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# Pathogen Spread and Air Quality Indoors - Ventilation Effectiveness in a Classroom

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**ABSTRACT**

In the course of the Covid-19 pandemic, the airborne transmission route has been given a significant role [1]. One preventive measure is the use of increased air exchange through the supply of outside air or the use of air filtration devices [2]. In classrooms the level of carbon dioxide is also of special interest [3].

In this study the ventilation effectiveness in a classroom was examined using computational fluid dynamics (CFD) to investigate different ventilation options in terms of their 3-dimensional impact in the space. In total, seven different cases were compared, three cases with mixing ventilation and four cases with displacement ventilation. In two cases the recirculation rate was 100 % but potentially harmful particles in the air were filtered by HEPA H14. In one case acrylic panels were placed on each desk between two neighboring students. The occupancy in the classroom was a teacher and either 24 or 12 students, full or half occupancy respectively. All occupants emitted carbon dioxide, one student emitted virus-laden airborne particles (subsequently known as just particles). The position of the particle emitting student was varied. The ventilation effectiveness after 45 minutes was examined.

The results show, if there is one main contaminant source, the use of the local air quality index is crucial, since neither the air change rate nor the local air change index sufficiently reflect the risk of exposure to possibly harmful particles. In several cases the ventilation effectiveness in the breathing zone of some persons was only about 20 %. The affected persons would have been exposed to pathogen concentrations about five times higher than it would be expected based on the air exchange rate. Frequently, increased particle concentrations occur in the proximity of the infectious person, but it

cannot be concluded that only persons in the immediate proximity would be affected by a possible infection transmission. Walls and other surfaces affect the room air flow as well as the particle spread through their presence and through convection in case of existing temperature differences between the surface and the air. Therefore, high particle concentrations can also be observed in a considerable distance from the infectious person.

All mixing ventilation cases showed a similar ventilation effectiveness but in cases with an air purifier the carbon dioxide concentration reached hygienically unacceptable levels, since no fresh air was supplied. The ventilation effectiveness in cases with displacement ventilation was significantly higher than in others.

## INTRODUCTION

Mechanical ventilation is usually justified in order to ensure a good air quality and to reduce the risk of pathogen transmission via airborne particles indoors. A common indicator of the expected air quality or exposure level to possibly harmful particles is the air change rate ACH. It is defined as the ratio of the supply air volume flow rate and the room volume. Other definitions address the necessity to differentiate between the ability of a ventilation system to exchange the air and to remove contaminants. Furthermore, it is possible to define global values for a room as well as local values for an area of interest, more details in [4].

The local air change index in the breathing zone is defined according to equation 1. It quantifies the ability of the ventilation system to provide fresh air in the breathing zone.

$$\varepsilon_b^a = \frac{\text{shortest possible air change time}}{\text{local mean age of air in the breathing zone}} \quad (1)$$

The shortest possible air change time is equivalent to the nominal time constant $\tau_n$ defined in equation 2. The local mean age of air in the breathing zone $\bar{\tau}_b$ can be determined experimentally using tracer gas technique or applying a passive scalar source term in the simulation.

$$\tau_n = \frac{\text{room volume}}{\text{supply air volume flow rate}} = \frac{1}{\text{ACH}} \quad (2)$$

This index is 1 for fully mixed flow. A lower value indicates a lower local air change rate than in perfect mixing ventilation. In case of a pronounced short circuit flow, the index can be close to zero. When the air in the breathing zone has nearly supply air characteristics, the index can be orders of magnitude higher than in fully mixed flow.

The local air quality index in the breathing zone is defined in equation 3. It represents the ability of the ventilation system to remove contaminants from the breathing zone.

$$\varepsilon_b^c = \frac{\text{concentration of the cont. in the exhaust air}}{\text{concentration of the cont. in the breathing zone}} \quad (3)$$

This index is also 1 in perfect mixing ventilation and has a similar range as the local air change index. Values below 1, mean that the air quality is worse and values above 1 are better than in fully mixed flow.

## METHODS

The results were obtained by a CFD study. A typical classroom with a base area of 60 $m^2$ and a height of 3 m was set up (8.57 m x 7 m x 3 m). A teacher and either 24 or 12 students represent full or half occupancy. Each person exhales 20 l/h carbon dioxide [5]. The initial carbon dioxide concentration in the room and the supply air is 400 ppm. The supply volume flow rate is always 1000 $m^3/h$, corresponding to 5.56 air changes per hour. A low outdoor air temperature is assumed. The inside surface temperature of the exterior wall and the windows is 19 °C and 18 °C respectively. The surface temperature of the interior walls, the floor is 20 °C. The temperature of the supply air is equal to the exhaust temperature in cases with no external air supply and 20°C otherwise. Each occupant has a heat load of 100 W. Other surfaces are adiabatic.

One student emits potentially harmful particles. The position varies as highlighted red in Figure 1. The particle flow rate is 50 P/s. The initial particle concentration in the room and in the supply air is zero. The case characteristics are summarized in Table 1. Mixing ventilation cases are prefixed with MV and displacement ventilation cases with DV. Selected room models are depicted in Figures 1 to 3. Fresh air is either supplied by four evenly spaced swirl diffusers on the ceiling or by a displacement ventilation unit in the back of the classroom. In the cases with an air purifier, no fresh air is supplied. The air is recirculated, the particles are filtered 100 %, as a simplified assumption. Figure A1 shows the swirl diffuser, Figure A2 the air purifier and Figure A3 the displacement ventilation unit.

