SUPPORTING INFORMATION

Indoor Air Quality in California Homes with Code-Required Mechanical Ventilation

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Recruitment and Screening

Most participants were recruited through postcards mailed to addresses identified on a real estate website (Zillow.com), targeting single-family, detached homes built 2011 or later. Some participants learned of the study via referrals. LBNL attempted to contact all who expressed interest through the study website or by telephone. On contact, participant eligibility was confirmed and participant responsibilities, including keeping windows closed, were described. This process identified 103 eligible and interested candidates and led to monitoring in 72 homes. Most of the other 31 candidates did not respond to three attempts to schedule visits or withdrew before the first scheduled visit. One consented participant withdrew between the first and second visits. Another was excluded when the field team found during the first visit that the home was built before 2011. These participants received a $75 gift card. Two monitored homes did not have compliant ventilation systems and are not included in the data reported herein.

Information Collected for House and Equipment Characterization

- House information: floor area and ceiling heights; number of stories, bedrooms, full and half baths, and other rooms on each floor; attached garage, number of parking spots, etc.
- Whole-house mechanical ventilation system. Noted basic design (exhaust, supply, or balanced); type of control; make, model and rated flow; and fan settings.
- Other ventilation equipment: bath and toilet room exhaust fans, kitchen range hood, and any laundry exhaust fans. Noted make, model and rated flow, type of control for each fan; and for kitchen note if range hood is microwave or simple range hood.
- Heating and cooling system(s). Noted type of system (all were forced air), make and model, capacity (in tons and Btuh) and whether system was zoned. Noted dimensions and location of each return and locations of filter(s) if not at the return air grille. Noted location(s) and types of thermostats. For each filter in a forced air heating or cooling system, recorded make, model and performance rating and visually assessed condition of filter; also took photo. Identified and characterized thermostat and marked location on floor plan.
- Attic. Noted whether it was vented or unvented and the type of insulation. Photographed ductwork, gas furnace, exhaust fans, and vents.
- Gas-burning appliances. Noted make, model and firing rates of all burners or photographed nameplate. Noted locations on floor plans.

Floor plans were generally obtained from builders' websites; otherwise they were sketched on site. Photos were taken of the home exterior, garage, gas appliances, mechanical ventilation equipment, air filters, and any special features.

Specification of Air Quality Monitoring Equipment

Table S1. Specifications of air pollutant monitoring equipment

Parameter	Device make and model	Range and Resolution	Accuracy in Product Literature	Other
Temperature	Onset HOBO UX100-011	Range: -20° to 70°C. Resolution: 0.024°C at 25°C	±0.21°C from 0° to 50°C	Response time: 4 min in air moving 1 m/s Drift: <0.1°C per year
Temperature	Extech SD800	0 to 50°C	±0.8°C	
Relative humidity	Onset HOBO UX100-011	Range: 1% to 95% (non-condensing); Resolution: 0.05%	±2.5% from 10% to 90%; up to ±3.5% at 25°C including hysteresis	Response time: 11 sec to 90% in airflow of 1 m/s Drift: <1% per year typical
Relative humidity	Extech SD800	Range: 10-90%	±4%RH below 70%; 4% of reading + 1% for 70–90% range	
Particulate matter, $PM_{2.5}$	MetOne ES-642 MetOne BT-645	Range: 0-100 mg/m^3. Resolution: 0.001 mg/m^3.	± 5% traceable standard with 0.6um PSL	
Carbon dioxide, CO_2	Extech SD800	Range: 0-4000 ppm; Resolution: 1 ppm	±40 ppm under 1000 ppm; ±5% >1000 ppm[a]	
Nitrogen Dioxide	Aeroqual 500 Series	Range: 0 to 1 ppm	± 0.02 ppm within 0 to 0.2 ppm range	
Formaldehyde	GrayWolf (Shinyei) Multimode Monitor	20 to 1000 ppb	± 4ppb for <40ppb, ± 10% of reading for ≥40ppb	30 min resolution; 20 ppb is lowest reliable value with stated accuracy

[a] Extech monitors did not achieve this performance when compared to a calibrated PPSystems EGM-4 in an injection-decay experiment in a small, room-sized chamber during monitoring as described in the text.

Table S2. Comparison of study design and measurement methods HENGH and CNHS studies of indoor air quality and ventilation in single family detached homes

Parameter	HENGH	CNHS
Number of Homes	70	108
Year Built (Monitoring)	2011-2017 (Jul 2016 – Apr 2018)	2002-2005 (Aug 2006 – March 2007)
Dwelling Unit Mechanical Ventilation (Operational Systems)	All 70 homes had systems that met 2008 or later California code: 64 exhaust; 6 supply.	13 homes had systems that met ASHRAE 62.2-2004: 8 balanced (HRV); 5 with duct connecting FAU to outdoors and controller for ventilation. 9 homes had duct connecting FAU to outdoors but no controller for ventilation.
Gas Cooking Appliances	Cooktops: 100% Ovens 43%	Cooktops: 2% Ovens: 27%
Natural Ventilation	Occupants agreed to not use windows for ventilation.	Occupants asked to use windows as they do normally.
Duration	~7 days	~24 hour
Locations for IAQ parameter measurements	• Living, dining or family room: $PM_{2.5}$, CO_2, NO_X, NO_2, formaldehyde. • Master bedroom: CO_2 and formaldehyde. • Other bedroom(s): CO_2 • Outside: $PM_{2.5}$, NO_X, NO_2, formaldehyde.	• Living, dining or family room: VOCs, CO_2, CO, formaldehyde in all homes; $PM_{2.5}$ in 28 homes; NO_2 in 29 homes. • Outside: formaldehyde at each cluster of 2-3 homes (n=39); $PM_{2.5}$ and NO_2 at 11 clusters.
Air Contaminant Measurement Methods	• Formaldehyde, NO_2, NO_X: time-integrated passive samplers. • Formaldehyde: colorimetric sensor/photometer, 30-min logs • $PM_{2.5}$: Estimated by photometry with indoor adjusted using time-integrated filter samples. • CO_2: Passive, NDIR, 1-min	• Formaldehyde, NO_2, 10 VOCs: time-integrated, pumped samples • $PM_{2.5}$: time-integrated pumped filter samples with size selective inlets and gravimetric analyses. • CO_2: Passive, NDIR, 1-min • CO: Passive, Electrochemical, 1-min

Parameter	HENGH	CNHS
	• T: thermistor sensor • RH: Thin film capacitive sensor	• T: thermistor sensor • RH: Thin film capacitive sensor
Air Contaminant Measurement QA/QC	• Formaldehyde, NO_X, NO_2: duplicates, field blanks, manufacturer's recommended sampling rate. • $PM_{2.5}$: zero at sample start, span adjustment calculated from simultaneous gravimetric samples at 8 indoor locations. • CO_2: baseline and span checks at middle of study. No adjustment of field data. • NO_2: baseline and span checks prior to sampling in most homes. • T and RH sensors used factory calibration with no field calibrations.	• Formaldehyde, $PM_{2.5}$, NO_2, 10 VOCs: duplicates, field blanks, sampling rate measurements at start and stop. • CO_2 and CO: zero and span calibration at start and stop of sampling at each home and corresponding adjustment of field data. • T and RH sensor calibration prior to field session and corresponding adjustment of field data.
Record of natural ventilation use.	Participant affirmed that windows would not be used for ventilation, per study requirements. Loggers on two most-used doors. No loggers or signage on windows. Daily log asked for hours that any windows were opened but not the amount opened.	Occupants instructed to operate windows normally. Loggers on windows that occupants reported to use most frequently, and signage with logs on all windows for occupants to record hours and amount opened.
Method to measure or estimate outdoor air ventilation rate	Estimated from measured mechanical airflows and modeled infiltration with unbalanced ventilation.	Measured with perfluorocarbon tracer (PFT) gas.

Abbreviations: HRV = Heat recovery ventilator; FAU = forced air unit; NDIR = non-disperse infrared.

Locations of Ambient Air Quality Monitoring Stations Used to Estimate Outdoor $PM_{2.5}$

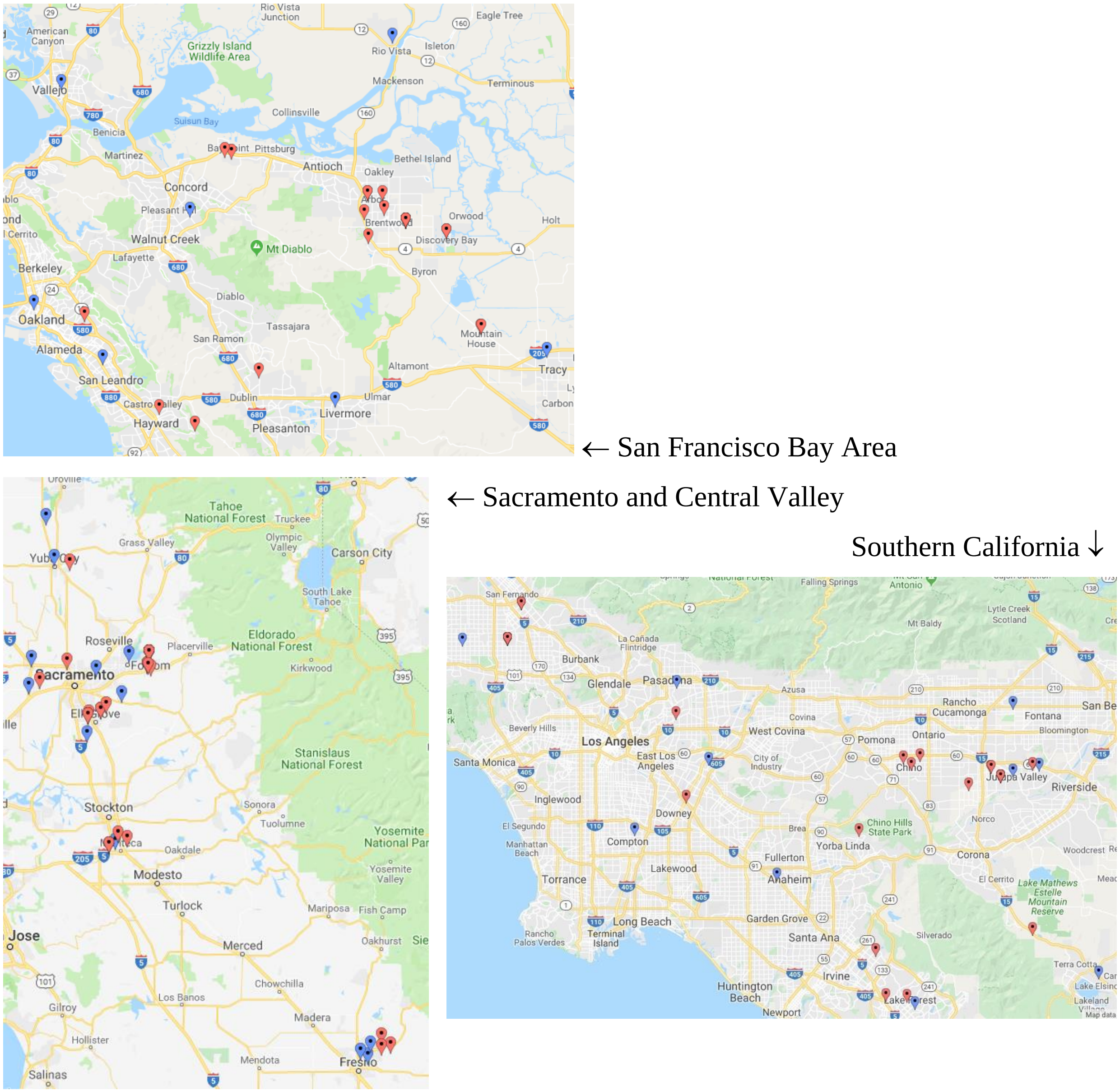

Figure S1: Locations of PM2.5 air monitoring stations (blue) in relation to study homes (red).

