MAX-PLANCK-INSTITUT
FÜR CHEMIE

Provisional Documentation Exhaust Air Unit for Class Rooms

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1 Preface

Dear parents, students, teachers and other interested parties,

Special times require special action. We, from the Max Planck Institute for Chemistry in Mainz, thought a lot about how to contribute to efforts easing the social situation during the pandemic and tackling the unique challenges within schools.

Aerosols are a main focus of our scientific work, and so it is not surprising that we have been studying the efficiency of all kinds of face masks and the propagation of aerosols in closed rooms for months, which leads us more or less directly to research projects within schools.

Beyond our purely scientific interest, however, we also saw a concrete need for action, not only because we too have children at school, but also because, as a publicly funded institution, we have a great interest in the common good.

We have developed a simple and pragmatic proposal of a low-cost exhaust air system for DIY construction, which can improve the indoor air hygiene sustainably. Especially for the large number of classrooms, that are difficult to ventilate, we currently see this as an effective and sustainable solution.

We would like to emphasize that this document is of a provisional nature and will be supplemented gradually as necessary. This also applies to the interpretation of the measurement data presented in this document and the information on parts lists and the construction description. Every day we receive requests and offers to support the project. For example, if components such as manifolds were available in large quantities, we will update this information.

Finally, we would like to emphasize that our system does not replace the continuous compliance with safety measures such as the wearing of masks. Rather, it can supplement them in order to reduce the risk of infection with the corona virus during lessons.

2 Disclaimer and Terms of Use

The contents of this document have been prepared with the usual care. The client accepts no liability for the correctness and completeness of the documents. In particular, no guarantee is given that the exhaust air system described here fulfils the functions described and is suitable for the use shown or intended. Applications shall be opened immediately after the expiry of the time limit. The sending of this document and its use does not constitute a contractual or other legal relationship.

3 Function

The exhaust air system developed by us takes in exhaled air, which may contain viruses or bacteria, specifically with the help of extractor hoods from the direct vicinity of people sitting at tables. The exhaust air enters a central pipe via connecting pipes and is led outside through a tilted window by means of a fan.

The air rising on a warm body supports the intake and, together with the exhaled air, brings it directly into the extractor hood within about ten seconds.

The supply air can be supplied through a tilted window or an open door, as with normal manual ventilation. Alternatively, it can be supplied from outside via filters. The cross-section of the air inlet opening should be at least half the cross-section of the central pipe. The supply air opening should not be located vertically above the exhaust air opening, but preferably well below it.

4 Dimensioning

To determine the necessary air flows, we estimate the volume of air heated by the body in the boundary layer between a person and the air as follows: approx. 5 cm (thickness of the boundary layer) x 80 cm (circumference of the person). With a vertical velocity of approx. 15 cm/s (measured), this results in a flow of 6 l/s. With two people sitting at one table, you need a flow of about 12 l/s (equivalent to 43 m^3/h) through our exhaust hood. For a classroom with 26 students and one teacher, the total is 14 (tables) x 43 m^3/h = 600 m^3/h.

For a typical classroom volume of 200 m^3, this corresponds to a room air exchange rate of approx. 600 m^3/h / 200 m^3 = 3/h, equivalent to an optimal impulse ventilation per 40 min.

The system should be mountable open under a ceiling, should not cause any weight problems with regard to the ceiling load-bearing capacity, should be low-noise and, if possible, should also be energy-saving. Therefore, fans with low power (20 W), relatively large diameter, low speed and low differential pressure (4 Pa) are recommended.

This results in an inner diameter for the connecting pipes of approx. 70 mm with a maximum length of 3 m. In order to have sufficient reserves for future applications such as the combination with circulating air filters or heat recovery, we take the next larger DN90.

The inner diameter of the main pipe with the average length of 8 m results from the requirement of a pressure drop of not more than 1 Pa/4 m due to the pneumatic balancing to at least 250 mm. For practical reasons, we have chosen a diameter of 315 mm as this size is directly compatible with standard floor fans. Furthermore, the associated circumference of 1 m is also suitable for 1 m wide rolls of various materials.

For pneumatic adjustment, perforated discs made of cardboard or similar are clamped into the tubes for shorter connecting tubes. For the dimensioning of the holes of these discs we plan to publish a calculation mask, so that the suitable disc can be calculated from the respective pipe length and the longest pipe. Measurements on the last test installations have shown a deviation of the fluxes of almost 20 % without the adjustment at length differences of approx. 2,3 m.

5 Measurements

5.1 Test setup

- The test set-up consisted of a central tube and 9 suction tubes, which ended centrally above the edges of the school desks. The tables were arranged in a regular rectangular pattern. The height of the suction was approx. 2 m, i.e. approx. 70 cm above a sitting student.
- Aerosol and CO_2 measurements were taken at the central table of the arrangement. Here, the extraction was carried out either with a simple extraction hood (approx. 60 cm diameter) or without.
- Fresh air was supplied to the classroom from the outside via a gap-open (approx. 5 cm) bottom light.
- The waste heat of two students was simulated per table with a 100W red light installed on a chair inside a cardboard box (test specimen).

- For the measurements, an ultrasonic nebulizer (filled with equipment for fog machines) and a CO_2 source were installed at the possible head height of a potentially infectious student.
- The sample air was led through a tube from the end of a movable arm to an optical particle counter (OPC, Grimm 1.108, dp > 300 nm) and an optical CO_2 measuring device (Gascard NH, Edinburgh Instruments). Thus, at different positions relative to the source and to the exhaust, the aerosol and CO_2 concentration could be measured very easily.
- The flow velocity in the tubes and the upward movement in the convection zone of the test specimen was measured with a TSI hot-wire anemometer.

5.2 Measurements and Results

- The vertical velocity of the air generated by the test specimen is of the order of magnitude of approx. 10 cm/s, which was used in advance for dimensioning the system (see above).
- The flow velocities in the 6 long intake pipes were between approx. 1.6 and 2 m/s. The differences were due to the quality of the production of the foil tubes, with wrinkled tubes showing lower fluxes. The velocity in the 3 short pipes was consistent at approx. 2.5m/s (flow about 9 l/s). For the requirements of the test measurements a better adjustment was not necessary.
- Using the CO_2 measurement in the central pipe in front of the fan, the room air exchange rates were measured at different fan speeds and window positions and with the door closed. Without a fan we get about 0.15/h with closed windows, about 0.3/h with a tilted bottom light, about 1.5/h with a fan on level 2, about 2/h on level 3. The following measurements were taken with the fan at level 2 throughout, i.e. at a nominal room air exchange rate of 1.5/h, see figure 1.

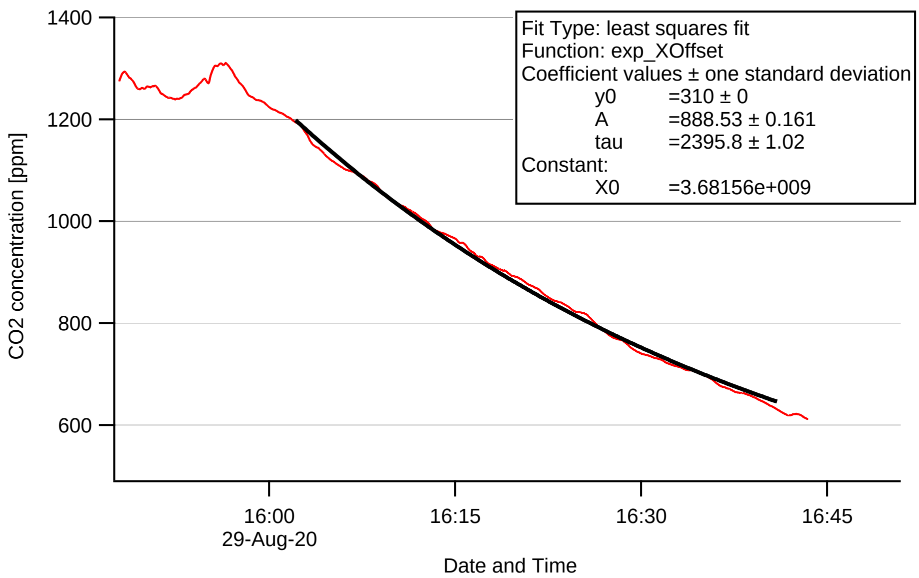


Figure 1: Measurement of the room air exchange rate with CO_2, the exponential fit amounts to 3600 s/h / 2423 s = approx. 1.5/h.