The physics was modelled using the realizable k-ε-turbulence-model, buoyancy and surface to surface thermal radiation models. First, a steady flow field was computed. Then an unsteady simulation (URANS) with passive scalars representing air, carbon dioxide and ideally airborne particles was performed for 45 minutes. The molecular Schmidt number for carbon dioxide in air was set to 1.14 [6]. The particle spread was modelled with a convective only passive scalar.

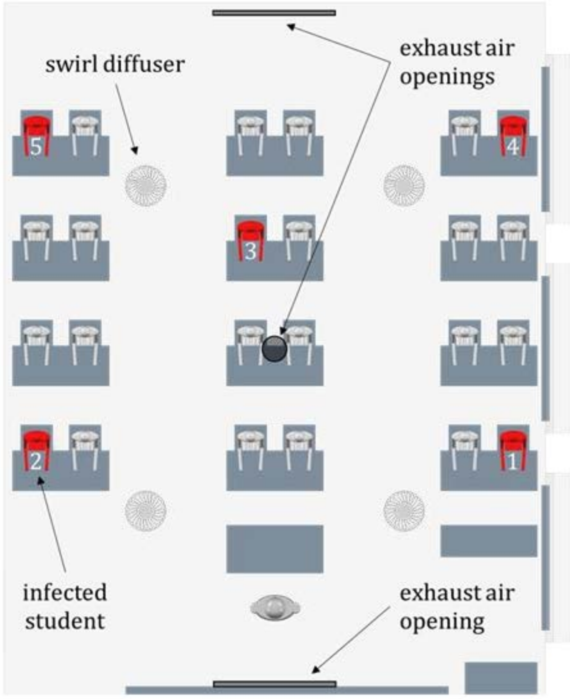


*Figure 1: Classroom, case MV-A-1, positions of the particle emitting student are highlighted in red*

*Table 1. Cases*

| Case | Supply Air | Exhaust Air | Recir-culation Rate | Pan-els | Occu-pancy |
|---|---|---|---|---|---|
| MV-A-1 | Ceiling, 4x | Ceiling, 3x | 0 % | no | full |
| MV-B-1a | Air purifier, upper part | Air purifier, lower part | 100 % | no | full |
| MV-B-1b | Air purifier, upper part | Air purifier, lower part | 100 % | yes | full |
| DV-A-1 | Ventila-tion unit, lower part | Ventila-tion unit, upper part | 0 % | no | full |
| DV-A-2 | Ventila-tion unit, lower part | Ventila-tion unit, upper part | 0 % | no | half |
| DV-B-1 | Ventila-tion unit, lower part | Ceiling, 4x | 0 % | no | full |
| DV-B-2 | Ventila-tion unit, lower part | Ceiling, 4x | 0 % | no | half |

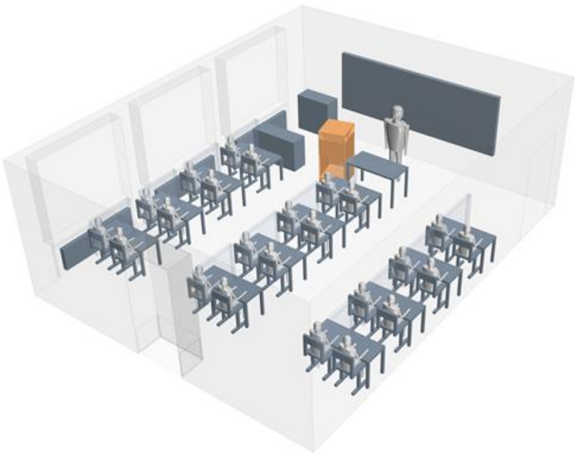

*Figure 2: Classroom, case MV-B-1b*

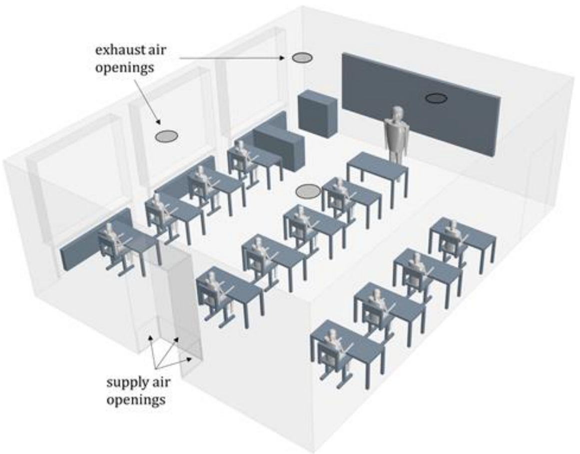


*Figure 3: Classroom, case DV-B-2*

The breathing zone was defined according to [7]. A spherical volume with a radius of 10 inches (25.4 cm) was placed around the nose and mouth, see Figure A4. Volume averaged values in the breathing zone and mass flow averaged values in the exhaust were extracted. Mean values were calculated from average values in the breathing zones of all occupants, except the particle emitting student, when calculating the air quality index $\varepsilon_b^c$ for particles. As the position of the particle emitting student varied, the mean air quality index for particles was finally calculated as a mean value over the means for the five different positions of the emitting person, note Figures A5 to A14 in the Appendix.

**RESULTS AND DISCUSSION**

Table 2 shows the mean values in the breathing zone of the local air change index, the air quality index for carbon dioxide and the local air quality index for particles as a mean value over the five positions of the infectious student.

The air change index of 0.90 in case MV-A-1 is, being below but close to 1, typical for mixing ventilation. The air quality index for carbon dioxide is 0.69 and for particles 1.08. These values lie within the common range. In perfect mixing ventilation both indices would be equal to 1.

