The effect of air purifiers and curtains on aerosol dispersion and removal in multi-patient hospital rooms

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A SENSOR COMPARISONS

The accuracy of low-cost optical PM sensors signal is affected by (i) the omission of particles smaller than minimum detectable size (< 300 nm); (ii) influence of temperature and (iii) Relative Humidity (RH) (Malings et al., 2019). Calibration or collocation alongside scientific grade instruments is needed for the PM sensors and gas-phase sensors (Zimmerman et al., 2018; Malings et al., 2019, 2020). However, we were interested in the spatial differences in concentrations and concentration decay times, thus we require only linearity and consistency between sensors.

A.1 Collocation

A collocation test was conducted prior to Day 3. All 6 RAMP sensors used in this study were placed in an unventilated room (10’x8’x23’) with uniform mixing created by running a BlueAir 411 without the filter in place. The atomizer and solution were the same as used in the hospital room tests. NaCl particles were then introduced diagonally across from the sensors. All sensors picked up the PM10 signal at the same time. The temperature and Relative Humidity (RH) were constant as well. Figure A.1 shows the time-series plots for the collocation test. The difference in magnitude of sensor concentrations should not affect the results presented in this study as we focus on the decay rate (to calculate effective ACH) and transport time. Pearson correlation between sensors is good (Table A.1).

We expect that the true difference in calibration between the sensors is actually less than indicated here, however. In this experiment, the sensors were stacked on a table and there may have been a small gradient away from the surface. This effect is quite evident in the first part of the experiment because the discrepancies are larger and variable.

The aerosol source rate can be estimated from the initial slope of the concentration curves (sensor-averaged) knowing the room volume. Naturally there are large uncertainties in the true mass of the particles (as determined optically), but because the same sensors are used in the hospital experiments, we expect that this source estimate can be used to interpret the hospital measurements.

A.2 Relative humidity variations

The relative humidity in the hospital room was not controlled but only varied a small amount between test days (30-55%) and by much smaller amounts on any given test day (Figure A.2). Data for test days 3 and 4 are not shown here but patterns are similar, with RH 52 to 56%.

A.3 Temperature variations

Temperature of the hospital is controlled at room level through the supply of conditioned air, but there are relatively large temperature variations (Figure A.3). Data for test days 3 and 4 are not shown here but patterns are similar, with T increasing from 19 to 23 °C over the course of the day. Using the correction factors previously published (Malings et al., 2020) and using sample RH (50%) and T (22°C), it is estimated that raw PM$_{2.5}$ measurements of 10 µg m$^{-3}$ and 100 µg m$^{-3}$ correspond to a corrected PM$_{2.5}$ of 9.6 µg m$^{-3}$ and 71.2 µg m$^{-3}$. A different RH (30%) and same T(22°C) would result in similar values: 10 µg m$^{-3}$ (8.57 µg m$^{-3}$) and 100 µg m$^{-3}$ (65.88 µg m$^{-3}$) where values in parenthesis
FIGURE A.1 PM10, Temperature and Relative Humidity during collocation

TABLE A.1 Pearson correlation coefficients during collocation.

|       | PM_1002 | PM_1008 | PM_1010 | PM_1039 | PM_1040 |
|-------|---------|---------|---------|---------|---------|
| PM_1002 | 1       | 1       | 0.99    | 0.99    | 1       |
| PM_1008 | 1       | 1       | 0.99    | 0.99    | 1       |
| PM_1010 | 0.99    | 0.99    | 1       | 0.97    | 0.99    |
| PM_1039 | 0.99    | 0.99    | 0.97    | 1       | 0.99    |
| PM_1040 | 1       | 1       | 0.99    | 0.99    | 1       |

indicate corrected PM$_{2.5}$ concentrations. Fortunately, variations in RH during a given test day were <3 % at most and would therefore not affect the comparisons made later. The Mailings correction is non-linear at low concentrations,
especially when the contributions of sub-300nm particles is important, but this is not likely the case for the NaCl that dominates the concentrations in our experiments. We use the PM10 channel in all that follows.

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** FIGURE A.2** Relative humidity by sensor for test days 1-3.

** FIGURE A.3** Temperature by sensor for test days 1-3.

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**references**

Malings, C., Tanzer, R., Hauryliuk, A., Kumar, S.P.N., Zimmerman, N., Kara, L.B., Presto, A.A., Subramanian, R., 2019. Development of a general calibration model and long-term performance evaluation of low-cost sensors for air pollutant gas monitoring. Atmospheric Measurement Techniques 12, 903-920. URL: https://amt.copernicus.org/articles/12/903/2019/, doi:10.5194/amt-12-903-2019.
Malings, C., Tanzer, R., Hauryliuk, A., Saha, P.K., Robinson, A.L., Presto, A.A., Subramanian, R., 2020. Fine particle mass monitoring with low-cost sensors: Corrections and long-term performance evaluation. Aerosol Science and Technology 54, 160–174. doi:10.1080/02786826.2019.1623863.

