Supplemental Information

Overview of HOMEChem: House Observations of Microbial and Environmental Chemistry

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S1. Supplemental figures.

Figure S1. View of open kitchen area with main inlet line for most trace gas and particle measurements near the refrigerator. Inlets were insulated between house and instrument trailers. The dishwasher and sink are apparent in the kitchen. Aerosol size distribution instruments are located on the shelves and kitchen counters. Low-cost sensors and a Portable Optical Particle Sensors (POPS, Table 4) are located on the top of the kitchen cabinets between the kitchen and living space.

Figure S2. View of interior of house from front window facing the living area. The LIF-FAGE and spectrometer and are situated next to the window.

Figure S3. The cooking space consists of an oven plus stove, with counter areas.

Figure S4. The UTest house.

Figure S5. View of instrument trailers around test house.

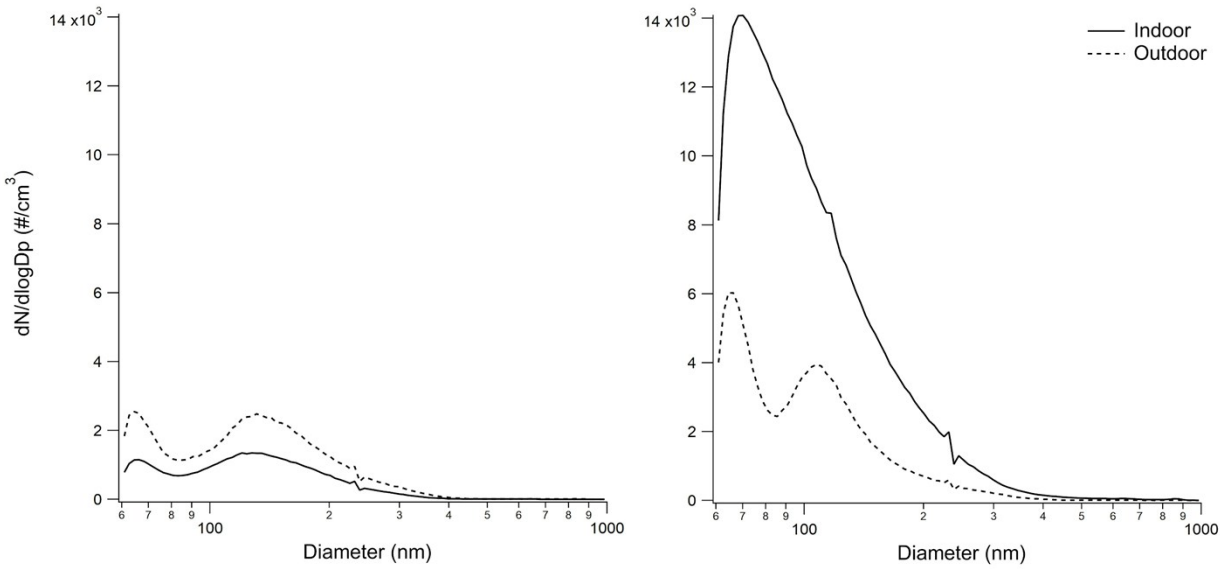

Figure S6. Aerosol number concentration indoor (solid line) and outdoor (dashed line) during an unoccupied, background period (left) and a cooking event (right).