In the cases with an air purifier MV-B-1a and MV-B-1b, the recirculation rate is 100 %. The air and carbon dioxide circulate, the particles are filtered 100 %. Therefore, the local air change index as well as the air quality index for carbon dioxide are meaningless and omitted for these cases.

Table 3 shows absolute mean values of average values in the breathing zones, analogous to Table 2. After 45 minutes the carbon dioxide levels reach 2442 ppm in the case MV-B-1a and 2498 ppm in the case MV-B-1b, 2042 ppm and 2098 ppm above the outdoor level respectively. Indoor carbon dioxide levels should not exceed 800 ppm above the outdoor levels [8]. However, the air quality index for particles is higher than in MV-A-1. The acrylic panels in MV-B-1b show a small advantage compared to MV-B-1a in this setting.

All mixing ventilation results show a mean air quality index close to 1. No general conclusions on health effects can be drawn here, since the particle concentration in the room varies considerably, thus, the inhaled dose does too, see Figures A7 to A10 in the Appendix. There are cases with an air quality index of roughly 20 %, meaning the inhaled doses are five times higher than expected with estimation using the air change rate.

The air change index is similar in all displacement ventilation cases and is around 70 % higher than with mixing ventilation in MV-A-1. The air quality index is multiple times higher than in the mixing ventilation cases. Generally, the position of the exhaust openings does not change the flow field much, but it can change, to some extent, the concentration field. The cases DV-A and DV-B differ only in the position of the exhaust openings, but the air quality index for particles varies significantly. There is a notable difference between air quality index for particles with full and half occupancy with no clear tendency. The absolute particle concentration is nevertheless lower at half occupancy, see Table 3.

The local particle concentrations vary considerably, also in the cases with displacement ventilation. But in contrast to the mixing ventilation cases, the air quality index is mostly significantly above 1, though with minimum values only slightly higher than in mixing ventilation cases, see Figures A11 to A14 in the Appendix.

The relative standard deviation, defined as the ratio of the standard deviation to the mean, is in all cases much smaller for carbon dioxide than for particle concentrations. This indicates, that for the assumption of nearly perfect mixing it is essential the contaminant sources are evenly distributed in the room.

In summary, it is questionable to use global quantities like the air change rate or mean values of any other indicators to assess infection transmission risks.

*Table 2. Ventilation effectiveness*

| Case | $\varepsilon_b^a$ | $\varepsilon_b^c$, CO2 | $\varepsilon_b^c$, particles |
|---|---|---|---|
| MV-A-1 | 0.90 | 0.69 | 1.08 |
| MV-B-1a | - | - | 1.07 |
| MV-B-1b | - | - | 1.20 |
| DV-A-1 | 1.51 | 0.93 | 64.31 |
| DV-A-2 | 1.48 | 0.79 | 42.54 |
| DV-B-1 | 1.55 | 0.94 | 16.06 |
| DV-B-2 | 1.54 | 0.79 | 15.89 |

*Table 3. Absolute values of the concentrations*

| Case | CO2 concentration (ppm) | Particle concentration ($P/m^3$) |
|---|---|---|
| MV-A-1 | 1197 | 189 |
| MV-B-1a | 2442 | 259 |
| MV-B-1b | 2498 | 173 |
| DV-A-1 | 898 | 53 |
| DV-A-2 | 788 | 49 |
| DV-B-1 | 887 | 52 |
| DV-B-2 | 787 | 38 |

## CONCLUSIONS

Ventilation as well as particle filtering can reduce the risk of an aerosol infection transmission. However, with ventilation both the particle and the carbon dioxide concentrations can be reduced. A key question is what quantity may serve as a reliable indicator for the exposure risk. It has been shown that unlike the local air quality index, the air exchange rate does not reflect the exposure risk, when there is a single contaminant source, because of the local variations of the particle concentration and thus the differences in the inhaled doses are overlooked. In addition, any averaging may result in significant underestimation of the total exposure risk. When a possible infection transmission is of particular concern, then the minimum concentration levels or the exceedance of predefined thresholds as well as their spatial prevalence should get more attention than the mean values.

In order to assess the potential health risks resulting from the inhalation of potentially infectious particles, the spatial distribution of the aerosol particles is required. The position and emission characteristics of the contaminant source as well as the type of ventilation and the location of the supply and exhaust air openings among other factors may influence the spatial distribution of the particle concentration significantly. In the studied cases, high particle concentrations frequently occur in the proximity of the infectious person. However, it cannot be concluded that only persons in the immediate proximity are exposed to high particle concentration, as these can also be observed in a considerable distance to the infectious person. In addition to the concentration, the exposure time and the associated inhaled dose are of importance when assessing the infection risk [9].