The measurements were carried out over one day under different experimental conditions. The aerosol concentration in the extracted air (in the extraction pipe) and in the room air (between two extraction pipes) was determined alternately. The collection efficiency of the extraction system can be determined by comparing the two measurements. The further apart the measured values are, the more targeted the extraction is. When the concentration in the room air (background) no longer changes, a stable condition is reached. The efficiency of the plant can be determined from the concentration ratio.

The raw data of the measured total concentrations are shown in figure 2.

The measurement was performed in 3 blocks

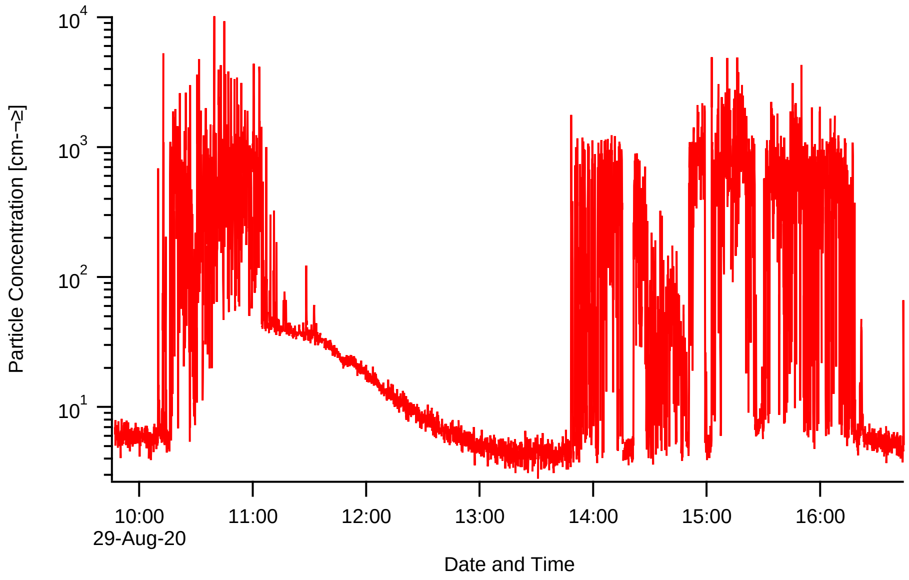


Figure 2: total concentration of particles measured by the OPC

1. aerosol measurement without extractor hood until the concentration in the room air remained stable. (aerosol generation from approx. 10:15 to 11:35 h)
2. measurement of the aerosol lifetime (i.e. the time until an aerosol has evaporated) by the exponential decrease of the room air concentration without aerosol generation (approx. 12:00 to 13:30 h)
3. aerosol measurement (aerosol generation from approx. 13:50 to 16:25 h; between 14:20 and 14:50 h the emission rate decreased due to idling of the aerosol generator and was corrected by refilling)

5.3 Lifetime

The lifetime of the aerosol particles caused by evaporation/sedimentation results from the exponential drop to 3600 s/h /1478 s = 2.5/h. Corrected by the room air exchange rate of 1.5/h, approx. 1/h remains, see figure 3.

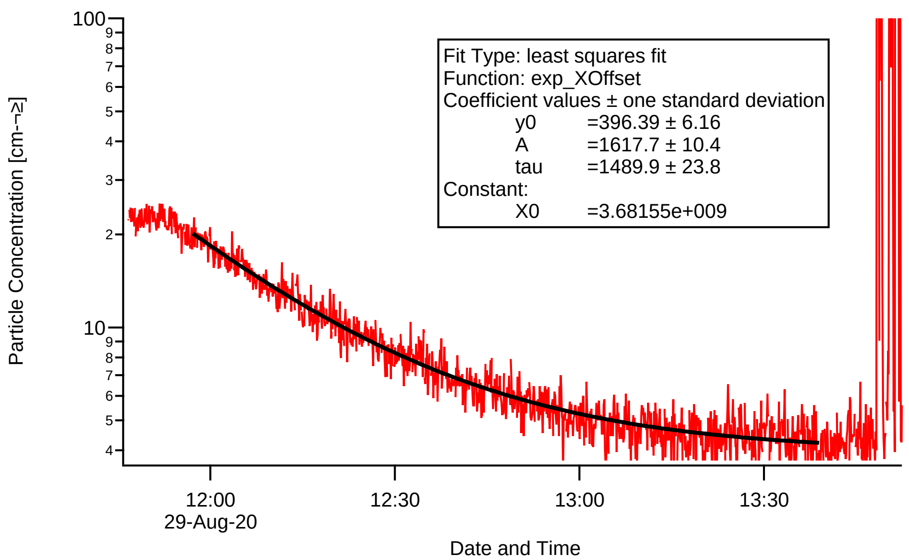


Figure 3: total concentration of particles measured by the OPC, aerosol generator switched off

5.4 efficiency without a hood

In the first measuring block without extractor hood (Fig. 4), measurements were taken at various distances from the extraction unit

1. at 15 cm distance (10:28 to 10:31 h)
2. at 30 cm distance (11:05 to 11:15 h)
3. in 100 cm distance (from 11:30 h)
4. without distance (remaining time)

The following can be observed:

- The different distances of the sample inlet to the center of the suction tube do not result in significant differences in the ambient air concentration (background). The aerosol concentration has therefore already decreased to the background value at a distance of 10 cm from the source or the rising plume. There is no noticeable widening of the exhaust plume on the way to the extraction system.
- When sampling the centre of the suction opening, a maximum of approx. 1,000 aerosol particles/cm^3 is measured. If one assumes that the detected maximum values correspond to the emission concentration of the generator (which is certainly rather a lower limit), an emission rate of 1,000 / cm^3 results with a volume flow in the suction pipe of approx. 9 l/s * 9,000 cm^3/s = 0.9*1e7 particles/s. With a loss rate (lifetime) of the particles of 2.5/h = 7*1e-4/s a theoretical stable room air concentration of approx. 65 particles/ cm^3 is calculated. But at the end of the first measuring block at 11:30 only a stable room air concentration of about 30 particles/cm^3 was measured. Which indicates a collection efficiency of the pipe of at least approx. 1 - 30 / 65 = 54%, see figure 4. From the raw values the background of 6 particles/cm^3 before aerosol generation (10:00 h) was deducted.

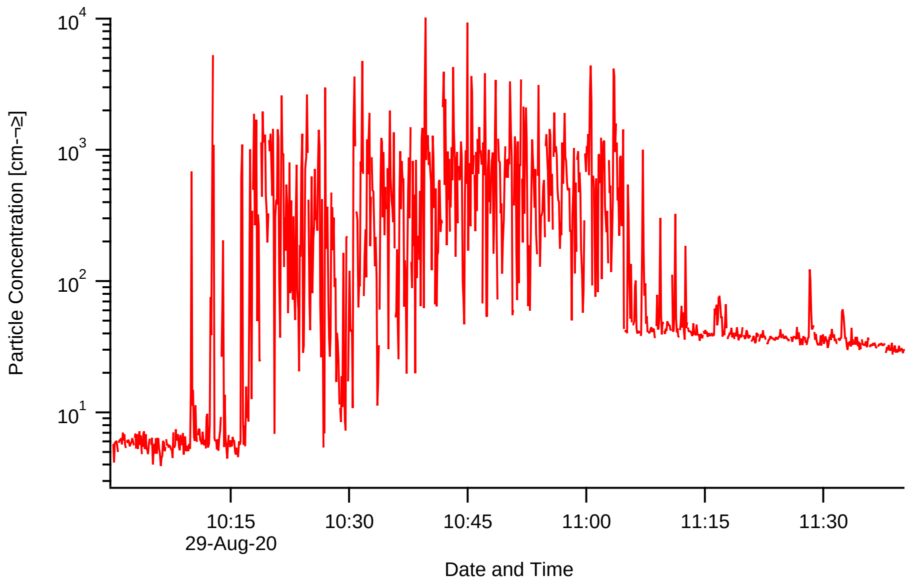


Figure 4: total concentration of particles measured by the OPC, without hood

5.5 efficiency with hood

The aerosol concentration of the discharged air was measured close to the centre of the exhaust hood (see figure 5). While the indoor air concentration was measured at certain times at a distance of 120 cm from the extraction opening to investigate again the increase due to non-extracted aerosol.