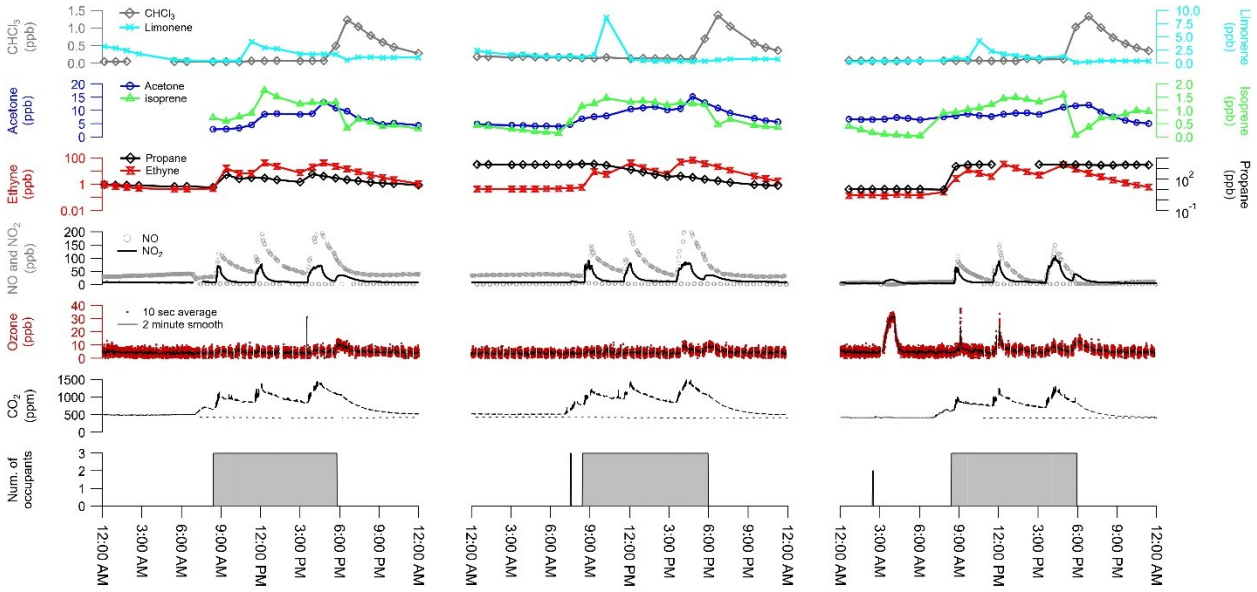

Figure S7. Similar to Figure 7, trace gas data during the three days of layered experiments. Empirical data are typically reproducible in terms of major features of the trace gas concentrations. Note that researchers entered the house 7-7:30 am for instrument maintenance and preparation, accounting for the initial rise in CO_2 (exhaled human breath) and drop in NO_x (door opening exchanges indoor and outdoor air). On the third layered day, an ozone addition experiment at ~3 am caused clear perturbations in the O_3 and NO_x timeseries.

S2. Surface analysis methods

In AFM/AFM-IR analyses, deposited particles were identified with a lower height threshold of 2.00 nm relative to the underlying glass, and sized according to their spherical equivalent volume diameter to account for differences in deposition morphologies:

$$d_{eq,V} = \sqrt[3]{\frac{V}{6\pi}} \qquad \text{(S1)}$$

A film equivalent thickness ($z_{eq,f}$) was calculated by taking the ratio of the summed volume of all particles over the projected surface area for each AFM image:

$$z_{eq,f} = \frac{\sum_{i=1}^{n} V}{A_{proj}} \qquad \text{(S2)}$$

We note that these offline surface analyses are limited to species that do not readily desorb from the surface passively or during sample transport; therefore, these results should be interpreted as

a characterization of the surface evolution due to semi- and low-volatility organic compounds and non-volatile particulate matter.

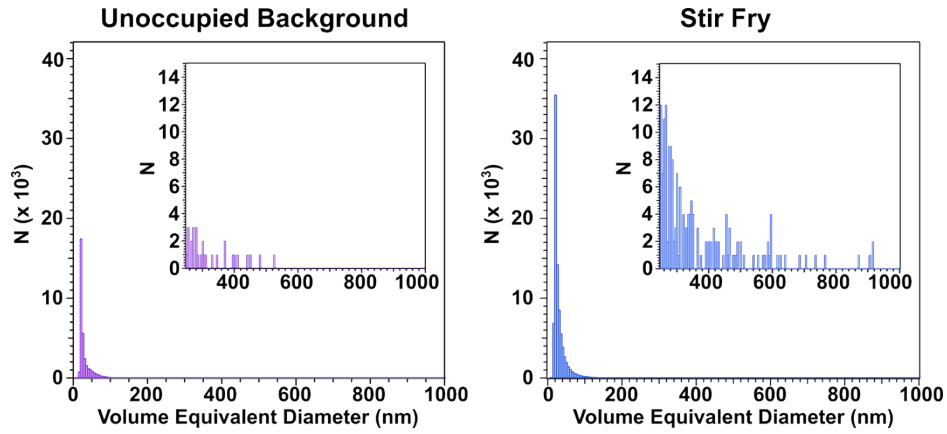

Figure S8. Histograms of the summed size distributions for particles from 8 separate 30 µm × 30 µm images taken on a single glass sample from the unoccupied background (left) and stir-fry (right) events. The stir fry exposed glass shows an enhancement in depositions across all sizes.

