SUPPORTING INFORMATION

Increased Indoor Exposure to Commonly Used Disinfectants
during the COVID-19 Pandemic

Guomao Zheng,1 Gabriel M. Filippelli2,3, Amina Salamova1*

1 Paul H. O’Neill School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana 47405
2 Center for Urban Health, Indiana University-Purdue University Indianapolis (IUPUI), Indianapolis, Indiana 46202
3 Environmental Resilience Institute, Indiana University, Bloomington, Indiana 47405

*Corresponding author:
Amina Salamova
702 N Walnut Grove Ave., Bloomington, IN 47405
Email: asalamov@indiana.edu

Number of pages: 14
Number of Figures: 4
Number of Tables: 6
**Chemicals and reagents.** Nineteen native standards, including benzyldimethylhexylammonium chloride (C6-BAC), benzyldimethyloctylammonium chloride (C8-BAC), benzyldimethyldecylammonium chloride (C10-BAC), benzyldimethyldecylammonium chloride (C12-BAC), benzyldimethyltetradecylammonium chloride (C14-BAC), benzyldimethylhexadecylammonium chloride (C16-BAC), stearyldimethylbenzylammonium chloride (C18-BAC), dioctyldimethylammonium bromide (C8-DDAC), didecyldimethylammonium bromide (C10-DDAC), dodecyldimethylammonium bromide (C12-DDAC), dimethylditetradecylammonium bromide (C14-DDAC), didecyltrimethylammonium bromide (C16-DDAC), hexadecyltrimethylammonium bromide (C18-DDAC), octyltrimethylammonium chloride (C8-ATMAC), decyltrimethylammonium bromide (C10-ATMAC), dodecyltrimethylammonium chloride (C12-ATMAC), tetradecyltrimethylammonium chloride (C14-ATMAC), hexadecyltrimethylammonium chloride (C16-ATMAC), and octadecyltrimethylammonium chloride (C18-ATMAC) were purchased from Sigma-Aldrich (St. Louis, MO, USA). Two labeled standards, including benzyltrimethylammonium-d$_7$ chloride (d$_7$-C12-BAC) and benzyltrimethyltetradecylammonium-d$_7$ chloride (d$_7$-C14-BAC) were obtained from Toronto Research Chemicals (Toronto, ON, Canada). All solvents and chemicals used in this study were HPLC grade or higher.

**Instrumental analysis.** An ultra-performance liquid chromatograph coupled to a triple-quadrupole mass spectrometer (Agilent 1290 Infinity II UPLC – 6470 QQQ-MS) in the positive electrospray ionization (ESI+) mode was used for the analysis. The UPLC separation was carried out using an Acquity UPLC BEH C$_{18}$ column (50 mm, 2.1 mm i.d., 1.7 μm thickness, Waters, Milford, MA) heated to 30 °C. The mobile phase consisted of 0.1% formic acid in water ($A$) and 0.1% formic acid in acetonitrile ($B$). The gradient was as follows: 10% $B$ for 0.5 min initially, then increased to 100% $B$ at 6 min and held for 4 min, returned to 10% $B$ at 10.5 min and equilibrated
for 3.5 min after every run. The injection volume and flow rate were 5 μL and 0.4 mL/min, respectively. The nebulizer, gas flow, gas temperature, capillary voltage, sheath gas temperature, and sheath gas flow were set to be 25 psi, 10 L/min, 300 °C, 3500 V, 350 °C, and 12 L/min, respectively. A multiple reaction monitoring (MRM) mode was used for data acquisition. The optimized MRM transitions, fragmentors, and collision energies are presented in Table S4. The representative chromatograms of samples and standards are shown in Figure S4.

Quality assurance and quality control. Six procedural blanks and six spiked samples prepared with Ottawa sand (muffled at 400 °C for 4 hours) were extracted together with the dust samples. The spiked amount was 50 ng for each analyte and the average absolute recoveries for the spiked samples (mean ± standard error) were 113 ± 5, 117 ± 3, 110 ± 4% for BACs, DDACs, and ATMACs (see Table S5 for each analyte’s recovery). The recovery of the surrogate standard d7-C12-BAC was 118 ± 4%. The recoveries above 100% may be related to matrix interferences, but are all within the accepted limits.1 Blanks constituted less than 0.1% of the sample levels. Method detection limits (MDLs) were set at three times the standard deviation of the target analyte levels detected in blanks. For compounds not detected in blanks, MDLs were based on a signal-to-noise ratio of three. Blank levels and method detection limits for each QAC are included in Table S6. All data were blank-corrected by subtracting blank levels from sample levels.