- 2:09 pm to 3:03 pm

- 15:25 hrs to 15:30 hrs
- and from 4:18 pm

To test the influence of the heat emission of the test specimen on the vertical convection, the heating of the test specimen was switched off at 15:40, i.e. the vertical transport was only supported by the waste heat of the aerosol generator (approx. 20W).

The following can be observed:

- If the sample inlet is located in the centre of the end of the suction hose, a maximum of approx. 600 particles/cm^3 are measured in phases of low variability. Here one would expect with non-selective suction a steady-state concentration of about 40 particles/cm^3 in the background. But on average only about 7/cm^3 were measured in the background, which differs by about 1/cm^3 from the measured background at 10:00 h. The collection efficiency of the pipe would then be 1 - 1/40 = 97%.
- The comparatively low variability of the particle concentration e.g. at about 14:55 h suggests that the collection efficiency reaches 100% under favourable conditions.
- It can be clearly seen that the variability of the particle concentration increases considerably after switching off the heating of the test sample at 15:40 h. So at first it can be said, at least qualitatively, that the convection generated by the warm body considerably supports the quantitative extraction of the particles even in case of disturbances of the air movement, e.g. by wind pressure on the gap-open bottom light in the room.

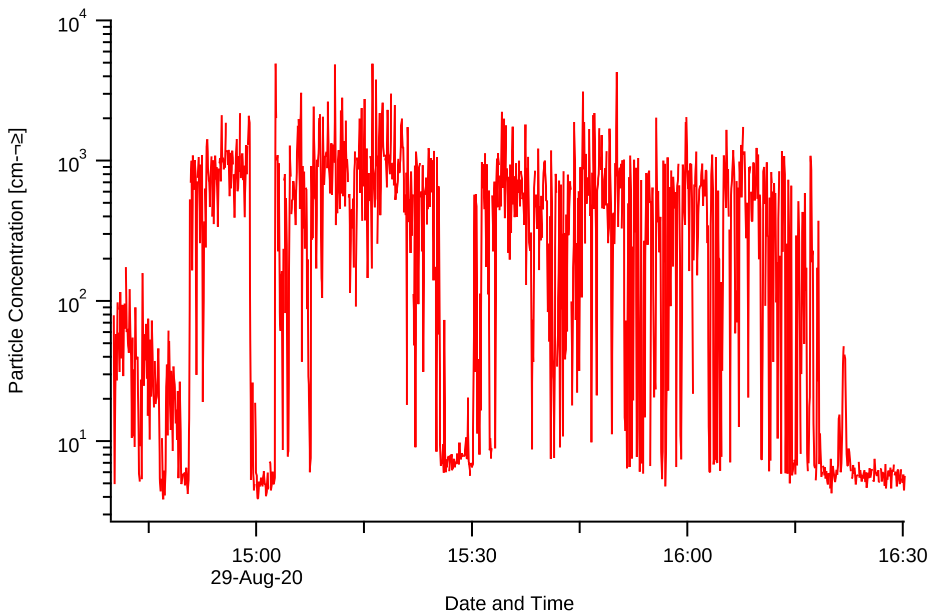


Figure 5: total concentration of particles measured by the OPC, with hood

5.6 Simulations

In the course of the measurements we also considered to what extent heating and cold window fronts in winter could disturb the convection dynamics in the classroom. That's why we simulated the flows in the classroom, first in 2D. The results are shown in image 6, without Student, and in image 7, with Student.

The small white rectangle at the bottom right of the picture represents the heating, the window is located at the right edge of the picture. In the second picture the outlines of the student are roughly modelled with rectangles in the centre.

One can see that the convection system formed by the warm heating and the cold window hardly enters the room.

If a pupil sits near the heating and the window, the two convection cells unite, i.e. the direction of flow in the area of the pupil practically does not change, the transport of the exhaled air of the pupil upwards is supported rather than weakened.

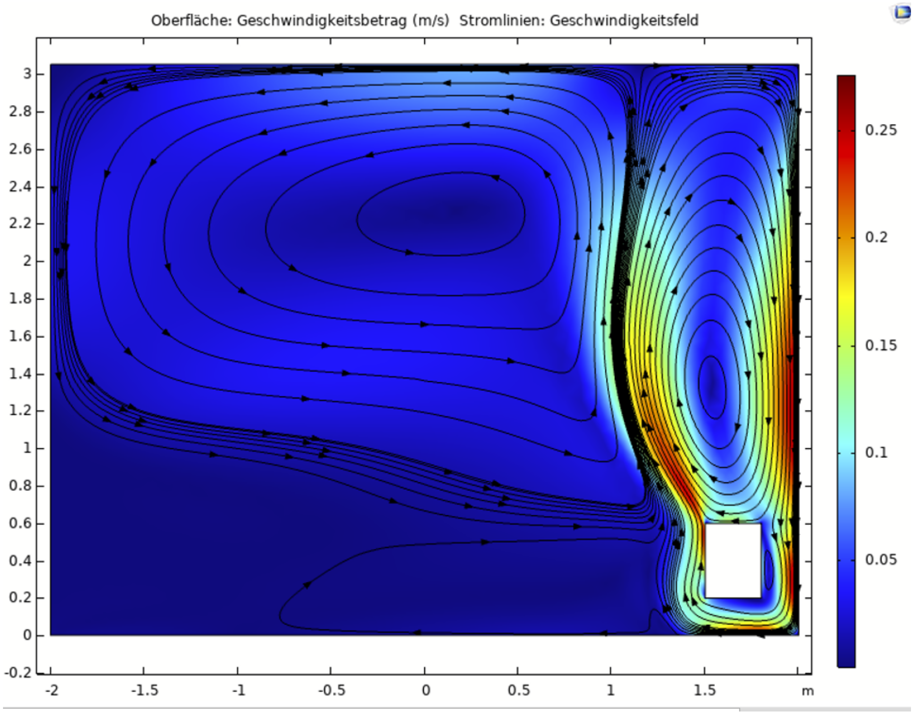


Figure 6: Simulation of the room air flow heating/windows without students

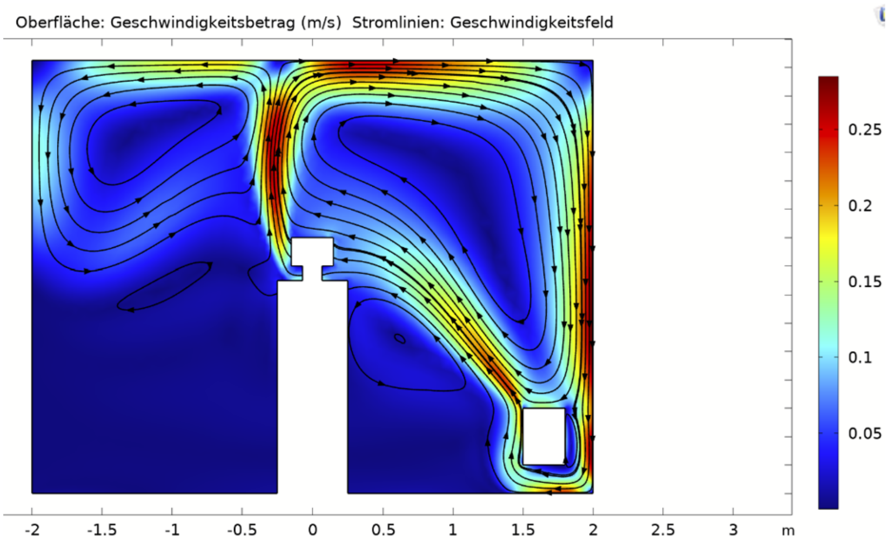


Figure 7: Simulation of room air flow heating/windows with student

5.7 Summary

The results of the preliminary measurements presented here suggest that the proposed system can significantly reduce the risk of infection caused by infectious aerosol (by 90% under the most favourable conditions) and motivate us to develop a system suitable for mass production.