Quality Assurance Procedures for Air Quality Monitors

The indoor and outdoor $PM_{2.5}$ monitors were co-located for roughly one hour during the instrument deployment visit at each home. In most cases the co-location was outdoors at the location of the outdoor monitor. Co-located comparisons were available from 45 homes. In two of the homes, the two monitors measured very different concentrations likely because the outdoor monitor had a heated inlet that was set to activate when relative humidity reached above 60%, and the indoor monitor did not. The heated inlet prevents condensation that could damage the instrument. The indoor monitor did not have a heated inlet because high humidity is generally not a concern when sampling indoors. At the two homes during the one-hour co-location test, the outdoor monitor measured high concentration of $PM_{2.5}$ (51 and 60 $\mu g/m^3$ at Home 063 and 068, respectively). Without the heated inlet, the co-located indoor monitor measured 111 and 78 $\mu g/m^3$, respectively. The two homes were sampled in winter (January 2018) in Tracy and Manteca CA, where high humidity condition in the morning likely explained this difference between the co-located indoor and outdoor $PM_{2.5}$ monitors. Excluding these two cases, the co-located indoor and outdoor $PM_{2.5}$ monitors agreed to within 1.9 $\mu g/m^3$ on average (median = 0.9 $\mu g/m^3$), with the outdoor monitor reporting lower concentrations than the indoor monitor in 79% of the indoor side-by-side deployments. This is likely because the heated inlet intended to prevent condensation resulted in some volatilization of organics in the outdoor particles. The results of the brief side-by-side deployment of indoor and outdoor MetOne photometers at each home are provided in Figure S2**.**

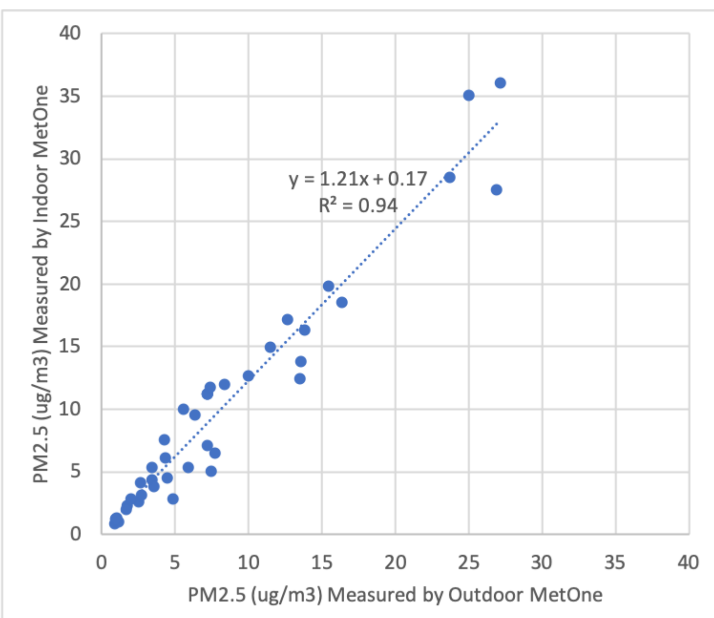

Figure S2. Results of side-by-side deployment of indoor and outdoor MetOne photometers at each house, typically outdoors.

The Extech CO_2 monitors were co-located for 1 hour at each home or at a warehouse where the field team prepared equipment before a visit. The field team confirmed that CO_2 monitors agreed with one another to within a range of 100 ppm. Extech monitors were also calibrated at LBNL during two breaks in sampling, with 5 units checked during Feb 2017 and 7 units (including two from first round) checked during Dec 2017. On each occasion, the monitors were set up in a well-mixed room along with an EGM-4 gas analyzer (PP systems, Amesbury, MA, USA). The EGM-4 was separately calibrated using standard gas of known CO_2 concentrations between 0 and 2500 ppm. During each event, CO_2 concentrations in the chamber were raised by injection of pure CO_2 then left to decay with air exchange. Hourly concentrations were calculated for each monitor. The first-hour means were 1056 and 1537 ppm for the two events. Decay periods were 26 and 7 hours to final-hour concentrations of 420 and 529 ppm. Hourly average concentrations reported by the Extech units differed (high to low range) by 71–86 ppm during the first spike-decay and 111–168 ppm during the second. Averaged over the full spike-decay intervals, differences between Extech units and the EGM-4 ranged from -20 ppm to 84 ppm.

The Aeroqual 500 NO_2 monitor was calibrated before each visit with zero gas and a 1 ppm NO_2 standard gas. Monitor response was adjusted to match those values following manufacturer instructions. Despite this calibration step, there was generally a substantial, positive offset in the time-integrated NO_2 concentration measured by the Aeroqual when compared with the concentrations measured using the passive sampler. Further processing of the Aeroqual NO_2 data is required, which is beyond the scope of this paper.

Weighing of Filters for Gravimetric $PM_{2.5}$ Determination

Gravimetric samples were collected on 37 mm diameter, 2.0 micron pore size, Pall Teflo filters with ring. Prior to deployment, filters were preconditioned for 24 hours at controlled temperature and humidity conditions (47.5 +/- 1.5 % RH and 19.5±0.5 ºC), passed over a deionizing source to remove static charge and weighed twice using a Sartorius SE2-F balance. Pre-weighed filters were loaded into the pDR-1500 photometers and were shipped to GTI for deployment. After a week of monitoring, GTI shipped the pDR monitors back to LBNL. LBNL removed the filters, and repeated the preconditioning and weighing procedures. The collected mass was determined as the post-sampling versus pre-sampling mass difference. The field blank was subtracted from the sample mass. Sampled air volume was taken from the pDR. Mass concentration was calculated as collected PM mass / sample air volume. The sample flow rate of the pDR was checked in the lab before and after each field use.

Passive Sampler Procedures and Quality Assurance

Ogawa samplers were prepared according to manufacturer protocols. Prior to assembly for field deployment, all parts of the samplers were washed thoroughly with deionized water and allowed to dry thoroughly in a laboratory at LBNL. Sample pads were stored in the refrigerator in their original packaging until they were inserted into samplers. After samplers were assembled with new sample pads, they were placed in sealed amber plastic bags (Ziploc) and shipped to the field team in an insulated box with ice packs to keep them cool.

All passive samplers were shipped to LBNL for analysis. To avoid damage to the chemical samplers from extreme temperatures, samplers were mailed in an insulated shipping container with ice packs to keep them cool. The samples were extracted and analyzed following the protocols provided by each company (Ogawa & Company 2017; SKC, Inc. 2017). All Ogawa samples were extracted for analysis within 30 days from when the samplers were assembled.

For each NO_X and NO_2 sample we subtracted the mass determined from the field blank at the same home before calculating the sample period concentrations of NO_X, NO_2 and NO as the difference between the adjusted NO_X and NO_2 concentrations. For two homes that did not have a field blank, we subtracted 0.15 micrograms for NO_2 and 0.22 micrograms for NOx, which are the mean mass determined from all available field blanks; these masses correspond to 0.9 ppb of NO_2 and 1.3 ppb of NOx for a 7-day collection period. Following blank subtraction, 4 indoor and 5 outdoor NO_2 samples and 1 indoor and 6 outdoor NO_x samples had negative concentrations; the occurrence of negative values results from variability in the blank correction and low sample masses. These negative NO_2 and NO_x concentrations were retained when calculating summary statistics. Analysis of 64-paired duplicates of indoor samples found that agreement in NO_2 concentrations was within 0.6 ppb on average (median = 0.3 ppb). When available, duplicates were averaged to provide a better estimate of the indoor concentrations of NO, NO_2, and NOx. Sampling rates were calculated using co-located temperature and relative humidity measurements following manufacturer instructions.

The formaldehyde concentration determined by passive sampler at each home also was adjusted by the effective sample period concentration determined from the field blank at the same home. For the eleven homes that did not have a formaldehyde passive sample field blank, we subtracted 0.15 micrograms, which is the mean mass determined from all available field blanks (and corresponds to 0.6 ppb for a 7-day collection period). Sixty-six paired indoor formaldehyde samples agreed to within 1.0 ppb on average (median = 0.7 ppb). When available, duplicates were averaged to provide a better estimate of the indoor concentrations. A sampling rate of 20.4 ml/min were used following manufacturer instructions.

The UMEx contains an internal blank within each sampler that can potentially be used for convenience instead of deploying a separate field blank sampler. However, analysis of the internal blank suggested that even though it was not directly exposed to the sampling air, some formaldehyde was collected, possibly because the compartment isolating the internal blank was not completely airtight. The average analyte mass determined from internal blanks of indoor samples was 0.6 micrograms; this is 4 times the field blank value noted above.

Formaldehyde indoor emission rates E ($\mu g/m^3$-h) were calculated using a simple mass-balance equation assuming well-mixed, steady state condition. The same method was applied by Offermann (2009) to estimate indoor emission rates of formaldehyde and other VOCs.

$$E = (C_i - C_o) \times AER \qquad (1)$$

Outdoor formaldehyde concentration (C_o, $\mu g/m^3$) was subtracted from the indoor concentration (C_i, $\mu g/m^3$) measured at the central location, assuming that there is no loss in formaldehyde as the outdoor air enters through the building envelope. Air exchange rate (AER, 1/h) is assumed to be the only mechanism that removals formaldehyde from the indoor air. Air exchange rate was estimated from natural infiltration airflow and mechanical airflow using sub-additivity, as described later in the Methods.

Potential Impact of Low Air Speeds on Passive Sampler Data

The sampling rates of passive samplers may be impacted by low air speeds at the sampler inlet, as discussed by Offermann and Hodgson (2018)[1] and papers cited therein. At very low air speeds, diffusive uptake to the passive sampler causes a reduction in analyte concentration at the face of the air sampler relative to the surrounding indoor air, resulting in an effective increase in the diffusive path length and lower sampling rate.

