Title
Participant Assisted Data Collection Methods in the California Healthy Homes Indoor Air Quality Study of 2011-13

Author
Mullen, Nasim A.

Publication Date
2013-09-02

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Participant Assisted Data Collection Methods in the California Healthy Homes Indoor Air Quality Study of 2011-13

Nasim A. Mullen, Jina Li, Brett C. Singer

Environmental Energy Technologies Division
Indoor Environment Group
Lawrence Berkeley National Laboratory
Berkeley, California, USA

August 2013

Funding was provided by the California Energy Commission through Contract 500-09-042 and by the U.S. Dept. of Energy Building America Program under Contract DE-AC02-05CH11231.

DISCLAIMER

Participant Assisted Data Collection Methods in the California Healthy Homes Indoor Air Quality Study of 2011-13

Nasim A. Mullen, Jina Li, Brett C. Singer*
Indoor Environment Group, Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory, Berkeley, California, USA

***Corresponding author contact information:**
Lawrence Berkeley National Lab, 1 Cyclotron Road, MS 90-3058, Berkeley, CA 94720;
Email: BCSinger@lbl.gov; Tel: 1-510-486-4779

Key words: aldehyde; carbon monoxide, cooking pollutants; exposure; formaldehyde; gas appliances; passive sampler; unvented combustion

Abstract

From November 2011 to March 2013, air quality was measured over 6-day periods in 324 residences across California using a mail-out strategy. All interactions with study participants, from recruitment, to data collection, to communication of results, were conducted with remote communication methods including conventional mail, electronic mail, telephone and text messaging. Potential participants were reached primarily by sharing study information with community groups and organizations that directed interested individuals to complete an online screening survey. Pollutant concentrations were measured with sampling equipment that was mailed to participants' homes with deployment instructions. Residence and household characteristics and activity data were collected via two phone surveys and an activity log. A comparison of responses to survey questions completed online versus over the phone indicated that a substantial fraction of participants (roughly 20%) required a researcher's assistance to respond to basic questions about appliance characteristics. Using the printed instructions and telephone assistance from researchers, roughly 90% of participants successfully deployed and returned sampling materials accurately and on schedule. The mail-out strategy employed in this study was found to be a cost-effective means for collecting residential air quality data.

1. Introduction

Air pollutant concentrations inside of homes can be substantially higher than outdoors and highly variable across homes. Since many people spend more time at home than in any other microenvironment (Klepeis et al., 2001), data on pollutant concentrations in homes are critical to understanding exposures across the population. There have been relatively few and infrequent large residential air pollutant exposure studies in the U.S. (Wallace et al., 1991; Sexton et al., 1995; Weisel et al., 2005; Johnson et al., 2009; Rodes et al., 2010), partly owing to the cost and complexity of the requisite air monitoring at many dispersed sites. Identifying lower cost data collection approaches is a priority for expanding knowledge of air pollutant exposures in U.S. homes.

Air pollutant exposure studies involving human subjects require the following steps: study design, protocol review and approval by an institutional review board, outreach and recruitment, screening and selection, deployment and retrieval of air sampling and other monitoring equipment, characterization of the exposure environment and relevant sources, and data processing and analysis. Deploying and recovering monitoring devices and characterizing the environment typically are done by researcher(s) during visits to study homes. The cost of these study elements can be lowered by reducing or eliminating researcher visits to study homes. This can be accomplished by asking participants to pick-up and/or return monitoring equipment at a central location, by asking participants to return by mail samplers that have been deployed by researchers, or by distributing all sampling materials by mail.

The mail-out approach is potentially the most efficient and flexible, allowing sampling at geographically dispersed sites over variable durations and periods. Concerns about these alternative approaches focus on whether participants can correctly deploy samplers and whether accurate information about the environment can be obtained without a visit by a trained researcher.

Our review of the literature identified three indoor air quality studies that have used a mail-out strategy for data collection from a large sample of homes. Two of these studies were conducted in the 1980's. In the first study, nitrogen dioxide (NO_2) concentrations were sampled in 137 homes by deploying passive samplers for one-week periods, eight times throughout a year (Spengler et al., 1983). In this study, researchers visited homes to deploy and retrieve samplers for the first one-week period. During this visit, the researchers instructed participants how and where to deploy the samplers. For the seven subsequent sampling periods, participants were mailed sampling materials, along with prepaid return mailers. The authors did not comment on the success of the mail-out method, though they did note that only 9-12 of the 137 participants dropped out of the study, implying that the remaining participants successfully received and returned the seven sampling packages via mail. In the second such study, passive formaldehyde samplers were mailed to homes for one-week sampling periods (Sexton et al., 1986). Sampling was conducted in pilot, summer and winter phases involving 51, 663 and 553 homes, respectively (472 homes were included in both the summer and winter phases). This study was conducted entirely by mail, including solicitation of volunteers, placement and recovery of monitors, collection of data on occupant and housing characteristics, and communication of test results. During the pilot phase, research staff visited 47 of the homes to ensure that participants had correctly placed samplers; 44 of the 47 homes (94%) had done so. For the summer and winter phases of the study, researchers made no visits to the homes. The rate of successfully deployed and returned samplers for the pilot, summer and winter phase was 93%, 87% and 72%, respectively. The only other IAQ study we have identified that is based primarily on a mail-out strategy was not conducted until two decades later (Johnson et al., 2009). In this study, passive samplers were mailed to 104 homes for deployment both indoors and outdoors. Half of these homes were sent NO_2 and volatile organic compound (VOC) samplers for 7-day deployments and the other half were sent NO_2 and polycyclic aromatic hydrocarbons (PAH) samplers for 1 or 2 day deployments. However, instead of mailing sampling packages back to researchers, participants were instructed to deliver the package to researchers at an appointed time and place. The households invited to participate were selected from participants of two concurrent air quality studies. Of the 104 participating households, 92 (88%) completed the air sampling requirements, and 65 (63%) were fully compliant with all study expectations.

The present study used a mail-out approach to measure air pollutant concentrations in 323 homes across California. Data regarding characteristics of the homes and households were collected via two participant interviews conducted by telephone. All contact with participants, from recruitment to study completion, was conducted via traditional mail, electronic mail, phone or text messaging. To our knowledge, this represents the first residential air quality study to use a variety of modern-day communication methods to engage study participants in the data collection process, and to reduce the burden on research staff. This paper presents a detailed description of the methods used in this study and an evaluation of the success rates of the different strategies employed. Overall, the mail-out approach to collecting residential air quality samples was found to be successful and is recommended for use in future studies.

2. Methods

2.1 Participant Recruitment and Selection

Recruitment. Recruitment materials for this study included a website, one-page flyer, and email summary (Appendix A). All recruitment materials, as well as other materials subsequently used to communicate with selected participants, received approval from the Human Subjects Committee at Lawrence Berkeley National Laboratory (LBNL). The primary strategy for recruitment of participants was to share information about the study via email and phone communication with community organizations having contact with large numbers of individuals, with a request that they share information with their membership. In most cases, these communications were "cold calls," meaning that the researchers did not have a pre-existing relationship with the organization being contacted. While this approach allowed for contact with a large number of organizations, it also resulted in a low response rate. Organizations were generally first contacted via email, and subsequently by phone. Once contact was made, organization representatives were asked to forward the email announcement to an email distribution list, or were mailed flyers for physical distribution. Both physical and electronic announcements included a link to the project website (healthyhomes.lbl.gov/information) that provided an overview of the study and information about how to become a participant. In all, roughly 370 organizations were contacted, including roughly 100 neighborhood associations, 60 religious organizations, 50 student organizations or academic departments at 40 universities, 20 utility bill assistance programs, and 100 community-based organizations. Responses were received from roughly 20% of the organizations contacted, with neighborhood associations providing the highest proportion of participants overall and utility bill assistance programs providing the highest number of low-income participants. In the first year of the study, outreach was focused solely in Northern California. In the second year, organizations were contacted from across the state, but focus was placed on Southern California and the Central Valley. When individuals were contacted for outreach purposes, they were asked to refer others to the website or distribute flyers; no individual was contacted for the purpose of direct recruitment. We did not track the forwarding of information and no compensation was offered or awarded to anyone for sharing information about the study. Since participants were selected on a rolling basis, individuals who participated early in the sampling period were encouraged to refer friends and family to the informational website. Prior to the start of the second year of data collection, participants from the first year were emailed and encouraged to inform friends and family of the opportunity to participate.