## ACKNOWLEDGEMENTS

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## APPENDIX

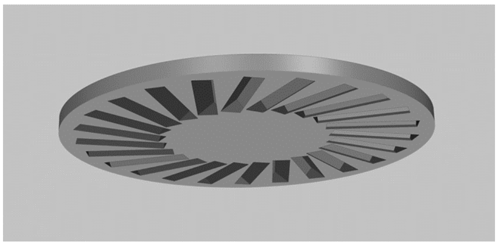


*Figure A1: Swirl diffuser (MV-A-1)*

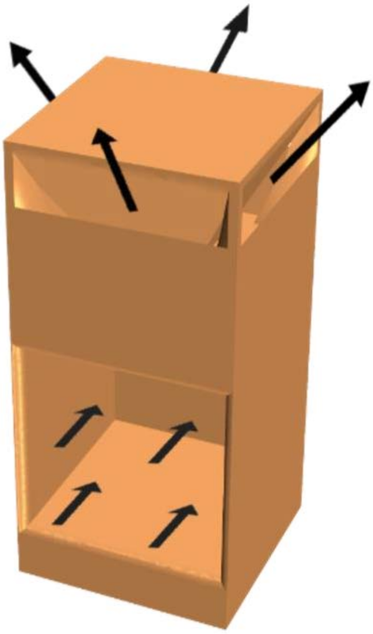


*Figure A2: Air purifier (MV-B-1)*

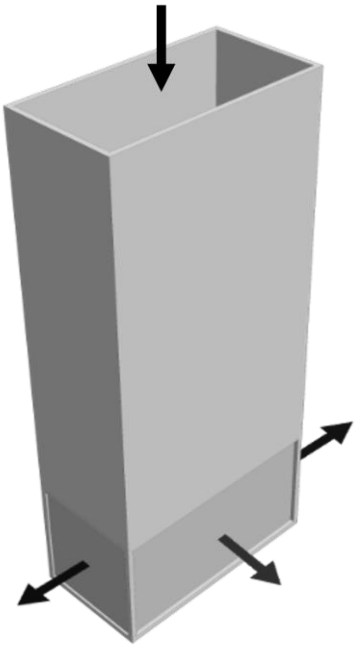


*Figure A3: Ventilation unit (DV-A)*

*Figure A4: The breathing zone indicated with a blue sphere*

**MV-A-1**
**CO2 concentration in the breathing zone (ppm)**

| | | | | | |
|---|---|---|---|---|---|
| 1117 | 1145 | 1213 | 1135 | 1167 | 1232 |
| 1146 | 1183 | 1113 | 1138 | 1184 | 1196 |
| 1167 | 1176 | 1256 | 1130 | 1175 | 1196 |
| 1206 | 1216 | 1210 | 1197 | 1398 | 1252 |
| | | 1375 | | | |
| Min | 1113 | Mean | 1197 | Max | 1398 |
| | | Std | 69 | | |

**MV-B-1a**
**CO2 concentration in the breathing zone (ppm)**

| | | | | | |
|---|---|---|---|---|---|
| 2425 | 2371 | 2439 | 2333 | 2427 | 2487 |
| 2397 | 2340 | 2417 | 2347 | 2407 | 2547 |
| 2427 | 2387 | 2360 | 2357 | 2484 | 2376 |
| 2425 | 2657 | 2606 | 2656 | 2471 | 2400 |
| | | 2511 | | | |
| Min | 2333 | Mean | 2442 | Max | 2657 |
| | | Std | 92 | | |

**MV-B-1b**
**CO2 concentration in the breathing zone (ppm)**

| | | | | | |
|---|---|---|---|---|---|
| 2370 | 2450 | 2478 | 2346 | 2368 | 2546 |
| 2372 | 2669 | 2536 | 2354 | 2508 | 2553 |
| 2395 | 2529 | 2462 | 2520 | 2443 | 2423 |
| 2823 | 2514 | 2668 | 2732 | 2424 | 2437 |
| | | 2527 | | | |
| Min | 2346 | Mean | 2498 | Max | 2823 |
| | | Std | 121 | | |

*Figure A5: Carbon dioxide concentration in the breathing zone*

**DV-A-1**
**CO2 concentration in the breathing zone (ppm)**

| | | | | | |
|---|---|---|---|---|---|
| 822 | 821 | 898 | 880 | 971 | 919 |
| 862 | 815 | 825 | 847 | 923 | 1104 |
| 837 | 834 | 773 | 795 | 857 | 1180 |
| 888 | 794 | 756 | 846 | 975 | 1117 |
| | | 1113 | | | |
| Min | 756 | Mean | 898 | Max | 1180 |
| | | Std | 117 | | |

**DV-A-2**
**CO2 concentration in the breathing zone (ppm)**

| | | |
|---|---|---|
| 739 | 825 | 723 |
| 692 | 745 | 848 |
| 707 | 758 | 901 |
| 828 | 756 | 826 |
| | 899 | |

| | | | | | |
|---|---|---|---|---|---|
| Min | 692 | Mean | 788 | Max | 901 |
| | | Std | 70 | | |

**DV-B-1**
**CO2 concentration in the breathing zone (ppm)**

| | | | | | |
|---|---|---|---|---|---|
| 800 | 830 | 883 | 861 | 901 | 853 |
| 848 | 820 | 808 | 883 | 976 | 1045 |
| 880 | 799 | 773 | 812 | 858 | 1014 |
| 888 | 787 | 739 | 851 | 1005 | 1141 |
| | | 1114 | | | |
| Min | 739 | Mean | 887 | Max | 1141 |
| | | Std | 105 | | |

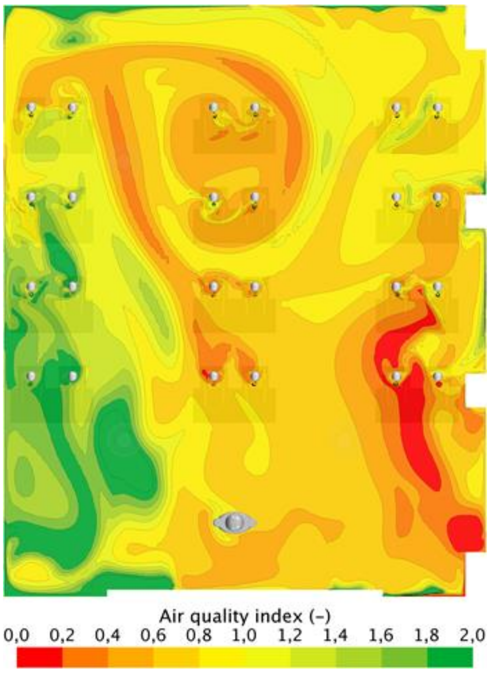
**DV-B-2**
**CO2 concentration in the breathing zone (ppm)**

| | | |
|---|---|---|
| 731 | 810 | 730 |
| 688 | 760 | 831 |
| 735 | 751 | 857 |
| 795 | 742 | 836 |
| | 970 | |

| | | | | | |
|---|---|---|---|---|---|
| Min | 688 | Mean | 787 | Max | 970 |
| | | Std | 74 | | |