6 FAQ (frequently asked questions)

6.1 How does the exhaust air system for classrooms work, which you have installed at the integrated comprehensive school in Mainz-Bretzenheim?

The air is taken up by extractor hoods installed above each table, led through smaller pipes into a large central tube mounted under the ceiling and blown outside by a fan on a tilting window. The fresh air can be supplied via another gap-open window or, preferably, if the corridors have openable windows, through the gap-open door.

A special feature of the system is that it takes advantage of the rising flow (convection) around the warm human body and thus transports the naturally exhaled air into the suction pipe within approx. ten seconds, i.e. before it is turbulently distributed throughout the room.

6.2 How expensive and complex is the installation?

The material costs are currently around 200 euros per classroom. The system is designed in a way that it can be set up by dedicated teachers, parents, and possibly also pupils. In addition to typical tools such as pliers and scissors, some special devices such as a soldering iron for joining wires or a plastic welding machine are useful. With some routine handling of the equipment and the corresponding materials (see list), a system can be installed by 4-6 people in four hours. In the successful attempt to equip the primary school Mainz-Marienborn (11 rooms) on one weekend with the support of parents and teachers, an average of 30 man-hours per room were required. The the size of the rooms was measured in advance and the distribution boxes were built at home.

6.3 How did you test how effective this low-tech approach for air purification is?

We performed measurements with aerosol and CO_2 sources installed on a seat at head height simulating an infected pupil. By positioning the sample inlet inside and outside the exhaust air system, the accumulation of aerosols in the exhaust air system can be determined directly as the ratio of the two measured values. If the aerosol generator is installed outside the extraction area of the extraction hood, the aerosol is not selectively extracted. A corresponding increase in aerosol concentrations can be seen throughout the classroom. In these measurements with simulated pupils a reduction of aerosols by a good 90 % was measured.

6.4 For what classroom type and geometry would such a system be useful?

The system is a modular system consisting of foil pipe segments that can be cut to size with scissors and distribution or connection pieces. Since the pipe segments are manufactured directly on site, there are no restrictions regarding type or geometry. However, the distribution of the school desks in an even grid considerably simplifies the construction. One only needs a tilting window and a power socket.

6.5 How great is the interest of schools and other institutions to copy the system?

Since the first press report on 30.10.2020 until today (10.11.2020) we have received over 2700 inquiries from headmasters, school authorities, private persons and various companies. The number of rooms to be equipped is in the tens of thousands. In principle, the system can be implemented using standard ventilation components. However, this would make it much more expensive, heavier and more complicated to install. In addition, these materials are not transparent, which could lead to darkening when mounted near or underneath lamps. We have not found any manufacturer on the market that offers components for extreme low pressure systems.

6.6 Is it possible to see the results of their examinations?

The provisional measurement results are attached. (2)

We are currently installing further automated CO_2 measurements, whose data will be made available soon.

6.7 Make sure to provide building instructions for the ventilation system?

For legal reasons we cannot publish a construction manual. We therefore describe here the construction of our test systems in detail, so that they can be reproduced with a little bit of craftsmanship.

6.8 Does your system meet common fire safety requirements and safety regulations?

Our system was tested and accepted in advance by experts of the responsible school authority with regard to fire protection and general safety regulations. Due to the type of construction, the use of existing windows and the materials (PE, PP), which are relatively harmless in terms of fire protection and are also used in other places in the classroom, there were only minor bureaucratic hurdles. Our system weighs about 10 kilos. Compared to the average fire load of approx. 200 kilos (chairs, clothing and teaching materials), which in the event of a fire could release some highly toxic gases, our system is almost negligible.

6.9 Must the window in your variant remain permanently tilted or can it be closed temporarily, e.g. at night for burglary protection?

Aerosols are removed continuously to keep the required power and noise levels low. The window retains its original function and is only equipped with a connection for the ventilator, which is practically airtight, regardless of the window position. Therefore, the window can and should be closed during the lesson-free period, and if a contact switch is used, the fan will even stop automatically. Thus, there is now additional risk of burglary. Alternative solutions are fans permanently installed in a window, which require much less effort and are even partly supported by school authorities and building management companies. One should definitely ask for that.

6.10 Does this system only protect against indirect infection? Are additional Plexiglas cutting panels recommended and what about a mouth-nose cover (face-masks)?

Yes, the system only reduces the risk of infection from the aerosols. If students who also meet during breaks or privately and sit at the same tables, no cutting disk are needed/meaningful. However, the risk reduction through everyday masks adds multiplicatively, i.e. both protection measures are correspondingly better.

6.11 How is your model suitable for mass use?

In our opinion, the system is suitable for the masses for all situations in which people are more or less in one place. Then the extractor hoods have maximum effect. Examples are schools, offices, restaurants.

6.12 What additional noise pollution can be expected from the fan? Is it possible to state this in decibel?

According to the manufacturer, the fan generates about 40 decibels when blowing free, but since it is cased in, we only expect 30 decibels at lower frequencies. This will be again measured. Initial feedback from affected teachers is positive and the fans do not seem to attract much attention in normal school life.

6.13 Doesn't the room air become particularly dry in winter due to constant ventilation?

On the contrary. Because the room air is nominally only changed about twice per hour, correspondingly less water is extracted from it every 20 minutes compared to the prescribed pulse ventilation.

6.14 To what extent do other heat sources such as heating and cold window fronts disturb thermal convection in the student area?

Preliminary simulations of indoor air flows have shown that the heating typically installed under the windows forms its own small-scale convection cell in interaction with the cold window front. This hardly seems to interfere with the space and strengthens the flow in the area of the next sitting pupils rather than weakening it. This should still be verified in the experiment. Intuitively, however, it is understandable, since the students represent the strongest heat source compared to heating and window fronts.

6.15 Why can hardly standard components from the ventilation technology be used?

Ventilation manufacturers usually build centralised systems with minimised space requirements and therefore use relatively high fan capacities and flow speeds. For practical, static and fire safety reasons, we have kept system pressures and flows low, because we need minimum weight, open construction, easy fabrication and low noise. Until now, only modified floor fans have been able to offer the necessary low power ratings.

6.16 Do you see your system as a competition to mobile room air filters or as a supplement?

In order to limit the average CO_2 concentration in classrooms to approx. 1000 ppm, as demanded by the Federal Environment Agency, 4-5 room air changes per hour are mathematically necessary. If you do not have a ventilation system and it is too cold for continuous ventilation, this can be achieved by airing three times per hour. If it is not possible to open a window, or if the windows are too small or only tiltable, retrofitting is inevitable in our view.

Since room air filters do not remove a CO_2, they can only be operated as a supplement to ventilation or in an absolute emergency. The installation performance recommended by manufacturers of room air filters and researchers also lies within the range achievable by 20-minute impulse ventilation. Position and airflow are significant for their effectiveness. Some researchers therefore prefer to use several small devices instead of one large one. The main cleaning effect is caused by the shock ventilation, the additional use of air purifiers typically only halves the risk of infection.

Bottom line: From our point of view, room air cleaners are no competition, but only a supplement to ventilation systems or impact ventilation - but not the other way round.

7 System Components

The system consists of several components:

1. window connection (picture 8)
2. fan box (picture 8)
3. pipe distributor (Figure 9)
4. central pipe segment (picture 10)
5. connecting pipe (picture 10)
6. extractor hood with bend (picture 10)
7. fixing material, hooks, binding wire (picture 13)

A modified table or floor fan (diameter approx. 300 mm) was used as a fan and built into a fan box that fits directly into the central tube.
The exhaust air window can be sealed with various materials (Figure 8). Covers of mobile air conditioning units are relatively easy to use (Figure 8b).

