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RESEARCH ARTICLE

Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

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Abstract

Early life exposure to air pollution is associated with adverse health outcomes in children however few studies have investigated children's air pollution exposures in urban settings in sub-Saharan Africa (SSA). We measured fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) in homes of infants in Nairobi, Kenya and conducted exploratory analysis of exposure factors. Questionnaires captured household characteristics and self-reported air pollution exposures. Indoor and outdoor 24-hour (24 h) concentrations were measured inside and 1 m outside the house. $PM_{2.5}$ was sampled using standard gravimetric procedures; CO was measured with direct-reading electrochemical sensors. Forty-eight homes were sampled at median infant age 11.5 months (range 0.8-26.2 months). During sampling, 66.7%, 18.8%, 10.4% and 10.4% of mothers, respectively, reported using liquefied petroleum gas (LPG), ethanol, electricity, and kerosene for cooking. Median indoor and outdoor 24 h $PM_{2.5}$ concentrations (n = 39) were 39.9 ug/m^3 (range, 12.8-519.6 ug/m^3) and 23.3 ug/m^3 (range, 2.6-68.2 ug/m^3), respectively. Most $PM_{2.5}$ concentrations (97% of indoor; 79% of outdoor) exceeded the World Health Organization (WHO) 24 h air quality guideline (AQG) of 15 ug/m^3. Median indoor (n = 47) and outdoor (n = 41) 24 h mean CO concentrations were 0.7 ppm (range, 0-33.9 ppm) and 0.0 ppm (range, 0-1.0 ppm), respectively. Mean indoor CO concentrations exceeded the WHO 24 h AQG of 6.2

Data availability statement: The deidentified data that support the findings of this study are available in the supporting information.

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ppm in 9% of homes. Despite frequent use of cooking fuels considered to be clean such as LPG and ethanol, $PM_{2.5}$ and CO levels in infant homes in urban SSA often exceeded the WHO AQGs. Expanded studies of children's air pollution exposures in urban SSA are needed to build awareness and inform policy.

Introduction

Early life exposure to combustion-related air pollutants such as particulate matter ≤ 2.5 um aerodynamic diameter ($PM_{2.5}$) is associated with adverse health outcomes in children [1,2]. Elevated levels of $PM_{2.5}$, carbon monoxide (CO), and other household air pollutants, from burning poorly ventilated, high-emitting cooking and lighting fuels such as biomass and kerosene, have been documented in both rural and urban sub-Saharan Africa (SSA) [2–8]. Although some urban households in Kenya and other SSA countries may have access to clean fuels, such as electricity, ethanol, and liquefied petroleum gas (LPG) [2,9], urban children are exposed to dirty household cooking fuels in addition to outdoor (ambient) air pollution [2]. The sources of ambient air pollution in urban SSA settings include poorly regulated industrial operations in residential areas, rubbish burning, and unpaved and highly trafficked roadways [2,8,10]. In naturally ventilated homes (i.e., homes without fans or other mechanical ventilation), such as those common in SSA, outdoor air pollution can affect indoor air quality. However, indoor air pollutants can also accumulate, even in homes using clean fuels, when cooking appliances are not properly vented (i.e., exhausted to the outdoors) and/or windows and doors are kept closed during cooking or other combustion activities.

Few studies to date have measured $PM_{2.5}$ and CO in non-biomass burning children's homes in urban SSA. Shupler et al. (2024) measured 24 h $PM_{2.5}$ and CO concentrations in kitchen air and personal air of mothers (n = 248) and children (n = 124) in 256 homes in peri-urban communities (i.e., urbanizing areas adjacent to city centers) in Kenya, Cameroon and Ghana, and outdoor 24 h $PM_{2.5}$ at several sites in each community [2]. Geometric mean concentrations of the 24 h $PM_{2.5}$ and CO in kitchen and personal air from biomass burning households were indeed higher than those using LPG [2]. However, even LPG using households had kitchen $PM_{2.5}$ concentrations exceeding the World Health Organization (WHO) 24 h air quality guideline (AQG) (15 ug/m^3), an outdoor limit designed to protect the general population from excess mortality from air pollution [11]. This may reflect infiltration of ambient air pollution indoors, particularly in the Ghana community where ambient $PM_{2.5}$ was higher (mean 31 ug/m^3) compared to that in Cameroon (mean 14 ug/m^3) and Kenya (mean 6 ug/m^3) communities [2,11]. Shezi et al. (2018) found a mean 24 h $PM_{2.5}$ of 38 ug/m^3 (median 28 ug/m^3) in 300 homes of low-income mothers and children in Durban, South Africa even though most (93%) reported using electricity for cooking [5]. In bivariate analyses, they found higher $PM_{2.5}$ in homes with indoor combustion activities (cooking, smoking, burning incense/candles) during sampling compared to none, and higher $PM_{2.5}$ in homes ≤ 1.6 km from a major road compared to those > 1.6

km away [5]. This illustrates the importance of both indoor and outdoor sources on indoor $PM_{2.5}$ in urban SSA children's homes.

To our knowledge, no studies to date have measured both indoor and outdoor $PM_{2.5}$ and CO in the homes of young children in urban SSA [2,8,10,12,13]. Measurements of indoor and outdoor pollutant concentrations allow for the quantification of the indoor/outdoor (I/O) ratio, an important parameter for both indoor air quality and epidemiologic studies. The I/O ratio, as its name suggests, is the ratio of measured indoor to outdoor air pollution concentrations, and is commonly used to understand the relative importance of indoor vs. outdoor environments on human exposures to particulate air pollution, which are due in part to indoor concentrations vs. outdoor concentrations as well as time spent indoors vs. outdoors [14,15]. Studies have measured $PM_{2.5}$ I/O ratios in a variety of residential settings [16–27]. The ratio has been found to be less than one in some studies where homes are well sealed, have air filtration or few indoor sources; but it has also been found to be greater than one in some studies where indoor smoking and combustion sources are present [14,24,25,26,27]. A previous study reporting both indoor and outdoor $PM_{2.5}$ concentrations exists for the N'gando informal settlement community in Nairobi, Kenya [4]. A few studies have measured indoor air quality in Kenya [28]; but there is a lack of $PM_{2.5}$ I/O data on urban communities in Nairobi, and data collected in the context of pregnancy and infancy are lacking. As part of a novel longitudinal pregnancy cohort study to understand exposure to air pollution and neurodevelopmental health among children in Nairobi, Kenya [11,29,30], we measured 24 h indoor and outdoor $PM_{2.5}$ and CO in a subset of infant homes. We also explored associations between the measured concentrations and household combustion activities and ventilation characteristics, both key influences on indoor air quality [31]. This study contributes empirical evidence on air pollution exposures among urban SSA infants. Such data are needed to help design interventions to reduce exposures and address inequities in morbidity [11,13,30].

Methods

Study population

The Air Pollution Exposures in Early Life and Brain Development in Children (ABC) Study is a prospective pregnancy cohort study which aims to test the association between prenatal exposure to air pollution and neurodevelopmental outcomes in Nairobi, Kenya [32]. Briefly, a convenience sample of N = 400 pregnant women attending routine antenatal care visits was enrolled from January 10 to November 29, 2022 from the Dandora II Health Centre, a publicly accessible health facility near the Dandora dump, a > 30-acre dumpsite with routine rubbish burning. Key eligibility criteria were pregnant and maternal age 18–40 years. To enable exploratory modeling of early life air pollution exposures, a convenience subset of 48 ABC participants was invited to participate in an air sampling home visit (described below). During the recruitment phase of the study, one to two women were invited for this air sampling visit each week. There were no pre-specified exclusion criteria for participation in air sampling.

Written informed consent for study procedures was obtained from study participants. Study procedures were approved by the Kenyatta National Hospital/University of Nairobi Ethics and Research Committee and the University of Washington Human Subjects Division.

Enrollment and home visit interviews

At enrollment, a study clinician interviewed participants using a structured questionnaire. The questionnaire included questions on maternal demographics (e.g., age, education, employment, household characteristics related to indoor air pollution exposures and ventilation (e.g., number of rooms, people per room, and number of doors, windows and vents), and household and other daily behaviors involving combustion (e.g., use of cooking fuel, candles, incense, mosquito coils or repellent, rubbish burning, cigarette and marijuana smoking) and their frequency (daily, most days, some days, rarely, not at all). Fuels included electricity, LPG, paraffin (kerosene), ethanol-based fuel, wood, and charcoal.

During the air sampling set-up and take-down visits, participants were interviewed and reported the following: sources of indoor and outdoor air pollution (e.g., fuel use indoors and outdoors; own or neighbors' outdoor cooking smoke (< 20 m); and sources near (< 1 km) the home including vehicles exhausts, dumpsite, factories, rubbish burning, charcoal or brick making, dusty roads, construction dust, and burning tires. At the take-down visit, participants were interviewed on indoor combustion activities (e.g., use of cooking fuels, incense, candles, kerosene lamp(s), mosquito repellent, and rubbish burning), and outdoor air pollution observed near the home during the prior 24 hours. A laser measure (GLM 20, Bosch GmbH, Gerlingen-Schillerhöhe, Germany) was used to measure kitchen dimensions and distance from the outdoor sampling equipment to the home's closest outer wall.

$PM_{2.5}$ measurements

Twenty-four-hour $PM_{2.5}$ indoor and outdoor samples were collected at participating homes using Harvard Impactors loaded with 37 mm, 2 um pore size, polytetrafluorethylene filters (SKC, Eighty Four, Pennsylvania, USA), drawn by SKC AirChek-XR5000 pumps with a flow rate of 1.8 L/min. Indoor samples were collected in the kitchen/cooking area and outdoor samples were collected approximately 1 m from the outer wall of the home, at breathing height (i.e., ~ 1.8 m from the ground) in both cases. Pumps were calibrated by the manufacturer to U.S. National Institute of Standards and Technology (NIST) traceable standards and flow rates were checked at deployment and take-down using a DryCal® DC-Lite Medium flow meter (Mesa Laboratories, Lakewood, CO, USA) also calibrated to NIST traceable standards. Samples with flow rates of 1.4-2.2 L/min were considered acceptable. Impactors were cleaned, wrapped in aluminum foil, and stored in zipper lock bags between deployments and nitrile gloves were worn during all sampling and filter handling activities.

Filters were pre- and post-conditioned and weighed following U.S. Environmental Protection Agency (EPA) protocols [33] in a temperature and humidity-controlled laboratory at the Department of Chemistry, University of Nairobi, using a Shimadzu AUW220D semi-microbalance (Shimadzu Corporation, Kyoto, Japan). The balance sensitivity is 10 ug minimum display and a repeatability (SD [standard deviation]) of ≤ 50 ug. However, we assessed repeatability of the balance as ± 20 ug using triplicate weights of 50 mg and 100 mg NIST traceable working mass standards. Based on this, ± 20 ug (for each of the triplicate weights) was used as the acceptance criterion for valid filter mass. Temperature (T) and relative humidity (RH) in the laboratory were monitored continuously using a Lascar EasyLog EL-WiFi-TH Temperature & Humidity Data Logger (Lascar Electronics, Erie, PA, USA). In general, the difference in RH between pre- and post-weighing was ≤ 3% for each sample, with a range of 0–20%. RH differences between pre- and post- filter weighing were considered in terms of their possible impact on concentration uncertainties. Percentage differences ≥ 10% were considered to have a non-negligible impact on the uncertainties and the related filters were therefore rejected.

Filters were inspected for holes or tears before deployment and again before weighing, and defective filters were rejected. The assembled impactors with sample filters were wrapped with aluminum foil and transported to the sampling site in a tightly sealed cooler box. Three blank filters (two from the laboratory and a field blank) were analyzed for each batch of 10 filters. A field blank was a primary sample filter loaded on the impactor, carried along with other filters and not used for sampling. Control charts of field and laboratory blank mass differences (post minus pre weight) revealed no apparent pattern. The method detection limit, calculated as three times the median absolute deviation of the field blanks mass differences (n = 30), was 21 ug. Two outdoor samples were below this value; the machine values were used for these samples in data analyses. Filter masses were calculated as the mean of triplicate weights and filter mass difference was calculated as the post minus the pre filter mass. Mass differences were divided by the volume of air sampled to calculate the $PM_{2.5}$ concentrations. Two pairs of collocated indoor and one pair of collocated outdoor duplicate samples were collected, and precision was calculated as the relative percent difference between duplicates concentrations. Finally, to evaluate how much the indoor home space is protected from infiltration of outdoor air pollutants, $PM_{2.5}$ I/O ratios were calculated by dividing the indoor by the outdoor concentration for homes with complete measurements. A lower ratio indicates more protection [16,19–22,34,35].

CO measurements

Indoor and outdoor CO was measured using electrochemical EL-USB-CO sensors (Lascar Electronics Ltd., Whiteparish, UK) logging at 10 sec intervals and collocated with the $PM_{2.5}$ impactors. The manufacturer-rated measurement range is 0.0-300 ppm with a 0.5 ppm resolution [36]. Sensor data were checked for error messages and smoothed 1 min medians calculated. Precision was assessed by examining the slope, intercept, R^2, and root mean square error of bivariate regressions of 1 min CO data over the 24 h sample period between two collocated indoor and one collocated outdoor duplicate pair. The manufacturer stated accuracy is an overall error of ± 5 ppm or ± 4%.

Indoor and outdoor T and RH were also measured using HOBO® U12 Temp/RH Data Loggers (Onset, Bourne, MA, USA). These were collocated with the $PM_{2.5}$ and CO monitors and logged at 5 min intervals.

Statistical methods

Statistical analyses were conducted in R version 4.3.3 (R Foundation for Statistical Computing, Vienna, Austria). For the sensor data, descriptive statistics were calculated for the 24 h sampling period using 1 min smoothed (CO) or 5 min logged measurements (T and RH) for each participant. Time series of indoor and outdoor CO were plotted for each home using the 1 min smoothed data.

We assessed the normality of the 24 h measurements by visually inspecting histograms of raw and natural log transformed concentrations. We calculated descriptive statistics, Spearman correlation coefficients (ρ) between the indoor and outdoor $PM_{2.5}$ measurements and between the indoor $PM_{2.5}$ and CO measurements, and $PM_{2.5}$ I/O ratios. We also compared indoor and outdoor $PM_{2.5}$ and CO concentrations to the WHO 24 h AQGs. The 24 h WHO AQG for $PM_{2.5}$ (15 ug/m^3) is primarily an ambient limit (although it can apply to indoor environments as well) while the 24 h CO AQG (7 mg/m^3 or 6.2 ppm) is an indoor limit; both are designed to protect people from adverse health effects associated with chronic exposures [11,30]. We also considered the WHO 15 min, 1 h, and 8 h indoor CO AQGs, which are designed to protect residents from CO poisoning resulting from using improperly vented stoves and other faulty appliances indoors [30].

We used box plots, two-sample t-tests, and one-way analysis of variance to explore differences in natural log transformed indoor $PM_{2.5}$ and CO concentrations, and $PM_{2.5}$ I/O ratios, by selected household characteristics shown in the literature to influence indoor air pollutant concentrations. We categorized household characteristics as follows: number of persons (2–4 vs. 5–8), number of rooms (1 vs. 2–4), kitchen volume (m^3, continuous measurement), total external doors and windows (1–2 vs. 3–7), rug/carpet floor covering (no vs. yes), combustion activities (i.e., use of cooking fuels [LPG, ethanol, electricity, kerosene], candles, or mosquito repellent; no vs. yes) during air sampling, and the presence of environmental tobacco smoke (i.e., cigarette and/or marijuana smoke in the house; no vs. yes) during air sampling. We also used two-sample t-tests to explore differences in outdoor $PM_{2.5}$ concentrations by participant-observed outdoor air pollution near the home. The criterion employed for statistical significance was $p \le 0.05$. In sub-analyses, we divided the $PM_{2.5}$ I/O ratios into two groups at the median and repeated the analyses to see whether the household characteristics associated with higher indoor $PM_{2.5}$ differed between homes that were potentially less infiltrated from outdoor $PM_{2.5}$ (i.e., homes with I/O ratios less than the median) compared to homes that were potentially more infiltrated (i.e., homes with I/O ratios greater than the median). Last, we plotted 24 h mean indoor and outdoor T and RH by sample date, and visually explored associations between 24 h mean indoor and outdoor T and RH and indoor and outdoor $PM_{2.5}$ and CO using scatter plots with locally estimated scatterplot smoothing.