Exposure assessment. Estimated daily intakes (EDIs, ng/kg body weight [bw]/day via dust ingestion were calculated using Equation 1:

\[
\text{EDI} = \frac{(C_{\text{dust}} \times I_{\text{rate}}) \times T}{bw} \tag{1}
\]

where \(C_{\text{dust}}\) is the concentration of a chemical in dust (ng/g), \(I_{\text{rate}}\) is the ingestion rate (0.06 and 0.03 g/day for toddlers and adults, respectively),\(^2\) \(T\) is the time spent at home (assumed to be 1 day),\(^3\) and \(bw\) is the mean body weight (12 and 70 kg for toddlers and adults, respectively).\(^3\)
Data Analysis. Pearson coefficients were used to examine the correlations of logarithmically transformed QAC concentrations in dust, and a Mann-Whitney test was used for comparative statistics. The significance level was set at $p < 0.05$. 
**Table S1.** Pearson correlation coefficients for correlations among QAC concentrations in dust collected during the pandemic ($n = 40$).

|          | C6-BAC | C8-BAC | C10-BAC | C12-BAC | C14-BAC | C16-BAC | C18-BAC | C8-DDAC | C10-DDAC | C12-DDAC | C14-DDAC | C16-DDAC | C18-ATMAC | C10-ATMAC | C12-ATMAC | C14-ATMAC | C16-ATMAC | C18-ATMAC |
|----------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| C6-BAC   | 1.000  | .728** | .811**  | .669**  | .646**  | .755**  | .664**  | .404**  | .581**  | .530**  | .445**  | .431**  | .730**  | .600**  | .790**  | .386    | .039**  | .527**  | .654**  |
| C8-BAC   | 1.000  | .710** | .621**  | .583**  | .634**  | .512**  | .396**  | .208**  | .357**  | .299**  | .288**  | .549**  | .470**  | .575**  | .369**  | .413**  | .381**  | .505**  |
| C10-BAC  | 1.000  | .829** | .800**  | .854**  | .805**  | .570**  | .651**  | .323**  | .711**  | .593**  | .757**  | .391**  | .545**  | .493**  | .658**  |
| C12-BAC  | 1.000  | .941** | .866**  | .850**  | .727**  | .701**  | .642**  | .462**  | .275**  | .756**  | .629**  | .663**  | .579**  | .632**  | .603**  | .563**  |
| C14-BAC  | 1.000  | .921** | .801**  | .722**  | .710**  | .625**  | .398**  | .210**  | .719**  | .631**  | .658**  | .605**  | .613**  | .575**  | .591**  |
| C16-BAC  | 1.000  | .752** | .664**  | .764**  | .682**  | .412**  | .263**  | .706**  | .632**  | .680**  | .561**  | .542**  | .568**  | .771**  |
| C18-BAC  | 1.000  | .630** | .685**  | .573**  | .317**  | .176**  | .893**  | .805**  | .711**  | .443**  | .461**  | .454**  | .519**  |
| C8-DDAC  | 1.000  | .667** | .612**  | .398**  | .230**  | .796**  | .874**  | .457**  | .548**  | .612**  | .491**  | .493**  |
| C10-DDAC | 1.000  | .907** | .554**  | .418**  | .608**  | .580**  | .492**  | .625**  | .522**  | .702**  | .576**  |
| C12-DDAC | 1.000  | .686** | .533**  | .547**  | .517**  | .423**  | .611**  | .567**  | .697**  | .583**  |
| C14-DDAC | 1.000  | .814** | .371**  | .320**  | .217**  | .485**  | .512**  | .782**  | .361**  |
| C16-DDAC | 1.000  | .313** | .276**  | .175**  | .323**  | .367**  | .711**  | .184**  |
| C18-DDAC | 1.000  | .903** | .770**  | .396**  | .443**  | .505**  | .548**  |
| C8-ATMAC | 1.000  | .629** | .431**  | .421**  | .421**  | .516**  |
| C10-ATMAC| 1.000  | .364** | .270**  | .332**  | .633**  |
| C12-ATMAC| 1.000  | .664** | .628**  | .425**  |
| C14-ATMAC| 1.000  | .626** | .384**  |
| C16-ATMAC| 1.000  | .322** |
| C18-ATMAC| 1.000  |

* represents significance at $p < 0.05$; ** represents significance at $p < 0.01$. 

