Title

Home environment and indoor air pollution exposure in an African birth cohort study.

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Abstract

Background: Household indoor air pollution (IAP) is a global health problem and a risk factor for childhood respiratory disease; the leading cause of mortality in African children. This study aimed to describe the home environment and measure IAP in the Drakenstein Child Health Study (DCHS), an African birth cohort.

Methods: An antenatal home visit to assess the home environment and measure IAP (particulate matter, sulphur dioxide, nitrogen dioxide, carbon monoxide and volatile organic compounds (VOCs)) was done on pregnant women enrolled to the DCHS, in a low-socioeconomic, peri-urban South African community. Urine cotinine measured maternal tobacco smoking and exposure. Dwellings were categorised according to 6 household dimensions. Univariate and multivariate analysis explored associations between home environment, seasons and IAP levels measured.

Results: 633 home visits were completed, with IAP measured in 90% of homes. Almost a third of participants were of the lowest socio-economic status and the majority of homes (65%) lacked 2 or more of the dwelling category dimensions. Most households had electricity (92%), however, fossil fuels were still used for cooking (19%) and heating (15%) in homes. Antenatal maternal smoking prevalence was 31%; 44% had passive smoke exposure. Of IAP measured, benzene (VOC) was significantly above ambient standards with median $5.6\mu\text{g}/\text{m}^3$ (IQR 2.6-17.1). There were significant associations between the use of fossil fuels for cooking and increased benzene [OR 3.4 (95% CI 2.1-5.4)], carbon monoxide [OR 2.9 (95% CI 1.7 - 5.0)] and nitrogen dioxide [OR 18.6 (95% CI 3.9 - 88.9)] levels. A significant seasonal association was found with higher IAP levels in winter.

Conclusion: In this low-socioeconomic African community, multiple environmental factors and pollutants, with the potential to affect child health, were identified. Measurement of IAP in a resource-limited setting is feasible. Recognising and quantifying these risk factors is important in effecting public health policy changes.

Introduction

Household indoor air pollution (IAP) is a leading cause of morbidity and mortality globally(1) and a major risk factor for childhood respiratory disease and for severe disease.(2-4) Childhood respiratory disease, particularly pneumonia, remains the leading cause of under-5 mortality and morbidity in low- and middle-income countries (LMICs) including South Africa.(5-7)

The risk of exposure to IAP is particularly prevalent in LMICs where alternate fuels remain the main source of fuel for cooking and heating. Alternate fuel sources include solid fuels such as coal, biomass fuel such as wood, dung and crop residues and non-solid fuels like paraffin, liquefied petroleum and gas. Combustion of these products produces numerous by-products which contribute to household IAP.(8) The risk of developing childhood pneumonia is almost doubled following exposure to indoor biomass fuels, as is the long-term risk of developing chronic lung disease in adulthood.(9, 10)

In South Africa, despite increased electrification of areas, up to 40% of the population still use alternate fuel sources for household activities.(11, 12) In rural areas, up to 90% of households use biomass fuels as an energy source.(11, 13) Home environmental factors such as crowding, type of cook stove, ventilation and duration of exposure are also important contributors to exposure levels.(1, 11) The contribution of IAP exposure to the incidence and severity of childhood respiratory disease has not been well studied in an African setting. Quantifying indoor air pollution is difficult and there are few studies that measure IAP in individual homes on a large scale in this context.(1, 9, 11)

The aim of this study was to describe the home environments and measure IAP in the Drakenstein Child Health Study (DCHS), an African birth cohort study.(14) Further, we aimed to investigate the feasibility of intensive sampling in individual homes in a LMIC setting and to explore associations between home environmental factors and pollutant exposure.

Methods

The DCHS is located in the Drakenstein sub-district of the Western Cape, South Africa, a peri-urban area 60km outside Cape Town.(14) A prospective study to assess the home environment and household IAP exposure in participants was done from March 2011 until May 2014.