(a) a (b) b

Figure 8: Two possible variants for window sealing: (a) wooden conversion and (b) covers of mobile air conditioning units with Velcro Seal

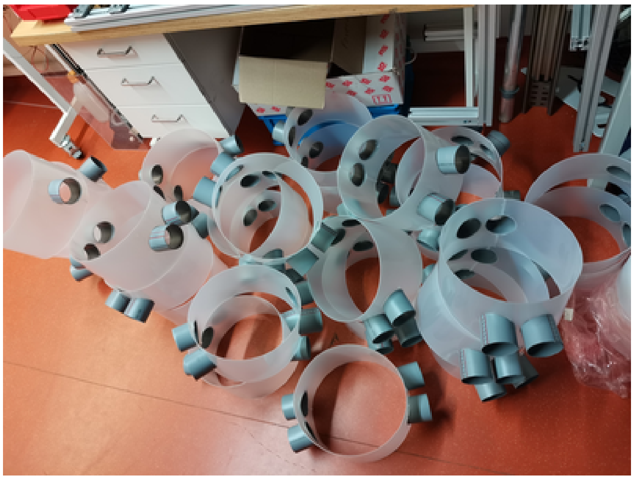


Figure 9: distributor with HT DN 75 pipe with socket

Figure 10: central tube, connecting tubes and hoods

8 Material

We have used the following materials so far, based on 17 extraction points in the room and an average extraction pipe length of 1.7 m and a ceiling height of 3.5 m. So far we have built the suction pipes with 75 mm inner diameter. In order to achieve a slightly higher flow at the same fan capacity, the next rooms in the IGS-Bretzenheim will be equipped with 90 mm wide exhaust pipes:

	Per room		
Big pipes			
Foil tube 500 mm 0,2 mm transparent	7,5	m	picture 19
Support grid PE N903 004 Roll: 1 m x 20 m	7,5	m	picture 18
Small pipes			
HT elbow DN 75 87° (alternatively DN 90)	17	St	Bild 22
HT-branch DN 75 87° (alternatively DN 90)	1	St	Picture 22
Support grid PE N902 010 roll: 1,2 x 100 m - cut into 26 cm strips	28,9	m	picture 18
Film tube 125 mm (alternatively 150 mm) 0.2mm transparent	28.9	m	image 19
Bonnets			
Flat film 0,2 mm on 2 m roll transparent	17	m^2	picture 17a
3 mm stainless steel in 3 m bars	17	St	Picture 17a
Tape Tesa 50 m x 5 cm glass fibre clear	5	m	
PP sheets 1,5 mm 2 x 1 m - cut into 181 mm strips	4,6	pieces	
HT DN 75 pipe 2 m (alternatively DN 90) - cut into 6,5 cm pieces	1,1	m	picture 9
Welding rod 4 mm PP	0,03	kg	picture 21
fastening material			
Cable tie Soft-Tie (26cm long)	66	St	Picture 20
Galvanized iron wire	15.4	m	picture 13
Wire clips (spring wire)	6	m	picture 13
fan+box			
PE/PP sheet 2 mm 2 x 1 m	0,5	St	
Fan: Table/floor fan 30 cm	1	pc	
Window sealing	1	St	Picture 8
Welding rod 4 mm PE	0,07	kg	Picture 21

9 Tools

9.1 The manifold welder

This is a self-manufactured turned part, which is operated with heating cartridges. You need it to build the manifolds (image 11). It has two functions:

1. make the through-hole
2. weld on the pipe section

Figure 11: distributor welding device (special tool self-made)

9.2 Shears/Sheet Shears

for mesh material, flat material and flanged pieces

9.3 Plastic Welding Machine

e.g. hot air blower with welding shoe (on the right in the picture 12)

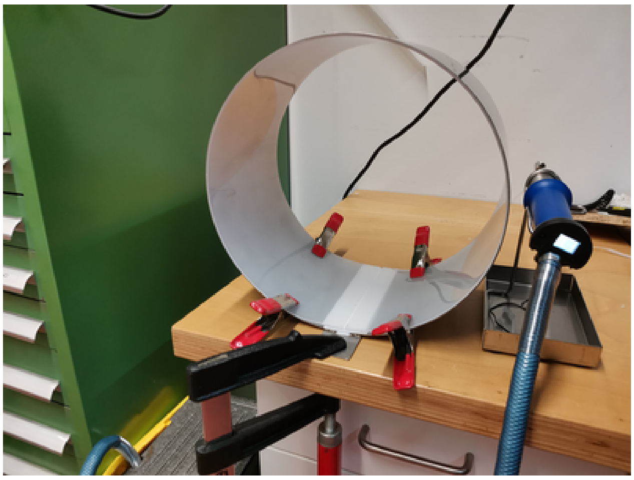


Figure 12: Plate merge and fix with staples. Right picture: Hot air blower with welding shoe.

10 Working Step by Step

10.1 Select Exhaust Window

Centered in the room and tiltable. Alternative: Skylight where the pane can be removed.

10.2 measure room dimensions

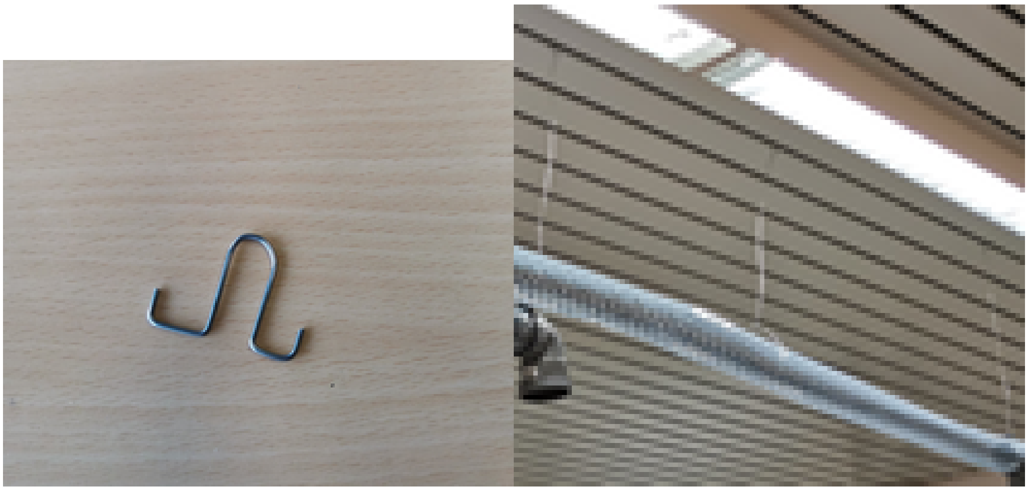
Ideally, the tables should stand in a regular grid. This helps the overview, during assembly and also ensures the required 1.5 m distance. Tighten the cord or find another reference point for the centre line of the central tube. Define the position of the distributors. 4 single pipes can be connected per distributor. Measure the distance between the occupied table edge centres and the corresponding distributors. In the production department

- the central tube segments are 8 cm shorter than the point-to-point measurement.
- the single tubes are 21 cm shorter than the point-to-point measurement.

10.3 funding

- mesh mats and tubular film in the packaging accessories trade
- plastic sheets in the DIY market/wholesale trade
- wire and HT drain pipe in the DIY store

10.4 fastening on ceiling



(a) a

(b) b

Figure 13: for mounting on the ceiling: (a) Hooks/eyelets bent from 1.5 mm spring steel wire for ceiling mounting and (b) galvanized iron wire

Due to its low weight, the system can be mounted on existing suspended ceilings. The most favourable variant is to bend 1.5 mm spring steel wire into suitable hooks/eyes (picture 13a). Screw-in hooks or special holders also work or are necessary for concrete ceilings.

10.5 distributor

The distributors are the most complicated part of the system. At the moment there are talks with manufacturers to have them mass-produced due to the great interest. However, as long as the parts are not yet available for purchase or if there is time and desire to do handicrafts, here is our procedure.