Since air speeds were not measured in HENGH homes, we rely on the data of Mathews et.al. (1989)[2] to assess the potential for low air speeds to bias the passive sampler measurements in residences. Matthews et al. used a TSI Model 1620 omnidirectional anemometer to measure air speeds during daytime hours in various rooms of six occupied homes and in an unoccupied research house. The overall median air speed measured in the six occupied homes was 318 cm/min. HVAC operation was found to substantially impact air speeds, by a factor of 5 in one house and by roughly a factor of 2 in two other occupied houses. The median measured air speeds with HVAC off in three occupied homes and the research house were 90, 198, 342, and 246 cm/min. Among the rooms studied, air speeds were lowest in the master bedroom, with median values during no HVAC use of 108 cm/min across the three occupied houses. The condition with the lowest measured air speeds was in a bedroom that was completely unoccupied; during HVAC off times median air speeds were 66 cm/min. HVAC operation was not tracked in HENGH; but the median HVAC run time was 1.1 h per 24 h in the CNHS.

Using a TSI Model 8475 omnidirectional anemometer, Offermann and Hodson reported an air speed of 27 cm/min in an unoccupied office overnight with no HVAC operation.

Using the data above as reference points, Offermann provided the following correction factors for the geometries of the UMEx and Ogawa samplers at selected air speeds.

Air Speed (cm/min)	UMEx CF	Ogawa CF
27	1.21	1.16
66	1.09	1.07
100	1.06	1.04
300	1.02	1.01

Using the daytime airspeeds measured with no HVAC operation and assuming that condition applied roughly half the time in HENGH master bedrooms, and also assuming higher airspeeds with occupancy during nighttime hours, the bias from low air speeds would be on the order of 3% for formaldehyde and 2% for NO_X and NO_2. A bedroom that is completely unoccupied during the daytime and similar to the one reported in Matthews could have a bias of 4-5% for formaldehyde and 3-4% for NO_X and NO_2. If any rooms commonly experienced conditions similar to those observed overnight in the Offermann office, the bias would be 8-10%.

[1] Offermann, F. J. and A. T. Hodgson (2018). Accurancy of Three Types of Formaldehyde Passive Samplers. Indoor Air 2018, Philadelphia PA, International Society of Indoor Air Quality Sciences.

[2] Matthews, T. G., C. V. Thompson, D. L. Wilson, A. R. Hawthorne and D. Mage (1989). "Air velocities inside domestic environments: An important parameter in the study of indoor air quality and climate." Environment International **15**: 545-550.

Adjustments to Formaldehyde Data from FM-801 Monitor

Output of the FM-801 formaldehyde monitor dropped precipitously during events of substantial gas cooking burner use, presumably owing to an NO_2 interference as described by Maruo et al.[3] FM-801data that were clearly affected by cooking were identified by visual review, considering data from the time-resolved NO_2 monitor and the cooktop and oven temperature sensors, and removed. Data marked as "<LOD" because they were below the 10 ppb quantitation limit were assigned a value of 7.3 ppb based on analysis of data from homes with the modified FM-801software that provided numerical results below 10 ppb.

Calculation of Outdoor Air Exchange Rate

First, mechanical fan flows were calculated by summing exhaust fan flows (whole house exhaust fan, and other fans in bathroom, range hood, clothes dryer) weighted by their average usage time. Since it was not practical to directly measure the airflow of the clothes dryers in most homes, we assumed dryer airflow of 125 cfm based on a recent report[4].

Airflows from mechanical fans were added to calculate balanced ($Q_{balance\_mech}$) and unbalanced ($Q_{unbalance\_mech}$) airflows by comparing minute by minute the amount of exhaust and supply air from usage data collected from each home. Next, air infiltration ($Q_{infiltration}$) was calculated using the flow coefficients and pressure exponents from average of pressurization and depressurization tests of building envelope leakage, determined as part of the DeltaQ Test, and using stack and wind coefficients following the ASHRAE Fundamentals Enhanced Model. Wind data were obtained from the nearest weather station[5]. Indoor and outdoor temperatures were monitored onsite. Photos of the house and surroundings were reviewed to determine the appropriate shelter class: either 4 (urban building on larger lots where sheltering obstacles are *more than* one building height away) or 5 (shelter produced by buildings or other structures that are *closer than* one house height away). The total ventilation rate was calculated following Equation 2, which uses a superposition adjustment (∅) to account for the sub-additivity of unbalanced mechanical airflows with air infiltration.

$$Q_{total} = Q_{balance\_mech} + Q_{unbalance\_mech} + \emptyset Q_{infiltraiton} \quad (1)$$

$$\emptyset = \frac{Q_{infiltration}}{Q_{unbalance\_mech} + Q_{infiltration}} \quad (2)$$

Field teams measured ceiling heights in the great room, kitchen, living room, dining room, bedrooms, and other parts of the house. Air exchange rate was computed using an approximate house-averaged ceiling height and floor area recorded by the field team.

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[3] Maruo, Y. Y., T. Yamada, J. Nakamura, K. Izumi and M. Uchiyama (2010). "Formaldehyde measurements in residential indoor air using a developed sensor element in the Kanto area of Japan." Indoor Air **20**(6): 486-493.

[1] ENERGY STAR reports rated fan flow of clothes dryer typically range between 100 and 150 cfm. https://www.energystar.gov/sites/default/files/asset/document/ENERGY_STAR_Scoping_Report_Residential_Clothes_Dryers.pdf

[5] Data obtained from www.wunderground.com. During periods when wind was reported as "calm", 1 mph (mile per hour) was assumed for calculating air infiltration rate.

Estimate of Potential Bias in Calculated Air Infiltration

While the ASHRAE Enhanced Model was developed from an extensive set of measured data and has been evaluated in several previous studies[6,7,8], it is nevertheless valuable to consider that it could have varied performance in specific applications.

For this study, we used data from the CNHS – which measured time-integrated outdoor air ventilation rates using perfluorocarbon tracer gases (PFTs) – to evaluate the method used to calculate the infiltration portion of air exchange in HENGH, which measured mechanical airflows but calculated infiltration and overall AER.

The analysis looked at 13 CNHS homes that that had no window opening and no continuous mechanical ventilation (just occasional bathroom, kitchen, and clothes dryer exhausts); the overall AERs in these homes were thus dominated by infiltration. For these 13 homes, we calculated infiltration/air exchange in the same manner as was done for the HENGH study. (The only difference was that the calculation was done with 1-minute indoor temperature and intermittent exhaust fan data for HENGH and 15-minute data for CNHS. The calculations used the following parameters:

- default stack and wind coefficients for n=0.67;
- on-site data for indoor air temperature and local Meteorological Station data for outdoor air temperatures and wind speeds;
- setting all 0 mph wind speeds to 1 mph;
- using the interpolated ASHRAE Fundamentals Shelter Factors;
- combining any intermittent mechanical airflow with infiltration using sub-additivity;
- calculating the weekly integrated AER as the harmonic mean of 15-min estimates.

For each of the 13 CNHS homes, we compared the AER measured by PFT to the calculated AER to determine a correction factor, which we consider to be applicable to the calculated infiltration portion of AER. The median correction factor for the 13 homes was 1.81 with a range of 1.04 – 2.11. While this is high compared to published comparisons of measurements to infiltration model calculations, our hypothesis is that it is mostly due to the difficulty in selecting appropriate wind shelter factors.

Since most of the HENGH homes had continuous mechanical exhaust systems, infiltration accounted for only a fraction of the total outdoor air exchange. To assess the potential impact of infiltration bias calculated for the CNHS homes on the AERs calculated for HENGH homes, we

[6] Walker, I.S. and Wilson, D.J., (1998), "Field Validation of Equations for Stack and Wind Driven Air Infiltration Calculations", ASHRAE HVAC&R Research Journal, Vol. 4, No. 2, pp. 119-140. April 1998. ASHRAE, Atlanta, GA. LBNL 42361.

[7] Francisco, P. and Palmiter, L. (1996). "Modeled and Measured Infiltration in Ten Single-Family Homes. Proc. ACEEE 1996.

[8] Wang, W., Beausoleil-Morrison, I. and Readon, J. 2008. Evaluation of the Alberta Air Infiltration Model Using Measurements and Inter-Model Comparisons. Building and Environment, 44. 309-318. doi:10.1016/j.buildenv.2008.03.005c

adjusted the calculated infiltration rates for all HENGH homes by a factor of 1.81, then used sub-additivity to combine the adjusted infiltration rates with the measured mechanical ventilation rates on a home-by-home basis. The median calculated adjustment factor for the total ventilation rates for HENGH homes is 1.18.

In addition to the potential bias from infiltration calculations, the calculated AERs for HENGH homes are also biased in some cases because the calculation assumed no window or door opening; any substantial use of windows or doors for ventilation would further raise AERs relative to calculated values.

Results

House Characteristics

Table S3. Sampled Homes by Cities and Climate Zones (N=70)

Gas Utility Service	Cal. Climate Zone	Cities (Number of Homes)	Homes	Total
PG&E	3	Discovery Bay (2), Hayward (2), Oakland (1)	5	48
	11	Marysville (1)	1	
	12	Brentwood (12), El Dorado Hills (10), Elk Grove (6), Manteca (4), Mountain House (2), Pittsburg (2), Davis (1), Dublin (1), Sacramento (1)	39	
	13	Clovis (3)	3	
SoCalGas	8	Irvine (2), Downey (1), Lake Forest (1), Yorba Linda (1)	5	22
	9	Van Nuys (5), Alhambra (1)	6	
	10	Jurupa Valley (5), Chino (4), Corona (1), Eastvale (1)	11	

Table S4. Sampled Homes by Seasons

Season	Months	Number of Homes
Winter	Dec-Feb	16
Spring	Mar-May	13
Summer	Jun-Sep	27
Fall	Oct-Nov	14
Total		70

Table S5. Sampled Homes by Year Built

Year Built	Number of Homes
2011	1
2012	7
2013	13
2014	17
2015	15
2016	14
2017	3
Total	70

Table S6. Age of Homes When Sampled[1]

HENGH Age When Sampled (years)	HENGH Number of Homes at Age	CNHS Percentile	CNHS Age When Sampled (years)
<1	2	Min	1.7
1	14	10th	2.4
2	32	25th	3.0
3	14	50th	3.4
4	4	75th	4.0
5	2	90th	4.3
No Response	2	Max	5.5
Total	N=70	N=108	

[1] CNHS data from Table 15 of Offermann et al. (2009)

Table S7: Sampled Homes by Floor Area

Floor Area (ft^2)	Homes	Floor Area (m^2)	Homes
<1500	5	<150	9
1500–1999	11	150–199	12
2000–2499	16	20–-249	15
2500–2999	16	250–299	22
3000–3499	14	300–349	6
≥3500	8	≥3500	6
Total	70	Total	70

Table S8: Sampled Homes by Number of Stories

Stories	Number of Homes
1	27
2	42
2.5	1
Total	70

Table S9: Sampled Homes by Number of Bedrooms

Bedrooms	Number of Homes
1	1
2	3
3	20
4	28
5	17
6	1
Total	70

Table S10: Sampled Homes by Number of Bathrooms

Bathrooms	Number of Homes
1–1.5	1
2–2.5	24
3–3.5	35
4–4.5	9
5–5.5	1
Total	70

Table S11: Locations of Gas Fireplaces

Location	Homes
Great room or living room	26
California room	3
Courtyard	1
Patio	2
No gas fireplace	38
Total	70

Household Demographics

HENGH homes are compared with data from American Housing Survey (2017 AHS). Data from the Public Use File (PUF)[9] were used to compare with demographic data of HENGH homes. The PUF provided data for four California metropolitan areas that were surveyed in 2017: Los Angeles-Long Beach-Anaheim, San Francisco-Oakland-Hayward, Riverside-San Bernardino-Ontario, and San Jose-Sunnyvale-Santa Clara. The first three of the four metropolitan areas were included in the national survey, and the last one was included in the metropolitan survey. Data from owner-occupied, single-family detached homes built after 2010 were selected from the 2017 AHS data for comparison with HENGH homes in the tables below.

