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

Guomao Zheng,1 Gabriel 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

Abstract

Staying safe during the COVID-19 pandemic requires frequent disinfecting of the indoor environment. Quaternary ammonium compounds (QACs or “quats”) are the major class of chemicals widely used as disinfectants in consumer products. While disinfection is necessary for a safe environment during the pandemic, the increased use of QACs is concerning as exposure to these compounds has been associated with adverse effects on reproductive and respiratory systems. We have determined the occurrence and distribution of 19 QACs in 46 residential dust collected before and during the outbreak of COVID-19. All QACs were detected in more than 90% of the samples at concentrations ranging from 1.95 to 531 μg/g (median 58.9 μg/g). Higher QAC concentrations were found in dust collected before the COVID-19 pandemic and in homes with higher disinfecting frequencies (p < 0.05). In addition, 7 products most frequently used in these homes were analyzed, and QACs were detected at concentrations reaching up to 16,600 mg/L. The QAC profiles in dust and in products were similar, suggesting that these products can be a significant source of QACs. Our findings indicate that the indoor exposure to QACs is widespread, raising concerns about increased exposure to these chemicals during the ongoing pandemic.
INTRODUCTION

The spread of the SARS coronavirus 2, which causes the disease COVID-19, has spurred a surge in the use of disinfectants to keep household environment safe.\(^1\) Intensified cleaning protocols during the COVID-19 pandemic specifically call for the increased use of disinfectants in homes and high-risk public spaces, such as schools, health and other care facilities, food service and work spaces.

Disinfecting products containing quaternary ammonium compounds (QACs), also referred to as “quats”, are recommended by the United States Centers for Disease Control and Prevention (CDC) and Environmental Protection Agency (EPA) for disinfecting procedures specifically targeting the SARS coronavirus 2.\(^2\) QACs are the major class of disinfectants and antimicrobials used in cleaning products, biocides, personal care products, and biomedical materials.\(^3,4\) QACs are salts of quaternary ammonium cations with at least one long hydrophobic chlorinated or
brominated hydrocarbon chain substituent and other short-chain substituents, such as methyl or benzyl groups. These compounds are able to enrich the adipose cell membranes of living organisms and thus disrupt the viral envelope and cell membrane and remove organic material. It is this property in particular that enables QACs to act as disinfectants and antimicrobials. The three most widely used QACs include benzylalkyldimethyl ammonium compounds (BACs, with C6-C18 alkylated chains), dialkyldimethyl ammonium compounds (DDACs, with C8-C18 alkylated chains), and alkyltrimethyl ammonium compounds (ATMACs, with C8-C18 alkylated chains) (Figure 1). The C12-, C14-, and C16-BACs, and C10- and C18-DDACs are high production volume chemicals in the United States.

Animal and human studies show that exposure to QACs is linked with reproductive and neurodevelopmental toxicity, as well as with a significant increase in asthma triggers and other breathing problems. In addition, QACs increase the permeability of outer membranes of living organisms and their long-term use may disrupt the protective lipid membranes of the skin and potentially increase the absorption of toxic substances. Hence, the increased use of household disinfectants and other cleaning agents containing QACs during the COVID-19 pandemic is of significant concern.

QACs have been detected in wastewater sludge, surface waters, and soil. A few studies have reported high levels of QACs in fruits, food additives, milk, and other dairy products. However, their occurrence in the indoor environment has not been investigated. Household dust has long been recognized as a reservoir and a major human exposure pathway for many environmental contaminants, especially for children. Due to their low volatility, QACs are easily attached to solid airborne particles and absorbed to dust, where they are unlikely to degrade. This leads to long-term contamination of the indoor environment, which is likely to last
long after the pandemic.\textsuperscript{18} Therefore, a better understanding of the increased exposure to QACs during and after the COVID-19 pandemic is essential in order to assess its potential effects on human health.

This is the first study to investigate the occurrence and distribution of 19 QACs in residential dust collected before and during the outbreak of COVID-19 in the United States; to evaluate the effect of disinfecting procedures on QAC levels in dust; and to assess daily intakes of QACs in the indoor environment.

**MATERIALS AND METHODS**

*Sample collection and analysis.* Forty-six house dust samples were collected from homes in Indiana, United States. Six of them were obtained during 2018-2019 (before the outbreak of the COVID-19 pandemic) as part of a citizen-science program (MapMyEnvironment.com). The rest of the samples were collected during June 2020 (during the COVID-19 crisis in the United States). Dust from vacuum containers and bags was transferred by the homeowner to resealable bags, delivered or shipped to the laboratory, and stored at room temperature until analysis. In addition, information on the frequency of cleaning or disinfecting and commonly used products in sampled homes was collected. Cleaning products (sprays and wipes) listed by participants were purchased from local markets for analysis.

All dust samples were sieved, and approximately 100 mg of dust was transferred to a glass tube, spiked with a surrogate standard (d\textsubscript{7}-C\textsubscript{12}-BAC), sonicated in 4 mL of acetonitrile for 1 hour, and centrifuged at 3000 rpm for 5 min. The supernatant was transferred into a clean tube and the residues were re-extracted with 4 mL of acetonitrile twice. The combined extracts were concentrated to 1 mL using nitrogen gas and spiked with an internal standard (d\textsubscript{7}-C\textsubscript{14}-BAC) used
for quantification of the target analytes. Ten μL of a cleaning product was diluted with 9.99 mL acetonitrile, and then 1 mL of the diluted solution was spiked with an internal standard (d7-C14-BAC). 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 of 19 QACs. The complete analyte list and details of the instrumental analysis and quality control and assurance measures are provided in the Supporting Information.