1. cut from flat material: 181 mm x 1000 mm
   This works best on a large pair of guillotine shears, but also works with hand shears for limited quantities.

2. one strip at a time to be welded together to form a large piece of pipe:

   - join the cut-to-size plate in a sheet until there is a gap of about 2 mm between the short sides (Figure 12)
   - fix the short sides with staples. We have built a helper made of stainless steel sheet (picture 12), which defines the shape and to which the ends can be fixed. It should also work if you clamp the two short ends at the right distance on a wooden plate.
   - cut off a piece of welding rod approx. 20 cm long
   - set the welding device to approx. 270°C and after reaching the temperature insert the welding wire, wait a short time until it becomes soft, then slowly guide the device under pressure across the gap.
   - allow to cool down and then release the fixation
   - Cut off/cut off excess welding wire

   The aim is to obtain the required concave gate on a small pipe section, which enables a form-fit welding to the previously manufactured large pipe section. This can be done very well with a band saw, but is also possible with hand or plate shears. A cutting template for printing out, which is placed around the pipe for marking purposes, can be found in the appendix.

   The procedure with band saw would be as follows:

   - relative to the axis of rotation of a band saw. The axis of rotation should be offset by approx. 16 cm perpendicular to the cutting direction and offset by approx. 5 cm in the opposite direction to the cutting direction. Axis e.g. could be a piece of pipe or round rod, which is put into a thick board.
   - into a short HT-PP pipe at the 11.5ċm mark, drill a hole corresponding to the diameter of the axis of rotation and place it on the axis of rotation.
   - now a long HT-PP pipe can be sawn into the required weld-on pieces relatively quickly. The saw blade should not be too wide; with a 6 mm wide one worked well in our superstructures.

3. melt 4 x hole and weld on flange (picture 14)

4. Close the manifold with flat material (1x per room)
   Cut out a washer with 309 mm diameter and weld it in (figure 15). The remaining edge can be used as a flat flange for the fan ring.

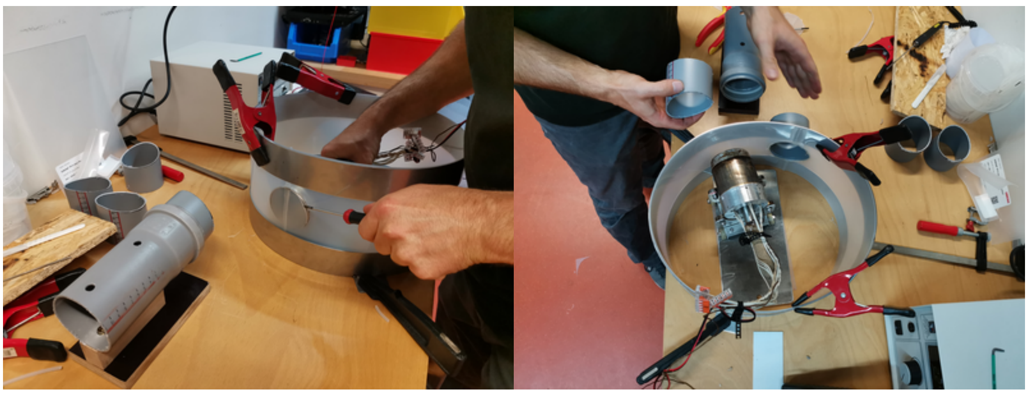


Figure 14: Melt hole and weld flange

Figure 15: cut out the disc as a conclusion and weld on later

10.6 central tube segments

1. cut the grid to the correct length
2. tube cut off about 5 cm longer on each side Roll up the grid and push it into the tube, supporting the two edges against each other every 15
,cm (picture 16)
3. finally insert the appropriate distributors. Afterwards the outer segments are mounted first.

(a) a

(b) b

(c) c

Figure 16: (a) cut the grid to the right length, roll it up and weave it, (b)(c) push the grid into the tube

10.7 connecting tubes

1. cut off the grid to the correct length (Figure 18a)

2. cut off tube about 5 cm longer on each side, roll the grid together and push it into the tube, weaving into each other for stability (see central tube)
3. To finish, place an HT-PP bracket with hood on one side and lay a suitable wire (see 10.9) around the bracket and twist slightly.

10.8 Bonnets

The hoods capture the warm exhaust air flow and direct it towards the extraction pipe. It is important that the canopy hangs more or less horizontally in the end.

1. Weld the 3 m stainless steel rods into rings to obtain a hoop with a diameter of approx. 90-95 cm (Figure 17a).
2. 1 m x 1 m Cut pieces from the flat film (Picture 17a)
3. place a small glass or similar (height approx. 8 cm) in the middle under the foil (picture 17a) Place a metal ring on the foil and use a foil marker to transfer the contour of the metal ring to the foil (Figure 17a) Remove the metal ring and glass and cut out all around at a distance of 4-5 cm from the marking (Fig. 17b).
4. Make a cut every approx. 15 cm in the direction of the centre up to the marking line (Fig. 17b).
5. hoop again, then turn the cut segments of the film all the way around to the mark and tack them on (Fig. 17c)
6. !!! Important!!!! Determine the centre of gravity (image 17d) and cut a hole with a diameter of 50 mm-60 mm around it (image 17e)
7. Carefully push the film over an HT-PP angle pipe section (Figure 17f).

(a) a (b) b

(c) c (d) d

(e) e (f) f

Figure 17: (a) flat foil and metal hoop with weld seam for hood + small glass in the middle, (b) mark metal hoop + cut out round + cut across the mark, (c) tack segments around metal hoop, (d) find and mark the center of gravity of the hood, (e) cut hole from the middle and (f) push pipe piece through the middle.

10.9 wire cutting

Before hanging up, fix the clips to the ceiling at the correct points and cut the iron wire.

- The central tube should hang at a height of approx. 2.3ṁ to 2.5ṁ. We used one wire per distributor. The required wire length is approximately: 2x(ceiling height - 2,5 m)+106 cm. The piece of wire is bent at both ends by about 3 cm to form a simple hook. When hanging, one side of the wire is hooked into the corresponding ceiling fixture, passed around a distributor at the bottom, and then the second end is also hooked into the ceiling fixture.
- The lower edges of the hoods should hang as close as possible above the persons without hindering them when getting up or in everyday life. In the schools we have set a height of the lower edge of the canopy of about 2.0 m. The hoods with angle piece themselves have a height of approx. 20
  ,cm and again 3 cm at each end are needed as hooks. This results in the wire length of ceiling height - 1.9 m.

10.10 Hanging Up

It has proved advantageous to first suspend the parts of the central pipe from the outside to the inside, then insert the central segments and then attach the suction pipes. Unused openings on the distributors must be closed.

10.11 Fans

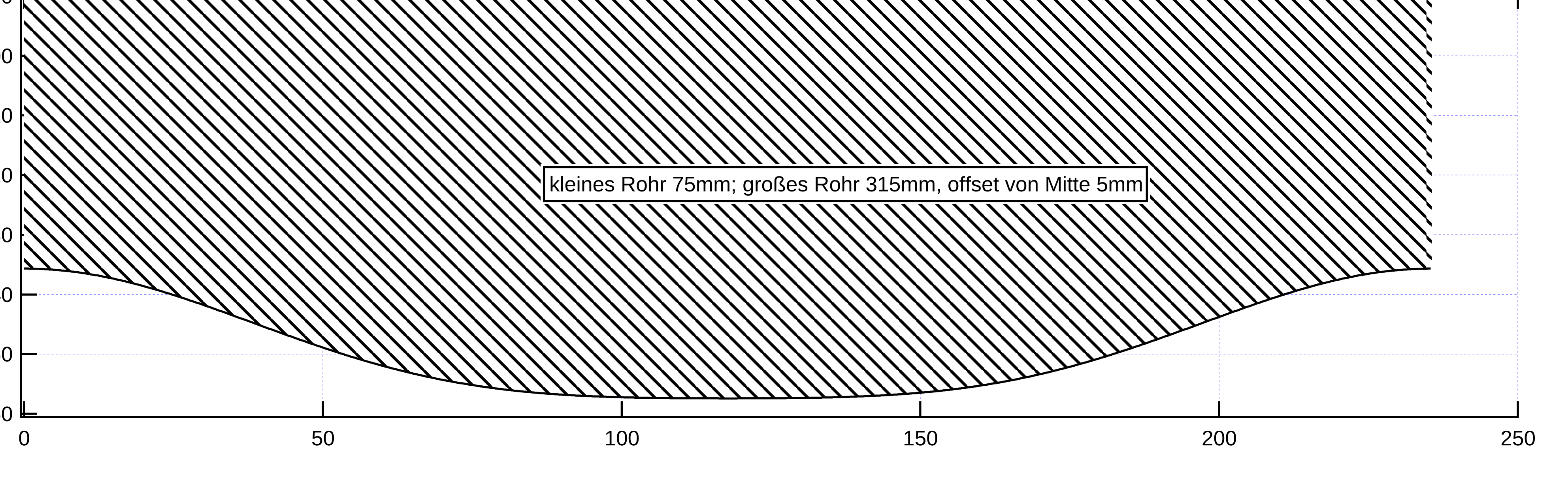
!!! CAUTION Only carry out changes to electrical equipment if you are suitable and after consultation with the responsible persons!!!