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Table S2. Concentrations in cleaning products commonly used in participants’ homes (mg/L). MDL: method detection limit.

|       | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 | Product 6 | Product 7 |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| **BACs** |           |           |           |           |           |           |           |
| C6-BAC | 283       | 0.0446    | 0.0171    | 0.0116    | <MDL      | 0.0179    | <MDL      |
| C8-BAC | 206       | 1.86      | 0.018     | 0.0146    | 0.0123    | 0.0039    | <MDL      |
| C10-BAC| 384       | 0.0513    | 0.0052    | 0.0037    | <MDL      | <MDL      | <MDL      |
| C12-BAC| 6240      | 208       | 16.7      | <MDL      | <MDL      | <MDL      | <MDL      |
| C14-BAC| 4240      | 567       | 76.7      | 0.77      | <MDL      | <MDL      | 0.208     |
| C16-BAC| 2480      | 425       | 49        | 0.138     | <MDL      | <MDL      | <MDL      |
| C18-BAC| 60.9      | 141       | 10.2      | 0.327     | <MDL      | <MDL      | 0.0352    |
| **∑BAC** | 13800    | 1340      | 153       | 1.27      | 0.016     | 0.0218    | 0.243     |
| **DDACs** |           |           |           |           |           |           |           |
| C8-DDAC| 255       | <MDL      | <MDL      | <MDL      | <MDL      | <MDL      | <MDL      |
| C10-DDAC| 400      | 1.20      | 0.924     | 0.704     | 0.446     | 0.524     | 0.476     |
| C12-DDAC| 249      | 0.597     | 0.319     | 0.261     | 0.103     | 0.242     | 0.206     |
| C14-DDAC| 207      | <MDL      | <MDL      | 0.0156    | <MDL      | <MDL      | <MDL      |
| C16-DDAC| 164      | <MDL      | <MDL      | <MDL      | <MDL      | <MDL      | <MDL      |
| C18-DDAC| 170      | 1.16      | 0.211     | 0.259     | 0.172     | 0.125     | 0.127     |
| **∑DDAC** | 1440    | 2.96      | 1.45      | 1.24      | 0.721     | 0.891     | 0.809     |
| **ATMACs** |           |           |           |           |           |           |           |
| C8-ATMAC| 271       | <MDL      | 0.126     | 0.33      | <MDL      | 0.22      | <MDL      |
| C10-ATMAC| 221     | <MDL      | <MDL      | <MDL      | <MDL      | <MDL      | <MDL      |
| C12-ATMAC| 359      | <MDL      | <MDL      | <MDL      | <MDL      | <MDL      | <MDL      |
| C14-ATMAC| 71.5     | 4.35      | 1.93      | 1.75      | 3.01      | 1.79      | 1.44      |
| C16-ATMAC| 146      | 0.228     | 0.0494    | 0.446     | 0.292     | 0.0252    | 0.0284    |
| C18-ATMAC| 246      | 0.103     | <MDL      | 0.563     | <MDL      | <MDL      | <MDL      |
| **∑ATMAC** | 1310    | 4.68      | 2.11      | 3.09      | 3.31      | 2.04      | 1.47      |
| **∑QAC**   | 16600    | 1350      | 156       | 5.6       | 4.04      | 2.95      | 2.52      |
Table S3. Median QAC concentrations (μg/g) in dust samples collected from Indiana homes with increased \((n = 29)\) and not changed \((n = 11)\) disinfection frequencies, and more frequent \((1-5 \text{ per week}, n = 27)\) and less frequent \(< 1 \text{ per week}, n = 13\) disinfecting during the COVID-19 pandemic. Contributions \((\text{contr.}, \%)\) of each QAC to the \(\Sigma\) QAC concentrations are also included.

| BACs   | Increased Median | Contr | Not changed Median | Contr | More disinfecting Median | Contr | Less disinfecting Median | Contr |
|--------|------------------|-------|-------------------|-------|-------------------------|-------|-------------------------|-------|
| C6-BAC | 0.00422          | 0.01  | 0.00161           | 0.01  | 0.00432                 | 0.01  | 0.00229                 | 0.01  |
| C8-BAC | 0.0843           | 0.2   | 0.0256            | 0.2   | 0.106                   | 0.2   | 0.0352                  | 0.1   |
| C10-BAC| 0.0708           | 0.1   | 0.0234            | 0.2   | 0.0699                  | 0.1   | 0.0234                  | 0.1   |
| C12-BAC| 15.0             | 27    | 6.10              | 40    | 16.6                    | 28    | 9.10                    | 32    |
| C14-BAC| 12.4             | 23    | 2.38              | 16    | 14.2                    | 24    | 3.46                    | 12    |
| C16-BAC| 4.23             | 7.7   | 0.827             | 5.5   | 4.79                    | 8.1   | 1.1                     | 3.9   |
| C18-BAC| 1.28             | 2.3   | 0.233             | 1.6   | 1.44                    | 2.5   | 0.612                   | 2.2   |
| ΣBAC   | 37.5             | 59    | 11.4              | 55    | 39.9                    | 63    | 14.3                    | 51    |