Data analysis. Detailed information on estimated daily intake (EDI) calculations is provided in the Supporting Information. Pearson coefficients were used to examine the correlations of logarithmically transformed QAC concentrations in dust, and analyses of variance (ANOVA) were used for comparative statistics. The significance level was set at \( p < 0.05 \).

RESULTS AND DISCUSSIONS

Concentrations in dust. Each of the 19 QACs analyzed in these samples was detected in > 90% of the samples at μg/g concentration levels (Table 1). The total QAC concentration (\( \Sigma \text{QAC} \), the sum of 19 QACs) ranged from 1.95 to 531 μg/g (median 58.9 μg/g). BACs were the major group of QACs found in dust at a median \( \Sigma \text{BAC} \) concentration (the sum of 7 BACs) of 27.1 μg/g, followed by \( \Sigma \text{DDAC} \) (median 12.3 μg/g; the sum of 6 DDACs), and \( \Sigma \text{ATMAC} \) (median 8.78 μg/g; the sum of 6 ATMACs), accounting for 56, 26, and 18% of the \( \Sigma \text{QAC} \) concentrations, respectively. C12- and C14-BACs were the most abundant QACs, and contributed 29% and 22% to the \( \Sigma \text{QAC} \) concentrations, respectively. Among the DDACs and the ATMACs, C10- and C18-DDACs and C16-ATMAC were the most abundant, respectively, and contributed 7.9-11% to the \( \Sigma \text{QAC} \) concentrations. Overall, these 5 compounds comprised about 80% of the \( \Sigma \text{QAC} \) concentrations.
This high proportion is likely related to high production volumes and to the wide application of these individual QACs. Moreover, these concentrations were significantly higher than those in dust collected from Indiana homes before the COVID-19 crisis (median 35.9 ng/g, \( p < 0.05 \); Figure 2A and Table S5). Significant correlations were found among QAC concentrations (Table S3), suggesting common sources for these compounds.

These results indicate humans can be exposed to high concentrations of QACs in the indoor environment. When compared with the levels of other environmental contaminants reported in dust from the United States, the median QAC concentration in this study was about 3 times higher than that for organophosphate esters (16.8 μg/g)\(^6\) and about 1,000 times higher than that for per- and polyfluoroalkyl substances (84.5 ng/g).\(^7\) On the other hand, these QAC levels were about 6 times lower than that for phthalates (median 396 μg/g).\(^8\) Incidentally, QACs have been detected in the ambient environment, although at lower levels; for example, they are present in urban estuarine sediment from New York, United States (median 29 μg/g)\(^9\) and in surface sediment from the Great Lakes (2.4 to 4.9 μg/g).\(^10\)

**Concentrations in cleaning products.** Table S4 shows the QAC concentrations in 7 cleaning and disinfecting products indicated as commonly used in the homes that were sampled. All three QAC groups were detected in the analyzed products, but at widely varied concentrations. Products 1 and 2 had the highest \( \sum \)QAC levels, reaching 16,600 and 1350 mg/L and accounting for 1.66% and 0.135% by weight, respectively. These concentrations were 10-1000 times higher than those in the rest of the products (2.52-156 mg/L). BACs were the predominant compounds in Products 1-3, contributing 83, 99, and 98% to the \( \sum \)QAC concentrations (Figure S1). This contribution went down to 0.4-23% in Products 4-7. It should be noted that Products 1 and 2 are included in the EPA’s list of disinfectants effective for the SARS-CoV-2.\(^11\)
The effects of disinfecting practices on QAC levels in dust. Seventy-two percent of participants have indicated that they have increased the frequency and intensity of cleaning and disinfecting procedures in their homes since the beginning of the COVID-19 pandemic. Overall, the ∑QAC concentrations in homes with increased disinfecting frequencies during the COVID-19 crisis (median 65.2 μg/g) were significantly higher than in homes that did not change their disinfecting routine (median 21.7 μg/g, p < 0.05) (Figure 2B and Table S5), suggesting that the intensified disinfecting practices can significantly increase exposure to QACs in the indoor environment.

The ∑QAC levels in homes that reported cleaning and disinfecting from one to few times a week were significantly higher than in homes that did not do weekly disinfecting or use disinfecting chemicals (p < 0.05, Figure 2C). Overall, the homes with higher frequencies of cleaning had the ∑QAC concentration twice as high as that in homes with less frequent cleaning (medians 123 vs. 41.2 μg/g).

Ninety percent of households reported using a disinfecting product for their cleaning routine, and more than 80% of these households regularly used Products 1, 2, and 7. Figure 3 compares the average contributions of the three QAC groups, BACs, DDAC, and ATMACs, in these three products and in dust samples from homes that regularly used only these three products. The contributions of BACs, DDACs, and ATMACs in dust were similar to those in products (58, 24, and 18% vs. 64, 14, and 22%, respectively). The similarity between the profiles in dust and products suggests that disinfecting products frequently used in homes could be a significant source of these compounds in these homes.