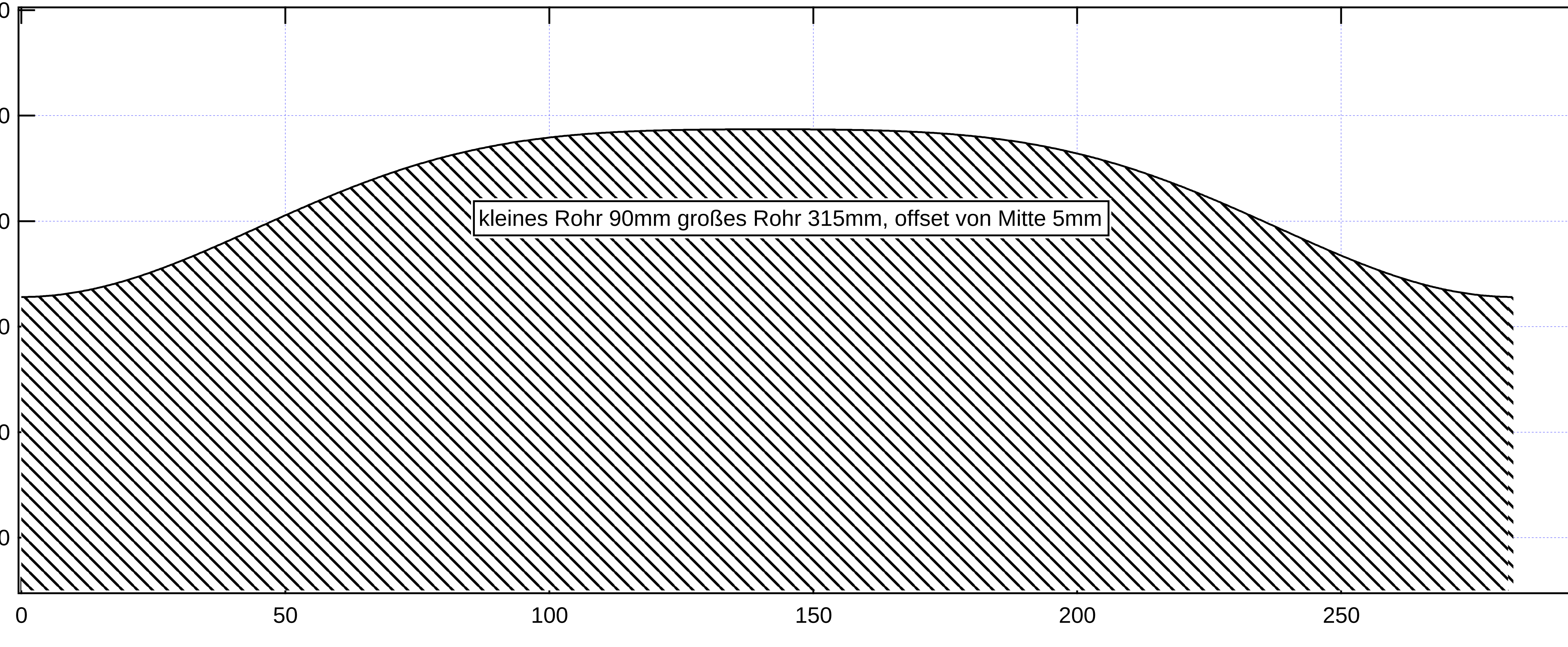
There are many alternatives for fans. We have chosen a simple table fan (Tristar ve-5953) made of metal, which has a diameter of 30 cm and can run in 3 stages. To use the fan, it must be modified as follows. Alternatively, there are also axial-tube fans that fit directly into the central tube, but still require speed control.

1. the motor from the stand
2. grid on correct diameter
3. flat material cutting 181 mm x 1000 mm
4. to be welded together to form a pipe section
5. fasten the motor to the pipe section with cable ties
6. to stage 1 or 2 before installation in the pipe.

10.12 exhaust window connection

The window connection is very individual. The easiest way is to have a suitable person replace a glass pane with a board at the right height so that the fan can blow outwards relatively unhindered. Other possibilities are the use of window seals, as they are sold for mobile air conditioners, or the construction of a box in front of the window (see picture 8)

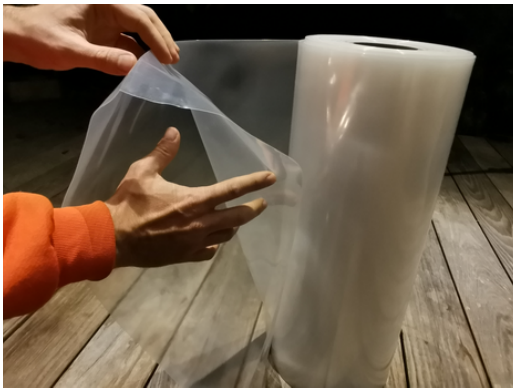

kleines Rohr 75mm; großes Rohr 315mm, offset von Mitte 5mm
0
50
100
150
200
250


kleines Rohr 90mm großes Rohr 315mm, offset von Mitte 5mm
0
50
100
150
200
250

(a) a

(b) b

Figure 18: (a) cut support mesh PE N902 into 26 cm strips and (b) support mesh PE N903



(a) a

(b) b

Figure 19: (a) film tube 500 mm 0.2 mm for large pipes and (b) film tube 125 mm 0.2 mm for small pipes

Figure 20: cable tie for fastening

Figure 21: welding wire for manifold

Low-Cost-Abluftanlage

Projektstudie des Max-Planck-Institutes für Chemie in Mainz in Zusammenarbeit mit der Integrierten Gesamtschule Mainz-Bretzenheim