Estimating air change rates for a subset of homes

For a subset of homes with 24 h CO time series with CO decay events, we estimated air change rates (i.e., the number of times a space's air volume is completely removed and replaced per hour), using the decay of indoor CO concentrations produced by combustion activities. This is a common measure of household ventilation [31]. For time series with multiple decay events, we selected the event associated with afternoon or evening activities (1500–2300 h). Following Batterman (2017) [37], we fit a linear model to the log transformed CO concentrations during the period of CO decay, where the slope of the regression model is the air change rate (h^{-1}). We fit scatter plots and calculated Spearman ρ's between estimated air change rates and indoor $PM_{2.5}$ and CO concentrations. We also compared calculated air change rates to the ASHRAE and EPA recommended rate (0.35 h^{-1}) [38].

Inclusivity in global research

Additional information regarding the ethical, cultural, and scientific considerations specific to inclusivity in global research is included in the Supporting Information (S1 Checklist).

Results

Demographic and household characteristics

At enrollment, mothers who participated in air sampling had a median age of 27 years (interquartile range (IQR), 24–31 years); most (67%) reported having secondary-level education and 33% reported being employed (Table 1). The median monthly household rent was 4,000 Kenya Shillings (IQR: 3,000–5,500) (~33 United States Dollars). The median infant age (n = 47) was 11.8 months (IQR 6.8-16.5 months); one home was assessed 1.7 months before the baby was born. Half of the participants lived in a one-room dwelling (50%), 42% lived in rooms with one window, 85% lived in houses with only one door, and 14 (29%) lived in a house with > 4 residents. Virtually all homes sampled were in the residential units of multi-story buildings, with masonry stone walls and galvanized iron sheet or reinforced concrete slab roofing and consisted of 1–2 rooms with ventilation provided by 1–2 windows and doors.

Air measurements were conducted at 48 homes between July 13, 2022, and June 6, 2024. We summarized descriptives for demographics, cooking behavior and household characteristics of the air sampling participants versus the full ABC cohort (S1 Table). The air sampling participants had a higher proportion with primary education or less (16.7%) vs the full cohort (26.0%). There were also more ethanol users (31.3% vs 17.5%) and fewer kerosene users (37.5% vs 54.0%) compared to the full cohort.

Self-reported air pollution exposures during air sampling

During the air sampling period, the most commonly used fuel inside the homes was LPG (67%), followed by ethanol (19%) and kerosene (10%) (Table 2). Five participants (10%) reported using electricity and no other fuels. Other reported indoor combustion sources were candles (19%) and mosquito repellent (8%). No participants reported using incense or kerosene lamps or burning rubbish inside the home. Some reported exposure to smoke from their own outdoor cooking (4%) or a neighbor's (15%), while all said they were exposed to other cooking smoke, and 98% said they were exposed to vehicle smoke emissions from sources near home. Other commonly reported outdoor air pollution sources were smoke from the dumpsite (40%) and other rubbish burning (71%), dust from unpaved roads (85%) and construction dust (31%). One participant (2%) reported exposure to smoke from charcoal/brickmaking and none reported exposure to industrial/factory smoke.

Air measurements - completeness and precision

Among N = 48 homes, 39 (81%) had valid indoor $PM_{2.5}$ and 39 (81%) had valid outdoor $PM_{2.5}$ measurements. Samples were missing or invalid because of security concerns or lack of space (n = 5 outdoor), negative filter mass (n = 1 indoor), RH difference for pre vs. post weigh sessions > 10% (n = 7 indoor, n = 5 outdoor), and sampling duration 33% of target (n = 1 indoor). There were 47 (98%) valid indoor and 41 (85%) valid outdoor CO measurements. Invalid CO measurements were due to battery/equipment failure (n = 1 indoor, n = 2 outdoor). All valid indoor and outdoor $PM_{2.5}$ samples

Table 1. Selected demographic and household characteristics of study participants (N = 48).

Characteristic[a]	Detail	Frequency or median	Percent or IQR
Socio-demographics at study entry			
Infant age, months[b] (n = 47)	Median	11.8	6.8-16.5
Maternal age, years	Median	27	24-31
Maternal education level	Primary	8	16.7
	Secondary	32	66.7
	University or college	8	16.7
Maternal employment status	Homemaker or none	30	62.5
	Daily wage	6	12.5
	Small business	6	12.5
	Monthly salary	4	8.3
Monthly household rent (KES) (n = 41)	Median	4,000	3,000-5,500
Household characteristics at air sampling			
Type of housing	Small bungalow (single unit)	1	2.1
	Multi-unit dwelling (flats)	47	97.9
Number of persons in household	2-4	34	70.8
	5-8	14	29.2
Number of rooms	1	24	50.0
	2	16	33.3
	3 or more	8	16.7
Persons per room		3	2-4
Water source	Borehole/rainwater/river	0	0
	Water vendor	2	4.2
	Piped water outside house	40	83.3
	Piped water inside house	8	16.7
Type of toilet	Pit latrine	0	0
	Flush	48	100
Shared toilet	Yes	42	87.5
	No	6	12.5
Roof material	Metal sheets	33	68.8
	Concrete	15	31.3
Wall material	Metal sheets	1	2.1
	Stone	47	97.9
Floor material	Cemented	34	70.8
	Ceramic tiles	15	31.3
House ventilation features			
Number of external windows	0	1	2.1
	1	20	41.7
	2	19	39.6
	3 or more	8	16.7
Number of external doors (n = 47)	1	41	85.4
	2 or more	6	12.5
External openings (windows and doors) per room (n = 47)	Median number	2	1.5-2
Volume of cooking room (cubic meters)	Median	24.5	17.9-30.2
Household behaviors related to air pollution			
Rug or carpet floor covering	No	22	45.8
	Yes	26	54.2

(Continued)

Table 1. (Continued)

Characteristic[a]	**Detail**	**Frequency or median**	**Percent or IQR**
Indoor combustion/burning (cooking fuels)	Wood	1	2.1
	Charcoal	1	2.1
	Kerosene	18	37.5
	Ethanol (Koko fuel)	15	31.3
	Liquefied petroleum gas	40	83.3
	Electricity	5	10.4

IQR = interquartile range. Total percentages may exceed 100% as categories were not mutually exclusive. [a]N = 48 unless otherwise stated. [b]At air sampling.

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Table 2. Combustion related indoor and nearby outdoor activities reported during the 24 hour air sampling period.

Activity		**Detail**	**Frequency (N = 48)**	**Percent**
Indoor sources of air pollution				
Cooking fuel used during air sampling[a]		Wood	1	2.1
		Charcoal	1	2.1
		Kerosene	5	10.4
		Ethanol	9	18.8
		LPG	32	66.7
		Electricity	5	10.4
Other activities		Burning mosquito repellent	4	8.3
		Burning candles	9	18.8
		Cigarette use	2	4.2
		Marijuana use	4	8.3
Outdoor sources of air pollution				
Outdoor smoke from cooking close to the house		Own cooking	2	4.2
		Neighbor's cooking	7	14.6
Other activities contributing to air pollution away from the house but within one kilometer	Outdoor combustion sources	Other cooking	48	100
		Vehicle smoke	47	97.9
		Dumpsite	19	39.6
		Rubbish burning	34	70.8
		Industry or factory smoke	1	2.1
		Charcoal or brick making	1	2.1
	Non-combustion sources	Unpaved roads	41	85.4
		Construction dust	15	31.2

IQR = interquartile range. LPG = liquefied petroleum gas. Total percentages may exceed 100% as categories were not mutually exclusive. [a]Note: more than one fuel type may have been used.

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represented the full 24 h because > 80% of the 24 h period was captured: indoor range 19.6-24 h, outdoor range 19.6-24 h. The 47 valid indoor CO samples ranged from 24.0-24.2 h and the 41 valid outdoor CO samples ranged from 16.1-24.2 h. Two outdoor CO samples (16.1 h, 16.8 h) shorter than the target of 24 h ± 20% were analyzed as is. The $PM_{2.5}$ relative percent differences were 29% and 114% for the two indoor duplicate pairs and 11% for the outdoor pair. The relative percent difference for the two 24 h mean indoor CO duplicate pairs were 78% and 9%; for the outdoor duplicate pair, all measurements from both sensors were 0.0 ppm. For the two pairs of indoor CO duplicates, the slopes of the 1 min smoothed data were 1.1 and 1.4, intercepts were 0.0 and 0.1 ppm CO, R^2's were 1.0 and 0.9, and root mean squared errors were 0.2 and 0.4 ppm.

$PM_{2.5}$ concentrations

The 24 h indoor $PM_{2.5}$ concentrations ranged from 12.8-519.6 ug/m^3 with a median of 39.9 ug/m^3 (IQR 28.9-63.8 ug/m^3). Outdoor concentrations ranged from 2.6-68.2 ug/m^3 with a median of 23.2 ug/m^3 (IQR 16.7-33.5 ug/m^3) (Table 3). Indoor and outdoor $PM_{2.5}$ concentrations were correlated ($\rho = 0.42$, $p = 0.01$). The three participants with complete indoor $PM_{2.5}$ measurements who reported using only electricity and no other fuels during air sampling had lower indoor $PM_{2.5}$ than those who reported burning LPG, ethanol, kerosene, and/or wood indoors (geometric mean (geometric SD) 21.8 ug/m^3 (1.3) vs. 47.9 ug/m^3 (2.1), respectively (S2 Table). Indoor $PM_{2.5}$ did not differ significantly by number of persons, number of rooms, kitchen volume, total external windows and doors, rug/carpet floor covering, or kerosene, LPG, or ethanol fuel combustion during air sampling. Likewise, indoor $PM_{2.5}$ did not differ by environmental tobacco smoke in the home, or burning mosquito repellent, or candles during air sampling. Outdoor $PM_{2.5}$ did not differ significantly by reported exposure to smoke from their own outdoor cooking or a neighbors' cooking, or smoke from the dumpsite or rubbish burning, or dust from unpaved roads or construction (S3 Table).

For most homes (77%), the indoor $PM_{2.5}$ concentration was higher than the outdoor concentration (Fig 1). $PM_{2.5}$ concentrations exceeded the WHO 24 h AQG of 15 ug/m^3 in 79% of outdoor and 97% of indoor measurements. Two homes reporting no indoor combustion of any kind during air sampling had indoor $PM_{2.5}$ concentrations at or above the WHO 24 h AQG (15.5 and 25.8 ug/m^3, respectively) [11].

$PM_{2.5}$ I/O ratios

For the 36 homes with complete indoor and outdoor $PM_{2.5}$ measurements, $PM_{2.5}$ I/O ratios ranged from 0.5-18.3, with a median of 1.6 (IQR 1.1-3.0). When we categorized homes into those with $PM_{2.5}$ I/O ratios ≤ or> than the median ratio, indoor $PM_{2.5}$ did not differ significantly by reported exposure to smoke from any source considered, for either category, with two exceptions (S4 and S5 Tables). Among the homes with I/O ratios ≤ 1.6, indoor $PM_{2.5}$ differed by reported exposure to smoke from rubbish burning, with geometric mean indoor $PM_{2.5}$ 36.3 (1.6) ug/m^3 in the exposed (n = 15) vs. 19.3 (1.3) ug/m^3 in the unexposed group (n = 3). Among the homes with I/O ratios >1.6, indoor $PM_{2.5}$ differed by reported exposure to construction dust, with geometric mean indoor $PM_{2.5}$ 35.1 (6.3) ug/m^3 in the exposed (n = 5) vs. 79.6 (2.5) ug/m^3 in the unexposed group (n = 13).

CO concentrations

The 24 h mean indoor CO concentrations were higher than the outdoor concentrations at all homes (Fig 1). Indoor concentrations (n = 47) ranged from 0.0-33.9 ppm (median 0.7, IQR 0.3-2.4 ppm) and outdoor concentrations (n = 41) ranged

Table 3. 24 h indoor and outdoor $PM_{2.5}$ (ug/m^3) and CO (ppm) concentrations in the infants' homes (n = 48).

Pollutant	Units	N	Geo. mean (GSD)[a]	Range	Median	P25	P75	P95
Indoor $PM_{2.5}$	ug/m^3	39	45.1 ± 2.1	12.8-519.6	39.9	28.9	63.8	219.7
Outdoor $PM_{2.5}$	ug/m^3	39	22.7 ± 1.82	2.6-68.2	23.2	16.7	33.5	49.5
Indoor CO	ppm	47	2.9 ± 5.9	0.0-33.9	0.7	0.3	2.4	7.7
Outdoor CO	ppm	41	0.1 ± 0.2[a]	0.0-1.0	0.0	0.0	0.1	0.5

N = number of homes. Geo. = geometric. GSD = geometric standard deviation. P = percentile. $PM_{2.5}$ = particulate matter < 2.5 um. CO = carbon monoxide.
[a]Except where noted; otherwise, the arithmetic mean and standard deviation are provided.

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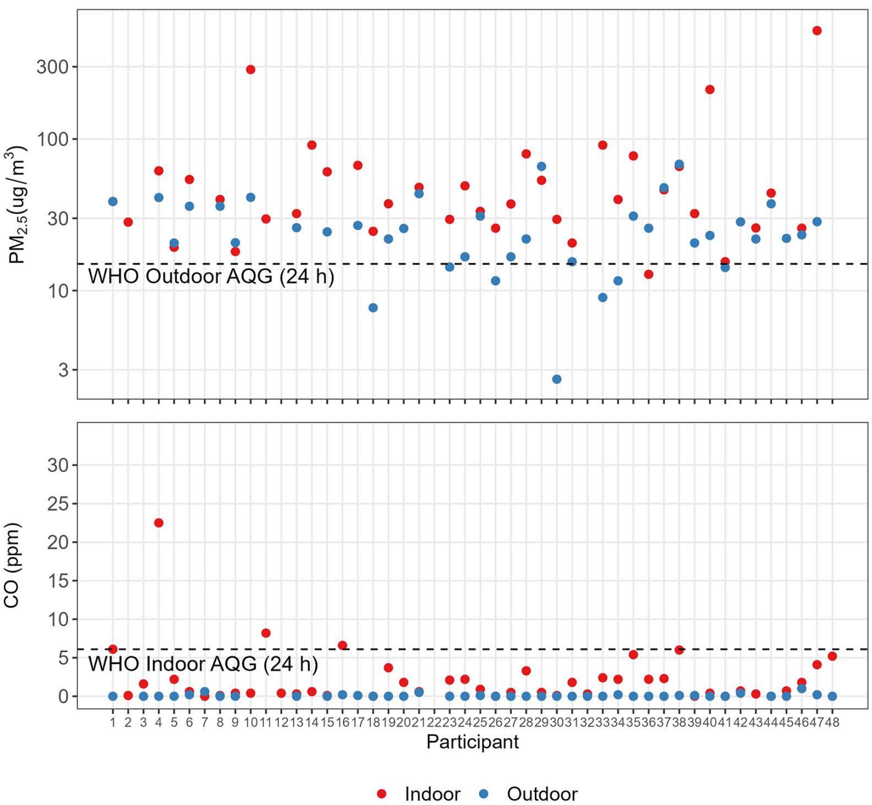

Fig 1. Measured 24 h $PM_{2.5}$ (ug/m³) (top) and 24 h mean CO (ppm) (bottom) concentrations (Note: top panel y-axis is log base 10 scale for better resolution of indoor vs. outdoor measurements).