Selection*.* Individuals interested in participating were directed to complete a screening survey (Appendix D) by either going to the project website or calling the research study director. Ultimately, 613 screening surveys were completed—575 through the website and 38 over the phone.

Owing to resource constraints, this study was not designed to capture a statistically representative sample of California homes with gas appliances. Rather, it was designed to preferentially collect data in homes that have one or more characteristics that are either known or hypothesized to impact pollutant concentrations and exposures. Thus, the goal of the selection process was to identify homes with characteristics that increase the likelihood and magnitude of pollutants entering the home from gas appliance use. Towards this aim, the screening survey responses were used to give homes a “hazard score” based on a rating system designed by researchers to roughly estimate the hazard of elevated combustion pollutant concentrations in homes (Table 2.1). Points were assigned to a home based on the presence and use of any unvented gas heaters, presence and use of gas cooking appliances (which were assumed to release some fraction of their exhaust into the home), and the location and use of gas heaters or water heaters within the home (indicating the possibility of backdrafting and spillage). The point sum was increased by a multiplicative factor for those homes that were smaller, newer, or had been recently weatherized, since homes with these characteristics are expected to have higher indoor concentrations for any given rate of indoor emissions. The multiplicative factor was increased for lower income households, on the premise that they are more likely to have lower quality appliances and to continue to use appliances even after performance degrades.

Table 2.1. Algorithm for determining a “hazard score” used to evaluate the likelihood of elevated pollutant concentrations resulting from gas appliance use.

Points for gas cooking appliances based on amount of use				
	<1x / wk	1-3x / wk	4-7x / wk	>7x / wk
Cooktop	1	1.5	2	3
Oven	1	1.5	2	3
Points for primary gas heater (evaluate per appliance).				
Unvented heater [a] in living space	3			
Unvented heater in adjacent space [b]	1.5			
Vented gas heater in living space	1			
Vented gas heater in adjacent space [b]	0.5			
Points for supplementary gas heater (evaluate per appliance).				
Unvented heater in living space	2			
Unvented heater in adjacent space [b]	1			
Vented gas heater in living space	0.5			
Vented gas heater in adjacent space [b]	0			
Points for gas storage water heater per number of residents (evaluate per appliance)				
	1-2 people	3-4 people	5+ people	
Vented water heater in living space	0.5	1	1.5	
Vented water heater in adjacent space [b]	-	0.5	1	
Multiplier for other household characteristics (*Sum points for categories below, add 1, then multiply by sum of points from above*)				
Year home was built	< 1995	1995-2005	> 2005	
	-	0.1	0.2	
Size of home (square feet)	< 500	500-1000	1000-1500	>1500
	0.3	0.2	0.1	-
Household gross income ($1000/year)	< 30	30-60	>60	
	0.3	0.1	-	
Weatherization renovations	No	Yes		
	-	0.2		

[a] Included use of gas oven for space heating.
[b] Adjacent space” includes attic, basement or attached garage.

Homes were selected for participation roughly 2 weeks in advance of the proposed sampling week. Thus, every week, 10-20 respondents to the screening survey were contacted and invited to participate. The two primary criteria considered when selecting homes each week were geography and hazard score. We aimed to geographically cluster the homes sampled each week, to allow more efficient sampling of outdoor concentrations by using the same outdoor measurements for sites in close proximity. Within a given geographic area, priority for selection was given to homes with a higher hazard score.

2.2 Participant interactions and interviews

The first contact with participants generally occurred over the phone, two weeks prior to the planned week of sampling. The approved protocol allowed for informed consent to be obtained from individuals over the phone; this involved reading to individuals an approved script of information, answering all their questions, and ensuring that they understood and agreed to the terms (Appendix B). The information included in the script was subsequently mailed to the participants. This initial phone conversation was also used to confirm the participant's availability and schedule a phone appointment for the following week. This first phone conversation generally lasted 10 minutes.

During the second phone appointment, a researcher administered the pre-measurement interview (Appendix D) and discussed logistics for the mailing of air samplers and the week of sampling. The pre-measurement interview was designed to collect information regarding the following: home age, size and degree of air-tightness; gas appliance technology, age, location, condition and frequency of use; presence of electric cooktop, oven, water heater and/or space heating equipment (in place of gas appliances); presence of other pollutant sources inside and outside of the home; and household demographics. Since researchers would not be visiting the homes, the interview provided key information about the home and appliances that would not otherwise be obtained. This second phone conversation generally lasted no more than 30 minutes.

A week following the pre-measurement interview, sampling materials were mailed in a 9.5 inch by 12.5- or 13-inch padded envelope, enclosed in an outer 12.5 inch by 15 inch Tyvek® envelope. The participants were instructed to discard the outer envelope, and use the inner padded envelope to mail the materials back at the end of the sampling period. Participants were given the option of having the samplers delivered and returned via the US Postal Service or FedEx, depending on which option was most convenient for them. Participants were sent a reminder email or called by phone a day prior to the package arrival, and were asked to set up the samplers within one day of their receipt using the detailed instructions provided to them (Appendix C). Individuals who had trouble setting up the samplers were instructed to call one of the researchers to have the set-up process described over the phone. Participants recorded the set-up and repackaging time on the provided instruction sheet, which they included in the return mailer. Following set-up, they were asked to take two photos of the samplers at each location—one showing the samplers up close and another showing the sampler placement in the room—and transmit the photos electronically (i.e. via email or text message) to the research study director so that correct placement could be confirmed. If the study director did not receive a phone call, text message or email within two days of the package arrival, the participant was called to confirm the package had been received and the samplers set up. Once set up, the intent was for the samplers to remain in place, undisturbed for 6 days. In the second year of the study, participants were provided with a cooking log designed to assist them with tracking cooking events during the sampling period (Appendix E). The decision to include the cooking log was primarily based on repeated feedback from participants during the first year that it was difficult to recall how frequently cooking had occurred during the previous week. Participants who received the cooking log were instructed to keep it in the kitchen and note the day, time, duration and a brief description of each cooking event. Other than tracking cooking activities, participants were asked to conduct their household activities as normal.

Near the end of the 6-days, all study participants were given an email or phone call to remind them to repackage the samplers using the provided instructions and to schedule a time for the post-measurement interview. This final phone interview was designed to characterize the activities of the home during the sampling period, including the following: frequency of use of the appliances, occupancy patterns, and use of other potential pollutant sources inside and outside of the home. Questions that might affect resident behavior were saved for the final interview. These included questions about frequency of kitchen exhaust fan use, reasons why the kitchen exhaust fan was not used (if applicable), and condition of the stovetop and oven (flame quality, operational problems etc.). Completion of the post-measurement interview marked the end of an individual's formal participation. One to six months following completion, participants were sent $75 and a report of results from their home (Appendix E). For the majority of participants, this marked the end of their interaction with researchers. Roughly 10% of the participants contacted researchers following receipt of the report to request more specific information regarding potential pollutant sources in their home and strategies for improving their indoor air quality.

In the first year of the study, there were 29 additional homes sampled for which the majority of participant interactions were the same as described above, except that sampling materials were deployed in the home by a visiting researcher, versus being mailed to and set-up by a resident. In the second year of the study this method of deployment was eliminated, as it was decided that it did not provide enough additional information to make it worth the extra effort. The methods used when visiting homes has been previously described (Less, 2012).