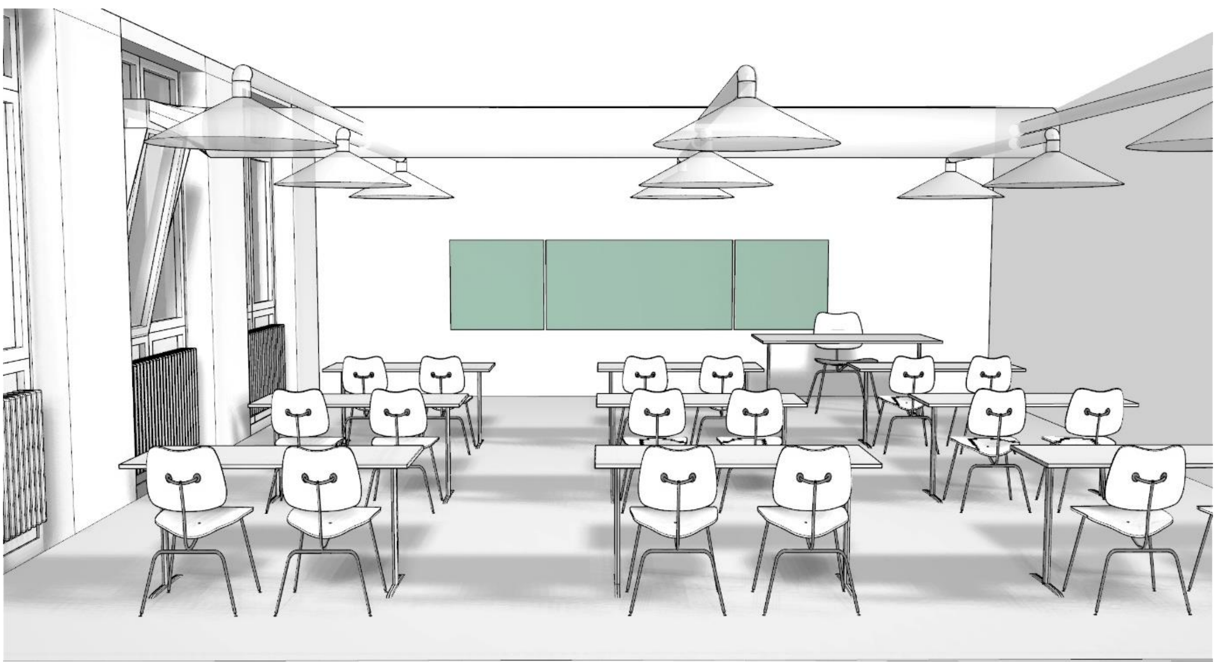
Antrieb: Schule in der Coronapandemie - Infektionsschutz

Idee: Ausnutzung der durch eine Person hervorgerufenen natürlichen Konvektion mit einem Abzug direkt über der Person.

Ziel: möglichst große effektive Wechselrate direkt bei den Personen bei geringer nomineller Wechselrate der gesamten Raumluft

Vorteile im Überblick:

- ***Ausnutzung der Konvektion (warme Luft steigt über Personen mit deren Aerosolen nach oben)***
- ***Abtransport von ca. 90% der Aerosole durch einen kontinuierlichen Abzug direkt über der Person***
- ***CO2-Reduzierung*** in den Klassenräumen – somit auch nach der Pandemie sinnvoll einsetzbar
- Niedriger Geräuschpegel
- deutliche ***Reduzierung des Wärmeverlustes*** gegenüber Stoßlüften alle 20 min.
- ***geringste Anschaffungskosten*** (weniger als 200 € Materialkosten pro Raum)
- ***geringste Betriebskosten*** (Strom für Ventilator vs. Energieersparnis bei Heizkosten)
- Niedrige Anforderungen: Steckdose und kippbares Fenster/Oberlicht
- Keine Umbaumaßnahmen an Fassade etc. notwendig
- Minimale Verdunkelung durch transparente bzw. helle Bauteile
- Individuelle und einfache Bedienung
- Das modulare System ist vielfältig anpassbar. Die entsprechende Umsetzung an einer Grundschule (Brunnenschule Marienborn) und einer Sportstätte (Turnabteilung der TSG 1846 Bretzenheim) ist bereits in Planung.



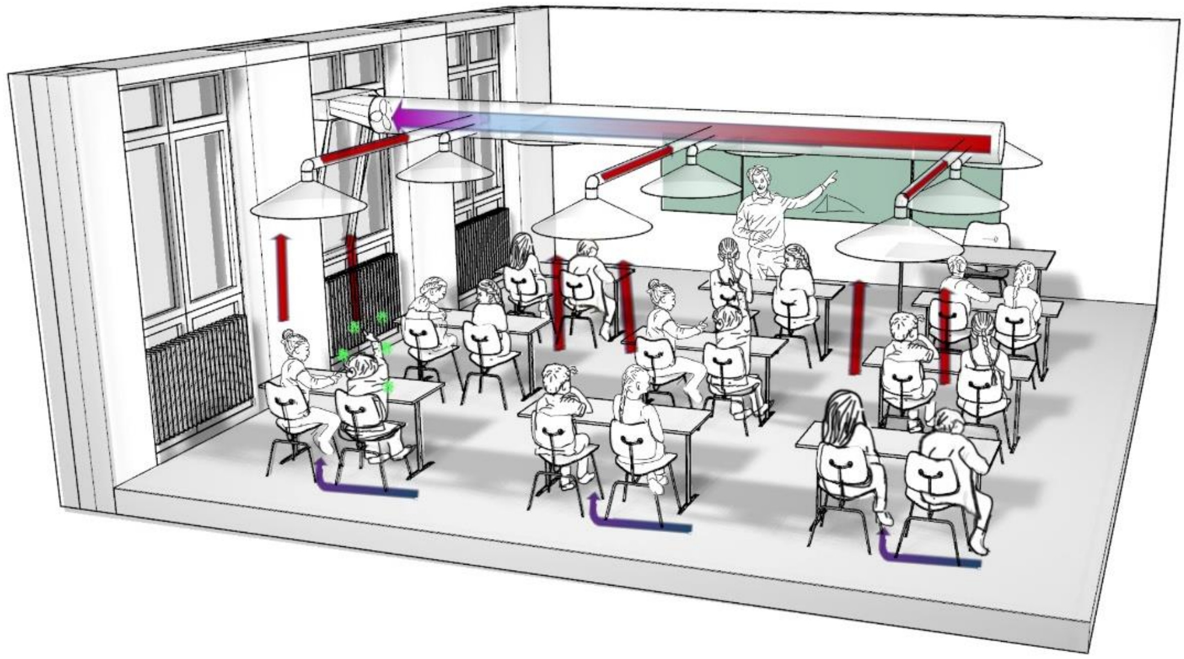
Luftströmungen und Aerosole in geschlossenen Räumen ohne Lüftung

Menschen stoßen Aerosole aus, die pathogene Keime, wie z.B. den Sars-COV-2 enthalten können. Große Tropfen fallen recht bald zu Boden, die kleinen Aerosole sind jedoch so leicht, dass sie über Stunden in der Luft verweilen können und sich durch Turbulenzen innerhalb weniger Minuten im gesamten Raum verteilen.

Abluftsystem des MPI für Chemie Mainz (Dr. F. Helleis):

Menschen sind insbesondere im Winter wärmer als die sie umgebende Luft im Raum. Daher kommt es zu sogenannten konvektiven, d.h. aufwärtsgerichteten Strömungen in der Raumluft, die die Aerosole mit potentiell infektiösen Viren mit nach oben tragen. Bei der neuen Anlage, werden diese, ähnlich wie bei einer Dunstabzugshaube, direkt oberhalb der Schüler aufgenommen und nach draußen geleitet. Für den Transport wird ein Ventilator genutzt, der die Abluft über ein gekipptes Fenster nach draußen bringt. Dementsprechend sieht das System eine eigene „Abzugshaube" für jeden Tisch vor. Diese Haube sorgt für ein zielgerichtetes „Einsammeln" der Aerosole. Die Frischluftzufuhr kann beispielsweise über ein leicht geöffnetes bzw. gekipptes Fenster erfolgen.

In der Regel wird die Effektivität des Lüftens bzw. der Lüftungsanlagen über die **nominelle Raumluftwechselrate** angegeben, also wie oft die gesamte Luft des Raums in einer Stunde ausgetauscht wird. Findet keine Wärmerückgewinnung statt, so bedeutet eine höhere Raumluftwechselrate jedoch auch einen stärkeren Wärmeverlust bzw. höhere Heizkosten. Das Ziel ist es nicht viel Raumluft gegen Frischluft zu tauschen (wie eine konventionelle Lüftung), sondern die potenziell kontaminierte Abluft der Personen zielgerichtet und damit effektiv zu entfernen. Bei Messungen konnte gezeigt werden, dass mit solch einem Abluftsystem bei einer nominellen Wechselrate, die einem stündlichen Stoßlüften entspricht, bereits ca. 77 % ohne Haube und mit Haube sogar über **90 % der Aerosole kontinuierlich entfernt werden**.



(a) a

(b) b

Figure 22: (a) HT angle DN 75 87° and (b) HT branch DN 75 87°