Table S12: Number of Occupants in Sampled Homes

Number of Occupants	Number of Homes in HENGH	% Homes in HENGH	% Homes in 2017 AHS
1	3	4%	13%
2	29	43%	28%
3	10	15%	18%
4	13	19%	24%
5	6	9%	9%
6	3	4%	5%
7 or more	3	4%	2%
No response	3	--	--
Total	70	100%	100%

[9] https://www.census.gov/programs-surveys/ahs/data/2017/ahs-2017-public-use-file--puf-.html

Table S13: Number of Occupants in Sampled Homes by Age Group

Number of Occupants Within Age Group	Homes with Designated Number of Occupants in Designated Age Group								
	Number of HENGH			% HENGH Homes			% Homes in 2017 AHS		
	Age 0–17	Age 18–65	Age 65+	Age 0–17	Age 18–65	Age 65+	Age 0–17	Age 18–65	Age 65+
0	41	8	49	60%	12%	72%	59%	12%	74%
1	7	7	10	10%	10%	15%	19%	17%	14%
2	14	41	9	21%	60%	13%	18%	42%	11%
3	3	8	0	4%	12%	0%	4%	15%	0%
4	2	2	0	3%	3%	0%	0%	9%	0%
5 or more	1	2	0	1%	3%	0%	0%	5%	0%
No response	2	2	2	--	--	--	--	--	--
Total	70	70	70	100%	100%	100%	100%	100%	100%

Table S14: Total Household Income in Sampled Homes

Income Range	Number of Homes in HENGH	% Homes in HENGH	% Homes in 2017 AHS
$35,000–$49,999	1	2%	18%
$50,000–$74,999	2	3%	12%
$75,000–$99,999	5	8%	10%
$100,000–$150,000	29	44%	20%
Greater than $150,000	29	44%	40%
No response	4	--	--
Total	70	100%	100%

Table S15: Education Level of Head of Household in Sampled Homes

Education Level	Number of Homes in HENGH	% Homes in HENGH	% Homes in 2017 AHS
No diploma	0	0%	6%
Completed high school	1	1%	16%
Some college	5	7%	15%
Associate's degree	2	3%	7%
College degree	23	34%	30%
Graduate or professional degree	36	54%	26%
No response	3	--	--
Total	70	100%	100%

Air Tightness

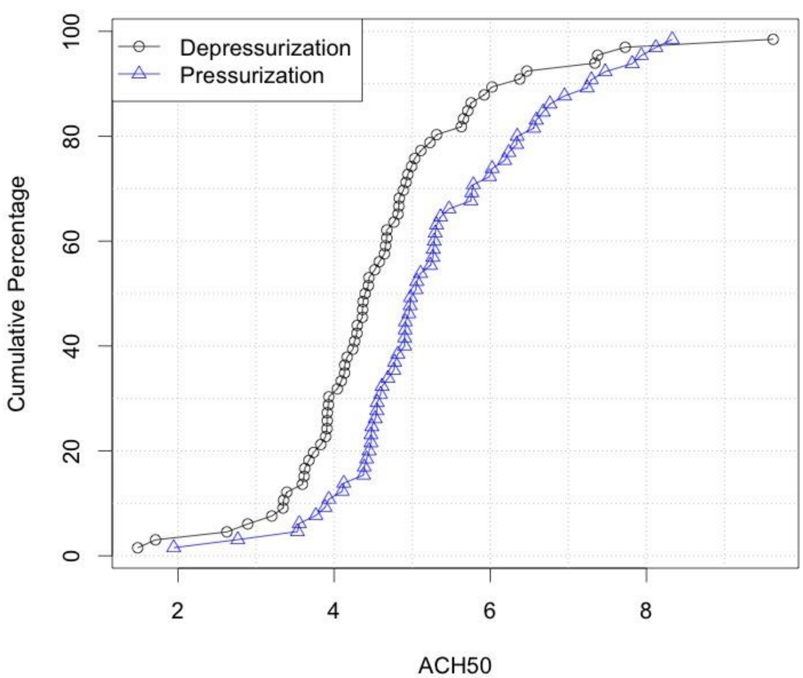


Figure S3: Distribution of ACH50 from Envelope Leakage Measurements

Ventilation and Filtration Equipment

Table S16: Whole House Ventilation System Type

System Type	Operation Mode	Fan Location(s)	Number of Homes
Exhaust	Continuous	Laundry Room	43
		Bathroom	9
		Attic	3
	Intermittent	Laundry Room	5
		Bathrooms (multiple)	4
Supply	Continuous	Attic	4
	Intermittent	None*	2
Total			70

*These central fan integrated supply (CFIS) systems had a duct with motorized damper that connected the outdoors to the return side of the forced air system, but no supply fan.

Table S17: Whole House Ventilation System Control

Whole-House Ventilation Control	Controller Labelled?	% On As-Found
On/Off Switch	No (N=42)	5%
	Yes (N=12)	58%
Programmable Controller	No (N=10)	50%
Thermostat	No (N=2)	0%
Breaker Panel	No (N=1)	100%
No Controller	No (N=3)	100%

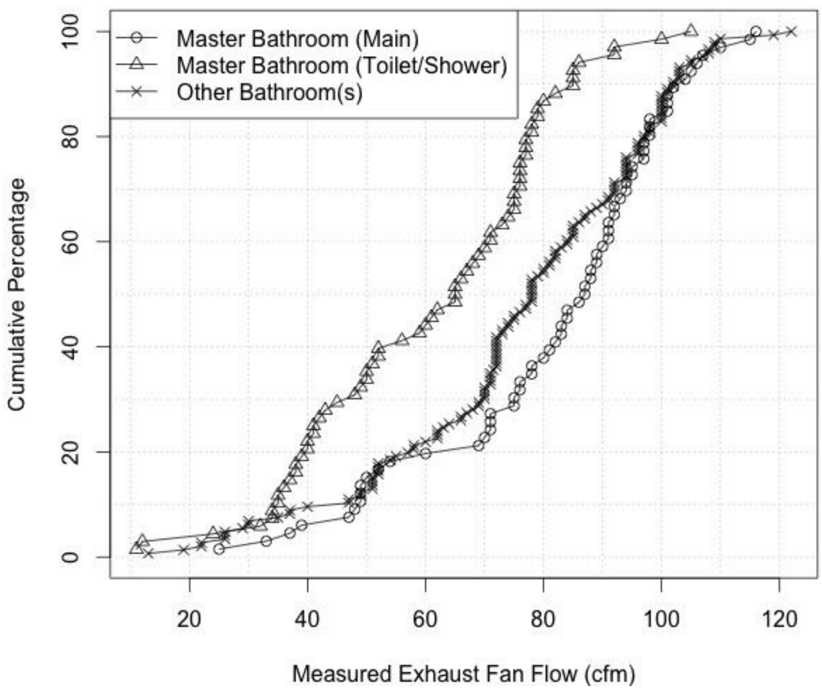


Figure S4: Bathroom Exhaust Fan Measured Flow Rates

Table S18: Air Filter MERV Ratings

MERV	Number of Air Filters
6	2
7	2
8	57
10	17
11	22
12	1
13	9
14	1
Total	111

Table S19: Time Since Last Air Filter Change

Marked or Estimated Time	Number of Air Filters
0 to 2 Months	33
3 to 5 Months	16
6 to 8 Months	17
12 to 15 Months	8
Never Changed	11
Total	85

Table S20: Condition of Air Filters Observed by Field Team

Air Filter Condition	Number of Homes	Number of Air Filters
Clean or Like New	20	39
Used or Dirty	29	65
Very Dirty	18	24
Total	67*	128

* Total excludes one home (113) without a central forced air system (this home had a minisplit heat pump with no filter for air quality), one home (127) without any air filters installed in the return air registers, and one home (117) for which field observations were missing.