2.3 Pollutant sampling instruments

Sampling was conducted in two phases from late November 2011 to mid-April 2012 and late October 2012 to mid-March 2013. During that time, 5 to 14 homes were sampled every week, with the exclusion of three to four weeks during the winter holidays. The pollutant concentration data collected from each home included time-resolved measurement of CO in the kitchen, and time-integrated measurement of formaldehyde, acetaldehyde, NO_2 and NO_X in the kitchen and bedroom. Time-integrated measurements of outdoor pollutants were made at a subset of homes. Thermistor data loggers were used to collect time-resolved measurement of environmental parameters at each sampling location and to monitor the use of furnaces. Thermocouple data loggers were used to monitor use of water heaters. A summary of the measured parameters is provided in Table 2.2

Table 2.2 Summary of pollutant and environmental monitoring instruments used in study

Parameter	Manufacturer, model	Data resolution	Location of deployment
	Measured at ALL homes		
Aldehydes [a]	Waters, Sep-Pak XPoSure	Time integrated	Bedroom, kitchen, outdoors[a]
NO_X, NO_2 [a]	Ogawa NO_X/NO_2 sampler	Time integrated	Bedroom, kitchen, outdoors[a]
CO (ambient)	Lascar, USB-EL-CO300	1-minute	Kitchen
T, RH (indoors)	HOBO, U10	1-minute	Bedroom, kitchen
Furnace operation (indicated by T)	HOBO, U10	1-minute	Furnace supply register
Water heater operation (T)	HOBO, U12-014	1-minute	Water heater exhaust flue
Water heater spillage (T)	HOBO, U12-014	1-minute	Top of water heater, adjacent to draft hood
T, RH (outdoors) [a]	HOBO, U23 Pro v.2	1-minute	Outdoors

[a] Outdoor sampling occurred at a subset of homes.

Participants were instructed to place the kitchen sampler assembly in a location that would not inconvenience the residents, and that was ideally at least 3 feet from the cooktop and oven, 6 feet from exterior doors and windows that were frequently opened and 2 feet from the floor and ceiling. However, in some cases, particularly in smaller kitchens, not all of the criteria were achieved. In households with children under the age of 18, participants were asked to place the second set of samplers in the bedroom of one of their children, ideally the youngest. They were given the option of locating samplers in another bedroom but in all cases participants chose to locate the samplers in the child's bedroom. In homes without children, samplers were placed in the bedroom of the head of household. The requested siting for bedroom samplers was on a surface that had not been recently lacquered, painted or refinished, that was convenient to the residents, and that was at least 6 feet from exterior doors and windows that were frequently opened and 2 feet from the floor and ceiling.

Furnace and water heater operation were monitored to help determine whether use of these appliances corresponded with changes in the CO concentration. Furnace operation was monitored by deploying a thermistor (HOBO U10) on one of the air supply registers. Water heater operation was monitored using a data logger that included an internal thermistor (HOBO U12) and attached thermocouple (Omega Engineering KMQXL-125E-6). The device was mounted on the top of the water heater so that the tip of the thermocouple was placed in the center of the exhaust flue, with the intention that the thermistor be far enough from the draft diverter to avoid large temperature increases when the appliance was venting properly. The thermocouple monitored operation of the water heater's main burner, and the thermistor placed outside the perimeter of the draft hood was intended to identify instances of spillage of hot exhaust gases. Spillage was identified by visually inspecting temperature traces to identify any instances when spikes in the exhaust temperature (measured by thermocouple) were followed by spikes in the temperature outside of the perimeter of the draft hood (measured by thermistor). Pictures of samplers set-up in the kitchen, bedroom, furnace and water heater of one home are shown in Figure 2.1.

Information regarding characteristics of the samplers and loggers deployed in each home is summarized in Table 2.2.

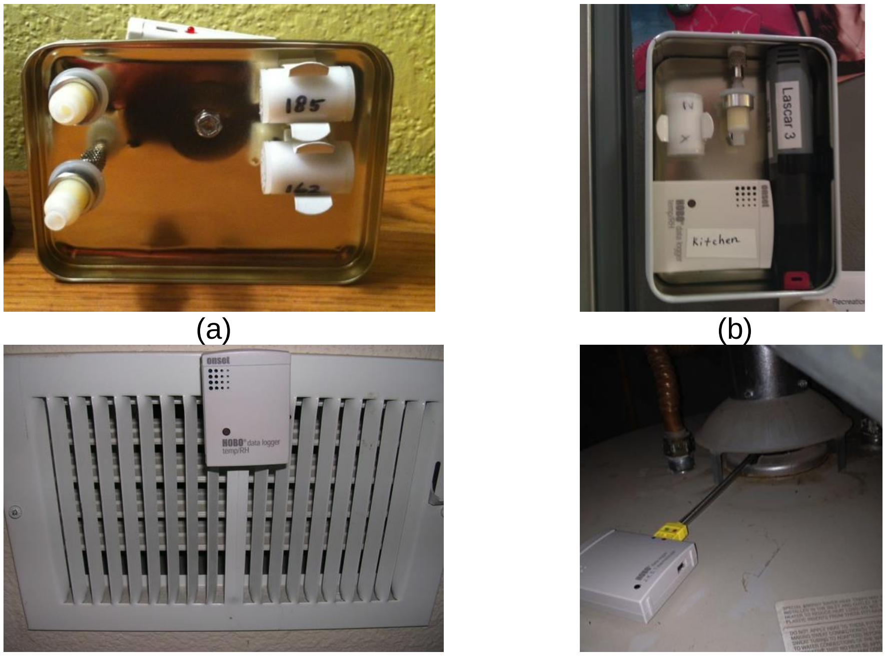

Figure 2.1. Example placement of (a) bedroom samplers (Note: temperature sensor is on the back of the tin), (b) kitchen samplers mounted on the refrigerator, (c) furnace sensor, (d) water heater sensor. Samplers/sensors were deployed and photographed by participants.

Outdoor sampling each week occurred at a minimum of one home that was considered representative of each spatial cluster of homes sampled that week. This resulted in 1 to 5 outdoor samples being collected each week. Effort was made to select homes in as few clusters as possible to minimize the number of outdoor samples needed each week. The main criteria for outdoor sampler placement were (1) a location that could easily and safely be accessed by the participant and (2) a location at which the samplers would not be at significant risk of disturbance (vandalism or exploration). As a result, outdoor sampling generally occurred at single-family homes with backyards or apartments with private balconies. Pictures of sampling packages set-up outdoors at two homes are shown in Figure 2.2. Outdoor samplers were deployed in closed tins with vent holes to provide protection from outdoor elements; thus, the samplers themselves are not visible in the pictures.

Figure 2.2. Outdoor sampler placement at two homes.

2.4 Sample Handling and Quality Assurance (QA) Procedures

Sample handling

A regular schedule for sampler preparation, deployment and processing was maintained throughout the sampling period. Prior to deployment, aldehyde cartridges were stored in a refrigerator until the morning of shipment. The NO_X samplers (which included samplers for both NO_X and NO_2) were generally assembled on the preceding Friday, and stored at room temperature in airtight bags. Packages were mailed to participants on Monday morning, and were usually received by Tuesday and rarely later than Wednesday. Participants were asked to set up the samplers as soon as possible, ideally within 24 hours, and to then repackage them six days later. Thus, participants who set up the samplers on Tuesday evening, which was most often the case, were asked to repackage them on the following Monday evening and mail them back Tuesday morning. The majority of returned packages were received at the lab on Wednesday or Thursday, though it was not uncommon to receive one or two packages on Friday. Within 24 hours of their arrival, packages were opened and their contents inventoried. Besides ensuring that all the sampling materials had been returned, the inventory also included checking that all of the airtight bags were well sealed and that the correct sensor IDs had been recorded for each home.

Following the inventory, aldehyde cartridges were stored in a freezer at -20 ºC and NO_X samplers were stored in a laboratory at room temperature to await analysis. Data loggers were downloaded within a few days of arrival, and were launched for deployment at the next set of sites. NO_X and aldehyde samplers were extracted within 1 week of arrival, and were analyzed within 1 week of extraction. According to information published by the manufacturers, exposed NO_X and NO_2 samples can be stored for 2-3 weeks and extracted samples can be stored for 90 days.[1] Exposed aldehyde samplers can be stored for 2 weeks and extracted samples are stable for up to 1 month.[2] Aldehyde sample extracts were analyzed by high-performance liquid chromatography (HPLC) and NO_X and NO_2 extracts were analyzed by ion chromatography (IC), using procedures provided by Waters Inc. and Ogawa & Co. Inc., respectively. Formaldehyde and acetaldehyde mass values output by the HPLC were converted to concentrations using the duration of deployment and the passive sampling rates determined in validation experiments described later in this report. NO_2 and NO mass values output by the IC were converted to concentrations based on the algorithm described by Ogawa & Co. Inc., using the measured T and RH and the noted sampling duration. Ogawa NO_X samplers have been validated by Singer et al. (2004). In the <10% of homes where T and RH data were not available for the kitchen or bedroom, value(s) measured in the other location at the home were used. In cases where there were no outdoor T and RH data, a value was acquired from a nearby weather station.