Exposure assessment. The estimated daily intakes (EDIs) of QACs via dust ingestion and dermal absorption were calculated for toddlers and adults for the homes with increased disinfecting
frequency during the COVID-19 pandemic and for the homes where the disinfecting routine did not change (Table 2). Overall, exposure to QACs for toddlers and adults via dust ingestion (9.31-326 ng/kg body weight [bw]/day) was up to 1000 times higher than that via dermal dust absorption (0.325-1.20 ng/kg bw/day), indicating that dust ingestion is the main exposure pathway to QACs. The highest ∑QAC EDI (327 ng/kg bw/day) was observed for toddlers in homes with increased disinfection. This EDI was about 10 times higher than that estimated for adults. The EDIs for BACs and DDACs were well below the tolerable daily intake thresholds for these two compound groups (1×10⁵ ng/kg bw/day) established by the European Food Safety Authority (EFSA). This study had several limitations. The sample size was small for both dust and products due to the efforts to finish the study during the time period of the COVID-19 pandemic. Only limited information on disinfecting practices in homes was collected (e.g., information on the disinfected area could not be obtained). In addition, the dust samples obtained from vacuum cleaners could contain dust collected before the pandemic. Nonetheless, this is the first study to assess human exposure to QACs in the indoor environment. The timing of this study is important considering the increased use of disinfectants due to the current COVID-19 pandemic. Our findings indicate that the indoor exposure to QACs is widespread and significantly higher in households with increased disinfecting frequencies due to the pandemic. The similarity between the profiles of QACs in products and dust collected from the same households suggests that the disinfecting products are a significant source of these compounds in homes. As the COVID-19 pandemic continues, the use of these compounds is expected to increase worldwide. Furthermore, more intense disinfecting procedures are advised for care facilities, schools, and other high-risk places, many of which serve populations most vulnerable to these exposures. Exposure to QACs can exacerbate respiratory and reproductive
diseases, and our findings call for urgent research on risks associated with the increased exposure to these chemicals.

ACKNOWLEDGMENTS

We thank the participating households for donating dust. The MapMyEnvironment program and related sampling effort is partially supported by NSF award ICER-1701132 to Filippelli and the Environmental Resilience Institute, funded by Indiana University’s Prepared for Environmental Change Grand Challenge Initiative.

SUPPORTING INFORMATION

Information on chemicals used in this study, instrumental methods, and quality control and assurance measures; correlations among QACs in dust; QAC dust concentrations grouped based on the disinfecting frequency; QAC concentrations and patterns in cleaning products.

REFERENCES


(5) Neu, T. R., Significance of bacterial surface-active compounds in interaction of bacteria


(14) BfR opinion No 032/2012, Health assessment of benzalkonium chloride residues in food. 2012.

(15) BfR opinion No 027/2012, Health assessment of didecyldimethylammonium chloride (DDAC) residues in food. 2012.


(21) Pati, S. G.; Arnold, W. A., Comprehensive screening of quaternary ammonium surfactants


(23) European Food Safety Authority, Reasoned opinion on the dietary risk assessment for proposed temporary maximum residue levels (MRLs) of didecyldimethylammonium chloride (DDAC) and benzalkonium chloride (BAC). *EFSA Journal* **2014**, *12*, 3675.
Table 1. Detection frequencies (DF,%), minimum (min), maximum (max), mean (with their
standard errors [SE]), and median concentrations of QACs in residential dust collected during the
outbreak of the COVID-19 outbreak in the United States (μg/g; n = 40), and a contribution (%) of
each QAC to the ΣQAC concentrations. MDL: method detection limit.