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from 0.0-1.0 ppm (median 0.0, IQR 0.0-0.1 ppm) (Table 3). The indoor $PM_{2.5}$ and CO concentrations were correlated ($\rho = 0.37$; $p = 0.02$).

Four of 47 homes (9%) had 24 h mean indoor CO concentrations exceeding the WHO AQG of 6.2 ppm [30]. Three of these reported using ethanol for cooking during air sampling while one used kerosene; none reported using LPG or electricity. The two homes reporting no indoor combustion of any kind during air sampling had 24 h mean indoor CO concentrations of 0.0 ppm and 1.8 ppm. Indoor CO did not differ by number of persons, number of rooms, kitchen volume, total external windows and doors, or use of electricity, LPG, or ethanol during air sampling (S6 Table). The kerosene using homes (n = 5) had higher 24 h mean CO compared to the 42 non-kerosene homes (geometric mean 3.3 (3.1) ppm vs. 0.6 (1.9) ppm, respectively), as did the mosquito repellent homes (n = 4) vs. the non-mosquito repellent homes (n = 43) (geometric mean 2.5 (10.7) ppm vs. 0.7 (2.0) ppm, respectively). Indoor CO did not differ significantly by tobacco or marijuana smoke presence or candle use.

For many homes sampled, the 24 h means did not reflect shorter-duration episodes of high indoor CO (i.e., ≥ 50 ppm) seen in the 1 min data. These episodes generally coincided with cooking and mealtimes, that is, morning, afternoon, and evening hours, and CO gradually decreased to as low as 0.0 ppm afterwards. To illustrate, Fig 2 shows the 1 min smoothed CO concentrations in three selected homes. Each panel shows higher indoor compared to outdoor levels, which were generally negligible, and two or three high CO episodes lasting several hours. Two (Fig 2A and 2B) used ethanol during air sampling while the third (Fig 2C) used kerosene. The Fig 2A home also burned mosquito repellent, the Fig 2B home reported presence of environmental tobacco smoke, and the Fig 2C home burned candles

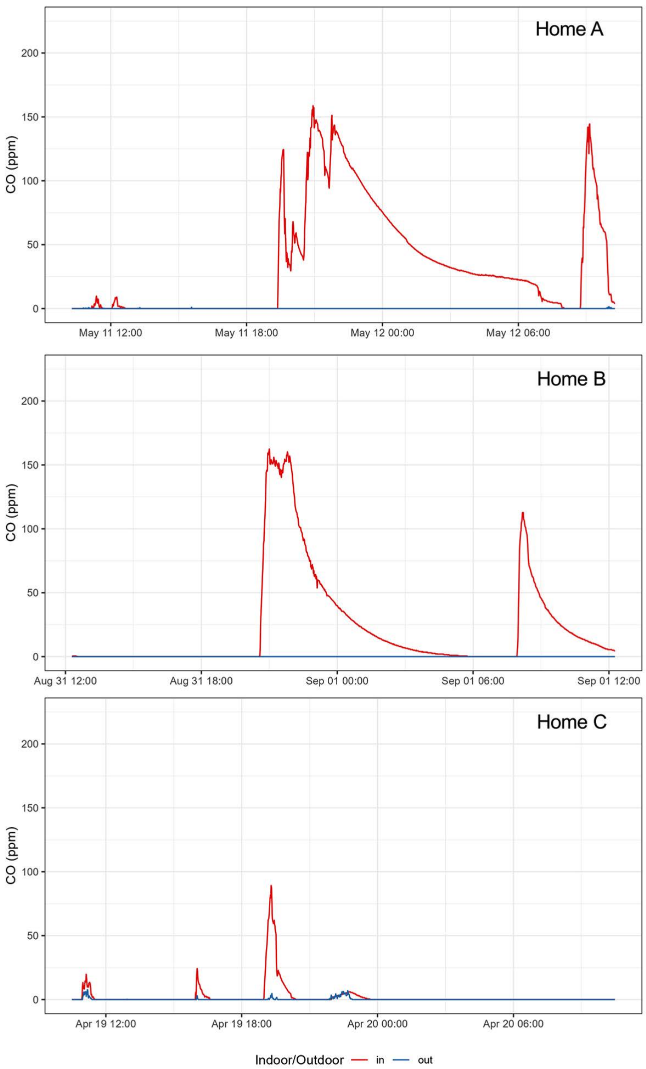

Fig 2. One minute smoothed indoor and outdoor CO concentrations during sampling at three homes.

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during air sampling. The Fig 2A and 2B homes exceeded the WHO 24 h AQG while the Fig 2C home did not. Additionally, six homes (13%) (including Fig 2A and 2B homes) exceeded the 1 h WHO AQG (30.6 ppm) and three (6%) (including Fig 2A and 2B homes) exceeded the 15 min WHO AQG (87.3 ppm) one or more times during the 24 h period [11,30].

Associations with temperature and relative humidity

The median indoor (n = 48) and outdoor (n = 44) T were 25.1°C (IQR 23.8-26.5°C) and 23.0°C (IQR 21.8-24.3°C), respectively, while the median indoor (n = 48) and outdoor RH (n = 44) were 65.1% (IQR 57.5-70.3%) and 66.8% (IQR 59.1-69.9%). In the scatter plots with smooth curve fits, associations were not visually apparent between T or RH and indoor or outdoor $PM_{2.5}$ (S1 Fig) or indoor or outdoor CO. (S2 Fig).

Estimated air change rates

Twenty-three homes had 24 h time-series with one or more CO decay events suitable for air change rate estimation. Estimated air change rates for these homes ranged from 0.3-7.7 with a median of 2.1 (IQR 1.3-3.6). The R^2 for these linear decay models ranged from 0.9-1.0 (S7 Table). Among the 23 homes, we did not observe a significant correlation between estimated air change rates and indoor $PM_{2.5}$ ($\rho = 0.15$, $p = 0.6$), but air change rates were inversely associated with 24 h mean CO ($\rho = -0.61$, $p = 0.002$) (S3 Fig). One home had an estimated 0.29 air changes per hour, below the ASHRAE and EPA recommended value of 0.35 h^{-1} [38]. This two-room home also had the highest 24 h mean indoor CO concentration despite having a kitchen volume of 26 m^3 (67^{th} percentile) and three external windows and doors.

Discussion

In this first study of indoor and outdoor $PM_{2.5}$ and CO in infants' homes in a densely populated SSA city [39], we found that indoor $PM_{2.5}$ concentrations exceeded the health-based WHO AQG in 97% of homes even though most reported using clean household fuels (i.e., electricity, LPG, ethanol) during air sampling. Outdoor $PM_{2.5}$ concentrations also exceeded the WHO AQG at 79% of the homes. Other Nairobi studies [4,40–42] also reported high outdoor $PM_{2.5}$ over sampling periods of 8–12 h, indicating urban air quality deterioration potentially due to contributing factors such as population increase, uncontrolled waste burning, unpaved roads, and vehicle exhaust.

In our study, the three homes who reported using electricity and no other fuels during sampling had lower indoor $PM_{2.5}$ compared to homes burning solid or liquid fuels, however their geometric mean still exceeded the WHO AQG, as did indoor $PM_{2.5}$ in the two homes reporting no indoor combustion of any kind during sampling. Bivariate exploratory analyses did not reveal differences in indoor or outdoor $PM_{2.5}$ by any other factor considered, possibly because of small sample sizes.

Indoor and outdoor $PM_{2.5}$ concentrations were moderately correlated, similar to previous studies in other urban residences in India, China, the USA, and Europe [19,26,43,44], possibly indicating the influence of outdoor sources on indoor $PM_{2.5}$. However, the wide range of $PM_{2.5}$ I/O ratios in the 36 homes with complete measurements made it difficult to discern the influence of outdoor $PM_{2.5}$ on indoor levels. When we divided homes into those potentially less infiltrated by outdoor $PM_{2.5}$ vs. those potentially more infiltrated, we found that indoor $PM_{2.5}$ was significantly higher in the potentially less infiltrated homes that reported exposure to smoke from nearby rubbish burning, possibly reflecting the influence of this outdoor source on indoor $PM_{2.5}$ although sample sizes were small (only three participants reported no exposure). Among the potentially more infiltrated homes, indoor $PM_{2.5}$ differed significantly by reported exposure to construction dust, but in the opposite direction from expected (i.e., non-exposed homes had higher indoor $PM_{2.5}$ than exposed homes). It is also theoretically possible that high indoor $PM_{2.5}$ in some homes influenced outdoor levels since we sampled so close (< 1 m) to the outer wall of the home [24]; however, since our participants were using mostly fuels considered to be clean, and not biomass, we did not evaluate this explicitly.

Our results indicate that indoor air quality is a concern for infant health in Nairobi despite the use of clean household fuels**.** Just over half (53%) of the urban households in the 2022 Kenya Demographic and Health Survey reported having access to clean cooking fuels [39]. Increased access to clean fuels is credited with considerable reductions in mortality and acute respiratory infections in children under 5 years old in recent decades including in SSA [45]. Despite the reported use of clean fuels, the indoor $PM_{2.5}$ concentrations we observed still exceeded the WHO AQG and were consistently higher than outdoor concentrations, likely reflecting a combination of ventilation, infiltration of outdoor $PM_{2.5}$, and indoor combustion activities [2,8,27]. Mutahi et al. (2021) also found higher indoor vs. outdoor 12 h gravimetric $PM_{2.5}$ concentrations in their small study of 15 one room homes in the N'gando informal settlement area of Nairobi in 2019 [4]. Most of the homes we sampled were only one or two rooms, where the infants likely spend much of their time which may lead to high exposures and health burden. The air change rates we estimated for 23 homes generally met the ASHRAE/EPA recommendation, except for one 2 room home (Fig 2B). This was an ethanol using home that also had the highest indoor

CO concentration, suggesting a need for counseling on the importance of opening windows and doors while cooking even when using clean fuels.

Indoor CO levels were generally low over the 24 hours although shorter episodes with concentrations exceeding the WHO 1 h and 15 min AQGs were observed in some homes during typical cooking hours. Outdoor CO concentrations were generally not detectable. The indoor CO concentrations we observed are similar to those reported by Orina et al. (2024) who sampled 71 homes in Mukuru informal settlement, Nairobi, using Lascar CO sensors logging at 1 min intervals [46]. Their 24 h indoor median, 2.9 ppm (IQR 1.2-5.4 ppm), was below the WHO AQG [46]. The indoor CO spikes we observed in some homes are a concern particularly in homes with infants and pregnant mothers. Once inhaled, CO binds to hemoglobin to form carboxyhemoglobin which disrupts tissue oxygenation, leading to poisoning signs and symptoms at carboxyhemoglobin levels > 10% [47]. During gestation, CO crosses the placenta and binds to fetal hemoglobin which has a higher affinity for both oxygen and CO than adult hemoglobin [48]. Fetal hemoglobin is still found in infant circulation during the first year of life; small amounts are present in maternal blood in pregnancy [49]. Although compensatory mechanisms exist to protect fetal, infant and adult brains from hypoxia during acute exposures [30], CO unbound from carboxyhemoglobin after acute or chronic, lower-level exposures can diffuse into nearby tissues causing oxidative stress, inflammation, apoptosis, and other types of damage, including neuronal damage [47,50]. The WHO 15 min, 1 h, and 8 h AQGs are designed to protect residents from CO poisoning resulting from using improperly vented stoves and other faulty appliances indoors, while the 24 h AQG is designed to be protective against health effects in adults from chronic exposures [30]. Safe exposure levels for infants are not currently known. Infants have nearly twice the oxygen consumption rate per unit body weight as adults [51], which likely means they have greater CO absorption per ppm of CO inhaled, thus guidelines aimed at protecting adults may not be protective for infants. Because of the potential for both acute CO poisoning as well as adverse neurodevelopmental and other effects at lower exposure levels [50], it is critical to remind expectant mothers and caregivers of infants to open windows and doors during cooking, even when clean fuels (e.g., ethanol) are used.

Strengths and limitations

This study provides novel insights into indoor and outdoor $PM_{2.5}$ and CO levels in urban SSA infants' homes. We used gold standard methods to measure indoor and outdoor $PM_{2.5}$ levels and compared both indoor and outdoor $PM_{2.5}$ levels to the WHO outdoor AQG since no indoor AQG currently exists for $PM_{2.5}$ [11]. The Lascar sensors we used to measure CO are commonly used and well-described in household air pollution studies. Field studies have reported that the devices offer a relatively low failure rate and moderate to high correlation when compared to higher quality instruments and other Lascar CO sensors [52], although others noted high relative standard deviations (e.g., 24%) [53]. While CO measurements can degrade over the course of years (e.g., 2–4 years), lower CO concentrations can prolong their useful lifespan. Due to the difficulty of obtaining calibration gases in Nairobi, we relied on span gas checks in the USA to identify potentially malfunctioning sensors and otherwise estimated measurement error according to manufacturer specifications. Future air pollution studies in Nairobi and other SSA locations would benefit from having the capacity to calibrate CO and other gas sensors locally.

Other challenges included the conspicuous nature of the indoor and outdoor air monitors, and other logistical constraints involved in acceptability of home visits, which may have impacted generalizability to the overall cohort and to the Dandora community. For example, security concerns limited outdoor sampling at some of the homes. Mothers in the sampled homes were also slightly more educated, and used a slightly different fuel mix than the full cohort (fewer kerosene users, and more ethanol users), limiting generalizability to the full cohort. Importantly, 83% of households in our air sampling cohort reported use of LPG on some or most days, whereas 53% of urban Kenyan households are estimated to have access to any clean fuel and technologies [9]. Although these observations point towards limited generalizability, they also suggest that urban Kenyans may have even higher exposures to unhealthy air indoors than in our subsample.

Although we followed protocols from prior studies [41,42] on where to set up equipment (i.e., in the main kitchen area, at breathing height), fixed monitors like these do not necessarily capture participants' personal exposures as personal monitors would. Further, we did not measure continuous $PM_{2.5}$ and were not able to capture peak exposure periods as we did with the continuous CO data. Finally, RH changes in the gravimetric laboratory invalidated some $PM_{2.5}$ measurements [33], limiting the sample size. The small sample overall limited our ability to explore factors influencing indoor and outdoor pollutant levels.

Conclusions

Our study provides novel data on $PM_{2.5}$ and CO levels in infant homes in Nairobi that could help inform the development of air quality regulations for $PM_{2.5}$ and CO in urban residential areas of Kenya. Both the indoor and outdoor $PM_{2.5}$ concentrations we measured were often above WHO AQGs, including in homes using clean fuels. These findings highlight the importance of improving indoor air quality, given that caregivers and infants spend much of their time indoors, which increases their exposures and potential health risks. The limited data on air quality in SSA calls for expanded studies on exposures to air pollution among children residing in urban settings in order to develop effective interventions, build public awareness, and inform policy.