Quality assurance

The following procedures were used to calculate the Minimum Detection Limits (MDL) and Limits of Quantification (LOQ) for formaldehyde, acetaldehyde, NO_2 and $NO_{X,}$ based on analytical methods. The MDL was calculated by taking the standard deviation of 7 samples of the same certified standard, and multiplying it by the students' t-value corresponding to a 99% confidence level and a standard deviation estimate with n-1 degrees of freedom, according to US EPA procedure (Title 40 Code of Federal Regulations Part 136, Appendix B, revision 1.11). The LOQ was calculated as 10 times the standard deviation of the 7 analyzed standard samples. Certified standards of 100 μg/L nitrite and nitrate, and of 8.79×10^{-3} μg/L formaldehyde and acetaldehyde were use for the analysis. This analysis was performed mid-way through the

[1] www.ogawausa.com/pdfs/prono-noxno2so206.pdfz
[2] www.waters.com/webassets/cms/support/docs/wat047204.pdf

data collection period. Excluding field blanks, seven aldehyde samples (outdoor) and one NO_2 sample (bedroom) were below the LOQ. The results for these samples were replaced with a value of 0.5 LOQ.

The following procedures were used to minimize and assess the frequency of contamination of the time-integrated samples. Prior to deployment, all parts of the Ogawa NO_X samplers were cleaned with deionized water and air-dried in a laboratory free of combustion sources; they were assembled and placed into sealable envelopes on the Friday before shipping out to participants. The aldehyde samplers required no assembly. They were transported to the participating homes in the individual airtight bags as shipped by the manufacturer. The seal on each airtight bag was checked upon receiving the returned samplers from the participants. The end caps on the aldehyde samplers provided a second level of protection from contamination in both directions. Contamination in the field was assessed by deploying duplicate and blank NO_X/NO_2 and aldehyde samplers at 1 to 3 homes every week, for a total of 67 blanks for each type of sampler and 57 and 64 aldehyde and NO_X/NO_2 duplicate samplers, respectively. Homes that received duplicate or blank samplers received one for each type of pollutant (i.e. NO_X/NO_2 and formaldehyde/acetaldehyde); however, no home received a set of both blank and duplicate samplers. Residents were instructed to deploy duplicate samplers in the bedroom and to keep field blanks in their airtight bags for the duration of the sampling period. Prior to mailing back the sampling package, they were instructed to open the bags of the field blanks, and remove the sampler for 10 seconds before replacing and resealing. This last step was intended to asses how commonly substantial contamination occurred in transit, due to an improperly sealed bag. The average concentration measured by the blank NO_X and NO_2 samplers was 8% greater than the LOQ. The averages measured by the blank formaldehyde and acetaldehyde samplers were 38% lower and 21% greater, respectively, than the corresponding LOQ. The average relative deviations for all pairs of NO_X, NO_2, formaldehyde and acetaldehyde duplicate samples were 3%, 7%, 5% and 5%, respectively.

The following procedures were used to assure quality in the analysis of time-integrated samples. Analytical blanks were included with every batch of samples run through the ion chromatography (IC) or high-performance liquid chromatography (HPLC) systems. For the IC analysis, a blank was included after every 5 samples to ensure that there was no carry-over contamination. Certified standards were purchased for each instrument. Target analytes were identified and measured by comparison to these standards. For the IC, a full calibration series was included with each set of samples analyzed. For the HPLC, one continuing calibration standard was included with each set of samples analyzed. A multipoint calibration series was run every 6 months on the HPLC system. Sample extracts were saved and rerun on occasion, either to confirm unusual results or to test the error introduced by a delay in the analysis of extracts.

The following procedures were used to assure quality of data from continuous monitors. During the data collection phase, CO sensors were calibrated roughly every 2-3 weeks. The CO calibration involved exposing 6 to 15 sensors to concentrations ranging from 0 to 50 ppm in a 3.8 L chamber. The CO calibration protocol was modified between the first and second phase of the study. During the first phase, CO sensors were exposed to spans of 0, 25 and 50 ppm. The calibration spans were achieved by titrating a CO concentration of 1000 ppm with ultra zero air using a Dynacalibrator (Valco Instruments Co. Inc., Model 760). The precise span level was calculated by measuring the flow rate of each gas at the beginning and end of the exposure period. An intercept adjustment was calculated based on the loggers response at zero and a slope was calculated from a best-fit linear regression of the logger's response to the three tested spans. Since the CO loggers do not record negative values, the majority produced a 0 ppm reading when exposed to zero air, thus resulting in a 0 ppm intercept. Prior to the start of the second data collection phase, a 100 ppm CO cylinder was purchased, and CO concentration spans of 2.5 and 5 ppm were added to the sequence. It was decided to exclude the CO spans of 0 and 50 ppm from the calibration analysis in phase two, since the loggers did not record negative values and concentrations of 50 ppm were never observed in the field. Thus, CO data from phase two was adjusted with a best-fit slope and intercept calculated from the sensor readings at 2.5, 5 and 25 ppm (1 h averages of CO exceeded 25 ppm at only 3% of sites). The mean $\pm$ one standard deviation slope and intercept calculated across loggers at the beginning and end of both sampling phases are summarized in Table 2.3. These parameters were calculated by treating the calibration span as the dependent variable and the instrument reading as the independent variable; thus, the instrument readings were adjusted by summing the product of the reading and the slope with the intercept.

Table 2.3. Calibration slope and intercept (mean $\pm$ one standard deviation) calculated across CO loggers at the beginning and end of the two sampling phases.

Period	Month, year	Slope	Intercept (ppm)
Start 1st phase	November, 2011	1.09 ± 0.02	-0.02 ± 0.05
End 1st phase	April, 2012	1.12 ± 0.05	-0.19 ± 0.39
Start 2nd phase	October, 2012	1.08 ± 0.08	0.09 ± 1.17
End 2nd phase	February, 2013	1.04 ± 0.06	1.01 ± 1.07

The CO sensors most often produce readings that were below the span concentration to which they were exposed. However, since the calibration intercept in phase one was calculated by taking the instrument reading at zero, the resulting intercept was most often zero. During the second phase of the study, when a best-fit intercept was calculated, the values spanned a wider range, with a trend towards a positive intercept. For both phases of the study, the mean slope adjustment was above one. Data collected at each home were adjusted using an average of the slope and intercept calculated from the calibration experiment that took place immediately before and after the sampling period at that home. In some cases, only one set of calibration parameters was available for adjustment of the readings.

The following procedure was used to confirm that samples and monitors from different locations within the homes were accurately tracked. NO_X/NO_2 holders were labeled, and upon return, were checked to ensure that residents had put samples into the bag correctly labeled for its location of deployment. The same was not done for the aldehyde samplers, due to the sampler configuration. However, the NO_X/NO_2 holders were found switched at only 4 of the 343 homes to which samplers were mailed; therefore, the switching of samplers between the bedroom and kitchen is not suspected to have been a significant source of error. The ID numbers of data loggers intended for deployment at each location in homes were recorded prior to departing the lab. Returned packages were inventoried and the records were checked to confirm that the correct ID numbers had been recorded.

The following procedure was used to characterize potential bias of NO_X and NO_2 measurements made within the outdoor enclosure box. Tests were performed on four occasions throughout the sampling period, by collocating multiple samplers outside a home in two different enclosure configurations for 6-day periods. One configuration was a relatively open dome-shaped enclosure that had been validated in past experiments (Singer et al., 2004). The second was a closed box enclosure with ~1 cm diameter holes drilled on several sides of the box and fitted with grommets. The latter configuration was used in this study because its lighter weight and smaller size made it easier to mail. The assumption was that the former configuration provided a measure of the true concentration, due to its more open design and evidence from past experiments (Singer et al., 2004). A picture of both types of outdoor enclosures is shown in Figure 2.3.