*Figure A6: Carbon dioxide concentration in the breathing zone*

In Figures A7 to A14, the blank (white) rectangle corresponds to the sitting position of the infectious student.




MV-A-1

Mean air quality index in the breathing zone, position 1

| | | | | | |
|---|---|---|---|---|---|
| 0.80 | 0.98 | 0.59 | 0.64 | 0.79 | 0.91 |
| 1.19 | 1.23 | 0.68 | 0.57 | 0.94 | 0.58 |
| 1.59 | 1.49 | 0.51 | 0.61 | 0.57 | 0.74 |
| 1.74 | 1.60 | 0.42 | 0.54 | 0.23 | |
| | | 0.89 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Min | 0.23 | Mean | 0.87 | Max | 1.74 |
| | | Std | 0.41 | | |

*Figure A7: Air quality index 1 m above the floor and mean air quality index in the breathing zone, MV-A-1, source position 1*

MV-A-1

Mean air quality index in the breathing zone, position 1

| | | | | | |
|---|---|---|---|---|---|
| 0.80 | 0.98 | 0.59 | 0.64 | 0.79 | 0.91 |
| 1.19 | 1.23 | 0.68 | 0.57 | 0.94 | 0.58 |
| 1.59 | 1.49 | 0.51 | 0.61 | 0.57 | 0.74 |
| 1.74 | 1.60 | 0.42 | 0.54 | 0.23 | |
| | | 0.89 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Min | 0.23 | Mean | 0.87 | Max | 1.74 |
| | | Std | 0.41 | | |

MV-A-1

Mean air quality index in the breathing zone, position 2

| | | | | | |
|---|---|---|---|---|---|
| 0.82 | 0.73 | 1.72 | 1.57 | 1.31 | 1.51 |
| 0.65 | 0.62 | 1.53 | 1.56 | 1.54 | 1.48 |
| 0.17 | 0.38 | 1.26 | 1.25 | 1.33 | 1.55 |
| | 0.23 | 1.37 | 1.37 | 1.56 | 1.40 |
| | | 1.09 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Min | 0.17 | Mean | 1.17 | Max | 1.72 |
| | | Std | 0.47 | | |

MV-A-1

Mean air quality index in the breathing zone, position 3

| | | | | | |
|---|---|---|---|---|---|
| 0.74 | 0.64 | 1.34 | 1.53 | 1.09 | 1.04 |
| 0.83 | 0.62 | | 1.49 | 1.22 | 1.52 |
| 0.76 | 0.65 | 1.45 | 1.35 | 1.44 | 1.40 |
| 0.57 | 0.58 | 1.42 | 1.55 | 1.56 | 1.49 |
| | | 1.01 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Min | 0.57 | Mean | 1.14 | Max | 1.56 |
| | | Std | 0.37 | | |

MV-A-1

Mean air quality index in the breathing zone, position 4

| | | | | | |
|---|---|---|---|---|---|
| 1.28 | 1.31 | 0.81 | 0.77 | 0.87 | |
| 1.69 | 1.59 | 0.88 | 1.05 | 0.16 | 0.57 |
| 2.00 | 1.93 | 1.00 | 1.05 | 0.77 | 0.45 |
| 2.28 | 2.14 | 1.03 | 0.98 | 0.87 | 0.80 |
| | | 1.26 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Min | 0.16 | Mean | 1.15 | Max | 2.28 |
| | | Std | 0.54 | | |

MV-A-1

Mean air quality index in the breathing zone, position 5

| | | | | | |
|---|---|---|---|---|---|
| | 1.02 | 1.09 | 1.03 | 0.86 | 0.93 |
| 0.18 | 0.75 | 1.04 | 1.12 | 0.93 | 1.16 |
| 0.77 | 1.02 | 1.20 | 1.14 | 1.18 | 1.07 |
| 1.39 | 1.39 | 1.25 | 1.20 | 1.24 | 1.15 |
| | | 1.28 | | | |

| | | | | | |
|---|---|---|---|---|---|
| Min | 0.18 | Mean | 1.06 | Max | 1.39 |
| | | Std | 0.25 | | |

*Figure A8: Mean air quality index in the breathing zone, MV-A-1*

**MV-B-1a**
**Mean air quality index in the breathing zone, position 1**

| | | | | | |
|---|---|---|---|---|---|
| 3.04 | 3.36 | 2.99 | 3.08 | 3.04 | 3.06 |
| 3.00 | 3.11 | 3.01 | 2.13 | 2.64 | 2.74 |
| 3.02 | 3.22 | 3.12 | 1.00 | 1.89 | 2.47 |
| 3.08 | 3.41 | 2.00 | 0.92 | 1.95 | |
| | | 2.72 | | | |
| **Min** | **0.92** | **Mean** | **2.67** | **Max** | **3.41** |
| | | **Std** | **0.68** | | |