Supporting information

S1 Table. Select demographic and household characteristics at enrollment of air sampling participants and the full ABC cohort.
(DOCX)

S2 Table. Tests of differences in indoor $PM_{2.5}$ concentrations by selected household characteristics and combustion activities during air sampling in a subsample of 39 homes.
(DOCX)

S3 Table. Tests of differences in outdoor $PM_{2.5}$ concentrations by participant reported exposure to air pollution from selected outdoor sources during air sampling in a subsample of 39 homes.
(DOCX)

S4 Table. Tests of differences in indoor $PM_{2.5}$ concentrations by selected household characteristics and combustion activities during air sampling in a subsample of 36 homes with complete indoor and outdoor $PM_{2.5}$ data, by $PM_{2.5}$ I/O ratio group.
(DOCX)

S5 Table. Tests of differences in indoor $PM_{2.5}$ concentrations by participant reported exposure to air pollution from selected outdoor sources during air sampling in a subsample of 36 homes with complete indoor and outdoor $PM_{2.5}$ data, by $PM_{2.5}$ I/O ratio group.
(DOCX)

S6 Table. Tests of differences in 24 h mean indoor CO concentrations by selected household characteristics and combustion activities during air sampling in a subsample of 47 homes.
(DOCX)

S7 Table. Estimated air changes per hour with the corresponding measured 24 h $PM_{2.5}$ (ug/m^3) and CO (ppm) concentrations in a subsample of 23 homes.
(DOCX)

S1 Fig. 24 h mean temperature (°C) and relative humidity (%) vs. 24 h $PM_{2.5}$ (ug/m^3) in a subsample of 39 homes.
(DOCX)

S2 Fig. 24 h mean temperature (°C) and relative humidity (%) vs. 24 h mean CO (ppm) in a subsample of homes (n = 47 indoor, n = 41 outdoor).
(DOCX)

S3 Fig. Scatter plots and Spearman correlations between estimated air changes per hour and natural log indoor $PM_{2.5}$ (top panel) and 24 h mean CO (bottom panel) concentrations in a subsample of 23 homes.
(DOCX)

S1 Checklist. Inclusivity in global research.
(DOCX)

S1 Data. Anonymized participant data and data dictionaries.
(XLSX)

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Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

Supporting information

S1 Table. Select demographic and household characteristics at enrollment of air sampling participants and the full ABC cohort.

		Air monitoring subsample (n = 48)		ABC cohort (N = 400)	
Characteristic	**Detail**	**Frequency or median**	**Percent or IQR**	**Frequency or median**	**Percent or IQR**
Socio-demographics at enrollment					
Maternal age, years	Median	27	24-31	26	23-31
Maternal education level	Primary	8	16.7	104[a]	26.0
	Secondary	32	66.7	232	58.0
	University or college	8	16.7	62	15.5
Maternal employment status	Homemaker or none	30	62.5	216	54.0
	Daily wage	6	12.5	45	11.3
	Small business	6	12.5	68	17.0
	Monthly salary	4	8.3	36	9.0
Monthly household rent (KES)	Median (renters only)	4,000 (n = 41)	3,000-5,500	3,500 (n = 330)	2,500-5,000
Household characteristics					
Type of housing[b]	Small bungalow (single unit)	1	2.1	N/A	N/A
	Multi-unit dwelling (flats)	47	97.9	N/A	N/A
Number of persons in household	2-4	34	70.8	337	84.3
	5-8	14	29.2	63[c]	15.8
Number of rooms	1	24	50.0	231	57.8
	2	16	33.3	120	30.0
	3 or more	8	16.7	49	12.3
Persons per room		3	2-4	2	1.5-3.0
Water source	Borehole/rainwater/ river	0	0	2	0.5
	Water vendor	2	4.2	10	2.5
	Piped water outside house	40	83.3	349	87.3
	Piped water inside house	8	16.7	49	12.3
Type of toilet	Pit latrine	0	0	12	3.0
	Flush	48	100	388	97.0
Shared toilet[d]	Yes	42	87.5	N/A	N/A
	No	6	12.5	N/A	N/A
Roof material	Metal sheets	33	68.8	338	84.5

Wall material	Concrete	15	31.3	58	14.5
	Metal sheets	1	2.1	23	5.8
	Stone	47	97.9	375	93.8
Floor material	Cemented	34	70.8	299	74.8
	Ceramic tiles	15	31.3	84	21.0
House ventilation features					
Number of external windows	0	1	2.1	10	2.5
	1	20	41.7	226	56.5
	2	19	39.6	111	27.8
	3 or more	8	16.7	23	5.8
Number of external doors	1	41[e]	85.4	359	89.8
	2 or more	6	12.5	41	10.3
Household behaviors related to air pollution					
Rug or carpet floor covering	No	22	45.8	263	65.8
	Yes	26	54.2	137	34.3
Fuels used by the household indoors	Wood	1	2.1	8	2.0
	Charcoal	1	2.1	44	11.0
	Kerosene	18	37.5	216	54.0
	Ethanol (Koko fuel)	15	31.3	70	17.5
	Liquefied petroleum gas	40	83.3	286	71.5
	Electricity	5	10.4	19	4.8

IQR = interquartile range. N/A = not available. [a]Includes 1 pre-primary and 2 never went to school. [b]Technician observed at air sampling visit; not collected at enrollment. [c]Includes one home with 9 people. [d]Collected at air sampling visit; not collected at enrollment. [e]1 missing response.

Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

Supporting information

S2 Table. Tests of differences in indoor $PM_{2.5}$ concentrations by selected household characteristics and combustion activities during air sampling in a subsample of 39 homes.

Characteristic/ activity	Detail	Count or median (IQR)	Geo. mean (ug/m³) (GSD) $PM_{2.5}$	Test statistic	*p*-value
Number of persons in household	2-4	25	41.7 (1.8)	t = - 0.77	0.45
	5-8	14	97.8 (145.2)		
Number of rooms	1	20	39.0. (1.7)	t = - 1.23	0.23
	2-4	19	52.6 (2.5)		
Kitchen volume	m³	22.4 (12.0)		F = 3.31	0.08
Total external windows and doors	1-2	18	38.6 (1.8)	t = -1.23	0.23
	3-7	21	51.5 (2.4)		
Rug or carpet floor covering	No	17	49.2 (1.8)	t = 0.66	0.51
	Yes	22	42.2 (2.4)		
Kerosene use	No	35	43.8 (2.2)	perm. test = 5.72	0.68
	Yes	4	58.1 (1.4)		
LPG use	No	15	35.9 (1.8)	t = -1.63	0.11
	Yes	24	52.0 (2.3)		
Ethanol fuel use	No	30	48.9 (2.2)	t = 1.43	0.17
	Yes	9	34.4 (1.8)		
Electricity only - no other fuels	No	36	47.9 (2.1)	perm. test = 47.24	0.01
	Yes	3	21.8 (1.3)		
Cigarette and/or marijuana smoke in the home	No	35	46.1 (2.2)	perm. test = 28.23	0.31
	Yes	4	37.4 (1.6)		
Burning mosquito	No	35	41.8 (1.9)	perm. test = -	0.96

repellent	Yes	4	88.8 (3.4)	114.09	
Burning candles	No	31	43.0 (2.1)	t = -0.75	0.47
	Yes	8	54.2 (2.2)		

IQR, interquartile range. Geo. mean, geometric mean. GSD, geometric standard deviation. Perm. test, test statistic of two-sample permutation test (for cell counts < 5).

Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

Supporting information

S3 Table. Tests of differences in outdoor $PM_{2.5}$ concentrations by participant reported exposure to air pollution from selected outdoor sources during air sampling in a subsample of 39 homes.

Characteristic/ activity	Detail	Count or median (IQR)	Geo. mean (ug/m^3) (GSD) $PM_{2.5}$	Test statistic	*p*-value
Smoke from dumpsite (within 1 km)	No	24	21.1 (2.0)	t = -0.64	0.53
	Yes	15	25.6 (1.6)		
Smoke from rubbish burning (within 1 km)	No	10	21.2 (1.3)	t = -1.87	0.07
	Yes	29	23.3 (2.0)		
Dust from unpaved roads (within 1 km)	No	5	26.7 (1.9)	t = 0.61	0.57
	Yes	34	22.2 (1.8)		
Construction dust (within 1 km)	No	27	23.2 (2.0)	t = 1.02	0.31
	Yes	12	21.6 (1.5)		

IQR, interquartile range. Geo. mean, geometric mean. GSD, geometric standard deviation.

Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

Supporting information

S4 Table. Tests of differences in indoor $PM_{2.5}$ concentrations by selected household characteristics and combustion activities during air sampling in a subsample of 36 homes with complete indoor and outdoor $PM_{2.5}$ data, by $PM_{2.5}$ indoor/outdoor (I/O) ratio group.

Characteristic/ activity	Detail	Count or median (IQR)	Geo. mean (ug/m^3) (GSD) $PM_{2.5}$	Test statistic	*p*-value
Homes with $PM_{2.5}$ I/O ratio £ median (1.6)					
Number of persons in household	2-4	11	32.6 (1.7)	t = -0.01	0.99
	5-8	7	32.7 (1.6)		
Number of rooms	1	8	31.9 (1.8)	t = -0.17	0.87
	2-4	10	33.3 (1.6)		
Kitchen volume	m^3	26.0 (15.7)		F = 1.12	0.31
Total external windows and doors	1-2	6	29.1 (2.0)	t = -0.57	0.58
	3-7	12	34.7 (1.5)		
Rug or carpet floor covering	No	7	40.0 (1.7)	t = 1.35	0.20
	Yes	11	28.7 (1.6)		
Kerosene use	No	17	32.0 (1.7)	--	--
	Yes	1	46.2		
LPG use	No	9	29.5 (1.8)	t = -0.87	0.40
	Yes	9	36.2 (1.4)		
Ethanol fuel use	No	12	33.5 (1.5)	t = 0.24	0.82
	Yes	6	31.2 (2.0)		
Electricity only - no other fuels	No	16	34.8 (1.6)	--	--
	Yes	2	20.0 (1.4)		
Cigarettes and/or marijuana smoke in the home	No	15	31.5 (1.6)	perm. test = -54.87	0.87
	Yes	3	39.4 (1.8)		
Burning mosquito repellent	No	16	31.7 (1.7)	--	--
	Yes	2	42.2 (1.4)		
Burning candles	No	17	31.7 (1.6)	--	--

Characteristic/ activity	Detail	Count or median (IQR)	Geo. mean (ug/m^3) (GSD) $PM_{2.5}$	Test statistic	*p*-value
	Yes	1	54.1		
Homes with $PM_{2.5}$ I/O ratio > median (1.6)					
Number of persons in household	2-4	11	52.9 (1.8)	t = -0.93	0.38
	5-8	7	82.4 (3.2)		
Number of rooms	1	9	45.3 (1.6)	t = -1.71	0.12
	2-4	9	87.3 (2.9)		
Kitchen volume	m^3	21.7 (7.7)		F = 2.39	0.1
Total external windows and doors	1-2	9	45.3 (1.6)	t = -1.71	0.11
	3-7	9	87.3 (2.9)		
Rug or carpet floor covering	No	9	54.0 (1.9)	t = -0.74	0.47
	Yes	9	73.2 (2.9)		
Kerosene use	No	15	62.9 (2.6)	perm. test = -88.67	0.96
	Yes	3	62.7 (1.5)		
LPG use	No	5	53.2 (1.6)	t = -0.66	0.52
	Yes	13	67.1 (2.7)		
Ethanol fuel use	No	16	64.7 (2.5)	--	--
	Yes	2	50.1 (1.5)		
Electricity only - no other fuels	No	17	66.3 (2.4)	--	--
	Yes	1	25.8		
Cigarette and/or marijuana smoke in the home	No	11	65.4 (2.4)	--	--
	Yes	1	32.2		
Burning mosquito repellent	No	16	54.9 (2.1)	--	--
	Yes	2	186.7 (4.3)		
Burning candles	No	12	64.4 (2.4)	0.16	0.88

Characteristic/ activity	Detail	Count or median (IQR)	Geo. mean (ug/m^3) (GSD) $PM_{2.5}$	Test statistic	*p*-value
	Yes	6	60.0 (2.4)		

IQR, interquartile range. Geo. mean, geometric mean. GSD, geometric standard deviation. Perm. test, test statistic of two-sample permutation test (for cell counts < 5). Note: test statistics not calculated for groups with < 3 observations.

Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

Supporting information

S5 Table. Tests of differences in indoor $PM_{2.5}$ concentrations by participant reported exposure to air pollution from selected outdoor sources during air sampling in a subsample of 36 homes with complete indoor and outdoor $PM_{2.5}$ data, by $PM_{2.5}$ I/O ratio group.

Characteristic/ activity	Detail	Count or median (IQR)	Geo. mean (ug/m^3) (GSD) $PM_{2.5}$	Test statistic	*p*-value
Homes with $PM_{2.5}$ I/O ratio £ median (1.6)					
Outdoor smoke from our own or neighbors' cooking	No	15	35.0 (1.5)	perm. test = 9.97	0.17
	Yes	3	23.1 (2.1)		
Smoke from dumpsite (within 1 km)	No	12	31.1 (1.7)	t = -1.53	0.17
	Yes	6	36.1 (1.4)		
Smoke from rubbish burning (within 1 km)	No	3	19.3 (1.3)	perm. test = -19.93	0.98
	Yes	15	36.3 (1.6)		
Dust from unpaved roads (within 1 km)	No	2	51.3 (1.4)	--	--
	Yes	16	30.9 (1.6)		
Construction dust (within 1 km)	No	12	35.3(1.6)	t = 0.72	0.48
	Yes	6	33.5 (18.9)		
Homes with $PM_{2.5}$ I/O ratio > median (1.6)					
Outdoor smoke from our own or neighbors' cooking	No	14	69.7 (2.5)	perm. test = 62.55	0.22
	Yes	4	43.9 (1.7)		
Smoke from dumpsite (within 1 km)	No	11	45.3 (1.9)	t = -1.53	0.17
	Yes	7	105.4 (2.6)		
Smoke from rubbish burning (within 1 km)	No	5	85.5 (2.9)	t = 0.74	0.49
	Yes	13	55.9 (2.2)		
Dust from unpaved roads (within 1 km)	No	3	64.8(2.8)	perm. test = -4.14	0.42
	Yes	15	62.5 (2.4)		
Construction dust (within 1 km)	No	13	79.6 (2.5)	t = 3.21	0.006
	Yes	5	35.1 (6.3)		

IQR, interquartile range. Geo. mean, geometric mean. GSD, geometric standard deviation. Perm. test, test statistic of two-sample permutation test (for cell counts < 5). Note: test statistics not calculated for groups with < 3 observations.

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Supporting information

S6 Table. Tests of differences in 24 h mean indoor CO concentrations by selected household characteristics and combustion activities during air sampling in a subsample of 47 homes.

Characteristic/ activity	Detail	Count or median (IQR)	Geo. mean (ppm) (GSD) CO	Test statistic	*p*-value
Number of persons in household	2-4	33	0.7 (2.0)	t = 0.71	0.49
	5-8	14	1.2 (1.9)		
Number of rooms	1	23	1.8 (2.3)	t = 0.79	0.43
	2-4	24	0.6 (2.0)		
Kitchen volume	m^3	24.6 (12.1)		F = 0.34	0.56
Total external windows and doors	1-2	20	2.0 (3.7)	t = -0.27	0.79
	3-7	27	0.7 (1.9)		
Kerosene use	No	42	0.6 (1.9)	t = -3.90	0.0003
	Yes	5	3.3 (3.1)		
LPG use	No	16	2.2 (4.4)	t = 0.18	0.86
	Yes	31	0.5 (1.4)		
Ethanol fuel use	No	38	0.6 (1.9)	t = 1.02	0.33
	Yes	9	3.7 (6.0)		
Electricity only - no other fuels	No	44	0.8 (2.2)	perm. test = 2.44	0.14
	Yes	3	0.0 (0.9)		
Cigarette and/or marijuana smoke in the home	No	41	0.9 (2.1)	t = 1.64	0.24
	Yes	6	0.5 (1.2)		
Burning mosquito repellent	No	43	0.7 (2.0)	perm. test = -7.61	0.96
	Yes	4	2.5 (10.7)		
Burning candles	No	39	0.9 (2.0)	t = 0.10	0.93
	Yes	8	0.6 (2.1)		

IQR, interquartile range. Geo. mean, geometric mean. GSD, geometric standard deviation. (Note: 6 0 ppm observations were recorded to 0.000001 ppm for natural log transformation). Perm. test, test statistic of two-sample permutation test (for cell counts < 5).