Figure 2.3. . Two enclosure configurations for NO_2 / NO_X sampling: Configuration on the left has been validated in past studies. Configuration on the right was designed specifically for this study.

The first outdoor validation experiment took place on 22 November 2011, simultaneous with pollutant sampling in the first set of homes in this study. The first experiment involved collocating a pair of samplers, each in a different type of enclosure, at the front of a single family home, and deploying a third sampler in a dome enclosure at the back of the home. The results of this experiment indicated that the true NO_2 and NO_X concentrations were, respectively, 31% and 34% higher than the concentration measured by samplers in the closed box. Consequently, the number of holes in the box surface was increased from four to six, which was the largest number of holes deemed possible without overly exposing the samplers to outdoor elements. This slightly modified design was used at homes sampled from Week 3 through Week 19, and for all homes sampled in the second sampling phase. The subsequent five outdoor validation experiments were initiated on 29 November 2011, 7 February 2012, 11 April 2012, 23 October 2012 and 19 January 2013 and involved collocating three pairs of samplers in each enclosure type for six day periods outside of a single home. For the first two experiments, the three pairs were deployed in different locations along the exterior of the home, while in the final three experiments the three pairs were located together. Results from all four experiments are shown in Table 2.4.

Table 2.4. Results from outdoor validation experiments. Each row corresponds to collocated samplers. The mean and relative standard deviation (RSD) are shown for samplers deployed simultaneously in like enclosures.

	NO_2 (ppb)		NO_X (ppb)		NO (ppb)	
Start Date MM/DD/YY	Box	Dome	Box	Dome	Box	Dome
11/22/11	12.3	16.0	30.7	42.6	18.3	26.6
		16.1		39.9		23.8
Mean (RSD)	12.3	16.1 (0.4%)	30.7	41.3 (4.6%)	18.3	25.2 (7.9%)
11/29/11	13.3	15.8	28.8	31.2	15.4	15.4
	14.8	17.3	31.5	33. 3	16.7	16.0
	12.2	15.8	27.9	29.2	15.7	13.4
Mean (RSD)	13.4 (9.7%)	16.3 (5.3%)	29.4 (6.4%)	31.2 (6.6%)	15.9 (4.3%)	14.9 (9.1%)
2/7/12	13.9	18.7	29.6	33.4	15.7	14.7
	18.2	18.8	29.5	31.8	11.3	13.0
	15.1	21.7	34.1	38.4	18.9	16.7
Mean (RSD)	15.7 (14.1%)	19.7 (8.6%)	31.1 (8.5%)	34.5 (10.0%)	15.3 (24.9%)	14.8 (12.5%)
4/11/12	5.1	5.7	6.0	7.4	0.7	1.2
	4.6	6.0	7.0	8.1	2.0	1.4
	4.9	5.5	4.7	6.9	-0.2	1.7
Mean (RSD)	4.9 (5.2%)	5.7 (4.4%)	5.9 (19.5%)	7.5 (8.1%)	0.8 (132%)	1.4 (17.6%)
10/23/13	16.6	18.2	31.6	38.7	15.0	20.4
	16.8	17.8	30.7	37.2	13.9	19.4
	16.4	17.7	30.8	36.8	14.3	19.1
Mean (RSD)	16.6 (1.1%)	17.9 (1.6%)	31.0 (1.6%)	37.5 (2.6%)	14.4 (3.8%)	19.6 (3.6%)
1/19/13	19.9	27.0	67.4	75.1	47.5	48.0
	23.1	24.3	68.9	72.0	45.9	47.7
	21.3	25.0	65.0	71.8	43.7	46.9
Mean (RSD)	21.4 (7.5%)	25.4 (5.6%)	67.1 (3.0%)	73.0 (2.5%)	45.7 (4.2%)	47.5 (1.2%)

An attenuation factor for NO_2 measured in the box was calculated from results of the last five experiments by linearly regressing the average concentrations measured in the box against the average simultaneously measured in the domes, with the intercept of the regression forced through zero (Figure 2.4). The resulting slope of 1.18 was used to adjust the NO_2 data measured by samplers deployed in the box-enclosures with additional openings. NO_2 concentrations measured in the initial box configuration during the first two weeks of sampling (i.e. the box with less openings) were adjusted using the ratio of concentrations measured in the box and dome enclosures in the first experiment (22 November 2011). Unlike NO_2, surface deposition is not expected to be a significant sink for NO. This expectation is supported by the NO data summarized in Table 2.4. Specifically, the relative deviation between the NO measured in the dome and box for the latter five experiments ranged from 0 – 121% with a mean of 16%, which is within range of the relative standard deviation measured between samplers deployed in like containers. Thus, the NO_X concentration was adjusted by taking the sum of the measured NO concentration and the adjusted NO_2 concentration.

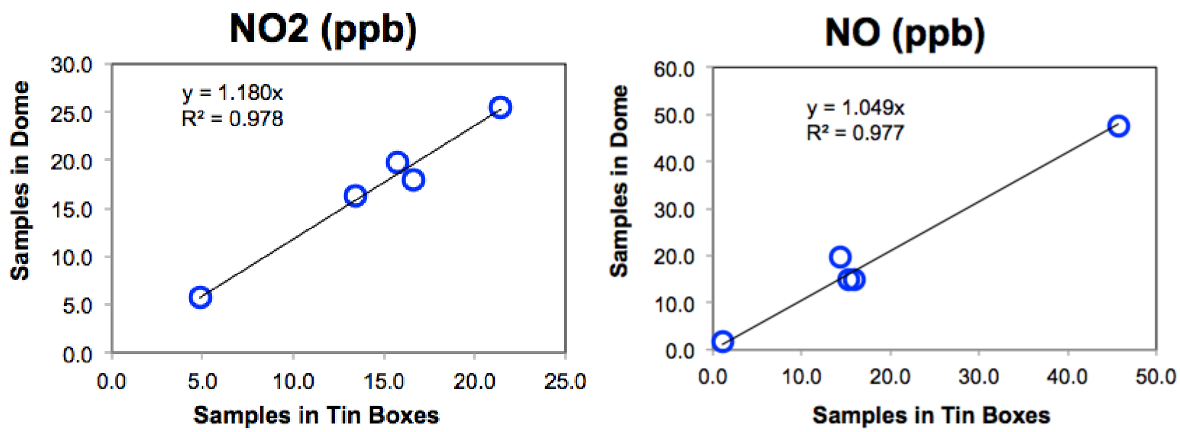

Figure 2.4. Linear regression of NO_2 and NO concentrations measured by samplers in two outdoor enclosure types. Each data point represents the average of three pairs of samplers deployed for a six-day period.

The cartridges used for aldehyde sampling are intended by the manufacturer to be used actively, not passively, as used in this study. However, a study conducted by Shinohara et al. (2004) reported that these aldehyde samplers could be used passively, and reported passive sampling rates of 1.48 and 1.23 mL/min for formaldehyde and acetaldehyde, respectively. In 2012, further testing performed at LBNL yielded passive sampling rates of 1.10 ± 0.09 and 0.86 ± 0.10 mL/min for formaldehyde and acetaldehyde, respectively (Mullen et al., submitted). These sampling rates were used to calculate formaldehyde and acetaldehyde concentrations measured in homes.

3. Results

3.1 Sample Characteristics

A total of 323 different homes were successfully sampled using the mail-out method. Of those homes, 264 were included based on screening survey answers that suggested greater potential for elevated combustion pollutant concentrations from gas appliances; these homes had a hazard score of 2.0 or greater with a mean score of 5.0 based on the scoring system shown in Table 2.1. The remaining 60 homes were selected to serve as controls, and had a mean hazard score of 0.7. These homes had either no gas appliances, had one or two vented gas appliances outside of the main living space, or had a gas appliance in the living space that was rarely used. A frequency distribution of the hazard scores is shown in Figure 3.1.