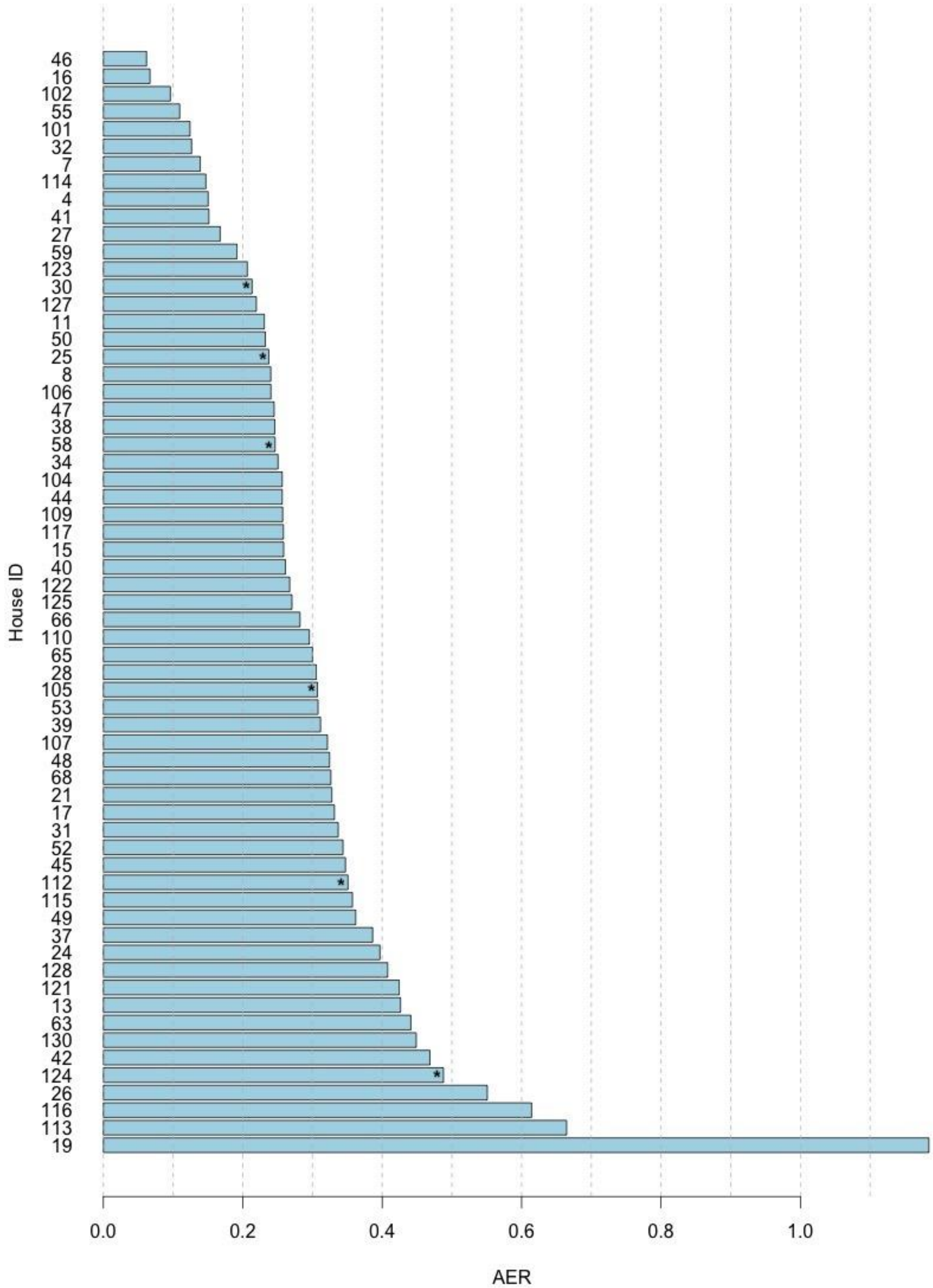


Figure S5: Total Estimated Air Exchange Rate

This plot includes estimates for 63 homes. It excludes four homes that used supply ventilation because the mechanical airflow could not be determined. The plot also excludes three homes with missing DeltaQ test result because building envelope airtightness is required to calculate air infiltration (part of total ventilation). There are six homes (*) where opening of the house-to-patio and/or garage door(s) for more than 3 hours per day on average may have increased the overall AER substantially.

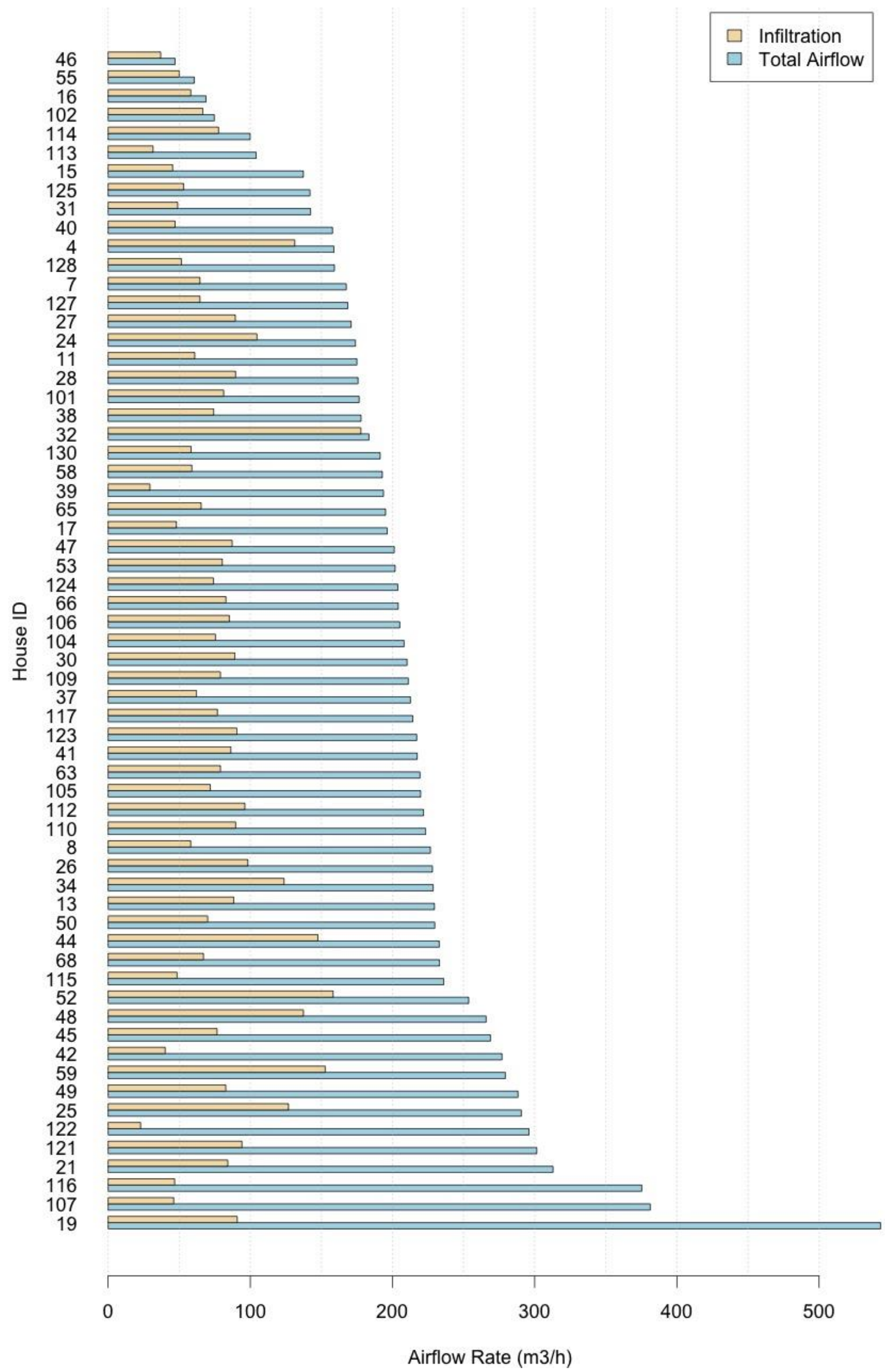


Figure S6: Infiltration and Total Airflow (Mechanical + Infiltration)

Mechanical airflow rates were calculated by summing all exhaust fans in a home. The estimated total outdoor airflow rates include both mechanical airflow and air infiltration. Data are plotted for 63 homes same as in Figure S5.

General Occupancy and Sources – From Survey

Table S21: How Frequently Are Candles Used in the Home

	Number of Homes
Never	13
A few times a year	23
A few times a month	16
A few times a week	11
Every day	5
No response	2
Total	70

Table S22: Number of Furry Pets in Homes

Number of Pets	Number of Homes
0	20
1	17
2	12
3	3
4 or more	2
No response	16
Total	70

Occupancy and Sources During Week of Monitoring

Table S23: Self-Reported Average Occupancy (Number of People) When Home Was Occupied

Average Occupancy	Number of Homes	Average Occupancy	Number of Homes
1 to <2 People	23	5 to <6 People	4
2 to <3 People	20	6 to <7 People	3
3 to <4 People	14	No Response	2
4 to <5 People	4	Total	70

Table S24: Self-Reported Average Occupied Hours per Day During Monitoring Week

Number of Occupied Hours	Number of Homes
> 23 Hours	16
20 to <23 Hours	27
16 to <20 Hours	17
12 to <16 Hours	3
6 to <12 Hours	3
< 6 Hours	2
No Response	2
Total	70

Table S25: Self-Reported Cooktop Use (Number of Times) During Monitoring Week

Number of Cooktop Use	Number of Homes
None	2
1–3 Times	16
4–6 Times	16
7–14 Times	26
15–21 Times	6
More than 21 Times	2
No Response	2
Total	70

Table S26: Self-Reported Oven and Outdoor Grill Use During Monitoring Week

	Number of Homes	
Number of Uses	**Oven**	**Outdoor Grill**
None	16	52
1 Time	14	9
2–3 Times	21	7
4–5 Times	11	0
6–8 Times	6	0
No Response	2	2
Total	70	70

Table S27: Average Cooking Activity Duration During One-Week Monitoring, Self-Reported

	Number of Homes		
Use Duration	**Cooktop**	**Oven**	**Outdoor Grill**
Less than 10 Minutes	3	3	0
10–30 Minutes	40	20	5
30–60 Minutes	20	24	8
>60 Minutes	3	5	3
No Usage Reported	2	16	52
No Response	2	2	2
Total	70	70	70

Table S28. CNHS Activities (Table 42 and 43 of Offermann et al. 2009):

- Toasting: n=50, median of 5 min
- Frying or sautéing: n=36, median of 17 min
- Baking: n=33, median of 45 min
- Broiling: n=11, median of 19 min
- Other cooktop: warming/boiling, n=47, median of 20 min
- Vacuuming: n=16, median of 25 min
- Sweeping or dusting: n=16, median of 12 min
- Candle burning, n=4 events, median of 165 min.
- Aerosol air fresheners or personal care products: n=30
- Large party or dinner gathering: n=3
- Other activities: dust, smoke or fumes: n=3, median 30 min

Air Pollutant Concentrations: Formaldehyde

Table S29 presents a comparison of formaldehyde measurements made at the main indoor site with the UMEx-100 time-integrated sampler and the weeklong average of the half-hourly resolved data obtained with the FM-801 monitor. Statistical significance tests suggest no difference in formaldehyde concentrations measured using the two methods: p-value = 0.09 (Student's paired t-test).

Table S29: Comparison of Time-Integrated Formaldehyde Measured with Two Methods

	SKC UMEx-100 Passive Sampler	GrayWolf FM-801 Monitor
Indoor Main (ppb)	N = 68	N = 69
Mean	19.8	18.9
Median	18.2	18.8
10^{th}–90^{th} Percentile	13–28	10–27

Similar to the finding (reported in the main paper) that formaldehyde measured by the UMEx was higher in the bedroom than at the main indoor site, FM-801 data collected in the bedroom also indicated higher period-averaged formaldehyde compared to data collected in the main indoor site (p-value = 4.5e-5 using Student's paired t-test). Among the 65 homes with valid FM-801 data in both locations, formaldehyde in the bedroom was >10% higher than in the living room in 35 homes and less than 90% in 4 homes. The median and 10^{th}–90^{th} ratios of bedroom to living room concentrations were 1.13 and 0.97–1.44. Using data from the FM-801, overnight concentrations in the bedroom were higher than the period-average at that location (p-value = 5.4e-6 using Student's paired t-test). Formaldehyde in the bedroom overnight was >10% higher than the period-average living room in 38 homes and less than 90% in 3 homes. The median and 10^{th}–90^{th} ratios of bedroom overnight to period-average living room concentrations were 1.19 and 0.97–1.52.

