Supplementary Materials: Ultrafine and Fine Particulate Matter inside and outside of Mechanically Ventilated Buildings

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1. Section A: Indoor and Outdoor UHSAS Number Concentration Plots

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3. Section C: Tables of Average and Standard Deviations for Indoor/Outdoor Ratio, Slope, and Correlation Coefficient

**Table S1.** Combined yearlong indoor/outdoor ratio, slope, and correlation coefficient for each building.

| Building Type | Day Type | Time of Day | Ratio Ultrafine | Fine | Slope Ultrafine | Fine |,rp |
|---------------|----------|-------------|----------------|------|----------------|------|-----|
| University    | All      | All         | 0.617          | 0.581| 0.451          | 0.279| 0.806| 0.656|
|               | Weekday  | Day         | 0.621          | 0.588| 0.512          | 0.410| 0.834| 0.809|
|               |          | Night       | 0.678          | 0.615| 0.451          | 0.416| 0.817| 0.768|
|               | Weekend  | Day         | 0.518          | 0.521| 0.260          | 0.073| 0.626| 0.270|
|               |          | Night       | 0.573          | 0.548| 0.474          | 0.332| 0.875| 0.782|
| Denver School | All      | All         | 0.644          | 0.670| 0.457          | 0.413| 0.770| 0.799|
|               | Weekday  | Day         | 0.654          | 0.707| 0.478          | 0.396| 0.892| 0.851|
|               |          | Night       | 0.597          | 0.604| 0.420          | 0.341| 0.834| 0.776|
|               | Weekend  | Day         | 0.757          | 0.763| 0.527          | 0.466| 0.526| 0.772|
|               |          | Night       | 0.565          | 0.572| 0.430          | 0.394| 0.936| 0.925|
| Office        | All      | All         | 0.632          | 0.642| 0.457          | 0.428| 0.903| 0.867|
|               | Weekday  | Day         | 0.548          | 0.579| 0.499          | 0.418| 0.942| 0.918|
|               |          | Night       | 0.678          | 0.686| 0.378          | 0.299| 0.879| 0.854|
|               | Weekend  | Day         | 0.572          | 0.620| 0.570          | 0.744| 0.894| 0.962|
|               |          | Night       | 0.840          | 0.748| 0.359          | 0.413| 0.813| 0.774|
| Boulder School| All      | All         | 0.676          | 0.635| 0.379          | 0.310| 0.818| 0.770|
|               | Weekday  | Day         | 0.583          | 0.569| 0.393          | 0.322| 0.813| 0.798|
|               |          | Night       | 0.738          | 0.638| 0.396          | 0.346| 0.835| 0.842|
|               | Weekend  | Day         | 0.612          | 0.642| 0.222          | 0.189| 0.861| 0.543|
|               |          | Night       | 0.948          | 0.873| 0.264          | 0.211| 0.735| 0.623|

All = All data from that building; Day = 6 am–8 pm; Night = 8 pm–6 am.

**Table S2.** Standard deviations of combined yearlong indoor/outdoor ratio and slope for each season.

| Building Type | Day Type | Time of Day | Ratio Standard Deviation Ultrafine | Fine | Slope Standard Deviation Ultrafine | Fine |
|---------------|----------|-------------|-----------------------------------|------|-----------------------------------|------|
| University    | All      | All         | 0.3502                            | 0.2263| 0.0069                           | 0.0067|
|               | Weekday  | Day         | 0.2972                            | 0.1800| 0.0112                           | 0.0098|
|               |          | Night       | 0.4381                            | 0.2255| 0.0117                           | 0.0127|
|               | Weekend  | Day         | 0.3414                            | 0.3245| 0.0169                           | 0.0135|
|               |          | Night       | 0.1734                            | 0.1773| 0.0162                           | 0.0165|
| Denver School | All      | All         | 0.4091                            | 0.3105| 0.0070                           | 0.0058|
### Table S3. Seasonal indoor/outdoor ratio, slope, and correlation coefficient.