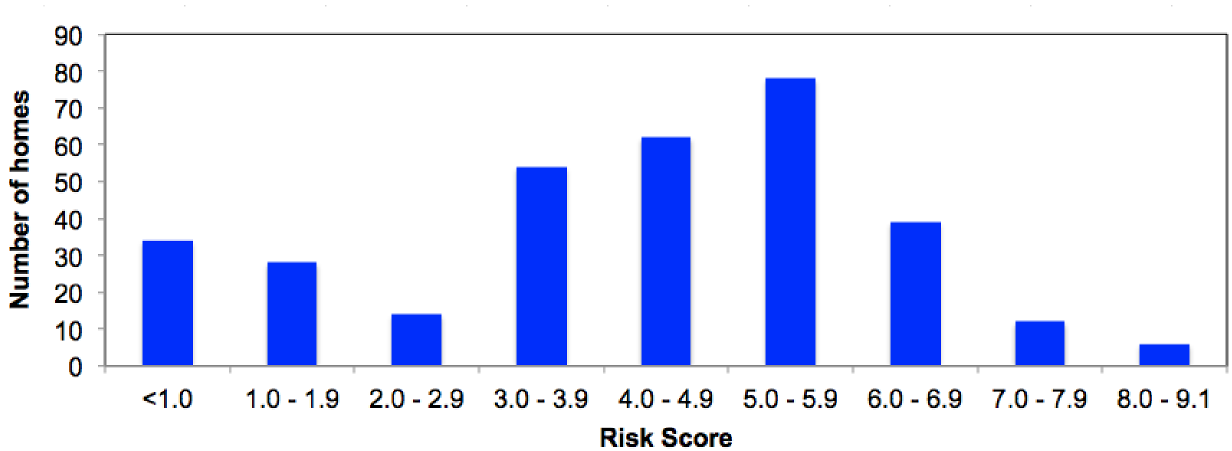

Figure 3.1. Frequency distribution of hazard scores calculated for the 323 homes sampled by mail.

Among the 323 homes, 158 were located in eight of the nine counties that comprise the San Francisco Bay Area: Alameda, Contra Costa, San Francisco, San Mateo, Santa Clara, Marin, Sonoma and Solano. There were 16 homes representing two of five counties in the Sacramento region: Sacramento and Yolo. There were 26 homes representing five of ten counties in the Central Valley: Fresno, Kern, Merced, San Joaquin and Tuolumne. There were two homes representing two of four counties on the Central Coast: Santa Cruz and San Benito. There were 85 homes representing all four of the counties making up the Los Angeles region: Los Angeles, Orange, Santa Barbara and Ventura. There were 28 homes representing both counties in the Inland Empire: Riverside and San Bernardino. Finally, there were 9 homes located in San Diego County. The sample population included both single-family (56%) and multi-family (44%) dwellings. The distribution of homes among the 25 represented counties is shown in Figure 3.2.

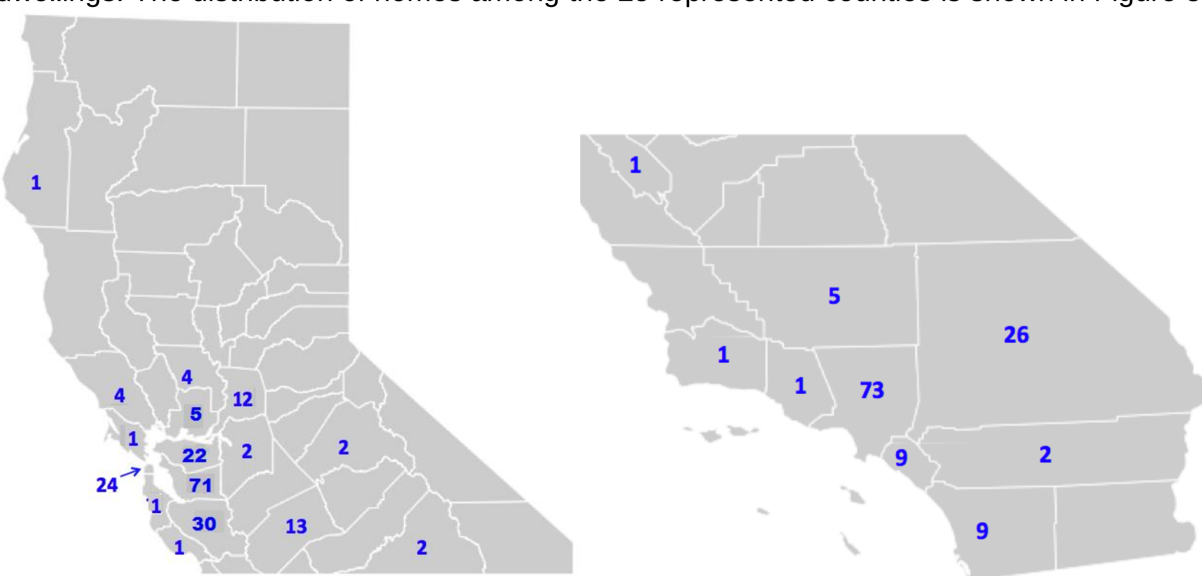

Figure 3.2. Number of homes sampled northern (left) and southern (right) California counties.

The sample population successfully overrepresented homes with frequently used unvented gas cooking appliances, which were hypothesized to increase the hazard of high pollutant concentrations. Specifically, there was at least one gas appliance in 90% of homes, and an unvented gas cooking appliance in 82%. A gas cooktop was reportedly used more than 7 times during the week of sampling in 53% of study homes, and was used 14 times or more in 26% of study homes. Participants reported that they either did not have a kitchen exhaust fan or that they rarely or never used it in 64% of homes. A summary of the gas appliance and kitchen exhaust use characteristics of the sample population is presented in Table 3.1.

Table 3.1. Gas appliance use and kitchen exhaust characteristics of sample population

	# in study	**% in study** [a]
Types of appliances present		
No gas appliances	33	10%
Vented gas appliances only (i.e. furnace and/or water heater)	25	8%
Unvented gas appliances only (i.e. cooking appliances)	129	40%
Vented and unvented gas appliances	136	42%
Gas cooktop and oven usage during sampling period		
7 times or less	94	29%
More than 7 times, less than 14 times	87	27%
14 times or more	83	26%
No gas cooking	57	18%
Did not answer	2	<1%
Vented kitchen exhaust fan usage when present		
Used most of the time	76	24%
Used about half the time	41	13%
Used rarely or never	132	41%
Did not answer	1	<1%
No functional exhaust fan present	73	23%

[a] Represents percentage of the total sample population.

A summary of the demographic data is presented in Table 3.2. Representation of different income brackets ranged from a low of 13% for the $25,000 to $50,000 bracket to a high of 25% for the $100,000 to $150,000 bracket. While a substantial fraction of the study sample (19%) had no resident with a college degree, the majority (53%) had at least one resident with a graduate degree. While the majority of households (51%) had only one or two occupants, the majority of participants' homes had a floor area below the average size of new homes in the Western region of the US in 2005 (National Association of Home Builders), with 26% of the homes having a floor area of less than 1000 sq. ft. and 85% having a floor area of less than 2000 sq. ft. The racial distribution of the sample was similar to that of the California population, which, according to the 2010 Census, is made up of 74% White, 7% Black, 2% American Indian or Alaskan Native, 14% Asian, and 38% Hispanic persons. (Note that because the US Census does not consider “Hispanic” as a race, individuals that report a Hispanic ethnicity are also counted within one of the race categories. Also, US Census data is tabulated per individual whereas statistics on the study population are tabulated per household). Thus, the primary difference between the ethnic distribution of the study sample and the California population is overrepresentation of the Asian/Pacific Islander and African-American populations and underrepresentation of the Hispanic/Latino population. Relative to the California population, there were lower far fewer households in this study with residents who were children or seniors.

Table 3.2. Demographics of study sample compared with demographics of the California population.