<table>
<thead>
<tr>
<th>QACs</th>
<th>DF</th>
<th>Min</th>
<th>Max</th>
<th>Mean ± SE</th>
<th>Median</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>BACs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C6-BAC</td>
<td>98</td>
<td>&lt;MDL</td>
<td>0.084</td>
<td>0.009 ± 0.003</td>
<td>0.004</td>
<td>0.01</td>
</tr>
<tr>
<td>C8-BAC</td>
<td>100</td>
<td>0.0022</td>
<td>7.58</td>
<td>0.460 ± 0.211</td>
<td>0.058</td>
<td>0.1</td>
</tr>
<tr>
<td>C10-BAC</td>
<td>100</td>
<td>0.0005</td>
<td>0.787</td>
<td>0.137 ± 0.032</td>
<td>0.054</td>
<td>0.1</td>
</tr>
<tr>
<td>C12-BAC</td>
<td>100</td>
<td>0.244</td>
<td>181</td>
<td>25.6 ± 5.77</td>
<td>12.6</td>
<td>29</td>
</tr>
<tr>
<td>C14-BAC</td>
<td>100</td>
<td>0.760</td>
<td>154</td>
<td>20.4 ± 5.04</td>
<td>9.55</td>
<td>22</td>
</tr>
<tr>
<td>C16-BAC</td>
<td>100</td>
<td>0.203</td>
<td>75.6</td>
<td>8.20 ± 2.45</td>
<td>3.17</td>
<td>7.3</td>
</tr>
<tr>
<td>C18-BAC</td>
<td>100</td>
<td>0.061</td>
<td>34.8</td>
<td>3.74 ± 1.27</td>
<td>1.16</td>
<td>2.7</td>
</tr>
<tr>
<td>ΣBAC</td>
<td>100</td>
<td>1.66</td>
<td>421</td>
<td>58.5 ± 13.7</td>
<td>27.1</td>
<td>56</td>
</tr>
<tr>
<td>DDACs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C8-DDAC</td>
<td>100</td>
<td>0.0148</td>
<td>20.2</td>
<td>3.55 ± 0.769</td>
<td>1.63</td>
<td>3.7</td>
</tr>
<tr>
<td>C10-DDAC</td>
<td>100</td>
<td>0.0219</td>
<td>32.8</td>
<td>6.75 ± 1.18</td>
<td>4.30</td>
<td>10</td>
</tr>
<tr>
<td>C12-DDAC</td>
<td>98</td>
<td>&lt;MDL</td>
<td>2.91</td>
<td>0.205 ± 0.087</td>
<td>0.047</td>
<td>0.1</td>
</tr>
<tr>
<td>C14-DDAC</td>
<td>100</td>
<td>0.0002</td>
<td>0.462</td>
<td>0.048 ± 0.015</td>
<td>0.016</td>
<td>0.04</td>
</tr>
<tr>
<td>C16-DDAC</td>
<td>100</td>
<td>0.0031</td>
<td>4.24</td>
<td>0.619 ± 0.117</td>
<td>0.374</td>
<td>0.9</td>
</tr>
<tr>
<td>C18-DDAC</td>
<td>100</td>
<td>0.0192</td>
<td>33.1</td>
<td>6.25 ± 1.33</td>
<td>3.47</td>
<td>7.9</td>
</tr>
<tr>
<td>ΣDDAC</td>
<td>100</td>
<td>0.0595</td>
<td>68.9</td>
<td>17.4 ± 2.66</td>
<td>12.3</td>
<td>26</td>
</tr>
<tr>
<td>ATMACs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C8-ATMAC</td>
<td>95</td>
<td>&lt;MDL</td>
<td>0.507</td>
<td>0.105 ± 0.0215</td>
<td>0.057</td>
<td>0.1</td>
</tr>
<tr>
<td>C10-ATMAC</td>
<td>93</td>
<td>&lt;MDL</td>
<td>6.76</td>
<td>0.628 ± 0.187</td>
<td>0.266</td>
<td>0.6</td>
</tr>
<tr>
<td>C12-ATMAC</td>
<td>100</td>
<td>0.0281</td>
<td>13.1</td>
<td>2.32 ± 0.491</td>
<td>1.25</td>
<td>2.9</td>
</tr>
<tr>
<td>C14-ATMAC</td>
<td>100</td>
<td>0.0034</td>
<td>2.51</td>
<td>0.388 ± 0.0718</td>
<td>0.275</td>
<td>0.6</td>
</tr>
<tr>
<td>C16-ATMAC</td>
<td>100</td>
<td>0.0116</td>
<td>61.3</td>
<td>7.90 ± 1.76</td>
<td>4.59</td>
<td>11</td>
</tr>
<tr>
<td>C18-ATMAC</td>
<td>100</td>
<td>0.0096</td>
<td>9.80</td>
<td>1.62 ± 0.321</td>
<td>0.841</td>
<td>1.9</td>
</tr>
<tr>
<td>ΣATMAC</td>
<td>100</td>
<td>0.235</td>
<td>66.5</td>
<td>12.9 ± 2.10</td>
<td>8.78</td>
<td>18</td>
</tr>
<tr>
<td>ΣQAC</td>
<td>100</td>
<td>1.95</td>
<td>531</td>
<td>88.9 ± 16.7</td>
<td>58.9</td>
<td>100</td>
</tr>
</tbody>
</table>
Table 2. Estimated daily intakes (EDIs; ng/kg body weight [bw]/day) of each QAC group via dust ingestion and dermal dust absorption for toddlers and adults in homes with the increased vs. not changed disinfecting frequencies during the COVID-19 pandemic.

<table>
<thead>
<tr>
<th></th>
<th>Increased</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Toddlers</td>
<td>Adults</td>
<td>Toddlers</td>
<td>Adults</td>
<td></td>
</tr>
<tr>
<td>Dust ingestion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>∑BAC</td>
<td>188</td>
<td>16.1</td>
<td>56.8</td>
<td>4.87</td>
<td></td>
</tr>
<tr>
<td>∑DDAC</td>
<td>68.2</td>
<td>5.84</td>
<td>31.4</td>
<td>2.69</td>
<td></td>
</tr>
<tr>
<td>∑ATMAC</td>
<td>60.3</td>
<td>5.16</td>
<td>15.7</td>
<td>1.35</td>
<td></td>
</tr>
<tr>
<td>∑QAC</td>
<td>326</td>
<td>27.9</td>
<td>109</td>
<td>9.31</td>
<td></td>
</tr>
<tr>
<td>Dermal absorption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>∑BAC</td>
<td>0.561</td>
<td>0.693</td>
<td>0.170</td>
<td>0.210</td>
<td></td>
</tr>
<tr>
<td>∑DDAC</td>
<td>0.204</td>
<td>0.252</td>
<td>0.094</td>
<td>0.116</td>
<td></td>
</tr>
<tr>
<td>∑ATMAC</td>
<td>0.180</td>
<td>0.222</td>
<td>0.047</td>
<td>0.058</td>
<td></td>
</tr>
<tr>
<td>∑QAC</td>
<td>0.974</td>
<td>1.20</td>
<td>0.325</td>
<td>0.401</td>
<td></td>
</tr>
<tr>
<td>Total exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(dust ingestion +</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dermal absorption)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>∑ BAC</td>
<td>188</td>
<td>16.8</td>
<td>57.0</td>
<td>5.08</td>
<td></td>
</tr>
<tr>
<td>∑ DDAC</td>
<td>68.4</td>
<td>6.09</td>
<td>31.4</td>
<td>2.80</td>
<td></td>
</tr>
<tr>
<td>∑ ATMAC</td>
<td>60.4</td>
<td>5.39</td>
<td>15.8</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td>∑ QAC</td>
<td>327</td>
<td>29.1</td>
<td>109</td>
<td>9.71</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Chemical structures of the three main QAC groups.