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Supporting information

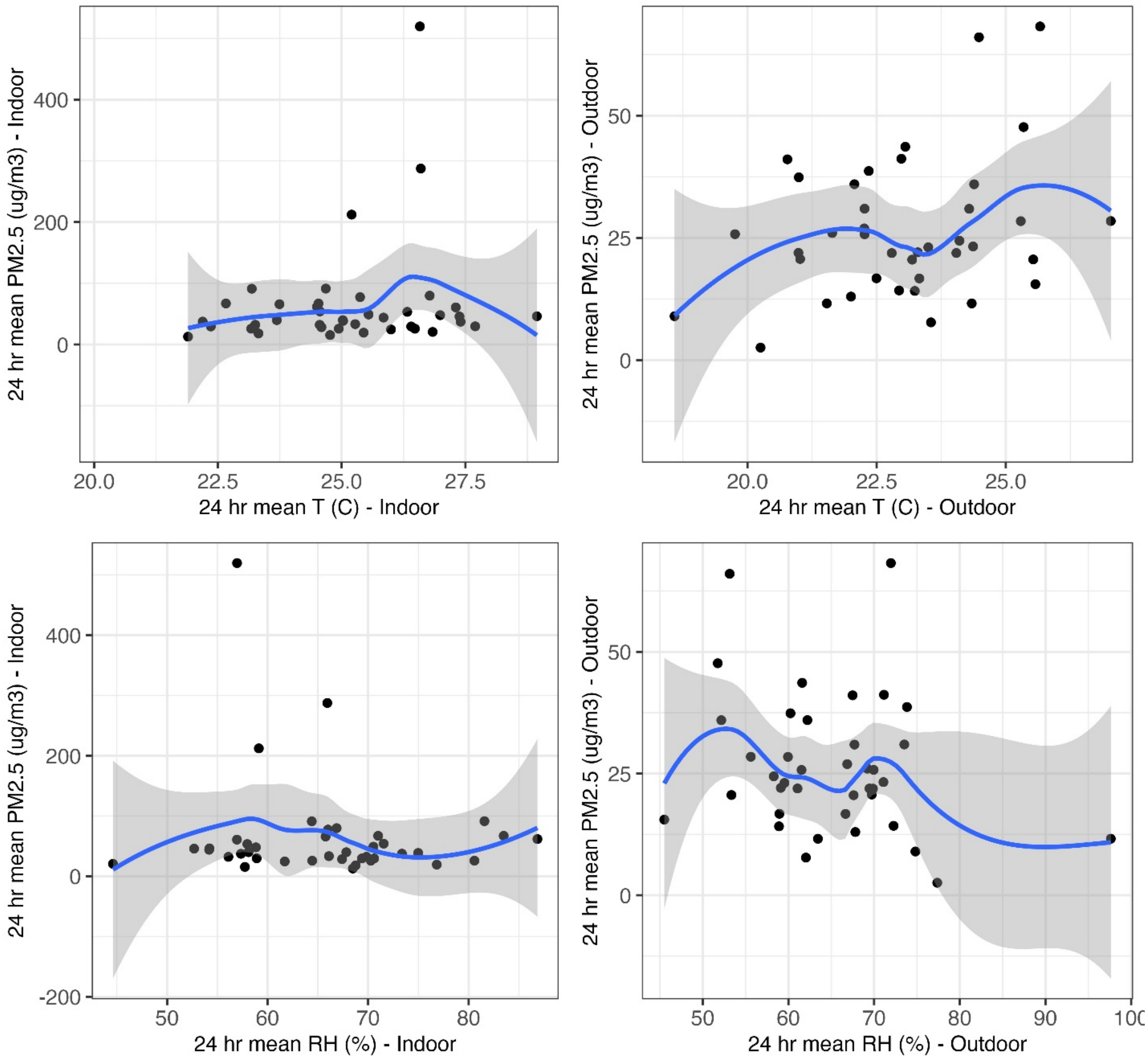
S7 Table. Estimated air changes per hour with the corresponding measured 24 h $PM_{2.5}$ (ug/m^3) and CO (ppm) concentrations in a subsample of 23 homes.

ID	Air changes per hour	Air changes per hour model (R^2)	$PM_{2.5}$ (ug/m^3)	CO (ppm)
1	1.57	0.93	38.67	6.10
2	7.47	0.98	49.09	2.20
3	1.22	0.99	NA	1.60
4	0.62	0.99	61.75	22.50
5	1.73	0.92	19.34	2.20
11	1.23	0.99	29.72	8.20
14	5.20	0.96	91.33	0.60
16	0.88	0.99	64.18	6.60
19	1.22	0.99	37.42	3.70
20	3.35	0.99	47.68	1.80
22	0.29	1.00	67.08	33.90
23	2.87	0.96	29.49	2.10
28	3.54	0.98	79.82	3.30
32	4.15	0.98	19.28	0.30
33	3.32	0.99	91.15	2.40
35	4.13	0.97	77.40	5.40
36	3.02	0.99	12.84	2.20
37	1.82	1.00	NA	2.30
38	1.34	0.99	NA	6.00
43	7.73	0.91	25.86	0.30
46	1.61	1.00	25.81	1.80
47	2.11	0.99	519.57	4.10
48	3.68	0.99	16.80	5.20

Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

Supporting information

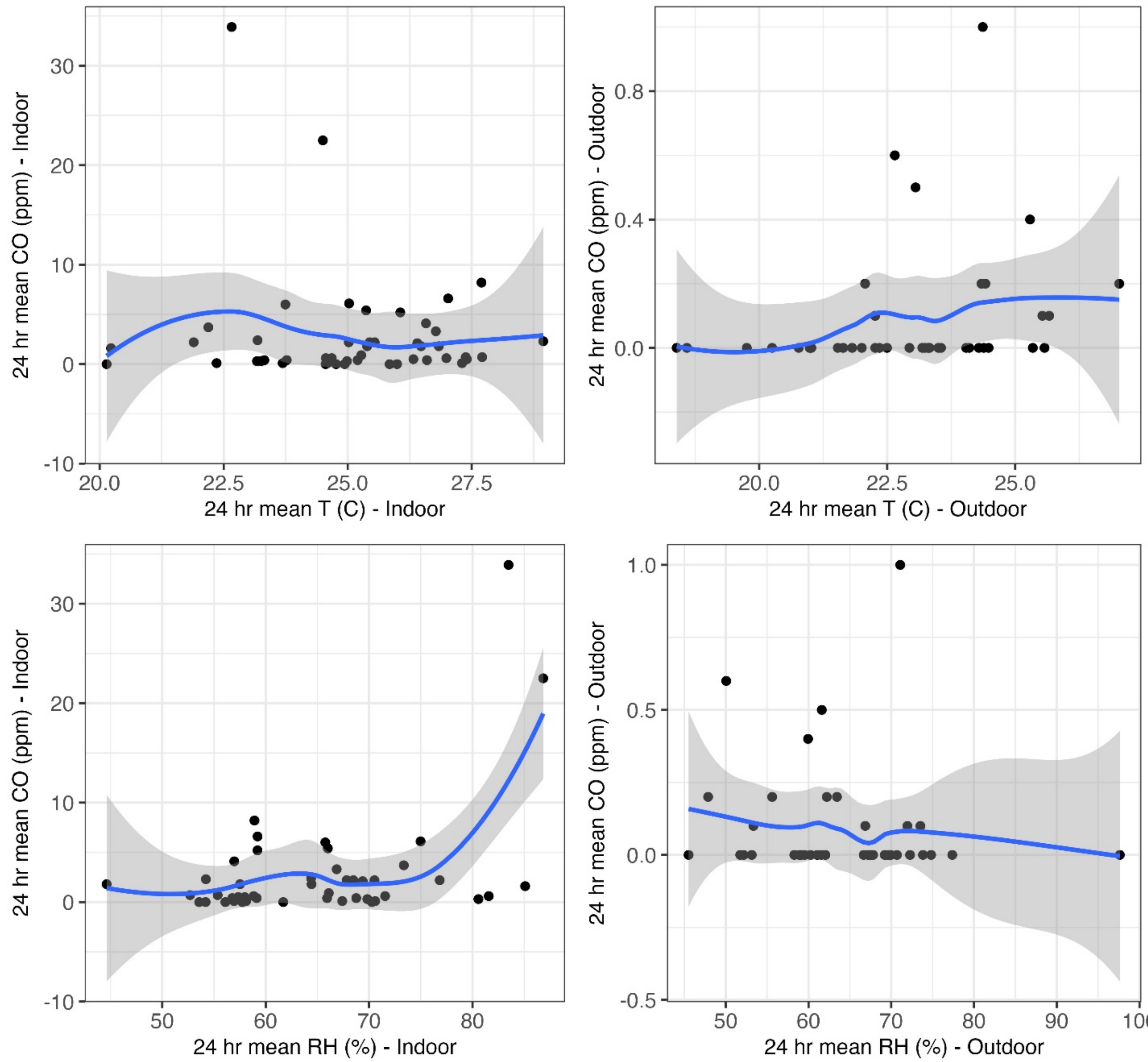
S1 Fig. 24 h mean temperature (°C) and relative humidity (%) vs. 24 h $PM_{2.5}$ (ug/m^3) in a subsample of 39 homes (blue lines and grey bands indicate fitted values and standard error of locally estimated scatterplot smoothing [LOESS] fit).



Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

Supporting information

S2 Fig. 24 h mean temperature (°C) and relative humidity (%) vs. 24 h mean CO (ppm) in a subsample of homes (n = 47 indoor, n = 41 outdoor) (blue lines and grey bands indicate fitted values and standard error of locally estimated scatterplot smoothing [LOESS] fit).



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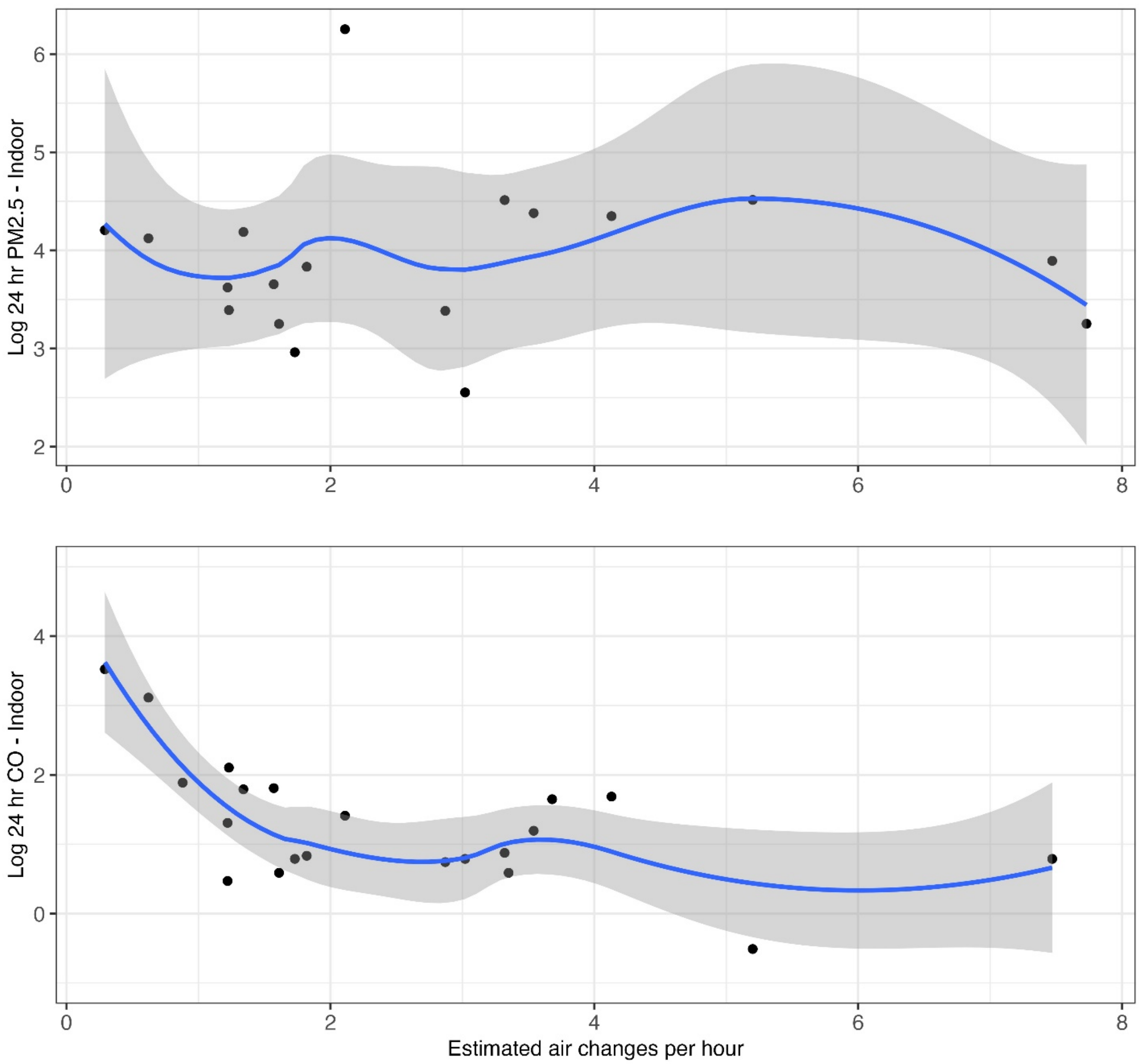
Supporting information

S3 Fig. Scatter plots and Spearman correlations between estimated air changes per hour and natural log indoor $PM_{2.5}$ (top panel) and 24 h mean CO (bottom panel) concentrations in a subsample of 23 homes (blue lines and grey bands indicate fitted values and standard error of locally estimated scatterplot smoothing [LOESS] fit).



Indoor and outdoor fine particulate matter and carbon monoxide concentrations in homes of infants in Nairobi, Kenya

Supporting information

S1 Checklist

Ethical considerations, permits and authorship

This section is applicable to all research types.

Provide details as to who granted permissions and/or consent for the study to take place in the Methods section of your manuscript. This should include the names of **all** ethics boards, governmental organizations, community leaders or other bodies that provided approval for the study. If individuals provided approval refer to these people by their role or title but do not list their name(s).

Reported on page number: As noted in the Methods section of the manuscript, this study was approved by the Human Subjects Division at the University of Washington, the Kenyatta National Hospital-University of Nairobi Ethics and Research Committee, and Kenya's National Commission for Science, Technology and Innovation. In addition, permission to recruit participants and conduct study procedures at the Dandora II Health Centre was provided by the Nairobi County Health Services Research Department, the Embakasi North Sub-County, and the Dandora II Health Centre Administration, and following discussion with the Dandora I and II community health workers.

If there were any deviations from the study protocol after approval was obtained please provide details of these changes in the Methods section of your manuscript.

Reported on page number: There were no deviations from the study protocol after approval was obtained.

Did this study involve local collaborators that are residents of the country where the research was conducted or members of the community studied? If you do not have any authors from said communities, please provide an explanation for this below.

Seven of 16 authors are Kenyan and reside in Nairobi, Kenya, where the study is based.

Human subjects research (e.g. health research, medical research, cross-cultural psychology)

Did you obtain written informed consent from a representative of the local community or region before the research took place? How did you establish who speaks for the community?

As described in the Methods section, written informed consent was provided by each study participant. In addition, written permission to recruit participants and conduct the study at the Dandora Health II Centre was granted by the Nairobi County Health Services Research Department, the Embakasi North Sub-County and the Dandora II Health Centre Administration.

Details of written informed consent obtained from study participants should be reported separately in the Methods section of your manuscript.

How did members of the local community provide input on the aims of the research investigation, its methodology, and its anticipated outcome(s)?

Key stakeholders from research, policy and regulatory networks in both paediatrics and in environmental health participated in a workshop in Nairobi, Kenya in 2019, entitled "Kenya Healthy Home Healthy Brain Project". Priorities for research and for technology transfer, including a focus on impact of air pollution and other neurotoxicants on neurodevelopment in urban Kenya, and building capacity for blood lead laboratory testing, air pollution sampling and neurodevelopmental assessment were emphasized at the workshop and were incorporated into the study described in this manuscript. Prior to enrolling study participants, the study team met with and received input from staff at the Dandora II Health Centre, including community health workers.