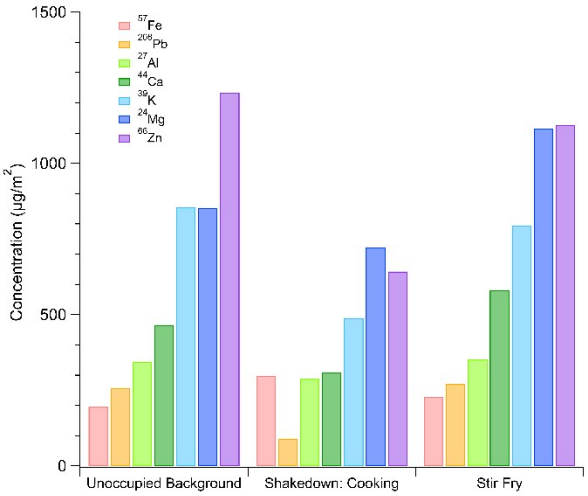

Figure S9. ICP-MS analysis of window glass samples (1.27 cm × 1.27 cm) that were exposed to different indoor relevant emissions during HOMEChem. Selected elements of detection include iron, lead, aluminum, calcium, potassium, magnesium, and zinc. Samples were extracted using a solution of Milli-Q water and ~2% HNO_3.

Table S1. ICP-MS analysis of window glass (1.27 cm × 1.27 cm).*

Sample	Mg	Al	K	Ca	Cr	Mn	Fe	Co	Ni	Cu	Zn	Pb
Unoccupied Background	852	343	854	465	21	5	197	3	6	62	1233	257

Cooking	722	289	487	310	29	4	297	3	3	25	642	91
Stir-Fry	1116	353	795	581	18	6	229	4	6	52	1127	271

* Units of measure are μg/m^2. All samples were analyzed in triplicate and measured results are well above calibrated limit of quantification. High background levels (also seen in laboratory blank not shown here) are attributed to the contaminating metals extracted from the window glass itself.

S3. Low-cost air quality sensors

Table S2. Summary of low cost air quality sensors

Sensor name	Measurements	Locations	Notes
Air Quality Egg (Wicked Device LLC)	PM_1, $PM_{2.5}$, PM_{10}, temperature, and relative humidity	Kitchen; living room	https://airqualityegg.com/home
PA-II-SD (Purple Air)	Size distribution of particles ranging from 0.3 – 10 μm in six bins (0.3, 0.5, 1, 2.5, 5, 10 μm), PM_1, $PM_{2.5}$, PM_{10}; temperature, and pressure	Kitchen; Living room	https://www.purpleair.com/
Speck (Airviz)	PM (0.5-3 μm) mass and number concentration	Kitchen	https://www.specksensor.com/
DC1700 (Dylos Corporation)	PM number concentration 2 size bins (>0.5 μm and >2.5 μm)	Kitchen; living room	http://www.dylosproducts.com Data only through June 14
Washington University (prototype units)	$PM_{2.5}$ and PM_{10}	Kitchen; living room	
Harvard_Rescue	PM_1, $PM_{2.5}$, and PM_{10}	Kitchen (×2), outside	Two more located in living room, but information did not transfer Two in the kitchen had different housings
Foobot	PM (0.3-2.5 μm),	9 units at different	https://foobot.io/

(Airboxlab)	TVOCs, CO_2, temperature, and humidity	indoor locations including kitchen, living room, and bed rooms	Data collection period June 23 – June 29
DustTrak 8520 (TSI Inc.)	$PM_{2.5}$	Kitchen	Data collection period June 23 – June 29

S4. House sensors

Table S3 provides an overview of available house sensors, and Figure S10 provides an example of information utilized from these sensors, linking window or door opening activities to increases in particle concentrations and environmental conditions (relative humidity and temperature).