	# in study	% in study	% in CA [a]
Types of appliances present			
Home rented	147	46%	43%
Home owned	176	54%	57%
Floor Area of home (sq. ft.)			
<1000	110	34%	22%
1000-2000	143	44%	46%
>2000	47	15%	32%
Did not answer	23	7%	
Number of residents			
1 – 2	164	51%	55%
3 – 4	116	36%	
5 or more	42	13%	45% [b]
Did not answer	1	<1%	
Presence of minors and seniors			
At least one resident <18 years old	51	16%	37%
At least one resident >64 years old	20	6%	25%
All residents between 18-64 years old	252	78%	38%
Highest education level of ANYONE in household [c]			
Less than Bachelors degree	60	19%	NA
Bachelors degree	90	28%	NA
Graduate degree	172	53%	NA
Did not answer	1	<1%	
Ethnicities represented by residents [d]			
Native American	7	1%	2%
Hispanic/ Latino	36	5%	38%
Black, African-American	45	14%	7%
Asian or Pacific Islander	80	30%	14%
White, Caucasian	219	76%	74%
Combined Gross Income			
<$25k	50	6%	22%
$25-49k	47	13%	22%
$50-74k	53	15%	17%
$75-99k	36	14%	12%
$100-150k	67	25%	14%
>$150k	36	18%	13%
Did not answer	34	6%	

[a] Home floor area data obtained from Residential Appliance Saturation Survey, 2009 (www.energy.ca.gov/appliances/rass/). Remaining data obtained from www.census.gov.
[b] Percent of households with 3 or more persons in CA.
[c] Educational attainment statistics were not available on a per household basis for the CA population.
[d] All race/ethnic categories that partially/fully characterize an individual/household are weighted equally, therefore percentages sum to greater than 100%. However, statistics for the study population are tabulated on a per household basis, whereas CA statistics are tabulated per individual.

A summary of all known characteristics of the sample population, based on responses to the initial and exit survey, is provided in Appendix F. This summary includes both homes to which samplers were mailed (n=323) and those that were visited by a researcher (n=29).

3.2 Participant Compliance

Causes for loss of data or impaired data quality due to participants' noncompliance were divided into five categories: unresponsive/dropped out, pictures not sent or sent late, cooking log not returned, samplers set up late, samplers returned late, samplers returned unsealed.

There were 13 participants who dropped out of the study after having gone through the consent process. For seven of these cases, the participants were considered to have dropped out because they could not be reached for their initial survey appointment. While it was not uncommon for participants to miss their phone appointments, these seven individuals were not reachable after multiple attempts, and were therefore removed from the study. In two cases, participants requested to be removed from the study prior to completing the initial survey, because upon further consideration they felt participation would be inconvenient for their household. In the four remaining cases, the participants dropped out after the package had been mailed to them. In one of these four cases, the participant had to leave home for emergency travel. In two other cases, the individuals decided participation would be too burdensome, after having received and reviewed the package. In the fourth case, researchers were unable to reach the individual for three weeks after the package had been mailed. Upon finally reaching the individual and ascertaining that he had not yet set up the samplers, he was asked to mail it back unopened, since the collected data would no longer be considered reliable. The four individuals that dropped out after having received the package mailed it back without delay. For 12 of the 13 individuals that dropped out, no payment was made. In the last case, the participant received a payment of $25, since he had already completed the initial survey and wished to continue, but was asked to send the package back, since three weeks had already transpired.

The request for pictures from each location where samplers were deployed was the most common type of participant noncompliance. The purpose of the pictures was two-fold. First, the study director reviewed the pictures at the beginning of the sampling period to ensure that samplers had been set up correctly. Second, researchers reviewed the pictures at the time of data processing and analysis in the case of an unusual or unexpected result. Over the course of the study, a few individuals declined to send pictures either because they did not have a camera, did not know how to electronically send the pictures, or did not feel comfortable sending pictures. A handful of other individuals did not provide any excuse for not sending pictures, but simply failed to do so. Individuals were reminded once to send pictures, but not prodded further. In the end, 23% of participants did not send any pictures. Pictures were sent at the end of the sampling period by 14% of participants; this did not allow researchers to provide feedback to the participants regarding placement of the samplers. In total, 63% of participants complied with the request to send pictures at the beginning of the sampling period. In most cases, the pictures provided a helpful indication of the location of the samplers and appliances in the home. There were only a few cases when the pictures provided an indication of incorrect or inappropriate placement. Specifically, on nine occasions, participants were asked to move the sampler assembly to a new location because it was either too close to the stove or oven, too close to an open window, or in an area that did not appear to have sufficient airflow. There was a tenth home for which review of the pictures following the sampling period made apparent that the participant had forgotten to remove the cap from one of the aldehyde samplers in a duplicate pair. Other than these instances, the pictures primarily provided evidence of correct sampler placement by the participants.

A hard copy of the cooking log was included in the package of every home included in the second phase of the study. The residents were asked by phone or email, days prior to the package arrival, to track the cooking activities on the log and return it with the rest of the materials. Ultimately, of the 196 participants that were mailed cooking logs, only 16 (8%) did not return them.

Participants were asked to deploy the sampling materials within 24 hours of their arrival, and to repackage the materials roughly six days later. The majority of participants followed these instructions, but a few did not. Overall, 24 of the 324 participants (7%) set up the sampling materials three or more days after the arrival of the samplers, with an average delay of roughly five days. In addition, 13 participants (4%) delayed in repacking the samplers, such that the sampling period lasted an average of roughly nine days, rather than the desired six days. Two of these homes had also set up the samplers late, which resulted in the package of samplers arriving at the lab two to three weeks after they had been mailed out by LBNL. However, in only two of these cases were the delays so significant that the data collected by time-integrated samplers were lost.

The instructions provided to the participants made clear that the time-integrated samplers should be repackaged in the same manner in which they had arrived. However, there were a few cases for which the samplers were not properly sealed. The aldehyde samplers had caps, which provided a second layer of protection. Any NO_X samplers that were sent back unsealed were discarded. Overall, there were 25 homes for which the NO_X sampler from at least one location had to be discarded because it was not properly sealed. There were 21 homes for which at least one aldehyde sampler was sent back unsealed, but in only 14 of these cases were the caps also missing, resulting in the samples being discarded.

3.3 Quality of participant survey data

Although the participant surveys differed in the types of data they collected, there were a few topical areas in which they overlapped, allowing for assessment of the quality of participant-provided data.

There were multiple questions that were similar or identical between the screening and initial surveys. A key difference was that the screening survey was primarily completed online and the initial survey was administered exclusively by telephone interview. Comparing responses to the common questions provides insight into participants' ability to provide information about their home, appliances, and kitchen exhaust system without researcher assistance.

There were 11 questions about appliance characteristics that were similar or identical between the initial and screening surveys. Table 3.3 provides a summary of the number of individuals who either provided a different response or replaced a “don't know” with an actual response during the telephone interview compared to unassisted responses online. Overall, roughly three-fourths of participants initially provided a different response to at least one of 11 questions regarding their appliance characteristics. The questions that most frequently received different responses were those regarding furnace type, kitchen exhaust fan type, and central furnace and water heater location. The question that most frequently received a “don't know” response in the online survey was whether the water heater was powered by gas or electricity. These results suggest that the more expensive telephone interview approach may have yielded more accurate information about the sites.

Table 3.3. Statistics on participants who provided different responses to questions in online, unassisted screening than those provided during the pre-monitoring “initial” survey administered by telephone interview. Individuals who answered, “don’t know” in the screening survey then provided a response in the initial survey are tabulated separately.

Question	# (%) Different Responses	# (%) Initially “Don’t know”
Primary heater type	64 (20%)	23 (7%)
Supplemental heater type	69 (21%)	14 (4%)
Location of central furnace	48 (22%)	19 (9%)
Location of wall furnace	8 (11%)	3 (4%)
Fireplace vent type	0 (0%)	6 (23%)
Water heater fuel type	7 (2%)	52 (16%)
Water heater location	70 (22%)	0 (0%)
Cooktop fuel type	12 (4%)	5 (2%)
Oven fuel type	17 (5%)	9 (3%)
Kitchen exhaust fan type	93 (29%)	11 (3%)
Kitchen range hood vent type	41 (17%)	27 (11%)

One key question that was common to both the initial survey and exit survey, both of which were conducted by telephone interview, concerned cooking frequency. In the initial survey, participants were asked to provide an estimate of the household’s cooking frequency during a typical week, whereas, in the exit survey, participants were asked to report how frequently they cooked during the previous week. A comparison between initial and exit survey responses for these questions may indicate the degree to which participants’ estimates of a “typical” cooking frequency of their households corresponds with the actual cooking frequency in a given week.