When engaging with the local community, how did you ensure that the informed consent documents and other materials could be understood by local stakeholders?

Informed consent documents and structured interview questions were translated in Kiswahili and submitted to the Kenyatta National Hospital – University of Nairobi Ethics and Research Committee for review and approval. All study staff who interact with participants are fluent in English and Kiswahili and are able to utilize the language of the study participant's preference.

Will the findings of the research be made available in an understandable format to stakeholders in the community where the study was conducted (e.g. via a presentation, summary report, copies of publications, etc.)? Please provide details of how this will be achieved.

Report back of results and air sampling methods have been shared via presentation at annual dissemination workshops held throughout the study. Workshops have included representatives from the Kenya Ministry of Health regulatory agencies, professional society members, academic institutions and staff working at the facility where the study is based, including community health workers and promoters. The venues for these meetings have included the University of Nairobi and the Dandora II Health Centre, where the study is based.

Non-human subjects research using specimens/ animals collected as part of the study, or those housed in archival collections. Examples include archaeology, paleontology, botany and zoology.

Did the permission you obtained from a local authority to perform the study include an agreement on access to outputs and benefit sharing? This may include procedures to enable fair distribution of the benefits and resources arising from the research performed. Please include any details of Prior Informed Consent and Benefit Sharing Agreements obtained. These may be required by field-specific regulations, for example the Convention on Biological Diversity (CBD) and the associated Nagoya Protocol.

N/A

If the material used in your study was imported, please A) provide the year it was imported and B) indicate whether permits were obtained to import/export the materials used, C) provide details of any permits obtained. If this information is not available, please indicate this.

N/A

If you used archival specimens, please state how the material used in your study was acquired by the institute it is held in and provide details of any permits obtained for the original excavations/ sample collection. If this information is not available, please indicate this.

N/A

How was the potential cultural significance of the materials collected in your study to local communities considered in your research design? Were Indigenous peoples and/or local researchers and institutions involved with archaeological excavations / collection of specimens? If so, please provide a description of their involvement.

N/A

If your manuscript includes photographs of human remains please indicate whether authors obtained permission from descendants or affiliated cultural communities to do so.

N/A

child_dob_tc	en_mom_ag	employ_recode	en_rent	housing_type	fhv_pplinhse	fhv_rooms_c	fhv_pplperro	fhv_wtr_src_	fhv_wtr_src_
26.1	38	Homemaker/no	5000	Multi-unit dv	5-8	2	2.5	No	Yes
25.7	39	Homemaker/no	5000	Multi-unit dv	2-4	2	2	No	Yes
2.9	27	Homemaker/no	NA	Multi-unit dv	2-4	NA	2	No	Yes
17.1	24	Homemaker/no	6000	Multi-unit dv	2-4	NA	2	No	Yes
26.2	21	Homemaker/no	4500	Multi-unit dv	2-4	1	4	No	Yes
19.7	24	Homemaker/no	4000	Multi-unit dv	5-8	2	3.5	No	Yes
3.6	21	Homemaker/no	NA	Multi-unit dv	2-4	NA	1	Yes	No
16	23	Homemaker/no	6000	Small bungal	2-4	NA	1	Yes	No
13	40	Homemaker/no	NA	Multi-unit dv	2-4	NA	4	No	Yes
19.4	27	Homemaker/no	4500	Multi-unit dv	5-8	2	4	No	Yes
11.5	26	Small business	6000	Multi-unit dv	2-4	NA	2	No	Yes
14.5	24	Homemaker/no	6000	Multi-unit dv	2-4	NA	1.3	Yes	No
12.7	23	Homemaker/no	4000	Multi-unit dv	2-4	NA	1.5	No	Yes
4.4	28	Small business	4000	Multi-unit dv	2-4	NA	4	No	Yes
17.4	23	Homemaker/no	3500	Multi-unit dv	2-4	1	3	No	Yes
7.6	23	Homemaker/no	3000	Multi-unit dv	2-4	NA	3	No	No
5.5	31	Homemaker/no	3000	Multi-unit dv	2-4	NA	4	No	Yes
6.1	23	Homemaker/no	5500	Multi-unit dv	2-4	NA	1	No	Yes
14.3	26	Small business	7000	Multi-unit dv	2-4	3 or more	1.3	No	Yes
9.6	30	Monthly salary	3500	Multi-unit dv	2-4	1	4	No	Yes
16.6	25	Homemaker/no	7000	Multi-unit dv	2-4	3 or more	1.3	Yes	No
7.1	26	Homemaker/no	4500	Multi-unit dv	2-4	NA	2.5	No	Yes
7.9	29	Homemaker/no	2500	Multi-unit dv	2-4	NA	5	No	Yes
16.5	26	Homemaker/no	2500	Multi-unit dv	2-4	1	3	No	Yes
18.6	25	Homemaker/no	2500	Multi-unit dv	2-4	1	4	No	Yes
13.9	35	Homemaker/no	2000	Multi-unit dv	2-4	NA	5	No	Yes
13.6	30	Daily wage	5000	Multi-unit dv	2-4	NA	5	No	Yes
20	21	Homemaker/no	2500	Multi-unit dv	2-4	1	3	No	Yes
16.4	34	Daily wage	NA	Multi-unit dv	5-8	2	3	No	Yes
-1.7	27	Monthly salary	2500	Multi-unit dv	2-4	NA	3	No	Yes
4.9	33	Daily wage	5500	Multi-unit dv	2-4	NA	1.7	Yes	Yes
9.5	25	Homemaker/no	4500	Multi-unit dv	2-4	NA	2	No	Yes
10.2	28	Small business	4000	Multi-unit dv	5-8	2	3	No	Yes
1	33	Monthly salary	2000	Multi-unit dv	2-4	NA	3	No	Yes
15.8	32	Daily wage	2000	Multi-unit dv	2-4	1	3	No	Yes
8.6	22	Homemaker/no	3000	Multi-unit dv	2-4	1	4	No	Yes
6.2	22	Homemaker/no	3000	Multi-unit dv	2-4	NA	4	No	Yes
10.5	30	Homemaker/no	3000	Multi-unit dv	2-4	1	4	No	Yes
6.4	22	Homemaker/no	NA	Multi-unit dv	2-4	NA	1	Yes	Yes
7.6	24	Homemaker/no	3500	Multi-unit dv	2-4	NA	2	No	Yes
10.2	36	Homemaker/no	5000	Multi-unit dv	2-4	NA	3	No	No
17.5	34	Small business	6000	Multi-unit dv	2-4	2	2	No	Yes
14.6	31	Monthly salary	8500	Multi-unit dv	2-4	3 or more	1.3	Yes	No
3.3	18	Homemaker/no	NA	Multi-unit dv	5-8	1	5	No	Yes
0.8	32	Small business	5000	Multi-unit dv	2-4	NA	3	Yes	No
6.2	34	Daily wage	NA	Multi-unit dv	5-8	2	2.5	No	Yes
11.5	27	Homemaker/no	5500	Multi-unit dv	5-8	2	2.5	No	Yes
7.3	26	Daily wage	2000	Multi-unit dv	2-4	NA	3	No	Yes

fhv_toilet_ty	fhv_toilet_sh	fhv_roof_ma	fhv_roof_tre	fhv_roof_cor	fhv_wall_me	fhv_wall_sto	fhv_floor_co	fhv_floor_ce	fhv_windows	fhv_extdoors
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	2	2
Flush toilet	Yes	No	No	Yes	No	Yes	No	Yes	2	2
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	2	1
Flush toilet	No	Yes	Yes	No	No	Yes	Yes	No	4	3
Flush toilet	No	No	No	Yes	No	Yes	No	Yes	4	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	No	Yes	1	1
Flush toilet	Yes	No	No	Yes	No	Yes	No	Yes	3	1
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	2	2
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	NA
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	Yes	3	2
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	No	Yes	No	No	No	Yes	No	Yes	3	1
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	2	1
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	No	Yes	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	3	1
Flush toilet	Yes	Yes	No	No	No	Yes	No	Yes	2	1
Flush toilet	Yes	No	No	Yes	No	Yes	Yes	No	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	No	Yes	1	1
Flush toilet	No	Yes	No	No	No	Yes	Yes	No	3	1
Flush toilet	Yes	No	No	Yes	No	Yes	No	Yes	2	1
Flush toilet	Yes	Yes	No	No	Yes	No	Yes	No	0	1
Flush toilet	Yes	Yes	No	No	No	Yes	No	Yes	2	2
Flush toilet	No	No	No	No	No	Yes	No	Yes	3	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1
Flush toilet	No	No	No	Yes	No	Yes	No	Yes	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	No	Yes	2	1
Flush toilet	Yes	No	No	Yes	No	Yes	No	Yes	2	1
Flush toilet	Yes	Yes	No	No	No	Yes	Yes	No	1	1

externaloper	fsl_kitchen_s	fsl_kitchen_l	fsl_kitchen_h	kitchen_volu	fhv_floorcov	fhv_fuel_woo	fhv_fuel_cha	fhv_fuel_ker	fhv_fuel_kok	fhv_fuel_lpg
1.5	2.64	2.70	2.54	18.1	No	Not at all	Not at all	Not at all	Indoor	Indoor
2	2.63	3.23	2.98	25.3	Yes	Not at all	Outdoor	Not at all	Not at all	Indoor
2	2.79	3.75	2.94	30.8	Yes	Not at all	Not at all	Not at all	Not at all	Indoor
1.5	3.04	3.14	2.35	22.4	No	Not at all	Indoor	Not at all	Indoor	Not at all
2	3.20	3.66	2.82	33.0	Yes	Not at all	Not at all	Not at all	Indoor	Not at all
1.5	2.81	2.99	2.35	19.7	Yes	Not at all	Outdoor	Indoor	Not at all	Not at all
2.3	1.66	1.82	2.88	8.7	No	Not at all	Outdoor	Indoor	Not at all	Indoor
1.3	2.12	2.56	2.37	12.9	No	Not at all	Not at all	Not at all	Not at all	Indoor
3	2.84	5.21	2.97	43.9	Yes	Not at all	Not at all	Indoor	Not at all	Indoor
1.5	2.65	3.12	2.98	24.6	Yes	Not at all	Outdoor	Not at all	Indoor	Indoor
2	2.65	3.43	2.13	19.4	Yes	Not at all	Not at all	Not at all	Indoor	Indoor
1.3	1.42	1.67	2.55	6.0	Yes	Not at all	Not at all	Not at all	Not at all	Indoor
2	1.58	2.67	2.53	10.7	Yes	Not at all	Not at all	Outdoor	Not at all	Indoor
2	3.04	3.58	2.30	25.0	No	NA	NA	NA	NA	Indoor
2	2.66	3.93	2.62	27.4	Yes	Not at all	Not at all	Indoor	Not at all	Indoor
2	2.94	4.16	2.47	30.2	Yes	Not at all	Not at all	Indoor	Not at all	Indoor
2	2.59	2.87	2.90	21.6	No	Not at all	Not at all	Indoor	Not at all	Indoor
NA	2.85	3.04	2.91	25.2	Yes	Not at all	Not at all	Indoor	Not at all	Indoor
1.7	2.40	3.29	2.78	22.0	No	Not at all	Not at all	Not at all	Indoor	Indoor
2	2.86	3.34	2.55	24.4	No	Not at all	Not at all	Not at all	Not at all	Indoor
1.3	1.59	2.41	2.53	9.7	Yes	Not at all	Outdoor	Not at all	Outdoor	Outdoor
1.5	2.34	4.35	2.55	26.0	No	Not at all	Not at all	Not at all	Indoor	Indoor
2	2.90	3.48	2.58	26.0	Yes	Not at all	Outdoor	Not at all	Not at all	Indoor
2	2.92	4.07	2.35	27.9	Yes	Not at all	Not at all	Not at all	Not at all	Indoor
3	2.84	3.94	2.94	32.9	Yes	Not at all	Not at all	Not at all	Indoor	Indoor
2	2.98	4.20	2.34	29.3	Yes	Not at all	Not at all	Not at all	Not at all	Indoor
2	2.79	4.10	2.72	31.1	No	Not at all	Not at all	Indoor	Not at all	Indoor
2	1.91	2.89	2.98	16.4	Yes	Not at all	Not at all	Indoor	Not at all	Not at all
1.5	3.14	3.37	3.05	32.3	Yes	Not at all	Outdoor	Indoor	Indoor	Indoor
2	2.58	4.74	2.88	35.2	No	Not at all	Not at all	Not at all	Not at all	Indoor
1.3	1.96	2.81	2.99	16.5	Yes	Not at all	Outdoor	Not at all	Indoor	Indoor
1.5	2.88	3.79	2.77	30.2	No	Not at all	Not at all	Indoor	Not at all	Indoor
1.5	2.31	2.91	2.44	16.4	Yes	Not at all	Outdoor	Not at all	Not at all	Indoor
2	2.23	3.06	2.89	19.7	No	Not at all	Outdoor	Indoor	Not at all	Not at all
2	1.90	2.97	3.12	17.6	No	Not at all	Outdoor	Indoor	Not at all	Not at all
2	2.78	4.09	2.85	32.4	No	Not at all	Not at all	Not at all	Indoor	Not at all
3	3.03	4.46	2.95	39.9	No	Not at all	Not at all	Indoor	Not at all	Indoor
2	2.91	3.40	3.08	30.5	No	Not at all	Outdoor	Not at all	Indoor	Indoor
1.3	1.46	3.38	3.19	15.7	No	Outdoor	Outdoor	Not at all	Not at all	Indoor
1.5	2.67	3.33	2.32	20.6	No	Not at all	Not at all	Not at all	Not at all	Indoor
0.5	4.91	2.53	49.02	608.9	Yes	Not at all	Not at all	Not at all	Not at all	Indoor
2	2.75	3.69	2.45	24.9	No	Not at all	Outdoor	Indoor	Not at all	Indoor
1.3	3.33	2.62	21.54	187.9	Yes	Not at all	Outdoor	Not at all	Not at all	Indoor
2	2.87	2.88	2.26	18.7	No	Not at all	Not at all	Indoor	Indoor	Indoor
3	3.01	3.49	2.38	25.0	No	Not at all	Not at all	Not at all	Not at all	Indoor
1.5	1.91	2.92	2.89	16.1	Yes	Not at all	Not at all	Indoor	Not at all	Indoor
1.5	2.22	2.75	2.59	15.8	Yes	Not at all	Not at all	Not at all	Not at all	Indoor
2	1.83	3.59	2.74	18.0	Yes	Not at all	Not at all	Not at all	Indoor	Not at all

fhv_fuel_ele	shv_ind_fuel	en_ind_fuel_	shv_ind_fuel	shv_ind_fuel	shv_ind_fuel	shv_ind_oth	shv_cig_smk	shv_marij_sr	shv_pt_out_	shv_pt_out_
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	Yes
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	Yes	No	No	No	Yes	No	No
Not at all	No	Rarely / not a	No	Yes	No	No	No	No	No	No
Indoor	No	Daily / most	No	No	No	Yes	No	No	Yes	Yes
Indoor	No	Some days	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	Yes
Not at all	No	Rarely / not a	No	No	Yes	Yes	No	No	No	No
Not at all	No	Rarely / not a	No	Yes	No	Yes	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	Yes	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
NA	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	NA
Not at all	No	Rarely / not a	Yes	No	No	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	Yes	No	No	No	No
Indoor	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	Yes	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	Yes	No	No
Not at all	No	Rarely / not a	No	Yes	No	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	Yes
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	Yes	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	Yes	No	No	Yes	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	Yes
Not at all	No	Rarely / not a	No	No	Yes	Yes	No	No	No	No
Not at all	No	Rarely / not a	No	Yes	No	No	No	Yes	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	Yes	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	Yes
Not at all	No	Rarely / not a	Yes	No	No	Yes	No	No	No	No
Not at all	No	Rarely / not a	Yes	No	No	No	No	No	No	No
Not at all	No	Rarely / not a	No	Yes	No	No	No	No	No	Yes
Not at all	No	Rarely / not a	Yes	No	No	No	No	No	No	No
Not at all	No	Rarely / not a	No	Yes	No	No	No	No	No	No
Not at all	Yes	Rarely / not a	No	No	Yes	No	Yes	No	Yes	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Indoor	No	Rarely / not a	No	No	No	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	Yes	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Indoor	No	Rarely / not a	No	Yes	No	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	No	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No
Not at all	No	Rarely / not a	No	No	Yes	No	No	No	No	No