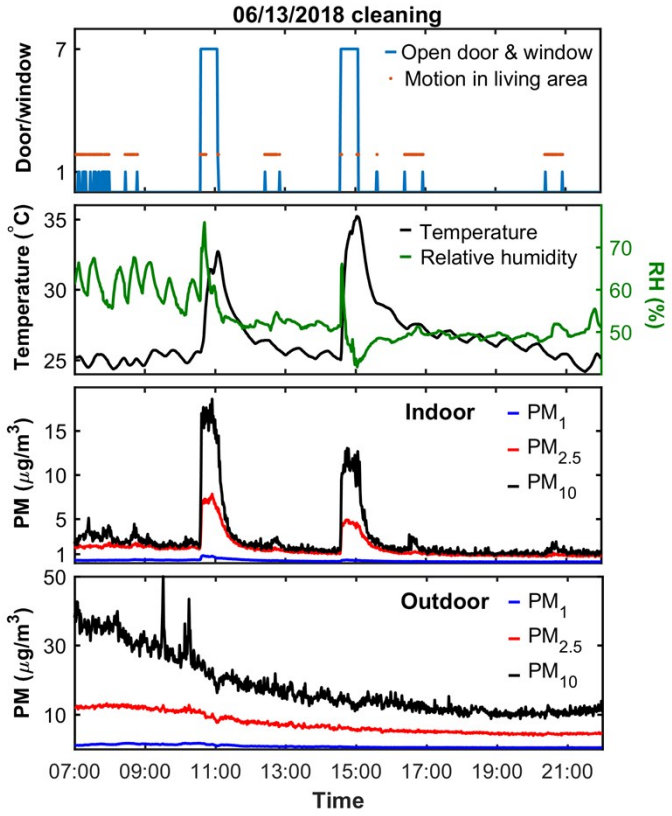

Figure S10. Time series plots of a representative experimental day (sequential cleaning, 13 June 2018). The top panel shows the number of open doors and windows, and motion detected in the living-kitchen area using smart sensor data. The second panel illustrates the temperature and relative humidity in the living-kitchen area. The bottom two panels display the particulate matter (PM) concentrations indoors and outdoors.

Table S3. Wireless sensor arrangement.

Sensor type	Sensor ID	Data type	Room/Target	Purpose
Motion	MT01	active; inactive	Living room	Movement
	MT02		Kitchen	Movement
	MT03		Master bedroom	Movement
	MT04		Bedroom 1[1]	Movement
	MT05		Bedroom 2[2]	Movement
	MT06		Bathroom_main	Movement
	MT07		Trailer_gas	Movement
	MT08		Kitchen_dining area	Movement
	MT10		Trailer_particles	Movement
Multipurpose[3]	MU01	open; closed	House door_front	Door open/close
	MU02		House door_back	Door open/close
	MU03		Bathroom_main_door	Door open/close
	MU04		Living room_window 1 (door side)	Window open/close
	MU05		Living room_window 2	Window open/close
	MU06		Kitchen_sink window	Window open/close
	MU07		Master bedroom_window 1 (near front door side)	Window open/close
	MU08		Master bedroom _window 2	Window open/close
	MU09		Bedroom 1_window	Window open/close
	MU10		Bedroom 2_window	Window open/close
	MU11		Master bedroom_door	Door open/close
	MU12		Bedroom 1_door	Door open/close
	MU13		Bedroom 2_door	Door open/close
	MU14		Bathroom_2nd_door	Door open/close
	MU15		Bedroom 2_closet door	Door open/close
	MU16		Kitchen_freezer	Door open/close
	MU18		Kitchen_fridge	Door open/close
	MU19		Kitchen_dishwasher	Door open/close
	MU21		Kitchen_oven	Door open/close
	MU22	active; inactive	Kitchen_table 1	Acceleration
	MU24		Living room_table 2	Acceleration
	MU26		Living room_table 3	Acceleration
	MU27	open; closed	Trailer_gas	Door open/close
	MU28		Trailer_particles	Door open/close
	MU29		Trailer_laser	Door open/close
Power gauge (numerical)	OU01	Watt	Kitchen_fridge	Appliance use
	OU02		Kitchen_dishwasher	Appliance use
	OU03		Kitchen_coffee maker	Appliance use
	OU04		Kitchen_toaster	Appliance use
	OU05		Kitchen_hot plate	Appliance use
Temperature/RH	RHS01	Temperature: °F	Kitchen_hood_left	Temperature/RH

(numerical)	RHS02	RH: %	Kitchen_dishwasher	Temperature/RH
	RHS03		Kitchen_oven	Temperature/RH
	RHS04		Kitchen_hood_right	Temperature/RH
	RHS05		Trailer_gas	Temperature/RH
	RHS06		Trailer_particles	Temperature/RH
	RHS07		Trailer_laser	Temperature/RH
	RHS08		Bedroom 2_register	Temperature/RH

[1] Bedroom 1 is the Guest bedroom (Figure 1)

[2] Bedroom 2 is also referred to as the Control room (Figure 1)

[3] Multipurpose sensor measures temperature, relative humidity, and acceleration.