Air Pollutant Concentrations: $PM_{2.5}$

A comparison of time-integrated $PM_{2.5}$ measured with the MetOne and Thermo pDR photometers and co-located gravimetric samples are provided in Table S30. **Table S30**

Table S30. Time-integrated $PM_{2.5}$ concentrations measured by MetOne and Thermo pDR-1500 photometers compared with gravimetric analysis of co-located filter samples.

House	City	Dates	MetOne	pDR	Filter	Filter/ MetOne	Filter/ pDR
Indoor PM2.5 (ug/m^3)							
025	Hayward	2017-03-23 to 03-30	3.7	4.5	4.7	1.3	1.1
026	Davis	2017-04-18 to 04-25	2.8	4.3	4.2	1.5	1.0
040	Discovery Bay	2017-05-23 to 05-30	2.1	3.2	2.8	1.3	0.9
029	Brentwood	2017-06-09 to 06-16	3.1	3.8	3.7	1.2	1.0
047	Clovis	2017-10-12 to 10-19	31.9	30.1	23.5	0.7	0.8
046	Clovis	2017-11-08 to 11-15	5.1	6.9	5.0	1.0	0.7
068	Manteca	2018-01-24 to 01-31	2.6	4.2	3.6	1.4	0.9
066	Manteca	2018-02-05 to 02-12	2.7	4.3	4.0	1.4	0.9
Outdoor PM2.5 (ug/m^3)							
025	Hayward	2017-03-23 to 03-30	NA	5.6	4.1	NA	0.7
026	Davis	2017-04-18 to 04-25	NA	3.4	4.4	NA	1.3
040	Discovery Bay	2017-05-23 to 05-30	4.5	5.1	4.8	1.1	0.9
029	Brentwood	2017-06-09 to 06-16	3.0	3.9	3.4	1.1	0.9
047	Clovis	2017-10-12 to 10-19	25.5	30.3	19.6	0.8	0.6
046	Clovis	2017-11-08 to 11-15	6.0	NA	NA	NA	NA
068	Manteca	2018-01-24 to 01-31	20.2	18.2	10.6	0.5	0.6
066	Manteca	2018-02-05 to 02-12	14.0	12.4	5.6	0.4	0.4

Analysis of Regulatory Air Monitoring Data to Estimate $PM_{2.5}$ Outside of HENGH Homes

We investigated the possibility of using regulatory ambient air monitoring station data to develop correction factors for photometers outside of the homes. We identified up to three regulatory air monitoring stations near each of the study home. Figure S1 show locations of the air quality monitoring stations in relationship to the study home. The air monitoring stations were all located within 30 km of the study home, selected to broadly represent the air quality at that location. Air monitoring stations sited to monitor near-road concentrations (located within 100 m of a major roadway) were excluded to avoid biases from traffic emissions. The daily mean $PM_{2.5}$ were obtained from AQMIS.

We applied inverse distance weighting to calculate the daily mean $PM_{2.5}$ at the study home, and calculated the mean $PM_{2.5}$ for the monitoring period (~6 days). Results of the inverse distance weighted ambient monitoring data are compared with the outdoor $PM_{2.5}$ measured using MetOne photometer in **Error! Reference source not found.**.

Table S31 shows the differences in mean $PM_{2.5}$ measured using the MetOne photometer and inverse distance weighted ambient monitoring data. Because the ambient monitoring data obtained from AQMIS are daily means, the results presented in Table S31Table S31 considered only days with full 24-h data as monitored by the MetOne photometer (i.e., partial days on first and last day of monitoring were excluded). The mean, median, and 10th percentile estimates of PM2.5 measured by the MetOne photometer were less than what was measured at the corresponding ambient monitoring station. This suggests that the MetOne photometer may have underestimated the outdoor PM2.5 relative to the ambient monitoring data at some of the homes. However, the reverse is true for other homes such that the MetOne photometer measurements were higher than the ambient monitoring data when compared at 90th percentile. No correction factor is applied to outdoor MetOne because of a lack of consistency when compared with the ambient monitoring data.

Table S31. Summary statistics (N=67) of the mean outdoor PM2.5 measured using MetOne photometer and inverse distance weighted ambient monitoring data.

	MetOne photometer (ug/m^3)	Nearby ambient air quality monitoring stations (ug/m^3)
Mean	9.3	10.5
Median	6.8	9.7
10th–90th	2.7–18.1	5.3–16.7

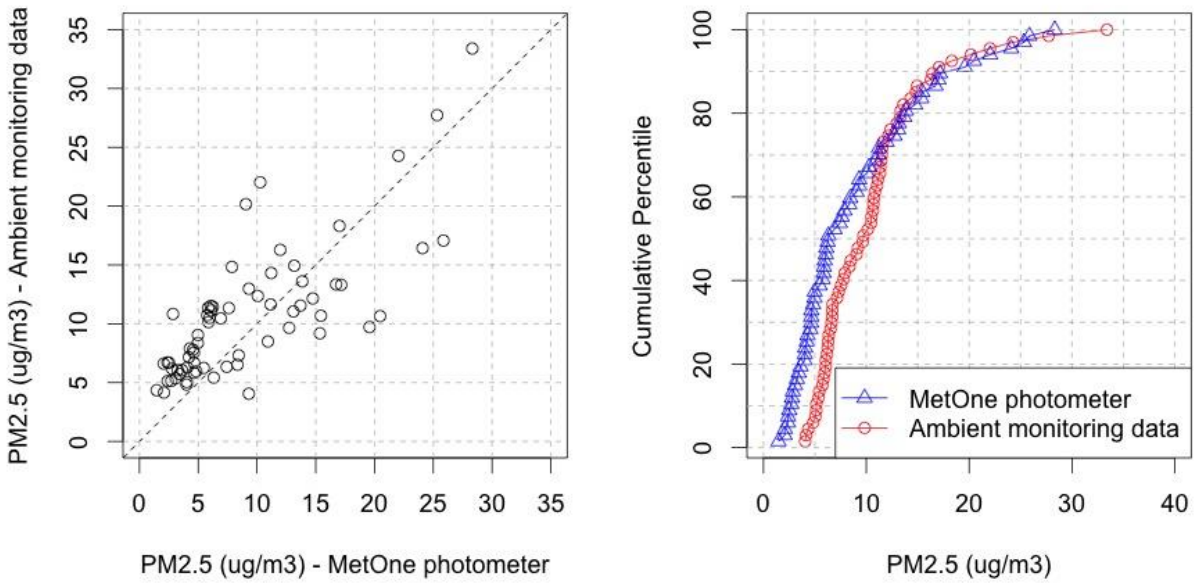


Figure S7. Comparison between mean outdoor $PM_{2.5}$ measured using MetOne photometer and inverse distance weighted ambient monitoring data (N=67).

Air Pollutant Concentrations: Nitrogen Dioxide and Nitric Oxide

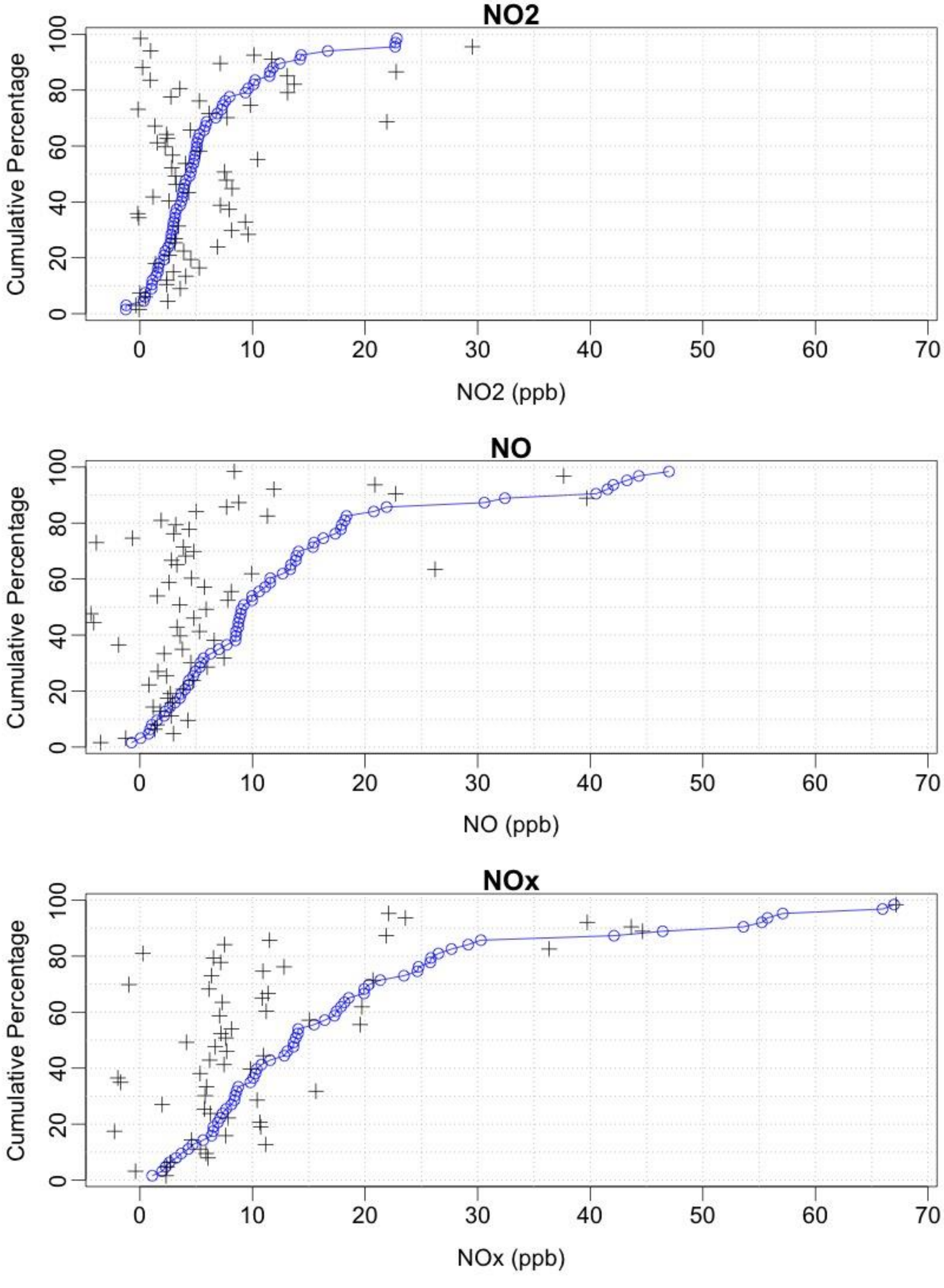


Figure S8: One-Week Integrated NO2, NO, and NOx Concentrations

Ranked ordered by indoor concentrations (blue circles), with corresponding outdoor concentrations plotted as black crosses.