Zimmerman, N., Presto, A.A., Kumar, S.P., Gu, J., Hauryliuk, A., Robinson, E.S., Robinson, A.L., Subramanian, R., 2018. A machine learning calibration model using random forests to improve sensor performance for lower-cost air quality monitoring. Atmospheric Measurement Techniques 11, 291–313. doi:10.5194/amt-11-291-2018.
A summary of all experiments is included in Table B.1. The delay time is the average [minutes] time delay between the atomizer being turned on and the concentration reaching 1 microgram per cubic meter. The decay time [tau, minutes] is obtained by fitting an exponential to the latter portion of the experiment, over which all sensors show a consistent decay rate (this can be assessed in the plots in the next section). For the whole-room metric, we have taken the median values rather than the average because in some experiments with long curtains, the north sensor exhibited a very long delay time as a result of never truly exhibiting the log-linear decay. The steady-state concentration (SSsource, µg/m³) is estimated assuming an exponential approach to the steady state value. Similarly, SSaway is for the 4 sensors in the other zones. The coefficient of variation reported here is the standard deviation of the SSaway values divided by the mean value.

The description includes some minor configuration variations that have been grouped into major categories reported in the main manuscript. For example, there was a small window-mounted exhaust fan operated in Experiment 13, off but unsealed in experiments 1-12, 14-19, and sealed from experiments 20-41. There is no detectable impact from this on any of configurations repeated through the 5 days.

### TABLE B.1 Summary of all experiments

| Exp | Description | delay | tau | SSsource | SSaway | Coef_var |
|-----|-------------|-------|-----|---------|--------|----------|
| 1   | Baseline    | 2.76  | 14.42| 387     | 156    | 0.28     |
| 2   | Baseline    | 2.76  | 14.07| 713     | 247    | 0.47     |
| 3   | Two purifiers (Blueair 411 in opposite corners), no curtains | 3.09 | 8.97 | 362 | 80 | 0.21 |
| 4   | Two purifiers (as above) + short curtains | 2.27 | 8.77 | 409 | 174 | 0.71 |
| 5   | 4 corners, no curtains | 2.10 | 4.12 | 457 | 80 | 0.20 |
| 6   | 4 purifiers (as above) + short curtains | 2.93 | 4.17 | 157 | 62 | 0.94 |
| 7   | Baseline, short curtains | 2.40 | 7.95 | 2939 | 145 | 1.11 |
| 8   | 4 corners short curtains | 1.53 | 4.18 | 229 | 86 | 0.38 |
| 9   | 4 corners short curtains, diffusers | 1.54 | 4.12 | 189 | 85 | 0.32 |
| 10  | 4 corners short curtains, diffusers | 2.45 | 3.70 | 222 | 69 | 0.19 |
| 11  | Btw beds--> center, short curtains | 1.39 | 3.35 | 77 | 47 | 1.18 |
| 12  | Btw beds--> wall, short curtains | 2.49 | 4.59 | 256 | 104 | 0.72 |
| 13  | Btw beds--> wall, short curtains, exhaust fan on | 1.83 | 5.13 | 191 | 74 | 0.10 |
| 14  | Exhaust fan only, curtains | 2.24 | 8.00 | 110 | 100 | 1.29 |
| 15  | 4 corners short curtains, diffusers | 2.50 | 3.52 | 332 | 59 | 0.48 |
| 16  | large purifier -- wall, short curtains | 2.85 | 4.34 | 79 | 38 | 1.92 |
| 17  | Atomizer in West, baseline + short curtains | 3.51 | NaN | 235 | 111 | 0.94 |
| 18  | Atomizer in West, curtains, 4 Blueair with diffuser | 3.07 | 3.82 | 199 | 141 | 0.73 |
| 19  | Atomizer in West, Btw beds--> wall, short curtains | 3.62 | 4.81 | 240 | 60 | 1.74 |
| 20  | Btw bed + curtains (exhaust fan sealed hereafter) | 2.80 | 8.34 | 459 | 20 | 2.73 |
| 21  | 4 corners (diffusers, short curtains) | 2.57 | 3.74 | 113 | 24 | 0.47 |
| 22  | Btw bed---> center, short curtains | 1.06 | 3.00 | 22 | 46 | 0.36 |
| 23  | Btw bed---> wall, short curtains | 3.11 | 2.80 | 62 | 33 | 0.99 |
| 24  | 4 corners (diffusers, long curtains) | 2.93 | 3.33 | 276 | 28 | 1.69 |
| 25  | 4 corners long curtains | 1.52 | 3.91 | 51371 | 75 | 0.41 |
| 26  | Btw bed---> wall, long curtains | 3.10 | 3.00 | 26 | 15 | 1.03 |
| 27  | Baseline with long curtains | 3.00 | 8.19 | 207 | 66 | 1.76 |
| 28  | Baseline with no curtains. Long experiments hereafter | 2.62 | 13.67 | 694 | 97 | 0.25 |
| 29  | 4 corners, no curtains | 2.37 | 5.18 | 755 | 50 | 0.14 |
| 30  | 2 HW to center with no curtains | 2.44 | 5.64 | 70 | 59 | 0.05 |
| 31  | Baseline with long curtains | 3.44 | 8.87 | 432 | 76 | 0.11 |
| 32  | 4 Blueair with long curtains | 3.17 | 4.12 | 578 | 49 | 0.21 |
| 33  | Bhw bed---> center, long curtains | 2.96 | 4.88 | 209 | 57 | 0.32 |
| 34  | Baseline, long curtains | 5.17 | 17.24 | 436 | 87 | 0.53 |
| 35  | 4 corners, long curtains | 3.50 | 4.86 | 325 | 53 | 0.19 |
| 36  | Btw bed---> center, long curtains | 2.82 | 5.67 | 186 | 61 | 0.26 |
| 37  | Baseline | 1.97 | 12.56 | 108 | 85 | 0.51 |
| 38  | 4 corners, no curtains | 2.25 | 5.39 | 280 | 61 | 0.13 |
| 39  | Btw bed---> center, no curtains | 1.75 | 6.66 | 104 | 72 | 0.10 |
| 40  | Baseline | 2.29 | 12.03 | 633 | 80 | 0.25 |
| 41  | 4 corners, short curtains | 2.80 | 4.83 | 511 | 57 | 0.09 |
SUMMARY PLOTS FOR ALL EXPERIMENTS