Study population and participants. This low socio-economic community accessed health care mainly in the public sector. Pregnant women were recruited from two primary health care clinics: Mbekweni (serving a predominately black African population) and Newman (serving a predominately mixed race population). Consenting pregnant women were enrolled between 20-28 weeks' gestation. Mothers completed study questionnaires and provided urine for analysis of urine cotinine as a measure of smoking and smoke exposure. Urine cotinine was measured using the IMMULITE^R 1000 Nicotine_Metabolite Kit (Siemens Medical Solutions Diagnostics^R, Glyn Rhonwy, United Kingdom). This provides a quantitative test using a competitive chemiluminescent immunoassay, which contained solid-phase beads coated with polyclonal rabbit anti-cotinine antibody.(15) Urine cotinine levels were classified as <10 ng/ml (non-smoker), 10-499 ng/ml, (passive smoker), or ≥500 ng/ml (active smoker).

Assessment of home environment and indoor air pollution (IAP) exposures. Self-reported questionnaires were administered at enrolment by trained staff. A self-reported assessment of socioeconomic status (SES) adapted from the South African Stress and Health Study (SASH) was done.(16) A composite SES score was developed based on current employment status and standardised scores of educational level, household income and a composite asset index made up of access to household resources, amenities and market access categorising participants as being lowest SES, low-moderate SES, moderate-high SES or high SES.

Home visits for assessment of the home environment and measurement of IAP were done antenatally within 4 weeks of enrolment. Both primary health care clinics, Mbekweni and Newman, had a dedicated team of two environmental fieldworkers trained to undertake home visits, administer questionnaires and set up equipment for IAP measurement. Field worker training was completed under the supervision of an accredited environmental laboratory (SGS Environmental Services^R). Each participant received an information leaflet reviewing the reasons for the home visit and the measures being conducted. Data were gathered on type of

home, its position and size, number of inhabitants, access to basic amenities, fuels used for cooking and heating, ventilation within homes and pesticides/cleaning materials used based on validated questionnaires.(17-21) An implementation of the Alkire-Foster method, a flexible technique used to incorporate a number of dimensions of poverty or well-being, that can complement poverty assessment(22, 23) was applied to the dwelling characteristics. Six dwelling factors were used; type of home (formal versus informal), primary building material (brick or cement versus other materials), water supply (piped into dwelling or yard), toilet facilities (non communal flush), kitchen type (separate room in house) and ventilation in the kitchen area (pipe or duct to exterior). Dwellings were then categorised according to the number of dimensions lacking. This method defines a dwelling as a “poor structure” if it lacks one-third or more of the factors considered. Size of the kitchen and main living room were measured using an ultrasonic measuring tool. The position of the home in relation to the road and passing traffic was also estimated.

The most common IAP were measured (Table 1). All measurements were done in the communal/main living room, away from windows and doors, approximately 1.5 meters from the ground. Devices were left in the home for 24 hours to 2 weeks depending on the measurement (Table 1).

Measurements processing and interpretation: Following collection, samples were stored in a refrigerator (under 8°C) to maintain a cold chain and transferred weekly to an accredited environmental laboratory for analysis. Samples were batched and analyses were conducted monthly. An average concentration based on the 2-week duration in the home was obtained for sulphur dioxide/nitrogen dioxide and volatile organic compounds; 24-hour averages were obtained for particulate matter. Carbon monoxide data was downloaded to a computer and the frequency of exceedance above the hourly ambient standard was calculated. Based on the 10 minute readings, total hourly concentrations were computed using the trapezium rule. Two consecutive ten minute CO readings were used to represent parallel sides of a trapezium and the 10 minute interval to represent the distance between the parallel sides (width). The trapezium formula; half the sum of the parallel sides multiplied by the width, was then applied. The sum of six consecutive trapezia areas to represent total CO concentration in an hour was then calculated. Using this approach hourly concentrations were then determined for the entire duration of the CO device in the household.

Ethics. The study was approved by the Faculty of Health Sciences Human Research Ethics Committee of the University of Cape Town and of Stellenbosch University, and by the Western Cape Provincial Health Research committee. Written informed consent was obtained from participants at the time of enrolment.