![Chemical structures](image)

Figure 2. The \( \sum \text{QAC} \) concentrations (μg/g) in dust collected from homes: A) during \((n = 40)\) and before \((n = 6)\) the COVID-19 pandemic; B) with increased \((n = 29)\) vs. not changed \((n = 11)\) disinfecting frequency during the COVID-19 pandemic; and C) more frequent (one to few times per week; \(n = 26\)) vs. less frequent (less than once a week or do not use disinfecting chemicals; \(n = 13\); three outliers were omitted) cleaning. Concentrations are shown as boxplots, representing the 25th and 75th percentiles; black lines represent the median; and the whiskers represent the 10th and 90th percentiles. The asterisks represent the statistical difference at \(p < 0.05\) based on one-way analyses of variance (ANOVA).
**Figure 3.** Comparison of the average contributions (%) of the three QAC groups to the $\Sigma$QAC concentrations in house dust and in the only three disinfecting products (Products 1, 2, and 7) regularly used in these homes.
Indoor Exposure to Commonly Used Disinfectants during the COVID-19 Pandemic

Guomao Zheng, Gabriel Filippelli, Amina Salamova

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

Chemicals and reagents. Nineteen native standards, including benzylidimethylhexylammonium chloride (C6-BAC), benzylidimethyloctylammonium chloride (C8-BAC), benzylidimethyldecylammonium chloride (C10-BAC), benzylidimethyldodecylammonium chloride (C12-BAC), benzylidimethyltetradecylammonium chloride (C14-BAC), benzylidimethylhexadecylammonium chloride (C16-BAC), stearyldimethylbenzylammonium chloride (C18-BAC), dioctyldimethylammonium bromide (C8-DDAC), didecyldimethylammonium bromide (C10-DDAC), didodecyldimethylammonium bromide (C12-DDAC), dimethylditetradecylammonium bromide (C14-DDAC), dihexadecyldimethylammonium bromide (C16-DDAC), dimethyldioctadecylammonium 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 benzyl-
dimethyldodecylammonium-d7 chloride (d7-C12-BAC) and benzyldimethylltetradecylammonium-d7 chloride (d7-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 C18 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 S1.

Quality assurance and quality control. Six procedural blanks and six spiked samples were extracted with the samples. The absolute recoveries for the spiked samples (mean ± standard error) were 113 ± 5, 117 ± 3, 110 ± 4% for BACs, DDACs, and ATMACs, respectively. The recovery of the surrogate standard d7-C12-BAC was 118 ± 4%. Blanks constituted less than 0.1% of sample levels. Blank levels and method detection limits for each QAC are included in Table S2. All data were blank-corrected by subtracting blank levels from sample levels.

Exposure assessment. Estimated daily intake rates (ng/kg body weight [bw]/day via dust ingestion were calculated using Equation 1:
\[ \text{EDI}_{\text{Dust ingestion}} \text{ (ng/kg bw/d)} = \frac{(C_{\text{dust}} \times I_{\text{rate}}) \times T}{bw} \]  

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),\(^1\) \( T \) is the time spent at home (assumed to be 1 day),\(^2\) and \( bw \) is the mean body weight (12 and 70 kg for toddlers and adults, respectively).\(^2\)

EDIs via dermal dust absorption were calculated using Equation 2:

\[ \text{EDI}_{\text{Dermal dust absorption}} \text{ (ng/kg/d)} = \frac{(C_{\text{dust}} \times BSA \times DAS \times FA) \times T}{bw} \]  