Air Pollutant Concentrations: CO_2

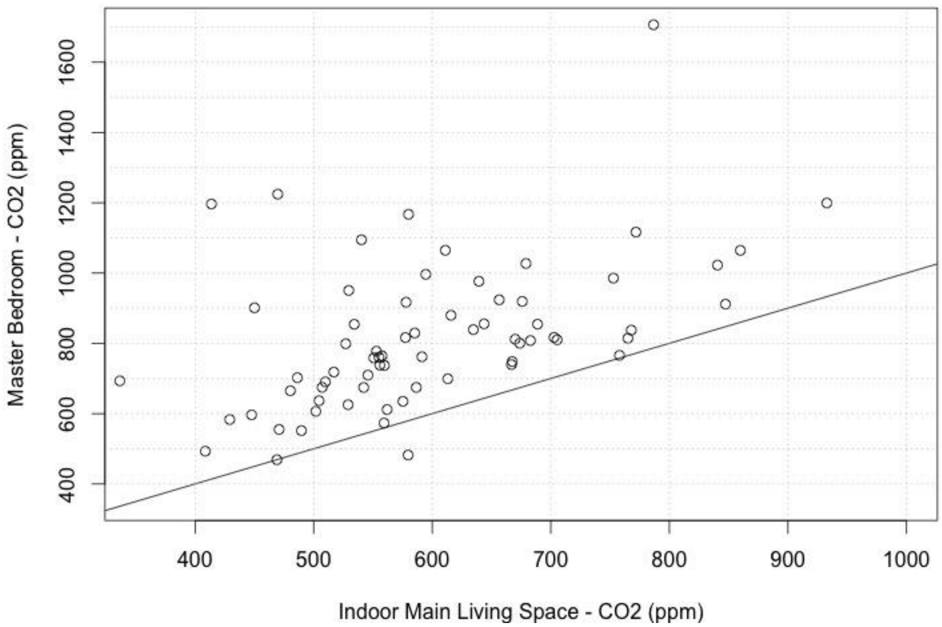


Figure S9: Overnight (midnight-5am) CO_2 measurements in indoor main living space and master bedroom.

IEQ Satisfaction by Ventilation System Operation

Tables S33 to S35 present air quality and comfort satisfaction reported by participants, divided by whether the dwelling unit ventilation system was operating when the research team arrived to the home. The Fisher's exact test for count data was performed to determine if there is an association between the ventilation system operating at that time and satisfaction. Survey responses for satisfaction were scored using a scale between 1 and 9. For the Fisher's test, satisfaction responses were classified into four groups: dissatisfied (1–4), neutral (5), satisfied (6–7), and very satisfied (8–9). Survey responses for frequency of a discomfort were provided using a 5-level scale: (i) never, (ii) a few times a year, (iii) a few times a month, (iv) a few times a week, and (v) every day. For the Fisher's test, frequency responses were classified into two groups: infrequent (i, ii, or iii) and frequent (iv or v).

Table 32. Air quality satisfaction reported by participants.

	To what extent are you satisfied or dissatisfied with indoor air quality in your home?		How would you rate the outdoor air quality where you live?		How would you rate your home in protecting you from outdoor air pollution?	
Ventilation As-Found	Off	On	Off	On	Off	On
Dissatisfied	3	3	11	8	3	2
Neutral	13	3	9	2	18	3
Satisfied	17	4	17	6	15	6
V. Satisfied	17	8	10	2	14	7
p-value	0.375		0.413		0.444	

Table 33. Satisfaction with seasonal temperature conditions by ventilation system status on first visit to home.

	Winter / Some rooms are too hot[1]		Winter / Some rooms are too cold[1]		Summer / Some rooms are too hot[1]		Summer / Some rooms are too cold[1]	
Ventilation As-Found	Off	On	Off	On	Off	On	Off	On
Infrequent	41	13	36	10	37	9	45	15
Frequent	6	4	12	8	13	9	2	1
p-value	0.435		0.144		0.081		1	

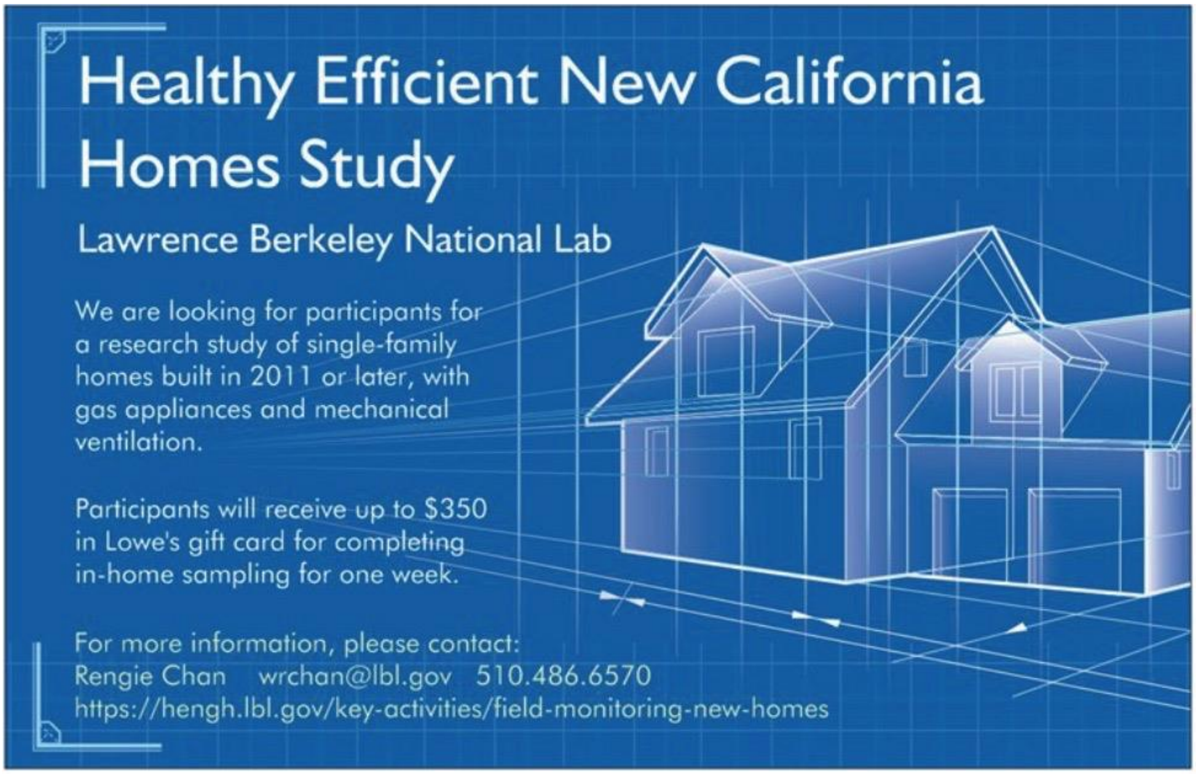
[1] Survey question: In [season], how often is the temperature in your home uncomfortable to any occupants because [condition]?

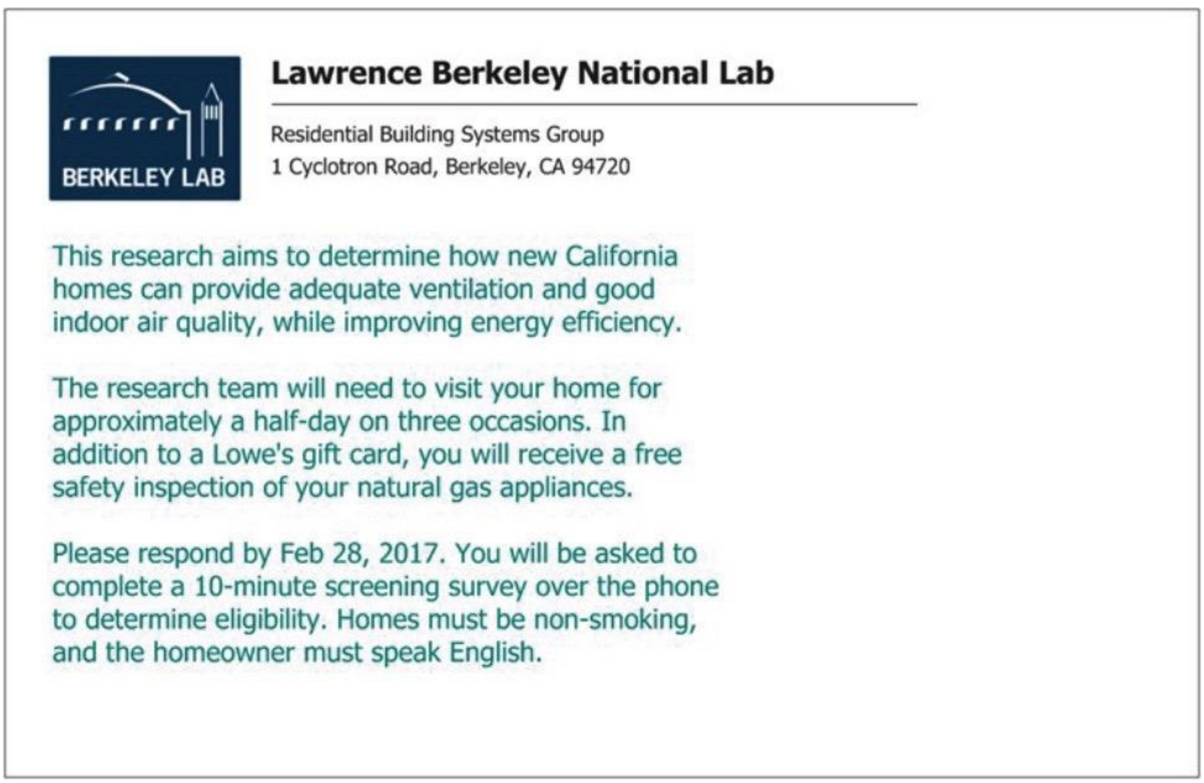
Table 34. Satisfaction with environmental parameters by ventilation system status on first visit to home.

	Too much air movement		Not enough air movement		Indoor air is too dry		Indoor air is too damp		Indoor air has musty odor	
Ventilation As-Found	Off	On	Off	On	Off	On	Off	On	Off	On
Infrequent	48	18	41	11	43	17	49	18	48	17
Frequent	1	0	8	7	5	1	1	0	1	0
p-value	1		0.094		1		1		1	

[1] Survey question: How often do the following conditions affect the comfort of occupants in your home? Frequent is on weekly or daily basis.

Recruitment Postcard





BERKELEY LAB

Lawrence Berkeley National Lab

Residential Building Systems Group
1 Cyclotron Road, Berkeley, CA 94720

This research aims to determine how new California homes can provide adequate ventilation and good indoor air quality, while improving energy efficiency.

The research team will need to visit your home for approximately a half-day on three occasions. In addition to a Lowe's gift card, you will receive a free safety inspection of your natural gas appliances.