| DDACs  |                  |       |                   |       |                         |       |                         |       |
|--------|------------------|-------|-------------------|-------|-------------------------|-------|-------------------------|-------|
| C8-DDAC| 2.18             | 4.0   | 0.420             | 2.8   | 1.69                    | 2.9   | 1.13                    | 4.0   |
| C10-DDAC| 5.96            | 11    | 0.956             | 6.3   | 6.89                    | 12    | 3.71                    | 13    |
| C12-DDAC| 0.0796          | 0.2   | 0.0178            | 0.1   | 0.0828                  | 0.1   | 0.0315                  | 0.1   |
| C14-DDAC| 0.0249          | 0.1   | 0.00718           | 0.1   | 0.0269                  | 0.0   | 0.0101                  | 0.0   |
| C16-DDAC| 0.494           | 0.9   | 0.143             | 1.0   | 0.435                   | 0.7   | 0.148                   | 0.5   |
| C18-DDAC| 3.48            | 6.3   | 1.45              | 9.6   | 3.54                    | 6.0   | 2.00                    | 7.1   |
| ΣDDAC  | 13.6             | 22    | 6.27              | 30    | 13.3                    | 21    | 7.22                    | 26    |

| ATMACs |                  |       |                   |       |                         |       |                         |       |
|--------|------------------|-------|-------------------|-------|-------------------------|-------|-------------------------|-------|
| C8-ATMAC| 0.0576          | 0.1   | 0.0233            | 0.2   | 0.0465                  | 0.1   | 0.0563                  | 0.2   |
| C10-ATMAC| 0.312           | 0.6   | 0.0844            | 0.6   | 0.312                   | 0.5   | 0.199                   | 0.7   |
| C12-ATMAC| 1.40            | 2.6   | 0.693             | 4.6   | 1.59                    | 2.7   | 0.752                   | 2.7   |
| C14-ATMAC| 0.382           | 0.7   | 0.0972            | 0.7   | 0.375                   | 0.6   | 0.184                   | 0.7   |
| C16-ATMAC| 6.30            | 11    | 1.32              | 8.8   | 5.50                    | 9.3   | 5.17                    | 18    |
| C18-ATMAC| 1.32            | 2.4   | 0.271             | 1.8   | 1.26                    | 2.1   | 0.517                   | 1.8   |
| ΣATMAC  | 12.1             | 19    | 3.15              | 15    | 10.1                    | 16    | 6.33                    | 23    |
| ΣQAC    | 65.2             | 100   | 21.7              | 100   | 64.6                    | 100   | 28.0                    | 100   |
Table S4. The optimized MRM transitions, fragmentors, and collision energies for target analytes.