Figure 3.3 displays a regression of the number of times residents reported cooking each meal in an average week (initial survey), against the number of times they recalled cooking during the week of sampling (exit survey). Note that in both cases, residents were asked to provide the amount of cooking that occurred during a full week (i.e. 7 full days). The resulting best-fit line is defined by the equation $y = 0.53x + 6.7$ ($R^2 = 0.37$), indicating that households with infrequent cooking during the week of sampling tended to estimate a higher cooking frequency on average, whereas homes with more frequent cooking during the week of sampling tended to estimate a lower cooking frequency on average. The cooking frequencies reported in the exit and initial survey tended to be most similar for households that reported cooking roughly 14 times per week. However, it should be noted that the overall correlation between responses from these two surveys is low. Differences between the two responses may be partly due to week-to-week variability around the average value predicted by residents. However, it may also be an indication that a person is better able to report how frequently their household cooked during a defined period of time, rather than estimating their household’s average cooking frequency over an undefined period of time.

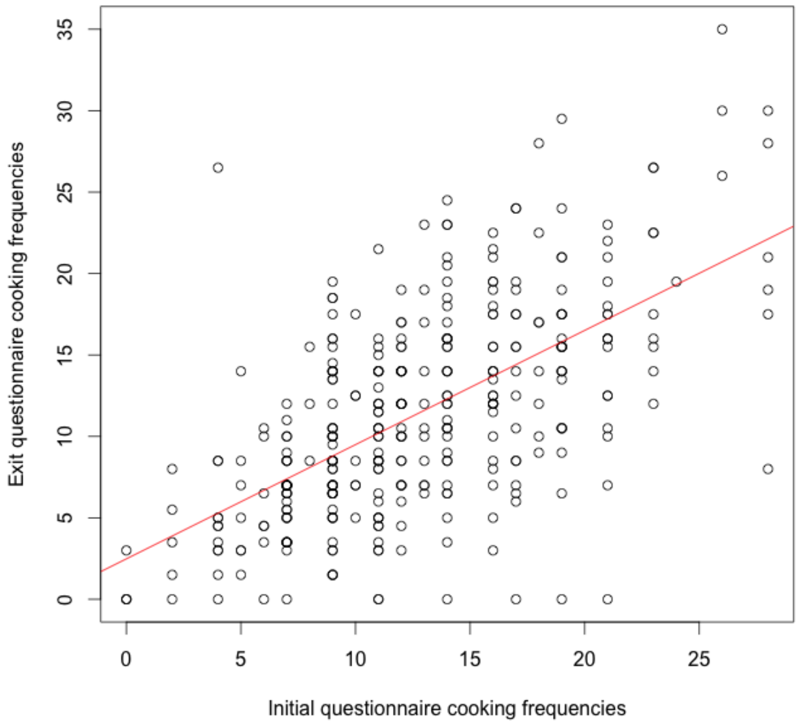

Figure 3.3. Regression of the cooking frequency during a typical week estimated by the participants, against the cooking frequency during the week of sampling reported by the participants. Regression line has equation y= 0.70x+2.5 and R^2 = 0.37.

4. Conclusions

The recruitment methods used in this study required minimal resources, and although they yielded a low response rate, allowed for cost-effectively contacting a large number of organizations and groups. In the end, the goal of oversampling homes with appliance characteristics that increased hazard of elevated pollutant concentrations, particularly frequent use of unvented gas cooking appliances, was successfully met. The goal of oversampling households with demographic characteristics hypothesized to put them at greater risk was not met; however, the ultimately selected sample population was characterized by demographics that were close to that of the total California population. The resulting group of study homes is not assumed to be representative of the California population; translating results of the study to the California population will require consideration of the distribution of the study population characteristics across California.

There was a high rate of compliance among study participants, which has been similarly observed by other indoor air quality studies utilizing mail-out strategies. Specifically, more than 95% of participants completed the study, more than 90% returned the cooking log, and roughly 90% set-up and returned the air sampling materials on time and according to instruction. The largest source of participant noncompliance was the sending of pictures of the air samplers following set-up (47%); however, this had been communicated to participants as more of a request than a strict requirement. A comparison of questions common to the screening survey completed online and the telephone interviews indicates that a substantial fraction of participants (roughly 20%) had difficulty answering basic questions about their appliance characteristics without the aid of a researcher. In addition, a low correlation was observed between participants' estimates of their households' typical cooking frequency and report of their households' cooking frequency during the week of sampling. Overall, results of this study provide evidence that the data necessary to conduct a large-scale indoor air quality study can be effectively collected remotely by communicating with study participants using a variety of methods (conventional mail, electronic mail, phone and text messaging).

5. References

Cozier Y.C., Palmer J.R., Rosenberg L., 2003. Comparison of methods for collection of DNA samples by mail in the Black Women's Health Study. Annals of Epidemiology 14, 117- 122.

Freeman B., Powell J., Ball D., Hill L., Craig I., Plomin R., 1997. DNA by mail: An inexpensive and noninvasive method for collecting DNA samples from widely dispersed populations. Behavior Genetics 27, 251-257.

Johnson M., Hudgens E., Williams R., Andrews G., Neas L., Gallagher J., Ozkaynak H., 2009. A participant-based approach to indoor/outdoor air monitoring in community health studies. Journal of Exposure Science and Environmental Epidemiology 19, 492-501.

Klepeis N.E., Nelson W.C., Ott W.R., Robinson J.P., Tsang A.M., Switzer P., Behar J.V., Hern S.C., Engelmann W.H., 2001. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. Journal of Exposure Analysis and Environmental Epidemiology 11, 231-252.

Le Marchand L., Lum-Jones A., Saltzman B., Visaya V., Nomura A.M.Y., Kolonel L.N., 2001. Feasibility of collecting buccal cell DNA by mail in a cohort study. Cancer Epidemiology, Biomarkers & Prevention 10, 701-703.

Less B., 2012. Indoor air quality in 24 California residences designed as high performance green homes. (Masters Thesis). Retrieved from eScholarship, University of California. http://www.escholarship.org/uc/item/25x5j8w6

Mullen N.A., Russell M.L., Lunden M.M., Singer B.C., 2013. Investigation of formaldehyde and acetaldehyde sampling rate and ozone interference for passive deployment of Waters Sep-Pak XPoSure samplers. Atmospheric Environment, accepted 30-July-2013. DOI:

Rodes C.E., Lawless P.A., Thornburg J.W., Williams R.W., Croghan C.W., 2010. DEARS particulate matter relationships for personal, indoor, outdoor, and central site settings for a general population. Atmospheric Environment 44: 1386-1399.

Sexton K., Liu K.S., Petreas M.X., 1986. Formaldehyde concentrations inside private residences: A mail-out approach to indoor air monitoring. Journal of Air Pollution Control Association 36, 698-704.

Sexton K., Kleffman D.E., Callahan M.A., 1995. An introduction to the National Human Exposure Assessment Survey (NHEXAS) and related phase I field studies. Journal of Exposure Analysis and Environmental Epidemiology 5: 229-232.

Singer B.C., Hodgson A.T., Hotchi T., Kim J.J., 2004. Passive measurement of nitrogen oxides to assess traffic-related pollutant exposure for the East Bay Children's Respiratory Health Study. Atmospheric Environment 38, 393-403.

Spengler J.D., Duffy C.P., Letz R., Tibbitts T.W., Ferris B.G., 1983. Nitrogen dioxide inside and outside 137 homes and implications for ambient air quality standards and health effects research. Environmental Science & Technology 17, 164-168.

Wallace L., Pellizzari E.D., Wendell C., 1991. Total Volatile Organic Concentrations in 2700 personal, indoor, and outdoor air samples collected in the US EPA Team Studies. Indoor Air 1, 465-477.

Weisel C.P., Zhang J., Turpin B.J., Morandi M.T., Colome S., Stock T.H., Spektor D.M., 2005. Relationship of Indoor, Outdoor and Personal Air (RIOPA). Health Effects Institute Research Report, Number 130 (Part I): 1-107.

Acknowledgements

Funding was provided by the California Energy Commission through Contract 500-09-042 and by the U.S. Dept. of Energy Building America Program under Contract DE-AC02-05CH11231. None of the authors has any actual or potential competing financial interests. We thank Marion Russell and Toshifumi Hotchi for their contribution to developing laboratory protocols and field sampling techniques used in this study.