Please respond by Feb 28, 2017. You will be asked to complete a 10-minute screening survey over the phone to determine eligibility. Homes must be non-smoking, and the homeowner must speak English.

Daily Activity Log

Provided below is the top page of the activity log. Participants were asked to complete a log table for each calendar day during which measurements were being made in the home. Participants were provided with paper sheets containing a log for each day.

Healthy Efficient New California Homes Study
Occupancy and Indoor Activities Data Log

<u>Instructions</u>: Please fill out this data log each day, or on the following day.

Please enter your best estimates. If you are unsure, please provide your best guess.
Do not list the names of any people.

Code number for home _________

Day 1: Date __________________ Date completed _______________

	Midnight to 7am	7am to 11am	11am to 1pm	1pm to 5 pm	5pm to 9pm	9pm to Midnight
Number of people in home						
Cooktop use Number of minutes						
Oven use Number of minutes						
BBQ/outdoor grill Number of minutes						
Vacuuming Number of minutes						
Window Use Number of minutes						
Other notable* indoor/outdoor events						

* For example, use of fireplace, candle, air freshener, air cleaner, humidifier, unusual outdoor air quality (wood smoke, wildfire), and so on.

Occupant Survey

Welcome to the 2015 California New Homes Survey!

This survey is part of a research study on new homes in California. This research will help inform how new homes can provide adequate ventilation and good indoor air quality, while reducing air infiltration and energy use.

This survey takes about 15 minutes to complete. It asks questions about your home, household activities, and demographics. You can skip questions that you do not want to answer.

This research is being conducted by Lawrence Berkeley National Laboratory (LBNL) with funding from the California Energy Commission. Results will be used only for research on how to provide adequate ventilation and improve indoor air quality. In order to protect your privacy, the data will be encrypted and password protected.

Please return your completed survey in the envelope provided.

If you have questions about the research study, please contact:

Max Sherman, Ph.D.

Principal Investigator, Residential Building Systems Group

Lawrence Berkeley National Laboratory

mhsherman@lbl.gov (510) 486 4022

Code number for home __________ Date completed ________________

Please answer to the best of your knowledge. You can skip any questions that you do not want answer.

A. Home and Household Characteristics

1. What year was your house built?
   Year Built: ………………

2. What is the size (floor area) of your home?
   Square Feet: ………………

3. What year did you move into this home?
   Year Moved In: ……………….

4. Do you own or rent your home?
   ……. Own (If yes → 5, skip otherwise)
   ……. Rent
   ……. Other

5. Are you the first owner of the property? Yes / No

6. How many people currently live in your home?
   Number of People: ……………..

B. Air Quality In and Around Your Home

7. To what extent are you satisfied or dissatisfied with the <u>indoor air quality</u> in your home?

Very Dissatisfied				Neutral				Very Satisfied
☐	☐	☐	☐	☐	☐	☐	☐	☐

8. How would you rate the <u>outdoor air quality</u> near where you live?

Very Poor				Neutral				Excellent
☐	☐	☐	☐	☐	☐	☐	☐	☐

9. How would you rate your home in protecting you from outdoor air pollution?

Very Ineffective				Neutral				Very Effective
☐	☐	☐	☐	☐	☐	☐	☐	☐

C. Comfort Level in Your Home

10. In <u>winter</u>, how often is the temperature in your home uncomfortable to any occupants because some room(s) are too hot or too cold?

	Never	Few times a year	Few times in a month	Few times a week	Every day
Too hot in some room(s).	☐	☐	☐	☐	☐
Too cold in some room(s).	☐	☐	☐	☐	☐

11. In <u>summer</u>, how often is the temperature in your home uncomfortable to any occupants because some room(s) are too hot or too cold?

	Never	Few times a year	Few times a month	Few times a week	Every day
Too hot in some room(s).	☐	☐	☐	☐	☐
Too cold in some room(s).	☐	☐	☐	☐	☐

12. How often do the following conditions affect the comfort of occupants in your home?

	Never	Few times a year	Few times a month	Few times a week	Every day
Too much air movement.	☐	☐	☐	☐	☐
Not enough air movement.	☐	☐	☐	☐	☐
Indoor air is too dry.	☐	☐	☐	☐	☐
Indoor air is too damp.	☐	☐	☐	☐	☐
Indoor air has musty odor.	☐	☐	☐	☐	☐

D. Natural Gas Appliances and Mechanical Ventilation

13. Which of the following heating appliances are used in your home? Select all that apply.
    .... Central gas furnace
    .... Gas fireplace/ log set
    .... Gas wall furnace
    .... Freestanding gas heater
    .... Central electric heating or heat-pump
    .... Baseboard electric wall heater
    .... Freestanding electric heater
    .... Wood fireplace
    .... Freestanding propane heater
    .... Freestanding kerosene heater
    .... Other. Please describe: ....
    .... Don't know

14. How often is the kitchen range hood or kitchen exhaust fan used when cooking with a cooktop?
    .... Always (5 out of 5 times)
    .... Most of the Time (4 out of 5 times)
    .... Sometimes (2 to 3 out of 5 times)
    .... Rarely (1 out of 5 times)
    .... Never (0 out of 5 times)
    .... Don't know

15. If the kitchen range hood or kitchen exhaust fan is NOT always used, what are the reasons for not using it? Select all that apply.
    .... Forget to turn it on
    .... Not needed for what is being cooked
    .... Too noisy
    .... Doesn't seem to remove cooking fumes or odors
    .... Open window instead
    .... Uses too much energy
    .... Other. Please describe: ....

16. Was the operation of the mechanical ventilation system explained to you when you bought or moved into the home?
    .... Yes
    .... No
    .... Don't know

17. Do you feel you understand how to operate your mechanical ventilation system properly?
    .... Yes
    .... No
    .... Not Sure

18. To what extent are you satisfied or dissatisfied with your mechanical ventilation system?

Very Dissatisfied				Neutral				Very Satisfied
☐	☐	☐	☐	☐	☐	☐	☐	☐

19. If you are NOT very satisfied with your mechanical ventilation system, what are the reason(s) for dissatisfaction? Select all that apply.
    ……. Too noisy
    ……. Too drafty
    ……. Difficult to operate
    ……. Difficult to maintain
    ……. Uses too much energy
    ……. Brings in dust, odor, or air pollutants from outdoor
    ……. Not effective
    ……. Other. Please describe: ………………………………….

E. Occupancy and Indoor Activities

20. On average, how many hours per day is your home occupied by at least one person, including day and night hours?

	Fewer than 8 hours per day	8 to 12 hours per day	12 to 16 hours per day	16 to 20 hours per day	More than 20 hours per day
Weekday	☐	☐	☐	☐	☐
Weekend	☐	☐	☐	☐	☐

21. On average, how many times per week is your cooktop and/or oven used for cooking, including boiling water?

	0 time per week	1 to 2 times per week	3 to 4 times per week	5 to 6 times per week	7 times per week
Breakfast	☐	☐	☐	☐	☐
Lunch	☐	☐	☐	☐	☐
Dinner	☐	☐	☐	☐	☐
Other cooking	☐	☐	☐	☐	☐

22. On average, how many <u>times per week</u> do the following activities occur inside your home? Enter "0" if occurrence is less frequent than once a week.

Use shower	(Times per week) …………………
Use bath or indoor Jacuzzi	(Times per week) …………………
Use dishwasher	(Times per week) …………………
Use washing machine	(Loads per week) ………………..
Hang clothes to dry indoors	(Loads per week) ………………..

F. Window Opening

23. On average, how many <u>hours per day</u> are your windows open?

	0 hour per day	1 to 2 hour per day	2 to 8 hours per day	8 to 16 hours per day	More than 16 hours per day
Summer	☐	☐	☐	☐	☐
Fall	☐	☐	☐	☐	☐
Winter	☐	☐	☐	☐	☐
Spring	☐	☐	☐	☐	☐

G. Indoor Activities

24. On average, how often do the following activities occur inside your home?

	Never	Few times a year	Few times a month	Few times a week	Every day
Smoking	☐	☐	☐	☐	☐
Burn candle or incense	☐	☐	☐	☐	☐
Vacuuming	☐	☐	☐	☐	☐
Use cleaning agent for floor cleaning	☐	☐	☐	☐	☐
Use spray air freshener	☐	☐	☐	☐	☐
Use pesticide spray	☐	☐	☐	☐	☐
Use paints, glue, solvents (e.g., hobbies, home repairs)	☐	☐	☐	☐	☐
Use humidifier	☐	☐	☐	☐	☐
Use dehumidifier	☐	☐	☐	☐	☐

H. Other Indoor Sources

25. Are plug-in or stick air fresheners, or other scented decorations, used in your home?
……. Yes
……. No
……. Don't know

26. Do occupants wear shoes in your home?
……. Yes
……. No
……. Don't know

40. How many dogs, cats, or other furry pets are in the home?
Number of Pets: ………………

I. Use of Air Cleaners

27. Do you use a stand-alone (portable) air filter, air purifier, or air cleaner in the home?
……. Yes
……. No
……. Don't know

28. Where is your stand-alone (portable) air filter, air purifier, or air cleaner located in your home? Select all that apply.
……. Master bedroom
……. Other bedroom(s)
……. Living room
……. Home office
……. Other. Please describe: ……………..

29. Has anyone in the household been diagnosed with asthma?
……. Yes
……. No
……. Don't know

30. Has anyone in the household been diagnosed with allergies?
……. Yes
……. No
……. Don't know

J. Demographic Information

The next questions will help us interpret the results of the survey. All responses will be kept confidential.

31. Please indicate the number of household member(s) in the following age categories.

	Number of household member(s)
0 to 17 Years Old	……………………
18 to 65 Years old	……………………
Over 65 Years old	……………………

32. What is the highest education level of head of household?
    …….. No schooling completed
    …….. 1 to 8th grade
    …….. 9th to 12th grade
    …….. Completed high school (high school diploma, GED credential)
    …….. Some college
    …….. Associate’s degree
    …….. College degree (Bachelor’s degree)
    …….. Graduate degree (Master’s, Professional school, Doctorate degree)

33. Please indicate <u>all</u> races and/or ethnicities of people living in your household.
    …….. American Indian, Alaska Native
    …….. Asian or Pacific Islander
    …….. Black, African American
    …….. Hispanic/ Latino
    …….. White, Caucasian
    …….. Other, specify: ………………….
    …….. Mixed race, specify: ………………….

34. What is the total income of all member(s) of your household combined?
    …….. Less than $35,000
    …….. $35,000 to $ 49,999
    …….. $50,000 to $ 74,999
    …….. $75,000 to $ 99,999
    …….. $100,000 to $150,000
    …….. Greater than $150,000

K. End of Survey

Thank you for filling out this survey! Your data is very valuable to our understanding of indoor air quality and mechanical ventilation in new California homes.

Please return your completed survey in the envelope provided.

If you have any questions about the survey, please contact: [LBNL contact provided]