where \( C_{\text{dust}} \) is the concentration of a chemical in dust (ng/g), \( BSA \) is the exposed body surface area (2564 and 4615 cm\(^2\) for toddlers and adults, respectively),\(^1\) \( DAS \) is the dust adhered to skin (0.01 and 0.04 mg/cm\(^2\) for toddlers and adults, respectively),\(^1\) \( FA \) is the fraction of contaminant absorbed by skin (0.007, unitless),\(^1\) \( T \) is the time spent at home (assumed to be 1 day),\(^2\) and \( bw \) is the mean body weight (12 and 70 kg for toddlers and adults, respectively).\(^2\)
<table>
<thead>
<tr>
<th>Compound</th>
<th>Abbreviation</th>
<th>Precursor ion [M-Cl/Br]+</th>
<th>Fragmentor (volts)</th>
<th>Product ions (m/z)</th>
<th>Collision energy (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzyldimethylhexylammonium chloride</td>
<td>C6-BAC</td>
<td>220.2</td>
<td>88</td>
<td>128.1</td>
<td>17</td>
</tr>
<tr>
<td>Benzyldimethyloctylammonium chloride</td>
<td>C8-BAC</td>
<td>248.2</td>
<td>103</td>
<td>91</td>
<td>29</td>
</tr>
<tr>
<td>Benzyldimethyldecylammonium chloride</td>
<td>C10-BAC</td>
<td>276.3</td>
<td>103</td>
<td>91.1</td>
<td>33</td>
</tr>
<tr>
<td>Benzyldimethyldecylammonium chloride</td>
<td>C12-BAC</td>
<td>304.3</td>
<td>113</td>
<td>212</td>
<td>25</td>
</tr>
<tr>
<td>Benzyldimethyldecylammonium chloride</td>
<td>C14-BAC</td>
<td>332.3</td>
<td>122</td>
<td>240</td>
<td>25</td>
</tr>
<tr>
<td>Benzyldimethylhexadecylammonium chloride</td>
<td>C16-BAC</td>
<td>360.4</td>
<td>146</td>
<td>268</td>
<td>25</td>
</tr>
<tr>
<td>Searlyldimethylbenzylammonium chloride</td>
<td>C18-BAC</td>
<td>388.39</td>
<td>127</td>
<td>296.3</td>
<td>29</td>
</tr>
<tr>
<td>Dioctyldimethylammonium bromide</td>
<td>C8-DDAC</td>
<td>270.3</td>
<td>156</td>
<td>158.2</td>
<td>29</td>
</tr>
<tr>
<td>Didecyldimethylammonium bromide</td>
<td>C10-DDAC</td>
<td>326.4</td>
<td>151</td>
<td>186</td>
<td>33</td>
</tr>
<tr>
<td>Didodecyldimethylammonium bromide</td>
<td>C12-DDAC</td>
<td>382.4</td>
<td>181</td>
<td>214</td>
<td>37</td>
</tr>
<tr>
<td>Dimethylditetradecylammonium bromide</td>
<td>C14-DDAC</td>
<td>438.5</td>
<td>151</td>
<td>242</td>
<td>41</td>
</tr>
<tr>
<td>Dihexadecyltrimethylammonium bromide</td>
<td>C16-DDAC</td>
<td>494.6</td>
<td>151</td>
<td>270</td>
<td>49</td>
</tr>
<tr>
<td>Dimethyldiotadecylammonium bromide</td>
<td>C18-DDAC</td>
<td>550.6</td>
<td>175</td>
<td>298</td>
<td>53</td>
</tr>
<tr>
<td>Octyltrimethylammonium chloride</td>
<td>C8-ATMAC</td>
<td>172.2</td>
<td>132</td>
<td>71.1</td>
<td>57</td>
</tr>
<tr>
<td>Decyltrimethylammonium bromide</td>
<td>C10-ATMAC</td>
<td>200.2</td>
<td>127</td>
<td>85.1</td>
<td>21</td>
</tr>
<tr>
<td>Dodecyldimethylammonium chloride</td>
<td>C12-ATMAC</td>
<td>228.3</td>
<td>137</td>
<td>85.1</td>
<td>25</td>
</tr>
<tr>
<td>Tetradecyltrimethylammonium chloride</td>
<td>C14-ATMAC</td>
<td>256.3</td>
<td>142</td>
<td>71.1</td>
<td>29</td>
</tr>
<tr>
<td>Hexadecyltrimethylammonium chloride</td>
<td>C16-ATMAC</td>
<td>284.3</td>
<td>132</td>
<td>85.1</td>
<td>29</td>
</tr>
<tr>
<td>Octadecyltrimethylammonium chloride</td>
<td>C18-ATMAC</td>
<td>312.4</td>
<td>142</td>
<td>71.1</td>
<td>33</td>
</tr>
<tr>
<td>Benzyldimethyldecylammonium-d7 chloride</td>
<td>d7-C12-BAC</td>
<td>311.34</td>
<td>122</td>
<td>98.1</td>
<td>37</td>
</tr>
<tr>
<td>(Surrogate standard)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Benzyl-d7)dimethylditetradecylammonium chloride (Internal standard)</td>
<td>d7-C14-BAC</td>
<td>339.38</td>
<td>127</td>
<td>98.1</td>
<td>41</td>
</tr>
</tbody>
</table>

**Table S1.** The optimized MRM transitions, fragmentors, and collision energies for target analytes.
Table S2. Blank levels and method detection limits (MDL), μg/g.