**MV-B-1a**
**Mean air quality index in the breathing zone, position 2**

| | | | | | |
|---|---|---|---|---|---|
| 0.30 | 0.22 | 0.42 | 0.34 | 0.41 | 0.46 |
| 0.32 | 0.27 | 0.48 | 0.55 | 0.71 | 0.61 |
| 0.33 | 0.20 | 0.56 | 0.75 | 0.78 | 0.83 |
| | 0.29 | 0.96 | 0.98 | 0.95 | 0.97 |
| | | 0.54 | | | |
| **Min** | **0.20** | **Mean** | **0.55** | **Max** | **0.98** |
| | | **Std** | **0.26** | | |

**MV-B-1a**
**Mean air quality index in the breathing zone, position 3**

| | | | | | |
|---|---|---|---|---|---|
| 0.41 | 0.52 | 0.61 | 0.64 | 0.53 | 0.52 |
| 0.31 | 0.48 | | 0.71 | 0.75 | 0.64 |
| 0.35 | 0.43 | 0.80 | 0.94 | 0.79 | 0.75 |
| 0.36 | 0.44 | 1.09 | 0.99 | 0.89 | 0.91 |
| | | 0.66 | | | |
| **Min** | **0.31** | **Mean** | **0.65** | **Max** | **1.09** |
| | | **Std** | **0.22** | | |

**MV-B-1a**
**Mean air quality index in the breathing zone, position 4**

| | | | | | |
|---|---|---|---|---|---|
| 1.01 | 0.89 | 0.59 | 0.70 | 0.44 | |
| 0.85 | 0.85 | 0.88 | 0.52 | 0.32 | 0.16 |
| 0.87 | 0.83 | 1.33 | 1.01 | 0.37 | 0.46 |
| 0.92 | 1.08 | 1.79 | 0.79 | 0.79 | 0.91 |
| | | 1.25 | | | |
| **Min** | **0.16** | **Mean** | **0.82** | **Max** | **1.79** |
| | | **Std** | **0.35** | | |

**MV-B-1a**
**Mean air quality index in the breathing zone, position 5**

| | | | | | |
|---|---|---|---|---|---|
| | 0.44 | 0.67 | 0.64 | 0.67 | 0.67 |
| 0.44 | 0.48 | 0.64 | 0.75 | 0.93 | 0.84 |
| 0.28 | 0.35 | 0.65 | 0.86 | 0.94 | 0.91 |
| 0.26 | 0.30 | 0.91 | 1.03 | 0.98 | 0.98 |
| | | 0.52 | | | |
| **Min** | **0.26** | **Mean** | **0.67** | **Max** | **1.03** |
| | | **Std** | **0.24** | | |

*Figure A9: Mean air quality index in the breathing zone, MV-B-1a*

**MV-B-1b**
**Mean air quality index in the breathing zone, position 1**

| | | | | | |
|---|---|---|---|---|---|
| 2.41 | 2.42 | 2.20 | 2.21 | 2.16 | 2.02 |
| 2.57 | 2.50 | 1.96 | 1.93 | 2.04 | 1.97 |
| 2.81 | 2.70 | 1.73 | 0.92 | 1.66 | 1.94 |
| 2.89 | 2.89 | 1.69 | 1.42 | 1.74 | |
| | | 2.44 | | | |
| **Min** | **0.92** | **Mean** | **2.13** | **Max** | **2.89** |
| | | **Std** | **0.48** | | |

**MV-B-1b**
**Mean air quality index in the breathing zone, position 2**

| | | | | | |
|---|---|---|---|---|---|
| 0.68 | 0.70 | 0.78 | 0.83 | 1.00 | 1.59 |
| 0.67 | 0.77 | 0.88 | 1.02 | 1.54 | 1.51 |
| 0.43 | 0.79 | 0.88 | 1.37 | 0.99 | 1.71 |
| | 0.33 | 0.84 | 0.79 | 1.51 | 1.19 |
| | | 0.25 | | | |
| **Min** | **0.25** | **Mean** | **0.96** | **Max** | **1.71** |
| | | **Std** | **0.40** | | |

**MV-B-1b**
**Mean air quality index in the breathing zone, position 3**

| | | | | | |
|---|---|---|---|---|---|
| 1.20 | 1.30 | 1.05 | 1.06 | 1.11 | 1.26 |
| 1.32 | 1.41 | | 1.12 | 1.12 | 1.23 |
| 1.55 | 1.69 | 1.14 | 1.10 | 0.94 | 1.36 |
| 1.27 | 1.48 | 1.62 | 1.17 | 0.89 | 0.82 |
| | | 0.96 | | | |
| **Min** | **0.82** | **Mean** | **1.22** | **Max** | **1.69** |
| | | **Std** | **0.22** | | |

**MV-B-1b**
**Mean air quality index in the breathing zone, position 4**

| | | | | | |
|---|---|---|---|---|---|
| 1.14 | 0.89 | 0.76 | 0.41 | 0.20 | |
| 1.05 | 0.70 | 0.89 | 0.49 | 0.64 | 0.60 |
| 1.04 | 1.13 | 1.11 | 0.95 | 0.81 | 0.74 |
| 1.14 | 1.26 | 1.69 | 1.18 | 0.78 | 0.75 |
| | | 1.21 | | | |
| **Min** | **0.20** | **Mean** | **0.90** | **Max** | **1.69** |
| | | **Std** | **0.32** | | |