S5. SO_2 Measurements

Sulfur dioxide (SO_2) measurements are clearly affected by a time lag, likely due to interactions with the PFA tubing. When the sampling inlet switches from the outdoor line to the indoor line, the observed SO_2 concentration increases for ~30 minutes before stabilizing, likely due to the lack of continuous inlet flow when not actively sampled and subsequent wall-air equilibration time. The SO_2 line switched between outdoor and indoor sampling every hour, but this timing was inadequate during the Thanksgiving events (i.e. the concentration never reached a steady value), and the inlet was maintained to sample only from indoors for the afternoon when it reached the peak indoor value. Both NO and polynuclear aromatics are known to interfere with fluorescence measurements of SO_2, although the instrument used during HOMEChem had an optical filter and scrubber designed to avoid these problems.

S6. Detailed experimental schedules

Sample prescribed schedules are below. Detailed logs of numbers of volunteers, activity times and modifications (e.g. weight of mopping solutions, cooking conditions and temperature) are included in the complete campaign dataset.

Description	Time	Activity	# volunteers
Shake-down day	8:00 - 8:45 AM	Researchers work on instruments	
	9:00 - 10:00 AM	~10 people come into the house and occupy it for 1 hour. Occupants can bring laptops, but no food.	10
	10:00 - 10:30 AM	Open all windows and doors and keep them open for 30 min. Keep house occupancy to a minimum.	3
	10:30 - 11:30 AM	10 people come into the house for 1 hour.	10
	12:00 - 12:30 PM	Cook a stir-fry and rice meal for 12 people. Log temperature of stir fry during cooking.	2
	12:30 - 1:30 PM	10-12 people come into the house and occupy it for 1 hour (eat stir fry)	10

	3:00 - 3:30 PM	Bleach mopping. One occupant mops kitchen and living room floors with a solution of bleach in water (1/4 cup per gallon, per manufacturer's instructions). Enter on the activity log computer: Your arrival time into the house, time you started mopping, the time you finished mopping. Leave the house when done.	1
	4:00 - 4:30 PM	Turn on the oven at 400 ºF with no food inside it. Leave it on for 20 min. Leave the house when done.	1
	4:30 – 7:00 PM	Passive sampler setup	
Unoccupied background	all day	Nobody allowed in the house.	
Sequential ventilation	7:50 AM	Volunteers enter house.	2
	8:05 AM	Open doors and windows.	
	8:20 AM	Close windows and doors. Stay outside the house.	2
	10:05 AM	Open doors and windows. Turn off AC.	2
	10:35 AM	Close windows and doors.	2
	12:05 PM	Open doors and windows.	2
	12:35 PM	Close windows and doors.	2
	2:05 PM	Open doors and windows.	2
	2:35 PM	Close windows and doors. Windows covered.	2
	4:05 PM	Open doors and windows.	2
	4:35 PM	Close windows and doors. Windows covered.	2
	6:05 PM	Open doors and windows.	2
	6:35 PM	Close windows and doors. Windows covered.	2
	8:05 PM	Open doors and windows.	2
	8:35 PM	Close windows and doors.	2
Sequential cleaning	7:00 – 8:15 AM	Researchers work on house instruments	
	8:25 AM	Volunteer for mopping enters the house.	1
	8:35 AM	Prepare mopping solution. Weigh bucket + solution + mop and enter in the activity log. Mop kitchen and living room floors. Weigh bucket + solution + mop and enter in the activity log. Leave the house (log the time). House stays unoccupied after the mopper leaves.	
	10:05 AM	Turn off AC thermostat (in kitchen). Open doors and windows.	2

	10:35 AM	Turn AC system back on (76 °F). Close windows and doors.	2
	11:55 AM	Volunteer for mopping enters the house.	1
	12:05 PM	Mopping (described above)	
	1:35 PM	Turn off AC thermostat, open doors and windows.	2
	2:05 PM	Turn AC system back on, Close windows and doors.	2
	3:25 PM	Volunteer for mopping enters the house.	1
	3:35 PM	Mopping (described above)	
	9:05 PM	Mopping (described above)	1
Sequential stir-fry	7:00 – 8:15 AM	Researchers work on house instruments	
	8:25 AM	Volunteers enter the house.	3
	8:35 AM	Cook stir fry for 3 following instructions printed and posted in the house. Load dishes in the dish washer. Wash pots. Wait to start dishwasher at end of the day. Clean counters with wet paper towel or soap. Stay in the house until the time listed below.	3
	10:05 AM	Turn off AC thermostat, open doors and windows.	3
	10:35 AM	Turn AC system back on, Close windows and doors.	2
	11:55 AM	Volunteers for cooking enter the house.	3
	12:05 PM	Cook stir fry for 3 (described above).	3
	1:35 PM	Turn off AC thermostat, open doors and windows.	3
	2:05 PM	Turn AC system back on, Close windows and doors.	2
	3:25 PM	Volunteers for cooking enter the house.	3
	3:35 PM	Cook stir fry for 3 (described above).	
	8:55 PM	Volunteers for cooking enter the house.	3
	9:05 PM	Cook stir fry for 3 (described above). Run dishwasher.	3
Staggered occupancy	7:00 – 8:15 AM	Researchers work on house instruments	
	9:05 AM	Group A: 2 -3 people enter the house. Occupy main living space.	2-3
	9:20 AM	Group B: 2 -3 people enter the house. Occupy main living space.	2-3
	9:35 AM	Group C: 2 -3 people enter the house. Occupy	2-3