<table>
<thead>
<tr>
<th>QACs</th>
<th>Blanks</th>
<th>MDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>C6-BAC</td>
<td>0.0003</td>
<td>0.0003</td>
</tr>
<tr>
<td>C8-BAC</td>
<td>0.0003</td>
<td>0.0001</td>
</tr>
<tr>
<td>C10-BAC</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>C12-BAC</td>
<td>0.0305</td>
<td>0.0025</td>
</tr>
<tr>
<td>C14-BAC</td>
<td>0.0046</td>
<td>0.0008</td>
</tr>
<tr>
<td>C16-BAC</td>
<td>0.0067</td>
<td>0.0006</td>
</tr>
<tr>
<td>C18-BAC</td>
<td>0.0006</td>
<td>0.0002</td>
</tr>
<tr>
<td>C8-DDAC</td>
<td>0.0004</td>
<td>0.0005</td>
</tr>
<tr>
<td>C10-DDAC</td>
<td>0.0131</td>
<td>0.0018</td>
</tr>
<tr>
<td>C12-DDAC</td>
<td>0.0039</td>
<td>0.0005</td>
</tr>
<tr>
<td>C14-DDAC</td>
<td>0.0004</td>
<td>0.0002</td>
</tr>
<tr>
<td>C16-DDAC</td>
<td>0.0007</td>
<td>0.0005</td>
</tr>
<tr>
<td>C18-DDAC</td>
<td>0.0040</td>
<td>0.0005</td>
</tr>
<tr>
<td>C8-ATMAC</td>
<td>0.0009</td>
<td>0.0015</td>
</tr>
<tr>
<td>C10-ATMAC</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>C12-ATMAC</td>
<td>0.0023</td>
<td>0.0017</td>
</tr>
<tr>
<td>C14-ATMAC</td>
<td>0.0156</td>
<td>0.0022</td>
</tr>
<tr>
<td>C16-ATMAC</td>
<td>0.0012</td>
<td>0.0009</td>
</tr>
<tr>
<td>C18-ATMAC</td>
<td>0.0005</td>
<td>0.0003</td>
</tr>
</tbody>
</table>
Table S3. Pearson correlation coefficients for correlations among QAC concentrations in dust (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**     | .309**     | .527**     | .654**     |
| C8- BAC  | 1.000   | .710**  | .621**   | .583**   | .634**   | .512**   | .396**   | .0298    | .357**    | .299**    | .288**    | .549**    | .470**     | .575**     | .369**     | .413**     | .381**     | .505**     | .654**     |
| C10- BAC | 1.000   | .829**  | .800**   | .854**   | .805**   | .570**   | .651**   | .599**   | .0323     | .231**    | .771**   | .593**    | .757**     | .391**     | .545**     | .493**     | .658**     |            |            |
| C12- BAC | 1.000   | .941**  | .866**   | .850**   | .727**   | .701**   | .642**   | .462**   | 0.275     | .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   | .830**  | .685**   | .573**   | 0.317    | 0.176    | .893**   | .805**   | .711**   | .443**    | .461**   | .454**    | .519**     |            |            |            |            |            |            |
| C18- BAC | 1.000   | .667**  | .612**   | .398**   | .230     | .796**   | .874**   | .457**   | .548**   | .612**    | .491**   | .493**     |            |            |            |            |            |            |
| DDAC     | 1.000   | .907**  | .554**   | .418**   | .608**   | .580**   | .492**   | .625**   | .522**   | .702**    | .576**   |            |            |            |            |            |            |            |
| C10- DDAC| 1.000   | .686**  | .533**   | .547**   | .517**   | .423**   | .611**   | .567**   | .697**   | .583**     |            |            |            |            |            |            |            |            |
| C12- DDAC| 1.000   | .814**  | .371**   | .320     | .217     | .485**   | .512**   | .782**   | .361**   |            |            |            |            |            |            |            |            |
| C14- DDAC| 1.000   | 0.313   | 0.276    | 0.175    | 0.323    | 0.367    | 0.771**  | 0.184    |            |            |            |            |            |            |            |            |            |
| C16- DDAC| 1.000   | .903**  | .770**   | .396**   | .443**   | .505**   | .548**   |            |            |            |            |            |            |            |            |            |
| C18- DDAC| 1.000   | .629**  | .431**   | .421**   | .421**   | .516**   |            |            |            |            |            |            |            |            |            |            |
| C8- ATMAC| 1.000   | .364**  | .270     | .332**   | .633**   |            |            |            |            |            |            |            |            |            |            |            |
| C10- ATMAC| 1.000  | .664**  | .628**   | .425**   |            |            |            |            |            |            |            |            |            |            |            |            |
| C12- ATMAC| 1.000 | .626**  | .384**   |            |            |            |            |            |            |            |            |            |            |            |            |            |
| C14- ATMAC| 1.000 | 0.322   |            |            |            |            |            |            |            |            |            |            |            |            |            |
| C16- ATMAC| 1.000 |            |            |            |            |            |            |            |            |            |            |            |            |            |            |
| C18- ATMAC| 1.000|            |            |            |            |            |            |            |            |            |            |            |            |            |            |

* represents significance at p < 0.05; ** represents significance at p < 0.01.
Table S4. QAC concentrations in cleaning products commonly used in participants’ homes (mg/L). MDL: method detection limit.

<table>
<thead>
<tr>
<th></th>
<th>Product 1</th>
<th>Product 2</th>
<th>Product 3</th>
<th>Product 4</th>
<th>Product 5</th>
<th>Product 6</th>
<th>Product 7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BACs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C6-BAC</td>
<td>283</td>
<td>0.0446</td>
<td>0.0171</td>
<td>0.0116</td>
<td>&lt;MDL</td>
<td>0.0179</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C8-BAC</td>
<td>206</td>
<td>1.86</td>
<td>0.018</td>
<td>0.0146</td>
<td>0.0123</td>
<td>0.0039</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C10-BAC</td>
<td>304</td>
<td>0.384</td>
<td>0.0513</td>
<td>0.0052</td>
<td>0.0037</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C12-BAC</td>
<td>6240</td>
<td>208</td>
<td>16.7</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C14-BAC</td>
<td>4240</td>
<td>567</td>
<td>76.7</td>
<td>0.77</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C16-BAC</td>
<td>2480</td>
<td>425</td>
<td>49</td>
<td>0.138</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C18-BAC</td>
<td>60.9</td>
<td>141</td>
<td>10.2</td>
<td>0.327</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>0.0352</td>
</tr>
<tr>
<td>∑BAC</td>
<td>13800</td>
<td>1340</td>
<td>153</td>
<td>1.27</td>
<td>0.016</td>
<td>0.0218</td>
<td>0.243</td>
</tr>
<tr>
<td><strong>DDACs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C8-DDAC</td>
<td>255</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C10-DDAC</td>
<td>400</td>
<td>1.20</td>
<td>0.924</td>
<td>0.704</td>
<td>0.446</td>
<td>0.524</td>
<td>0.476</td>
</tr>
<tr>
<td>C12-DDAC</td>
<td>249</td>
<td>0.597</td>
<td>0.319</td>
<td>0.261</td>
<td>0.103</td>
<td>0.242</td>
<td>0.206</td>
</tr>
<tr>
<td>C14-DDAC</td>
<td>207</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>0.0156</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C16-DDAC</td>
<td>164</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C18-DDAC</td>
<td>170</td>
<td>1.16</td>
<td>0.211</td>
<td>0.259</td>
<td>0.172</td>
<td>0.125</td>
<td>0.127</td>
</tr>
<tr>
<td>∑DDAC</td>
<td>1440</td>
<td>2.96</td>
<td>1.45</td>
<td>1.24</td>
<td>0.721</td>
<td>0.891</td>
<td>0.809</td>
</tr>
<tr>
<td><strong>ATMACs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C8-ATMAC</td>
<td>271</td>
<td>&lt;MDL</td>
<td>0.126</td>
<td>0.33</td>
<td>&lt;MDL</td>
<td>0.22</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C10-ATMAC</td>
<td>221</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C12-ATMAC</td>
<td>359</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>C14-ATMAC</td>
<td>71.5</td>
<td>4.35</td>
<td>1.93</td>
<td>1.75</td>
<td>3.01</td>
<td>1.79</td>
<td>1.44</td>
</tr>
<tr>
<td>C16-ATMAC</td>
<td>146</td>
<td>0.228</td>
<td>0.0494</td>
<td>0.446</td>
<td>0.292</td>
<td>0.0252</td>
<td>0.0284</td>
</tr>
<tr>
<td>C18-ATMAC</td>
<td>246</td>
<td>0.103</td>
<td>&lt;MDL</td>
<td>0.563</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
<td>&lt;MDL</td>
</tr>
<tr>
<td>∑ATMAC</td>
<td>1310</td>
<td>4.68</td>
<td>2.11</td>
<td>3.09</td>
<td>3.31</td>
<td>2.04</td>
<td>1.47</td>
</tr>
<tr>
<td>∑QAC</td>
<td>16600</td>
<td>1350</td>
<td>156</td>
<td>5.6</td>
<td>4.04</td>
<td>2.95</td>
<td>2.52</td>
</tr>
</tbody>
</table>
Table S5. Median QAC concentrations (μg/g) in dust samples collected from Indiana homes before the COVID-19 pandemic \( (n = 6) \), and in homes with increased \( (n = 29) \) vs. not changed \( (n = 11) \) disinfection frequencies during the COVID-19 pandemic. Percent contributions of each QAC to the total QAC concentrations are also included.