shv_pt_out_	shv_pt_out_	shv_pt_out_	shv_pt_out_	shv_pt_out_	shv_pt_out_	shv_pt_out_	shv_pt_out_	air_sample_r	air_sample_y	co_num_obs
Yes	Yes	Yes	Yes	No	No	Yes	Yes	May	2024	1440
Yes	Yes	No	Yes	No	No	Yes	No	May	2024	1440
Yes	Yes	No	No	No	No	Yes	No	July	2022	1453
Yes	Yes	No	Yes	No	No	Yes	Yes	September	2023	1440
Yes	Yes	No	Yes	Yes	No	Yes	Yes	May	2024	1440
Yes	Yes	No	Yes	No	No	Yes	Yes	October	2023	1440
Yes	Yes	Yes	No	No	No	Yes	No	July	2022	1440
Yes	Yes	No	Yes	No	No	No	Yes	September	2023	1440
Yes	Yes	Yes	No	No	No	Yes	No	May	2023	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	October	2023	1440
Yes	Yes	No	Yes	No	No	No	No	March	2023	1440
Yes	Yes	No	No	No	No	Yes	Yes	October	2023	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	May	2023	1440
Yes	Yes	No	No	No	No	No	Yes	November	2022	1440
Yes	Yes	No	No	No	No	Yes	No	March	2024	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	February	2023	1442
Yes	Yes	Yes	No	No	No	Yes	No	November	2022	NA
Yes	Yes	No	Yes	No	No	Yes	No	April	2023	1440
Yes	Yes	No	Yes	No	Yes	Yes	Yes	July	2023	1440
Yes	Yes	Yes	No	No	No	Yes	No	June	2023	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	January	2024	1440
Yes	Yes	Yes	No	No	No	Yes	No	May	2023	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	April	2023	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	February	2024	1440
Yes	Yes	No	Yes	No	No	Yes	No	March	2024	1440
Yes	Yes	No	Yes	No	No	Yes	No	September	2023	1440
Yes	Yes	No	Yes	No	No	Yes	Yes	September	2023	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	March	2024	1440
Yes	Yes	No	Yes	No	No	Yes	No	January	2024	1440
Yes	No	No	Yes	No	No	Yes	No	December	2022	1440
Yes	Yes	No	Yes	No	No	Yes	Yes	March	2023	1440
Yes	Yes	No	Yes	No	No	Yes	Yes	October	2023	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	August	2023	1440
Yes	Yes	No	Yes	No	No	No	Yes	April	2023	1440
Yes	Yes	No	Yes	No	No	Yes	No	May	2024	1440
Yes	Yes	No	Yes	No	No	Yes	Yes	August	2023	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	September	2023	1440
Yes	Yes	No	Yes	No	No	No	No	January	2024	1440
Yes	Yes	No	No	No	No	No	Yes	May	2023	1440
Yes	Yes	No	Yes	No	No	No	No	September	2023	1440
Yes	Yes	No	No	No	No	Yes	No	September	2023	1441
Yes	Yes	Yes	Yes	No	No	Yes	No	March	2024	1440
Yes	Yes	No	No	No	No	Yes	No	June	2024	1440
Yes	Yes	Yes	Yes	No	No	Yes	No	July	2023	1440
Yes	Yes	No	No	No	No	Yes	Yes	March	2023	1440
Yes	Yes	No	Yes	No	No	Yes	No	February	2024	1440
Yes	Yes	Yes	No	No	No	Yes	No	March	2024	1441
Yes	Yes	Yes	Yes	No	No	Yes	No	October	2023	1440

co_num_obs	co_mean_pp	co_mean_pp	co_sd_ppm_	co_sd_ppm_	co_min_ppm	co_min_ppm	co_max_ppm	co_max_ppm	lasco_runtim	lasco_runtim
1440	6.1	0	16.1	0	0	0	111.8	0	23.98	23.98
1440	2.2	0	8	0.2	0	0	75.2	4.2	23.98	23.98
1453	1.6	0	3.8	0	0	0	23.2	0	24.2	24.2
1440	22.5	0	39.2	0	0	0	162.5	0	23.98	23.98
1440	2.2	0	6.9	0	0	0	62	0	23.98	23.98
1008	0	0	0	0	0	0	0	0	23.98	16.78
1440	0	0.6	0	1.4	0	0	0	6	23.98	23.98
1440	0.1	0	0.7	0	0	0	9.5	1	23.98	23.98
1440	0.4	0	1.8	0	0	0	12.2	0	23.98	23.98
NA	0.4	NA	1.4	NA	0	NA	11.2	NA	23.98	NA
NA	8.2	NA	21.2	NA	0	NA	132.8	NA	23.98	NA
NA	0.4	NA	2.2	NA	0	NA	23	NA	23.98	NA
1440	0.3	0	1.1	0	0	0	10.8	0	23.98	23.98
NA	0.6	NA	1.6	NA	0	NA	17.2	NA	23.98	NA
1440	0.1	0	0.7	0	0	0	6.2	0	23.98	23.98
1442	6.6	0.2	13.8	2.1	0	0	85.2	43.2	24.02	24.02
1440	NA	0.1	NA	0.5	NA	0	NA	4.8	NA	23.98
1440	0	0	0.2	0	0	0	3	0	23.98	23.98
1440	3.7	0	10.4	0	0	0	62	0.8	23.98	23.98
1440	1.8	0	5.8	0	0	0	46.8	0	23.98	23.98
1440	0.6	0.5	0.9	1.1	0	0	4.2	4	23.98	23.98
1440	33.9	0	42.2	0.1	0	0	158.8	1.5	23.98	23.98
1440	2.1	0	4.6	0.1	0	0	25	1.5	23.98	23.98
NA	0.1	NA	0.4	NA	0	NA	6	NA	23.98	NA
1440	0.9	0.1	2.6	0.3	0	0	15	5.5	23.98	23.98
969	0.6	0.2	2.3	0.8	0	0	16.5	7.2	23.98	16.13
1440	0.5	0	1.5	0	0	0	11.2	0.5	23.98	23.98
1440	3.3	0	10.6	0.3	0	0	96.8	8.8	23.98	23.98
1440	0.5	0	1.5	0.1	0	0	14	1.5	23.98	23.98
1441	0.1	0	0.4	0.1	0	0	4	1.5	23.98	24
1440	1.8	0	5.2	0.2	0	0	93.2	2.2	23.98	23.98
7	0.3	NA	1.4	0	0	0	15.2	0	23.98	0.1
1440	2.4	0	8	0	0	0	73.2	0	23.98	23.98
1440	2.2	0.2	9.2	0.9	0	0	89.2	7.8	23.98	23.98
1440	5.4	0	18.6	0.2	0	0	120	7.2	23.98	23.98
1440	2.2	0	8.3	0.1	0	0	67.8	1.5	23.98	23.98
1440	2.3	0	5.7	0.3	0	0	29.5	2.8	23.98	23.98
1440	6	0.1	13.3	0.4	0	0	85.5	3.2	23.98	23.98
1441	0	0.1	0	0.3	0	0	0	2	23.98	24
1440	0.4	0	1.5	0	0	0	10.5	0	23.98	23.98
1440	0	0	0	0	0	0	0	0	24	23.98
1440	0.7	0.4	1	0.8	0	0	7	4	23.98	23.98
NA	0.3	NA	1.8	NA	0	NA	26.2	NA	23.98	NA
1440	0	0	0	0.1	0	0	0	1	23.98	23.98
1441	0.7	0	2.9	0.1	0	0	32.5	1.5	23.98	24
1440	1.8	1	4.9	1.8	0	0	41.5	7	23.98	23.98
1440	4.1	0.2	7	0.5	0	0	60.5	2.5	24	23.98
1440	5.2	0	13	0.2	0	0	58	2.5	23.98	23.98

lasco_setup_	lasco_setup_	airqc_lasco_i	airqc_lasco_(	airqc_lasco_(	in_pr_pm_cc	in_dup_pm_(	out_pr_pm_(	out_dup_pm	mean_temp_	mean_temp_
5/28/2024	5/28/2024	No	Yes	No	38.7	NA	38.7	NA	25.0	22.3
5/14/2024	5/14/2024	No	Yes	No	49.1	NA	16.7	NA	25.5	23.3
7/20/2022	7/20/2022	No	Yes	No	NA	NA	NA	NA	20.2	18.4
8/31/2023	8/31/2023	No	Yes	No	61.7	NA	41.1	NA	24.5	20.8
5/14/2024	5/14/2024	No	Yes	No	19.3	NA	20.6	NA	25.4	23.2
10/18/2023	10/18/2023	No	Yes	No	25.8	NA	11.6	NA	24.9	21.5
7/13/2022	7/13/2022	No	Yes	No	NA	NA	NA	NA	20.1	22.6
9/6/2023	9/6/2023	No	Yes	No	39.9	NA	36.0	NA	23.7	24.4
5/30/2023	5/30/2023	No	Yes	No	18.1	NA	20.7	NA	23.3	21.0
10/18/2023	NA	No	Yes	No	287.5	NA	41.2	NA	26.6	23.0
3/23/2023	NA	No	No	No	29.7	NA	NA	NA	27.7	NA
10/11/2023	NA	Yes	No	No	NA	NA	NA	NA	23.8	NA
5/17/2023	5/17/2023	No	Yes	No	32.2	NA	26.0	NA	23.3	21.6
11/16/2022	NA	No	No	No	91.3	NA	NA	NA	24.7	NA
3/20/2024	3/20/2024	Yes	Yes	Yes	60.8	28.4	24.4	21.9	27.3	24.1
2/7/2023	2/7/2023	No	Yes	No	NA	NA	NA	NA	27.0	24.4
NA	11/3/2022	No	Yes	No	67.0	NA	26.9	NA	24.5	22.3
4/4/2023	4/4/2023	No	Yes	No	24.6	NA	7.7	NA	26.0	23.6
7/27/2023	7/27/2023	No	Yes	No	37.4	NA	21.9	NA	22.2	21.0
6/8/2023	6/8/2023	No	Yes	No	NA	NA	25.7	NA	25.4	22.3
1/24/2024	1/24/2024	No	Yes	No	48.0	NA	43.6	NA	27.0	23.1
5/11/2023	5/11/2023	No	Yes	No	67.1	NA	13.0	NA	22.7	22.0
4/12/2023	4/12/2023	No	Yes	No	29.5	NA	14.3	NA	26.4	22.9
1/31/2024	NA	Yes	No	No	28.3	21.9	NA	NA	24.6	NA
3/27/2024	3/27/2024	No	Yes	No	33.3	NA	31.0	NA	25.3	22.3
9/27/2023	9/27/2023	No	Yes	No	54.1	NA	36.0	NA	24.6	22.1
9/13/2023	9/13/2023	No	Yes	No	37.3	NA	16.7	NA	27.4	22.5
3/27/2024	3/27/2024	No	Yes	No	79.8	NA	21.9	NA	26.8	24.0
1/24/2024	1/24/2024	No	Yes	No	53.4	NA	66.0	NA	26.3	24.5
11/30/2022	11/30/2022	No	Yes	No	29.5	NA	2.6	NA	22.4	20.3
3/2/2023	3/2/2023	No	Yes	No	20.6	NA	15.5	NA	26.8	25.6
10/4/2023	10/4/2023	No	No	No	NA	NA	NA	NA	25.0	21.4
8/9/2023	8/9/2023	No	Yes	No	91.2	NA	9.0	NA	23.2	18.6
4/19/2023	4/19/2023	No	Yes	No	39.9	NA	11.6	NA	25.0	24.3
5/28/2024	5/28/2024	No	Yes	No	77.4	NA	31.0	NA	25.4	24.3
8/2/2023	8/2/2023	No	Yes	No	12.8	NA	25.8	NA	21.9	19.8
9/6/2023	9/6/2023	No	Yes	No	46.2	NA	47.7	NA	28.9	25.3
1/17/2024	1/17/2024	No	Yes	No	65.9	NA	68.2	NA	23.7	25.7
5/25/2023	5/25/2023	No	Yes	No	32.2	NA	20.6	NA	24.6	25.5
9/27/2023	9/27/2023	No	Yes	No	212.2	NA	23.1	NA	25.2	23.5
9/13/2023	9/13/2023	No	Yes	No	15.5	NA	14.2	NA	24.8	23.2
3/13/2024	3/13/2024	No	Yes	No	NA	NA	28.4	NA	27.7	25.3
6/5/2024	NA	No	No	No	25.9	NA	21.9	NA	23.2	22.8
7/13/2023	7/13/2023	No	Yes	No	44.0	NA	37.4	NA	25.8	21.0
3/15/2023	3/15/2023	No	Yes	No	NA	NA	22.1	NA	27.4	23.3
2/28/2024	2/28/2024	No	Yes	No	25.8	NA	23.3	NA	26.5	24.4
3/13/2024	3/13/2024	No	Yes	No	519.6	NA	28.5	NA	26.6	27.0
10/4/2023	10/4/2023	No	Yes	No	NA	NA	NA	NA	26.1	21.8