		main living space.	
	9:50 AM	Group D: 2 -3 people enter the house. Occupy main living space.	2-3
	10:20 AM	Group A leaves the house	2-3
	10:35 AM	Group B leaves the house	2-3
	10:50 AM	Group C leaves the house	2-3
	11:05 AM	Group D leaves the house. House remains unoccupied for 60 min.	2-3
	12:05 PM	Turn off AC thermostat, open doors and windows.	2
	12:35 PM	Turn AC system back on, Close windows and doors.	2
	2:05 PM	Group E: 2 -3 people enter the house. Occupy main living space.	2-3
	2:20 PM	Group F: 2 -3 people enter the house. Occupy main living space.	2-3
	2:35 PM	Group G: 2 -3 people enter the house. Occupy main living space.	2-3
	2:50 PM	Group H: 2 -3 people enter the house. Occupy main living space.	2-3
	3:20 PM	Group E leaves the house	2-3
	3:35 PM	Group F leaves the house	2-3
	3:50 PM	Group G leaves the house	2-3
	4:05 PM	Group H leaves the house. House remains unoccupied for 60 min.	2-3
	5:05 PM	Turn off AC thermostat, open doors and windows.	2
	5:35 PM	Turn AC system back on, Close windows and doors.	2
Thanksgiving	6:30 AM	Those who need to access the house can come and go 6:30 am - 8:00 am.	0
	8:25 AM	Prepare Thanksgiving meal	4
	3:35 PM	Join Thanksgiving dinner and clean up (see Thanksgiving tab)	12+
	5:05 PM	Everyone leave the house.	0
Layered	7:00 – 8:00 AM	Researchers work on house instruments	0
	8:25 AM	Volunteers enter the house.	3
	8:35 AM	Cook breakfast for 3 (eggs, sausage, toast, cooked tomato, coffee). Load dishes in the dishwasher (run at the end of the day). Wash pots and pans.	

	10:05 AM	Mop floors with terpene solution (protocol above)	
	11:35 AM	Cook stir fry for 3 on stove.	
	12:35 PM	Wipe all countertops and tables with chlorine wipes.	
	1:05 PM	Make a pot of coffee	
	1:35 PM	Make toast	
	3:35 PM	Cook chili	
	5:05 PM	Kitchen cleanup. Load dishes in dishwasher. Run dishwasher.	
	5:35 PM	Mop floors with bleach solution (same protocol as sequential cleaning days). Everyone leaves the house.	

S7. CAPS NO_2 monitor measurements

The CAPS NO_2 monitor was calibrated with a NO_2 cylinder standard (9.86 ppm NO_2 ± 5% in N_2). A linearity check was performed on 30 May 2018. Both a calibration and a linearity check were done on 4 July 2018, providing a K value of 1.1021. Campaign data were processed using this K value, which was similar to the previous K value of 1.1048. The effect from the post-calibration is minor given the similarity in the K values.

An offset on the CAPS NO_2 was noted during the first days of the HOMEChem campaign. When sampling air was passed through a filter cartridge to remove NO_2, the monitor measured 4.9 ppb instead of 0 ppb. To ensure that the filter cartridge was functional, we sampled air from a 40 L Teflon bag that had been filled with clean air from an AADCO clean air generator (model 737-14A) that removes NO_x species. The CAPS calculated ~5 ppb NO_2 instead of 0 ppb. Pure nitrogen was also sampled by the NO_2 monitor using the 40 L Teflon bag and the concentration on the NO_2 monitor read 4-5 ppb. We performed a 'zero reference cycle' on the CAPS instrument on the morning of 9 June 2018, and 4.9 ppb was subtracted from measured NO_2 concentrations before this point. After 9 June 2018, these zero reference cycles were performed periodically and the data were corrected for any observed offset.