<table>
<thead>
<tr>
<th></th>
<th>Before COVID-19</th>
<th>Increased</th>
<th>Not changed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Contribution</td>
<td>Median</td>
</tr>
<tr>
<td><strong>BACs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C6-BAC</td>
<td>0.0014</td>
<td>0.01</td>
<td>0.00422</td>
</tr>
<tr>
<td>C8-BAC</td>
<td>0.0237</td>
<td>0.1</td>
<td>0.0843</td>
</tr>
<tr>
<td>C10-BAC</td>
<td>0.0166</td>
<td>0.1</td>
<td>0.0708</td>
</tr>
<tr>
<td>C12-BAC</td>
<td>5.71</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>C14-BAC</td>
<td>4.31</td>
<td>16</td>
<td>12.4</td>
</tr>
<tr>
<td>C16-BAC</td>
<td>1.23</td>
<td>4.6</td>
<td>4.23</td>
</tr>
<tr>
<td>C18-BAC</td>
<td>0.524</td>
<td>2.0</td>
<td>1.28</td>
</tr>
<tr>
<td>( \sum \text{BAC} )</td>
<td>14</td>
<td>43</td>
<td>37.5</td>
</tr>
<tr>
<td><strong>DDACs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C8-DDAC</td>
<td>1.4</td>
<td>5.3</td>
<td>2.18</td>
</tr>
<tr>
<td>C10-DDAC</td>
<td>5.22</td>
<td>20</td>
<td>5.96</td>
</tr>
<tr>
<td>C12-DDAC</td>
<td>0.0367</td>
<td>0.1</td>
<td>0.0796</td>
</tr>
<tr>
<td>C14-DDAC</td>
<td>0.0117</td>
<td>0.04</td>
<td>0.0249</td>
</tr>
<tr>
<td>C16-DDAC</td>
<td>0.59</td>
<td>2.2</td>
<td>0.494</td>
</tr>
<tr>
<td>C18-DDAC</td>
<td>2.91</td>
<td>11</td>
<td>3.48</td>
</tr>
<tr>
<td>( \sum \text{DDAC} )</td>
<td>10.4</td>
<td>32</td>
<td>13.6</td>
</tr>
<tr>
<td><strong>ATMACs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C8-ATMAC</td>
<td>0.0194</td>
<td>0.1</td>
<td>0.0576</td>
</tr>
<tr>
<td>C10-ATMAC</td>
<td>0.14</td>
<td>0.5</td>
<td>0.312</td>
</tr>
<tr>
<td>C12-ATMAC</td>
<td>1.52</td>
<td>5.7</td>
<td>1.4</td>
</tr>
<tr>
<td>C14-ATMAC</td>
<td>0.173</td>
<td>0.6</td>
<td>0.382</td>
</tr>
<tr>
<td>C16-ATMAC</td>
<td>2.23</td>
<td>8.3</td>
<td>6.3</td>
</tr>
<tr>
<td>C18-ATMAC</td>
<td>0.639</td>
<td>2.4</td>
<td>1.32</td>
</tr>
<tr>
<td>( \sum \text{ATMAC} )</td>
<td>8.32</td>
<td>26</td>
<td>12.1</td>
</tr>
<tr>
<td><strong>( \sum \text{QAC} )</strong></td>
<td>35.9</td>
<td>100</td>
<td>65.2</td>
</tr>
</tbody>
</table>
Figure S1. The pattern of QACs in cleaning products collected from participants’ homes (%).
References