sd_temp_c_i	sd_temp_c_o	min_temp_c	min_temp_c	max_temp_c	max_temp_c	mean_rh_in	mean_rh_ou	sd_rh_in	sd_rh_out	min_rh_in
-16.1	-14.6	22.7	18.7	28.4	28.6	75.0	73.8	10.9	12.3	57.4
-16.4	-15.1	22.5	20.2	28.8	32.4	70.5	66.7	9.9	13.1	52.3
0.4	3.2	19.7	14.6	21.9	24.9	85.1	67.2	4.7	14.5	59.0
-16.9	-14.1	23.3	16.9	27.6	31.9	86.8	67.5	4.8	16.4	73.6
-15.5	-14.2	22.6	19.0	30.2	30.5	76.8	67.6	13.4	16.1	47.9
-17.3	-17.3	23.2	20.6	25.8	23.9	70.3	97.6	3.6	3.8	62.9
1.9	8.6	17.5	13.8	23.7	41.2	53.6	50.1	10.0	21.7	38.5
-17.2	-13.2	22.8	18.0	25.3	34.7	58.1	52.2	9.4	17.0	37.5
-16.8	-14.7	21.9	17.3	25.6	29.3	68.8	69.7	4.3	13.7	60.1
-16.8	-14.1	25.1	19.1	28.3	36.1	65.9	71.1	3.9	16.1	58.3
-15.5	NA	24.6	NA	32.6	NA	58.9	NA	8.9	NA	39.6
-17.2	NA	23.3	NA	26.7	NA	56.8	NA	5.5	NA	44.5
-17.4	-15.1	22.5	18.4	24.7	29.3	69.8	69.2	4.1	11.7	61.4
0.5	NA	23.7	NA	26.5	NA	81.6	NA	3.9	NA	66.6
-16.5	-14.9	25.2	20.4	29.4	29.1	57.0	58.3	11.4	19.0	36.3
-17.3	-15.2	26.4	21.1	28.7	33.7	59.2	47.9	3.8	10.6	46.7
1.6	4.7	22.0	16.6	29.4	38.6	71.0	66.9	6.8	17.0	56.9
-15.7	-14.2	22.9	20.0	30.3	35.4	61.7	62.0	10.1	15.5	44.5
-16.2	-12.5	20.3	15.7	25.9	35.9	73.4	61.1	6.0	20.0	50.7
-16.8	-13.7	22.5	17.8	27.7	31.3	57.5	61.5	10.7	23.7	40.6
-17.0	-13.9	25.7	17.8	28.5	30.6	58.8	61.6	10.3	17.1	41.0
-17.2	-13.0	21.7	16.4	24.1	34.8	83.5	67.8	11.0	20.0	64.2
-16.5	-12.7	24.4	17.4	28.6	36.5	69.4	72.3	7.1	18.8	52.8
-17.5	NA	23.8	NA	25.6	NA	67.4	NA	6.1	NA	56.1
-16.1	-14.0	23.1	18.1	28.9	32.0	66.1	73.5	7.4	18.7	49.8
-17.3	-13.8	23.1	16.0	26.1	30.7	71.5	62.2	6.7	19.0	54.7
-16.1	-13.6	24.9	18.0	31.2	33.5	57.3	59.0	9.0	12.4	41.8
-16.9	-11.5	25.7	18.0	30.1	39.5	66.9	69.5	3.2	23.0	58.3
-17.0	-13.6	24.6	19.7	28.0	37.5	58.0	53.1	5.9	15.6	41.5
1.0	4.6	20.1	16.0	24.4	33.2	70.6	77.4	6.0	21.2	58.6
-16.4	-14.5	24.6	21.3	31.9	33.6	44.6	45.5	5.9	11.8	32.9
-16.5	-12.6	23.3	16.7	27.8	34.6	56.9	67.3	6.7	19.5	44.6
-16.9	-15.6	22.4	15.1	27.3	22.5	64.4	74.8	4.0	11.8	57.2
-16.1	-14.2	22.4	20.5	28.5	36.9	67.8	63.4	7.5	14.1	53.7
-15.0	-11.8	21.7	18.6	32.4	40.1	66.0	67.7	11.3	17.9	41.8
-16.7	-14.9	20.4	16.7	24.6	32.3	68.5	69.9	7.3	13.2	53.9
-14.1	-13.1	23.9	19.4	36.6	38.5	54.2	51.8	14.9	15.1	26.7
-12.4	-16.6	17.8	23.9	38.6	28.9	65.8	72.0	19.3	4.7	26.9
-16.0	-10.4	22.0	18.0	27.7	41.2	56.1	53.3	7.0	20.3	45.9
-17.1	-14.1	24.3	18.8	27.7	32.2	59.1	59.5	3.9	16.0	52.8
-14.6	-11.9	20.8	17.0	32.2	38.0	57.7	58.9	8.5	17.0	42.1
-16.0	-11.1	24.9	16.8	31.3	39.3	55.4	59.9	9.9	27.3	34.5
-17.5	-17.2	22.7	21.6	24.4	24.3	80.6	69.9	2.4	6.0	72.8
-16.1	-13.5	22.6	15.7	28.8	35.3	54.2	60.2	7.6	15.6	40.2
-16.3	-14.9	24.5	17.9	30.0	27.8	52.7	59.1	7.6	16.7	38.6
-15.7	-11.1	23.5	18.0	30.3	40.3	64.4	71.1	9.0	25.7	48.8
-17.2	-10.1	25.7	19.0	28.5	46.2	57.0	55.6	10.3	24.0	35.5
-15.5	-12.6	23.4	17.2	31.7	36.5	59.2	70.7	9.5	19.4	39.9

min_rh_out	max_rh_in	max_rh_out
51.0	93.2	87.3
40.6	84.7	83.0
39.3	91.2	82.4
33.3	94.0	89.7
37.4	93.9	86.7
63.5	76.1	100.0
15.0	68.4	79.5
25.3	74.5	78.6
40.8	76.9	85.7
32.5	74.3	90.4
NA	71.8	NA
NA	70.0	NA
43.7	79.7	84.3
NA	90.7	NA
26.3	71.4	85.7
26.5	68.2	62.2
25.8	80.0	92.7
29.4	76.9	80.5
22.1	85.7	87.8
26.0	75.7	89.0
33.7	79.1	86.7
30.3	94.9	93.5
29.6	78.0	92.7
NA	75.5	NA
33.3	77.0	95.7
31.9	83.7	95.5
34.1	70.6	72.0
25.6	73.6	93.7
20.8	66.0	73.0
34.9	80.2	100.0
27.6	58.3	68.7
28.3	69.7	88.4
55.1	75.6	93.5
30.1	78.0	79.6
29.0	82.5	83.9
31.2	79.6	86.7
25.3	70.8	72.5
58.7	89.0	79.8
17.1	67.7	82.0
32.6	71.3	82.3
26.0	71.2	76.7
18.8	73.6	99.4
57.1	85.2	78.8
24.4	64.8	82.4
32.4	64.9	85.7
24.4	74.7	96.8
15.0	76.9	87.3
27.9	72.3	93.7

variable name	description	details	
child_dob_to_ftl_months	infant age (months) at air sampling	numeric	
en_mom_age	maternal age (years) at enrollment	numeric	
employ_recode	maternal employment status	categorical	
		Homemaker/none/student	
		Monthly salary	
		Daily wage	
		Small business	
en_rent	monthly household rent (Kenya Shillings) at enrollment	numeric	
		NA - missing	
housing_type	type of housing, technician observed	Multi-unit dwelling (flats)	
		Small bungalow (single unit)	
fhv_pplinhse_cat	number of persons residing in house at air sampling, se	categorical	
		2 - 4	
		5 - 8	
fhv_rooms_cat	number of rooms in home at air sampling, self-reporte	categorical	
		1	
		2	
		3 or more	
		NA - missing	
fhv_pplperroom_calc	persons per room	numeric, calculated, number of persons divided by number of rooms	
fhv_wtr_src_piped_water_inhse	piped water in the home at air sampling, self-reported	categorical	
		No	
		Yes	
fhv_wtr_src_piped_water_out	piped water outside the home at air sampling, self-rep	categorical	
		No	
		Yes	
fhv_toilet_type	type of toilet at air sampling, self-reported	categorical	
		Flush toilet	
		Pit latrine	
fhv_toilet_shared	shared toilet at air sampling, self-reported	categorical	
		No	
		Yes	
fhv_roof_mabati	mabati (silver) roof material at air sampling, self-repor	categorical	
		No	
		Yes	
fhv_roof_treated_iron	treated iron roof material at air sampling, self-reporte	categorical	
		No	
		Yes	*add mabati yes and treated iron yes to get total metal sheets frequency
fhv_roof_concrete	concrete roof material at air sampling, self-reported	categorical	
		No	
		Yes	
fhv_wall_metal	metal/iron sheets wall material at air sampling, self-re	categorical	
		No	
		Yes	
fhv_wall_stones	stones wall material at air sampling, self-reported	categorical	
		No	
		Yes	
fhv_floor_concrete	concrete/cement floor material at air sampling, self-re	categorical	
		No	
		Yes	
fhv_floor_ceramic_tiles	ceramic tiles floor material at air sampling, self-report	categorical	
		No	
		Yes	
fhv_windows	number of rooms in home at air sampling, self-reporte	numeric	
fhv_extdoors	number of external doors in home at air sampling, self-	numeric	
		NA - missing	
externalopenings_perroom	number of external openings (windows and doors) per r	numeric, calculated, number of external windows plus external doors divided by number of total number of rooms in home	
		NA - missing	
fsl_kitchen_short_m	kitchen width (m) at air sampling, technician measured	numeric, measured	
fsl_kitchen_long_m	kitchen length (m) at air sampling, technician measure	numeric, measured	
fsl_kitchen_height_m	kitchen height (m) at air sampling, technician measure	numeric, measured	
kitchen_volume_m3_fsl	volume (m3) of cooking room at air sampling set-up	numeric, calculated (fsl_kitchen_short_m*fsl_kitchen_long_m*fsl_kitchen_height_m)	
fhv_floorcover_carpet	rug or carpet floor covering at air sampling, self-report	categorical	
		No	
		Yes	
fhv_fuel_wood	wood used by the household before air sampling, self-r	categorical	
		Indoor	
		Outdoor	
		Not at all	
		NA - missing	
fhv_fuel_charcoal	charcoal used by the household before air sampling, se	categorical	
		Indoor	
		Outdoor	
		Not at all	
		NA - missing	
fhv_fuel_kero	kerosene used by the household before air sampling, se	categorical	
		Indoor	
		Outdoor	
		Not at all	
		NA - missing	
fhv_fuel_koko	koko fuel (ethanol) used by the household at enrollmen	categorical	
		Indoor	
		Outdoor	
		Not at all	
		NA - missing	
fhv_fuel_lpg	LPG used by the household before air sampling, self-rep	categorical	
		Indoor	
		Outdoor	
		Not at all	
fhv_fuel_electricity	electricity used by the household before air sampling, s	categorical	
		Indoor	
		Outdoor	
		Not at all	
		NA - missing	

variable name	description	details
shv_ind_fuel_wood_recode	wood used indoors during air sampling, self-	categorical
		No
		Yes once or yes more than once
en_ind_fuel_charcoal_recode	charcoal used by the household indoors at e	categorical
		Rarely/not at all
		Some days
		Daily/most days
shv_ind_fuel_kero_recode	kerosene used indoors during air sampling, s	categorical
		No
		Yes once or yes more than once
shv_ind_fuel_koko_recode	koko fuel (ethanol) used indoors during air s	categorical
		No
		Yes once or yes more than once
shv_ind_fuel_lpg_recode	LPG (liquefied petroleum gas) used indoors	categorical
		No
		Yes once or yes more than once
fhv_fuel_electricity	electricity used during air sampling, self-rep	categorical
		Not at all
		Indoor
		Outdoor
shv_ind_othrfuel_mosquitorepellan	mosquito repellent burned indoors during ai	categorical
		No
		Yes once or yes more than once
shv_ind_othrfuel_candles_recode	candles burned indoors during air sampling,	categorical
		No
		Yes once or yes more than once
shv_cig_smk_recode	cigarette smoke in the house during air sam	categorical
		No
		Yes once or yes more than once
shv_marij_smk_recode	marijuana smoke in the house during air sar	categorical
		No
		Yes once or yes more than once
shv_pt_out_pol_ownsmoke	residence near own outdoor cooking smoke	categorical
		No
		Yes
shv_pt_out_pol_neighbor	residence near neighbors' cooking smoke du	categorical
		No
		Yes
shv_pt_out_pol_cook_moke	residence near (within 1 km) other cooking s	categorical
		No
		Yes
shv_pt_out_pol_vehicle	residence near (within 1 km) vehicle smoke	categorical
		No
		Yes
shv_pt_out_pol_dumpsite	residence near (within 1 km) dumpsite smok	categorical
		No
		Yes
shv_pt_out_pol_rubishburning	residence near (within 1 km) rubbish burnin	categorical
		No
		Yes
shv_pt_out_pol_industry	residence near (within 1 km) industry or fac	categorical
		No
		Yes
shv_pt_out_pol_charcoal	residence near (within 1 km) smoke from m	categorical
		No
		Yes
shv_pt_out_pol_roads	residence near (within 1 km) unpaved/dusty	categorical
		No
		Yes
shv_pt_out_pol_dust	residence near (within 1 km) construction du	categorical
		No
		Yes

variable name	description	details
air_sample_month	month of sample take down (end of 24 h samp	character, taken from field log
air_sample_year	year of sample take down (end of 24 h samplir	character, taken from field log
co_num_obs_in	number of observations logged, indoor sample	numeric, calculated from number of observations NA - missing
co_num_obs_out	number of observations logged, outdoor sampl	numeric, calculated from number of observations NA - missing
co_mean_ppm_in	24-hr mean CO (ppm), indoor sample	numeric, calculated from 1 min means of 10 sec logged concentrations NA - missing
co_mean_ppm_out	24-hr mean CO (ppm), outdoor sample	numeric, calculated from 1 min means of 10 sec logged concentrations NA - missing
co_sd_ppm_in	24-hr standard deviation (SD) CO (ppm), indoo	numeric, calculated from 1 min means of 10 sec logged concentrations NA - missing
co_sd_ppm_out	24-hr standard deviation (SD) CO (ppm), outdo	numeric, calculated from 1 min means of 10 sec logged concentrations NA - missing
co_min_ppm_in	24-hr min CO (ppm), indoor sample	numeric, calculated from 1 min logged concentrations NA - missing
co_min_ppm_out	24-hr min CO (ppm), outdoor sample	numeric, calculated from 1 min logged concentrations NA - missing
co_max_ppm_in	24-hr max CO (ppm), indoor sample	numeric, calculated from 1 min logged concentrations NA - missing
co_max_ppm_out	24-hr max CO (ppm), outdoor sample	numeric, calculated from 1 min logged concentrations NA - missing
lasco_runtime_hr_in	sample duration (hours) calculated based on d	numeric, calculated
lasco_runtime_hr_out	sample duration (hours) calculated based on d	numeric, calculated
lasco_setup_date_in	earliest date in indoor sample	date (mm/dd/yy), from sensor NA - missing
lasco_setup_date_out	earliest date in outdoor sample	date (mm/dd/yy), from sensor NA - missing
airqc_lasco_in_dup_done	indoor duplicate sample collected	categorical: Yes, No
airqc_lasco_out_pr_done	outdoor primary sample collected	categorical: Yes, No
airqc_lasco_out_dup_done	outdoor duplicate sample collected	categorical: Yes, No
in_pr_pm_conc_ugm3	indoor primary sample air pm2.5 concentratio	numeric, calculated NA - missing
in_dup_pm_conc_ugm3	indoor duplicate sample air pm2.5 concentrati	numeric, calculated NA - missing
out_pr_pm_conc_ugm3	outdoor primary sample air pm2.5 concentrati	numeric, calculated NA - missing
out_dup_pm_conc_ugm3	outdoor duplicate sample air pm2.5 concentra	numeric, calculated NA - missing
mean_temp_c_in	24-hr mean temperature (°C), indoor sample	numeric, calculated from 5 min logged concentrations
mean_temp_c_out	24-hr mean temperature (°C), outdoor sample	numeric, calculated from 5 min logged concentrations NA - missing
sd_temp_c_in	24-hr standard deviation (SD) temperature (°C	numeric, calculated from 5 min logged concentrations
sd_temp_c_out	24-hr standard deviation (SD) temperature (°C	numeric, calculated from 5 min logged concentrations NA - missing
min_temp_c_in	24-hr min temperature (°C), indoor sample	numeric, calculated from 5 min logged concentrations
min_temp_c_out	24-hr min temperature (°C), outdoor sample	numeric, calculated from 5 min logged concentrations NA - missing
max_temp_c_in	24-hr max temperature (°C), indoor sample	numeric, calculated from 5 min logged concentrations
max_temp_c_out	24-hr max temperature (°C), outdoor sample	numeric, calculated from 5 min logged concentrations NA - missing
mean_rh_in	24-hr mean relative humidity, indoor sample	numeric, calculated from 5 min logged concentrations
mean_rh_out	24-hr mean relative humidity, outdoor sample	numeric, calculated from 5 min logged concentrations NA - missing
sd_rh_in	24-hr standard deviation (SD) relative humidity	numeric, calculated from 5 min logged concentrations
sd_rh_out	24-hr standard deviation (SD) relative humidity	numeric, calculated from 5 min logged concentrations NA - missing
min_rh_in	24-hr min relative humidity, indoor sample	numeric, calculated from 5 min logged concentrations
min_rh_out	24-hr min relative humidity, outdoor sample	numeric, calculated from 5 min logged concentrations NA - missing
max_rh_in	24-hr max relative humidity, indoor sample	numeric, calculated from 5 min logged concentrations
max_rh_out	24-hr max relative humidity, outdoor sample	numeric, calculated from 5 min logged concentrations NA - missing