**MV-B-1b**
**Mean air quality index in the breathing zone, position 5**

| | | | | | |
|---|---|---|---|---|---|
| | 0.60 | 0.60 | 0.61 | 0.73 | 1.17 |
| 0.15 | 0.46 | 0.62 | 0.78 | 1.12 | 1.08 |
| 0.28 | 0.83 | 0.75 | 1.14 | 0.66 | 1.21 |
| 0.34 | 0.75 | 1.09 | 1.02 | 1.09 | 0.85 |
| | | 0.60 | | | |
| **Min** | **0.15** | **Mean** | **0.77** | **Max** | **1.21** |
| | | **Std** | **0.30** | | |

*Figure A10: Mean air quality index in the breathing zone, MV-B-1b*

**DV-A-1**
**Mean air quality index in the breathing zone, position 1**

| | | | | | |
|---|---|---|---|---|---|
| 13.33 | 4.71 | 2.43 | 2.09 | 0.87 | 2.41 |
| 8.97 | 9.85 | 5.08 | 2.85 | 0.81 | 0.81 |
| 5.02 | 11.09 | 5.43 | 4.55 | 0.98 | 0.34 |
| 2.05 | 1.58 | 5.89 | 0.29 | 0.28 | |
| | | 0.26 | | | |

| Min | 0.26 | Mean | 3.83 | Max | 13.33 |
|---|---|---|---|---|---|
| | | Std | 3.72 | | |

**DV-A-1**
**Mean air quality index in the breathing zone, position 2**

| | | | | | |
|---|---|---|---|---|---|
| 6.32 | 3.67 | 4.31 | 6.13 | 3.92 | 11.37 |
| 1.60 | 2.79 | 7.06 | 7.54 | 4.29 | 4.13 |
| 0.62 | 3.99 | 11.46 | 21.05 | 4.85 | 2.09 |
| | 0.28 | 24.88 | 2.98 | 2.00 | 1.32 |
| | | 0.89 | | | |

| Min | 0.28 | Mean | 5.81 | Max | 24.88 |
|---|---|---|---|---|---|
| | | Std | 6.07 | | |

**DV-A-1**
**Mean air quality index in the breathing zone, position 3**

| | | | | | |
|---|---|---|---|---|---|
| 52.88 | 47.51 | 108.74 | 103.63 | 43.50 | 66.56 |
| 62.51 | 80.42 | | 195.46 | 81.70 | 41.51 |
| 140.37 | 93.58 | 193.01 | 343.13 | 203.17 | 53.80 |
| 173.49 | 200.53 | 908.29 | 270.89 | 152.88 | 157.56 |
| | | 359.09 | | | |

| Min | 41.51 | Mean | 172.26 | Max | 908.29 |
|---|---|---|---|---|---|
| | | Std | 180.85 | | |

**DV-A-1**
**Mean air quality index in the breathing zone, position 4**

| | | | | | |
|---|---|---|---|---|---|
| 28.01 | 10.29 | 2.64 | 1.26 | 0.57 | |
| 27.52 | 25.81 | 9.69 | 2.43 | 1.84 | 2.15 |
| 32.65 | 26.02 | 20.75 | 3.04 | 3.12 | 3.12 |
| 16.79 | 18.27 | 29.75 | 2.88 | 2.27 | 3.18 |
| | | 6.25 | | | |

| Min | 0.57 | Mean | 11.68 | Max | 32.65 |
|---|---|---|---|---|---|
| | | Std | 11.27 | | |

**DV-A-1**
**Mean air quality index in the breathing zone, position 5**

| | | | | | |
|---|---|---|---|---|---|
| | 2.54 | 12.88 | 215.90 | 201.88 | 536.03 |
| 2.45 | 2.65 | 9.06 | 222.07 | 212.95 | 199.29 |
| 7.02 | 5.09 | 10.41 | 675.87 | 239.15 | 103.63 |
| 9.08 | 10.83 | 65.32 | 118.66 | 96.55 | 64.24 |
| | | 47.68 | | | |

| Min | 2.45 | Mean | 127.97 | Max | 675.87 |
|---|---|---|---|---|---|
| | | Std | 171.38 | | |

*Figure A11: Mean air quality index in the breathing zone, DV-A-1*

**DV-A-2**
**Mean air quality index in the breathing zone, position 1**

| | | |
|---|---|---|
| 8.31 | 7.12 | 3.05 |
| 29.91 | 9.35 | 1.45 |
| 2.88 | 6.50 | 0.30 |
| 2.41 | 3.05 | |
| | 0.37 | |

| Min | 0.30 | Mean | 6.23 | Max | 29.91 |
|---|---|---|---|---|---|
| | | Std | 8.06 | | |

**DV-A-2**
**Mean air quality index in the breathing zone, position 2**

| | | |
|---|---|---|
| 2.27 | 6.31 | 3.10 |
| 7.71 | 7.53 | 6.51 |
| 0.47 | 12.66 | 6.09 |
| | 17.85 | 7.53 |
| | 5.43 | |

| Min | 0.47 | Mean | 6.96 | Max | 17.85 |
|---|---|---|---|---|---|
| | | Std | 4.62 | | |

**DV-A-2**
**Mean air quality index in the breathing zone, position 3**

| | | |
|---|---|---|
| 28.38 | 35.23 | 7.82 |
| 134.55 | | 14.68 |
| 132.27 | 25.59 | 26.91 |
| 115.61 | 28.17 | 23.72 |
| | 42.88 | |

| Min | 7.82 | Mean | 51.32 | Max | 134.55 |
|---|---|---|---|---|---|
| | | Std | 46.96 | | |