| Season  | Day Type | Time of Day | Ratio | Slope | rp |
|---------|----------|-------------|-------|-------|----|
|         |          |             | Ultrafine | Fine | Ultrafine | Fine |
| Summer  | Weekday  | Day         | 0.549  | 0.575 | 0.625 | 0.663 | 0.892 | 0.848 |
|         |          | Night       | 0.373  | 0.377 | 0.662 | 0.667 | 0.778 | 0.601 |
|         | Weekend  | Day         | 0.609  | 0.528 | 0.596 | 0.640 | 0.826 | 0.678 |
|         |          | Night       | 0.291  | 0.249 | 0.693 | 0.722 | 0.536 | 0.414 |
| Fall    | Weekday  | Day         | 0.495  | 0.411 | 0.621 | 0.616 | 0.912 | 0.874 |
|         |          | Night       | 0.401  | 0.331 | 0.630 | 0.590 | 0.856 | 0.863 |
|         | Weekend  | Day         | 0.564  | 0.472 | 0.767 | 0.713 | 0.537 | 0.772 |
|         |          | Night       | 0.318  | 0.262 | 0.797 | 0.649 | 0.821 | 0.795 |
| Winter  | Weekday  | Day         | 0.406  | 0.308 | 0.539 | 0.526 | 0.906 | 0.892 |
|         |          | Night       | 0.400  | 0.311 | 0.687 | 0.578 | 0.860 | 0.835 |
|         | Weekend  | Day         | 0.278  | 0.178 | 0.534 | 0.550 | 0.850 | 0.722 |
|         |          | Night       | 0.358  | 0.291 | 0.764 | 0.686 | 0.860 | 0.837 |
| Spring  | Weekday  | Day         | 0.534  | 0.405 | 0.619 | 0.650 | 0.904 | 0.871 |
|         |          | Night       | 0.364  | 0.483 | 0.715 | 0.718 | 0.796 | 0.901 |
|         | Weekend  | Day         | 0.670  | 0.447 | 0.625 | 0.700 | 0.927 | 0.687 |
|         |          | Night       | 0.528  | 0.523 | 0.681 | 0.700 | 0.873 | 0.748 |

### Table S4. Standard deviations for seasonal indoor/outdoor ratio and slope.

| Season  | Day Type | Time of Day | Ratio Standard Deviation | Slope Standard Deviation |
|---------|----------|-------------|---------------------------|--------------------------|
|         |          |             | Ultrafine | Fine | Ultrafine | Fine |
| Summer  | Weekday  | Day         | 0.1651   | 0.1302 | 0.0091   | 0.0117 |
|         |          | Night       | 0.3322   | 0.1929 | 0.0117   | 0.0196 |
|         | Weekend  | Day         | 0.1631   | 0.1526 | 0.0207   | 0.0283 |
|         |          | Night       | 0.1982   | 0.1606 | 0.0285   | 0.0349 |
| Fall    | Weekday  | Day         | 0.3144   | 0.2439 | 0.0062   | 0.0064 |
|         |          | Night       | 0.4633   | 0.3238 | 0.0077   | 0.0062 |
|         | Weekend  | Day         | 0.9130   | 0.5492 | 0.0449   | 0.0195 |
|         |          | Night       | 0.8226   | 0.3421 | 0.0131   | 0.0118 |
| Winter  | Weekday  | Day         | 0.2475   | 0.1816 | 0.0063   | 0.0051 |
|         |          | Night       | 0.6382   | 0.2637 | 0.0088   | 0.0075 |
|         | Weekend  | Day         | 0.3192   | 0.3117 | 0.0073   | 0.0073 |

All = All data from that building; Day = 6 am–8 pm; Night = 8 pm–6 am.
Table S5. Indoor/outdoor ratio, slope, and correlation coefficient of entire dataset by period of the week.

| Day Type | Time of Day | Ratio | Slope | $r_p$ |
|----------|-------------|-------|-------|-------|
|          |             | Ultrafine | Fine | Ultrafine | Fine | Ultafine | Fine |
| All      | Day         | 0.643   | 0.635 | 0.442   | 0.374 | 0.854   | 0.800 |
|          | Night       | 0.603   | 0.615 | 0.476   | 0.382 | 0.909   | 0.861 |
| Weekday  | Day         | 0.622   | 0.644 | 0.477   | 0.409 | 0.681   | 0.713 |
|          | Night       | 0.734   | 0.689 | 0.379   | 0.320 | 0.846   | 0.741 |
| Weekend  | Day         | 0.632   | 0.623 | 0.448   | 0.369 | 0.891   | 0.853 |
|          | Night       | 0.668   | 0.662 | 0.424   | 0.382 | 0.753   | 0.720 |
| Weekday  | Day         | 0.609   | 0.624 | 0.477   | 0.391 | 0.856   | 0.795 |
|          | Night       | 0.689   | 0.650 | 0.397   | 0.343 | 0.858   | 0.812 |

Day = 6 am–8 pm; Night = 8 pm–6 am.