RAMP PM10 measurements are shown in each plot with the symbols. Locations in the legend are described in the main manuscript. To determine the decay time (after the vertical dashed line), exponentials were fit to the data and the resulting fits are shown on the plots (appearing as straight lines on the log-linear plots). The fit was performed for times after 14 minutes for day 1-3 data and after approximately 28 minutes for day 4-5 data.

Also shown are the exponential approaches to steady state determined from the fit to the first portion of each experiment. The large symbols at 1 microgram per cubic meter indicate the “delay time” reported in the manuscript. Numerical data for each experiment is given in SI section B.

**FIGURE C.1** Experiment 1. Day1
FIGURE C.2  Experiment 2. Day 1

FIGURE C.3  Experiment 3. Day 1
FIGURE C.4  Experiment 4. Day 1. Purifiers in corners as Expt. 3. Short curtains.

FIGURE C.5  Experiment 5. Day 1
FIGURE C.6  Experiment 6. Day1 Purifiers in corners; short curtains.

FIGURE C.7  Experiment 7. Day 2 Window exhaust fan not sealed (as in Day 1).
FIGURE C.8  Experiment 8. Day 2

FIGURE C.9  Experiment 9. Day 2 Diffusers (mesh cones at purifier exhaust) had no detectable effect of flow, decay time or delay times.
FIGURE C.10  Experiment 10. Day 2

FIGURE C.11  Experiment 11. Day 2 Two Honeywell tower purifiers exhausting towards room center.
FIGURE C.12  Experiment 12. Day 2 Tower purifiers; exhaust direction reversed compared to Experiment 11.

FIGURE C.13  Experiment 13. Day 2 Identical to Expt. 12 but window-mounted fan on.
FIGURE C.14  Experiment 14. Day 2 No purifiers; short curtains; exhaust fan on.

FIGURE C.15  Experiment 15. Day 2
FIGURE C.16  Experiment 16. Day 2 "Atmosphere" purifier in aisle, centered on SW wall, exhausting towards wall.

FIGURE C.17  Experiment 17. Day 2 Atomizer on West bed, no purifiers; short curtains.
FIGURE C.18  Experiment 18. Day 2 Atomizer on West bed, corner purifiers.

FIGURE C.19  Experiment 19. Day 2
FIGURE C.20   Experiment 20. Day 3 Magenta marker is for a RAMP located at 1.5 m elevation just at the South edge of the East bed. Hereafter, exhaust fan is sealed.

FIGURE C.21   Experiment 21. Day 3
FIGURE C.22  Experiment 22 Day 3

FIGURE C.23  Experiment 23 Day 3
FIGURE C.24  Experiment 24. Day 3

FIGURE C.25  Experiment 25. Day 3
FIGURE C.26  Experiment 26. Day 3

FIGURE C.27  Experiment 27 Day 3
FIGURE C.28  Experiment 28. Day 4 Hereafter, experiments use doubled particle generation duration.

FIGURE C.29  Experiment 29. Day 4 Blue Air 411 purifiers in corner, as usual for this configuration.
FIGURE C.30  Experiment 30. Day 4 HW=Honeywell tower purifier, as for other between-bed tests.

FIGURE C.31  Experiment 31. Day 4
FIGURE C.32  Experiment 32. Day 4

FIGURE C.33  Experiment 33. Day 4
FIGURE C.34  Experiment 34. Day 5

FIGURE C.35  Experiment 35. Day 5
FIGURE C.36 Experiment 36. Day 5

FIGURE C.37 Experiment 37. Day 5
FIGURE C.38  Experiment 38. Day 5

FIGURE C.39  Experiment 39. Day 5
FIGURE C.40  Experiment 40. Day 5

FIGURE C.41  Experiment 41. Day 5