| Compound                                   | Abbreviation | Retention time (min) | Precursor ion [M-Cl/Br]+ | Fragmentor (volts) | Product ions (m/z) | Collision energy (volts) |
|--------------------------------------------|--------------|----------------------|--------------------------|--------------------|--------------------|--------------------------|
| Benzyldimethylhexylammonium chloride       | C6-BAC       | 2.82                 | 220.2                    | 88                 | 128.1              | 17                       |
| Benzyldimethyloctylammonium chloride       | C8-BAC       | 3.53                 | 248.2                    | 103                | 91                 | 29                       |
| Benzyldimethyldecylammonium chloride       | C10-BAC      | 4.12                 | 276.3                    | 103                | 91.1               | 33                       |
| Benzyldimethylldodecylammonium chloride    | C12-BAC      | 4.65                 | 304.3                    | 113                | 91                 | 41                       |
| Benzyldimethyltetradecylammonium chloride  | C14-BAC      | 5.13                 | 332.3                    | 122                | 91.1               | 41                       |
| Benzyldimethylhexadecylammonium chloride   | C16-BAC      | 5.53                 | 360.4                    | 146                | 91.1               | 41                       |
| Searyldimethylbenzylammonium chloride      | C18-BAC      | 5.85                 | 388.39                   | 127                | 296.3              | 29                       |
| Dioctyldimethylammonium bromide            | C8-DDAC      | 4.46                 | 270.3                    | 156                | 158.2              | 29                       |
| Didecyldimethylammonium bromide            | C10-DDAC     | 5.31                 | 326.4                    | 151                | 186                | 33                       |
| Didodecyldimethylammonium bromide          | C12-DDAC     | 5.93                 | 382.4                    | 181                | 214                | 37                       |
| Dimethyllditetradecylammonium bromide       | C14-DDAC     | 6.35                 | 438.5                    | 151                | 242                | 41                       |
| Dihexadecyldimethylammonium bromide        | C16-DDAC     | 6.63                 | 494.6                    | 151                | 270                | 49                       |
| Dimethyldioctadecylammonium bromide        | C18-DDAC     | 7.08                 | 550.6                    | 175                | 298                | 53                       |
| Octyltrimethylammonium chloride             | C8-ATMAC     | 2.73                 | 172.2                    | 132                | 85.1               | 21                       |
| Decyltrimethylammonium chloride             | C10-ATMAC    | 3.48                 | 200.2                    | 127                | 85.1               | 21                       |
| Dodecyldimethylammonium chloride            | C12-ATMAC    | 4.09                 | 228.3                    | 137                | 85.1               | 21                       |
| Tetradecyltrimethylammonium chloride        | C14-ATMAC    | 4.67                 | 256.3                    | 142                | 85.1               | 29                       |
| Hexadecyltrimethylammonium chloride         | C16-ATMAC    | 5.18                 | 284.3                    | 132                | 85.1               | 29                       |
| Octadecyldimethylammonium chloride          | C18-ATMAC    | 5.61                 | 312.4                    | 142                | 85.1               | 33                       |
| Benzyldimethylldodecylammonium-d7 chloride  | d7-C12-BAC   | 4.63                 | 311.34                   | 122                | 91.1               | 37                       |
| (Surrogate standard)                        |              |                      |                          |                    |                    |                          |
| (Benzyld7)dimethyltetradecylammonium chloride | d7-C14-BAC | 5.11                 | 339.38                   | 127                | 98.1               | 41                       |
|                                              |              |                      |                          |                    |                    |                          |
Table S5. Matrix spike recoveries of target analytes (%).

| Compounds  | Mean | Standard error |
|------------|------|----------------|
| C6-BAC     | 91   | 4.3            |
| C8-BAC     | 68   | 2.2            |
| C10-BAC    | 93   | 3.0            |
| C12-BAC    | 155  | 5.5            |
| C14-BAC    | 99   | 3.2            |
| C16-BAC    | 130  | 4.0            |
| C18-BAC    | 152  | 3.6            |
| C8-DDAC    | 90   | 2.8            |
| C10-DDAC   | 119  | 3.6            |
| C12-DDAC   | 112  | 5.0            |
| C14-DDAC   | 147  | 3.7            |
| C16-DDAC   | 120  | 3.8            |
| C18-DDAC   | 116  | 3.1            |
| C8-ATMAC   | 91   | 7.2            |
| C10-ATMAC  | 72   | 2.2            |
| C12-ATMAC  | 118  | 3.6            |
| C14-ATMAC  | 148  | 4.6            |
| C16-ATMAC  | 113  | 3.5            |
| C18-ATMAC  | 117  | 3.2            |
Table S6. Average blank levels and method detection limits (MDL), μg/g.

| QACs    | Blanks | MDL  |
|---------|--------|------|
| C6-BAC  | 0.0003 | 0.0003 |
| C8-BAC  | 0.0003 | 0.0001 |
| C10-BAC | 0.0001 | 0.0000 |
| C12-BAC | 0.0305 | 0.0025 |
| C14-BAC | 0.0046 | 0.0008 |
| C16-BAC | 0.0067 | 0.0006 |
| C18-BAC | 0.0006 | 0.0002 |
| C8-DDAC | 0.0004 | 0.0005 |
| C10-DDAC| 0.0131 | 0.0018 |
| C12-DDAC| 0.0039 | 0.0005 |
| C14-DDAC| 0.0004 | 0.0002 |
| C16-DDAC| 0.0007 | 0.0005 |
| C18-DDAC| 0.0040 | 0.0005 |
| C8-ATMAC| 0.0009 | 0.0015 |
| C10-ATMAC| 0.0001 | 0.0001 |
| C12-ATMAC| 0.0023 | 0.0017 |
| C14-ATMAC| 0.0156 | 0.0022 |
| C16-ATMAC| 0.0012 | 0.0009 |
| C18-ATMAC| 0.0005 | 0.0003 |
Figure S1. Chemical structures of the three main QAC groups.

Figure S2. QAC profiles in cleaning products commonly used in participants’ homes during the pandemic.
Figure S3. The results of the regression between the disinfecting frequency in homes sampled during the pandemic and the average total QAC dust concentrations (only QACs for which concentrations have significantly increased during the pandemic were included, see Table 1 in the main manuscript).
Figure S4. The representative chromatograms of the authentic standard (A, 5ppb) and samples (B).
References

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