Table S6. Standard deviations for entire dataset for indoor/outdoor ratio and slope by periods of the week.

| Day Type | Time of Day | Ratio Standard Deviation | Slope Standard Deviation |
|----------|-------------|--------------------------|--------------------------|
|          |             | Ultrafine | Fine | Ultrafine | Fine | Ultrafine | Fine |
| All      | Day         | 0.4226   | 0.3015 | 0.0026 | 0.0027 |
|          | Night       | 0.2589   | 0.1989 | 0.0034 | 0.0035 |
| Weekday  | Day         | 0.4565   | 0.2631 | 0.0042 | 0.0040 |
|          | Night       | 0.4897   | 0.4270 | 0.0120 | 0.0093 |
| Weekend  | Day         | 0.6045   | 0.4199 | 0.0067 | 0.0082 |
|          | Night       | 0.3594   | 0.2290 | 0.0027 | 0.0026 |
| Weekday  | Day         | 0.5426   | 0.4246 | 0.0066 | 0.0066 |
|          | Night       | 0.3462   | 0.2892 | 0.0037 | 0.0038 |
| Weekend  | Day         | 0.5043   | 0.3169 | 0.0036 | 0.0037 |
|          | Night       | 0.5043   | 0.3169 | 0.0036 | 0.0037 |

All = All data from entire dataset; Day = 6 am–8 pm; Night = 8 pm–6 am.

Table S7. Seasonal indoor/outdoor ratio, slope, and correlation coefficient for University building only, by HVAC usage.

| Season | HVAC Usage | Ratio | Slope | $r_p$ |
|--------|------------|-------|-------|-------|
|        |            | Ultrafine | Fine | Ultrafine | Fine | Ultrafine | Fine |
| Summer | on         | 0.642   | 0.648 | 0.539   | 0.600 | -       | -    |
|        | off        | 0.555   | 0.542 | 0.420   | 0.427 | -       | -    |
| Fall   | on         | 0.478   | 0.440 | 0.238   | 0.205 | -       | -    |
|        | off        | 0.375   | 0.417 | 0.354   | 0.319 | -       | -    |
| Winter | on         | 0.644   | 0.561 | 0.621   | 0.365 | -       | -    |
|        | off        | 0.788   | 0.666 | 0.380   | 0.269 | -       | -    |
| Spring | on         | 0.617   | 0.571 | 0.282   | 0.222 | -       | -    |
|        | off        | 0.616   | 0.570 | 0.382   | 0.193 | -       | -    |
| Total  | on         | 0.610   | 0.581 | 0.514   | 0.364 | 0.837   | 0.788 |

All = All data from entire dataset; Day = 6 am–8 pm; Night = 8 pm–6 am.
Table S8. Standard deviations for indoor/outdoor ratio and slope for University building only, by HVAC usage.

| Season | HVAC Usage | Ratio Standard Deviation | Slope Standard Deviation |
|--------|------------|--------------------------|--------------------------|
|        |            | Ultrafine | Fine | Ultrafine | Fine |
| Summer | on         | 0.183     | 0.128 | 0.012     | 0.0171 |
|        | off        | 0.183     | 0.132 | 0.012     | 0.0207 |
| Fall   | on         | 0.246     | 0.122 | 0.0147    | 0.0129 |
|        | off        | 0.122     | 0.043 | 0.017     | 0.0148 |
| Winter | on         | 0.472     | 0.322 | 0.0125    | 0.0069 |
|        | off        | 0.643     | 0.320 | 0.014     | 0.0134 |
| Spring | on         | 0.410     | 0.236 | 0.0359    | 0.0142 |
|        | off        | 0.334     | 0.297 | 0.0279    | 0.0189 |
| Total  | on         | 0.323     | 0.213 | 0.010     | 0.008 |
|        | off        | 0.410     | 0.245 | 0.010     | 0.009 |

Total = all seasons combined.

4. Section D: Indoor and Outdoor CO₂ Concentration Plots

Figure S31. Summer 2005: University Building, Boulder (week 1, coincides with UHSAS data).

Figure S32. Summer 2005: University Building, Boulder (week 2, coincides with AMS data).
Figure S33. Summer 2005: Denver School (week 1, coincides with AMS).

Figure S34. Summer 2005: Denver School (week 2, coincides with UHSAS).

Figure S35. Summer 2005: Office building, Denver.
Figure S36. Summer 2005: Boulder School.

Figure S37. Fall 2005: University Building, Boulder.

Figure S38. Fall 2005: Denver School.
Figure S39. Fall 2005: Boulder School.

Figure S40. Fall 2005: Office building, Denver.

Figure S41. Winter 2006: University Building, Boulder.
Figure S42. Winter 2006: Denver School.

Figure S43. Winter 2006: Office building, Denver.

Figure S44. Winter 2006: Boulder School.
Figure S45. Spring 2006: University Building, Boulder.

Figure S46. Spring 2006: Denver School.

Figure S47. Spring 2006: Office building, Denver.

