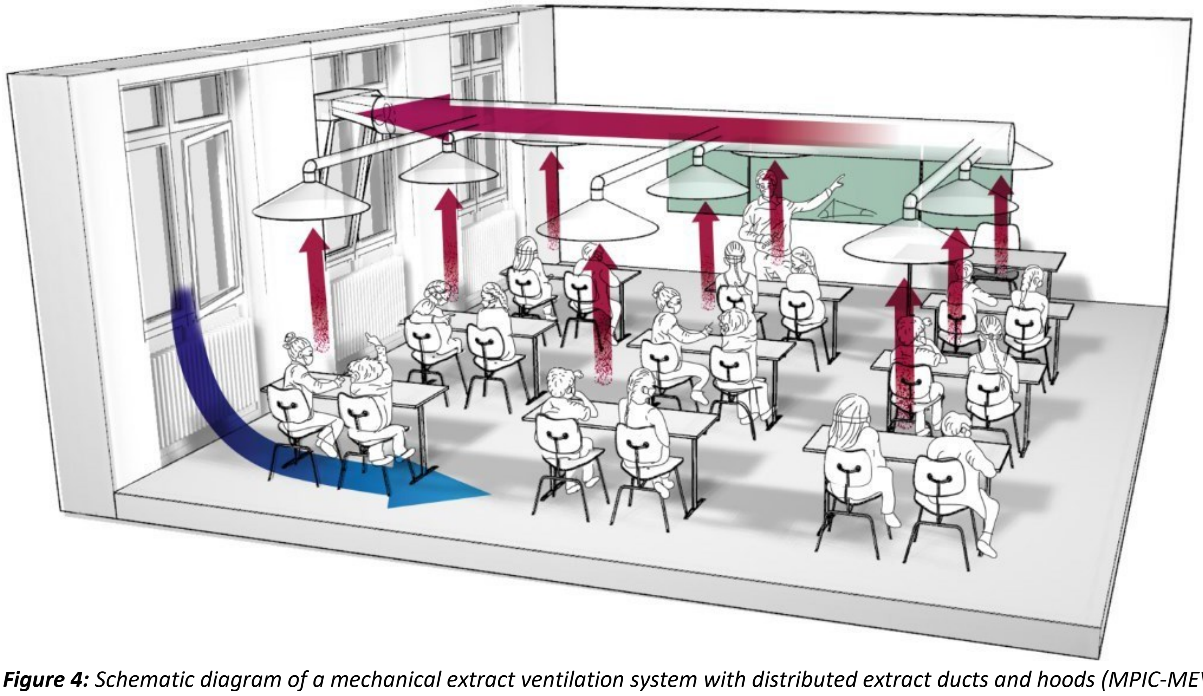

***Figure 4:** Schematic diagram of a mechanical extract ventilation system with distributed extract ducts and hoods (MPIC-MEV hood version) (ventilation-mainz.de).*