**DV-A-2**
**Mean air quality index in the breathing zone, position 4**

| | | |
|---|---|---|
| 7.34 | 3.51 | |
| 23.16 | 3.82 | 0.62 |
| 11.32 | 2.87 | 0.72 |
| 7.51 | 1.83 | 0.94 |
| | 2.04 | |

| Min | 0.62 | Mean | 5.47 | Max | 23.16 |
|---|---|---|---|---|---|
| | | Std | 6.47 | | |

**DV-A-2**
**Mean air quality index in the breathing zone, position 5**

| | | |
|---|---|---|
| | 18.35 | 68.89 |
| 5.59 | 32.90 | 148.77 |
| 11.40 | 174.80 | 229.25 |
| 102.07 | 411.29 | 245.33 |
| | 263.85 | |

| Min | 5.59 | Mean | 142.71 | Max | 411.29 |
|---|---|---|---|---|---|
| | | Std | 126.69 | | |

*Figure A12: Mean air quality index in the breathing zone, DV-A-2*

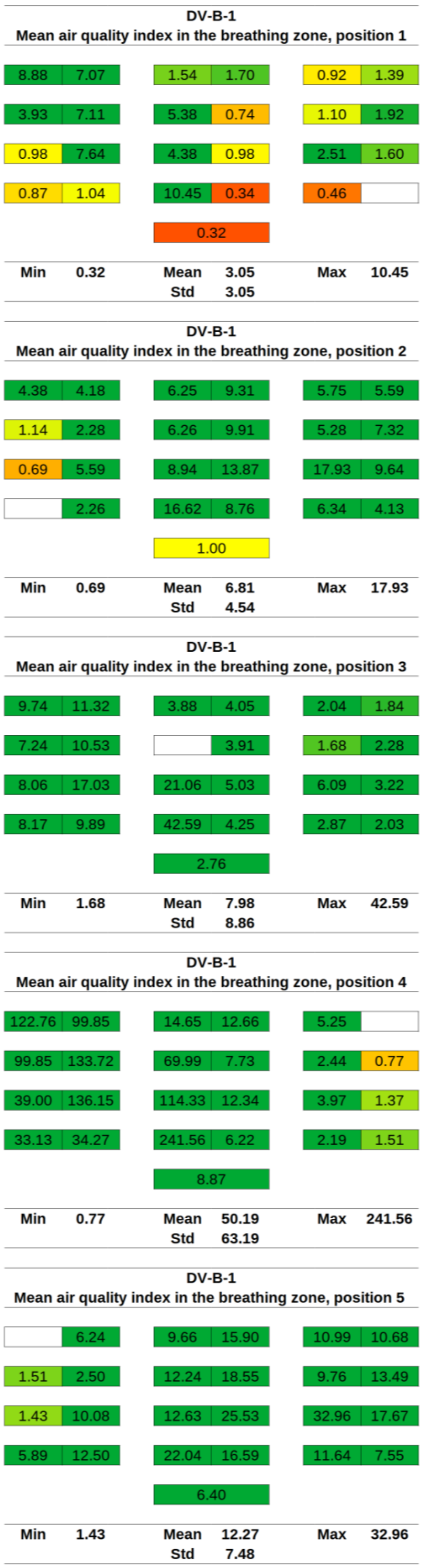



*Figure A13: Mean air quality index in the breathing zone, DV-B-1*

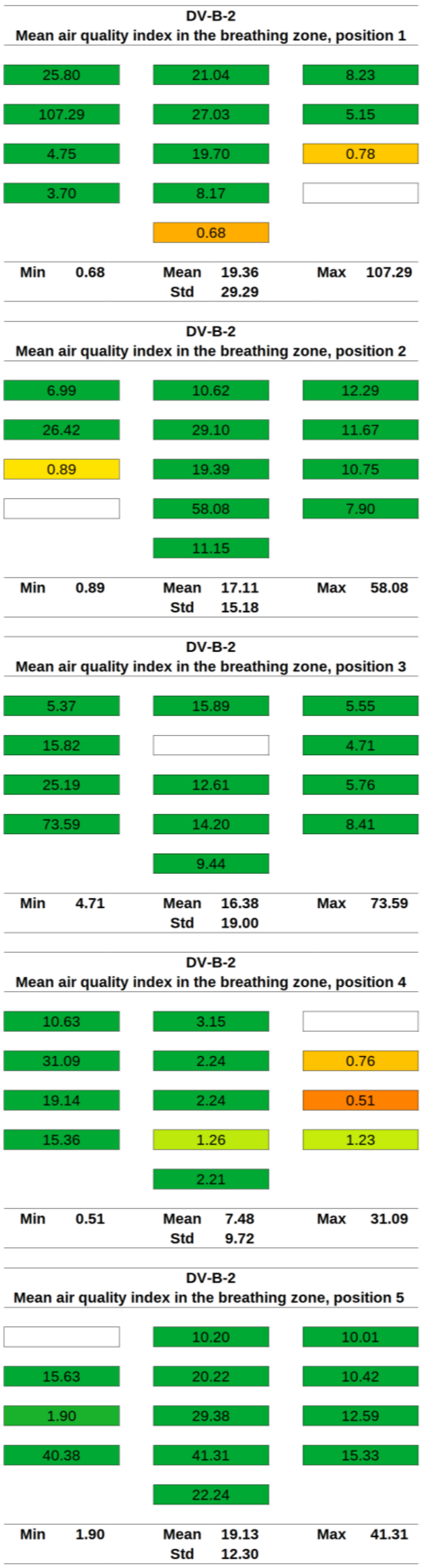



*Figure A14: Mean air quality index in the breathing zone, DV-B-2*