Figure S48. Spring 2006: Boulder School.
5. Section E: Tables of Average Lag Times and Standard Deviations

Table S9. Average (SD) lag times for each building.

| Building Type | Day Type | Time of Day | Lag Times, min. | Ultrafine | Fine |
|---------------|----------|-------------|-----------------|-----------|------|
| University    | All      | 63 (63)     | 72 (114)        |           |      |
|               | Weekday  | 9 (6)       | 15 (6)          |           |      |
|               | Night    | 33 (25)     | 30 (37)         |           |      |
|               | Weekend  | 100 (57)    | 56 (43)         |           |      |
|               | Night    | 68 (55)     | 88 (67)         |           |      |
| Denver School | All      | 24 (17)     | 15 (7)          |           |      |
|               | Weekday  | 12 (0)      | 12 (6)          |           |      |
|               | Night    | 69 (130)    | 99 (184)        |           |      |
|               | Weekend  | 21 (20)     | 9 (0)           |           |      |
|               | Night    | 93 (170)    | 138 (236)       |           |      |
| Office        | All      | 30 (7)      | 33 (29)         |           |      |
|               | Weekday  | 15 (6)      | 18 (10)         |           |      |
|               | Night    | 36 (14)     | 21 (34)         |           |      |
|               | Weekend  | 21 (6)      | 33 (6)          |           |      |
|               | Night    | 48 (26)     | 57 (17)         |           |      |
| Boulder School| All      | 56 (42)     | 24 (42)         |           |      |
|               | Weekday  | 8 (7)       | 24 (7)          |           |      |
|               | Night    | 44 (28)     | 32 (37)         |           |      |
|               | Weekend  | 48 (48)     | 44 (48)         |           |      |
|               | Night    | 44 (28)     | 104 (32)        |           |      |

All = All data from that building; Day = 6 a.m.–8 p.m; Night = 8 p.m.–6 a.m.

Table S10. Average (SD) lag times for each season.

| Season   | Day Type | Time of Day | Lag Times, min. | Ultrafine | Fine |
|----------|----------|-------------|-----------------|-----------|------|
|          |          |             |                 |           |      |
| Summer   | All      | 24 (12)     | 44 (35)         |           |      |
|          | Weekday  | 16 (7)      | 16 (7)          |           |      |
|          | Night    | 124 (121)   | 152 (195)       |           |      |
|          | Weekend  | 64 (69)     | 28 (18)         |           |      |
|          | Night    | 152 (171)   | 212 (233)       |           |      |
| Fall     | All      | 39 (18)     | 24 (17)         |           |      |
|          | Weekday  | 9 (6)       | 12 (10)         |           |      |
|          | Night    | 24 (26)     | 21 (42)         |           |      |
|          | Weekend  | 56 (37)     | 40 (39)         |           |      |
|          | Night    | 44 (18)     | 44 (18)         |           |      |
| Winter   | All      | 51 (32)     | 51 (32)         |           |      |
|          | Weekday  | 9 (6)       | 6 (7)           |           |      |
|          | Night    | 39 (27)     | 27 (25)         |           |      |
|          | Weekend  | 12 (17)     | 12 (10)         |           |      |
|          | Night    | 39 (28)     | 30 (29)         |           |      |
| Spring   | All      | 51 (70)     | 75 (118)        |           |      |
|          | Weekday  | 12 (0)      | 12 (0)          |           |      |
|          | Night    | 15 (6)      | 27 (30)         |           |      |
|          | Weekend  | 51 (48)     | 36 (49)         |           |      |
|          | Night    | 39 (62)     | 42 (69)         |           |      |

All = All data from that season; Day = 6 am–8 pm; Night = 8 pm–6 am.

Table S11. Average (SD) lag times for period of the week.
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Table S12. Seasonal Average (SD) lag times for university building only, by HVAC usage.

| Season | HVAC Usage | Ultrafine | Fine |
|--------|------------|-----------|------|
| Summer on | 12 | 12 |
| Summer off | 48 | 60 |
| Fall on | 24 | 12 |
| Fall off | 0 | 0 |
| Winter on | 12 | 24 |
| Winter off | 48 | 36 |
| Spring on | 12 | 0 |
| Spring off | 156 | 240 |
| Total on | 15 (5) | 12 (8) |
| Total off | 63 (57) | 84 (93) |

Standard deviations in parenthesis, where applicable; Total = all seasons combined.

6. Section F: Outdoor Hour-Averaged AMS Chemical Data Plots

Figure S49. Summer 2005: Denver School.
Figure S50. Summer 2005: University Building, Boulder.

Figure S51. Fall 2005: Denver School.

Figure S52. Fall 2005: University Building, Boulder.
Figure S53. Winter 2006: Denver School.

Figure S54. Winter 2006: University Building, Boulder.

Figure S55. Spring 2006: Denver School.
Figure S56. Spring 2006: University Building, Boulder.