Statistical Analysis

All data were entered into a relational database (Microsoft Access^R) and analysed using STATA version 12. Mann-Whitney tests were used to compare medians as well as their spread. Simple and multiple logistic regression were used to examine the associations between IAP measures and home environment characteristics. For each IAP measure exposure categories were determined following South African National Ambient Air Quality Standards.(24) The 2015 ambient air quality standard values were used with the following acceptable concentrations based on an averaging period of 1 year for each measure; PM10: 40ug/m³, SO2: 50ug/m³ NO2: 40ug/m³, benzene: 5ug/m³. For CO, a household should not have more than 88 hours in which the CO concentration was 30mg/m³ or above.(24) For each household, the number of hours that had an hourly CO concentration above the ambient hourly threshold was counted and expressed as proportion of the total duration of the device in the household. A household was deemed to be exposed to CO if the actual proportion of hours with CO level of 30mg/m³ and above exceeded 1%. Home environment and other characteristics considered for the model were based on factors that may influence IAP levels and included socioeconomic status, smoking status, dwelling categorisation, access to electricity, fossil fuel usage, number of people per sleeping room and dwelling proximity to passing traffic. Univariate analysis was done for each of the IAP measures in relation to the sociodemographic and household characteristics in order to obtain a “crude” odds ratio, All these variables were then applied to a multiple logistic regression model to obtain the adjusted odds ratio. The variables included were guided by previous literature.(1, 8, 25) Univariate analysis was used for seasonal associations with IAP. Regression diagnostics followed standard procedures.(26) All P-values and confidence intervals reported were two-sided at alpha 0.05.

Results

In this study period 633 mothers were enrolled, with 633 antenatal home visits completed. There was good acceptability of the placement of devices, with all mothers agreeing to placement; particulate matter (PM10) results were analysed for 592 homes (94%), sulphur dioxide (SO₂) for 600 homes (95%), nitrogen dioxide (NO₂) for 598 homes (95%), carbon monoxide for 505 homes (80%) and volatile organic compounds for 579 homes (91%). Where results included are fewer than total home visits completed, this was due to missing results or damaged devices.

Demographics and Home Environment. The population were predominantly of low socioeconomic status with more than half (52%) in the lowest or low-moderate SES category. Mbekweni had a higher proportion of participants in the lowest SES bracket (37%) compared to Newman (19%), $p < 0.001$. The median household size was 5 (IQR 3-6) people; homes in Newman had significantly more people median 5 (IQR 4-7) compared to Mbekweni median 4 (IQR 3-6), $p < 0.001$. A median of 3 (IQR 2-4) people per sleeping room was found across both sites. (Table 2)

Most homes (65%) lacked 2 or more of the dwelling categorisation dimensions with 7% of homes lacking all 6 dimensions. This was significantly higher in Mbekweni dwellings (11%) compared to Newman (3%) homes, $p < 0.001$. Most households (92%) had electricity, with significantly more in Newman (97%) compared to Mbekweni (88%), $p < 0.001$. Conversely, more Mbekweni homes (28%) used fossil fuels for cooking or heating compared to Newman homes in which 10% and 2% reported using fossil fuels for cooking and heating respectively. (Table 2) The majority of Mbekweni homes were estimated to be situated less than 50m away from continuously passing trucks. (Table 2)

Thirty-one percent of mothers were active smokers, with significantly more smokers at Newman (52%) than Mbekweni (11%). A further 44% of participants were passive smokers and this was higher in the Mbekweni participants (51%) compared to Newman (37%). (Table 2)

Indoor Air Pollution. The IAP measures were not normally distributed and hence the median and inter-quartile ranges were reported. The median concentration of particulate matter (PM10) measured in the homes was 33.1 (IQR 13-62.2) $\mu\text{g}/\text{m}^3$, below the ambient standard of 40 $\mu\text{g}/\text{m}^3$ with no significant difference between sites. Although the median for carbon monoxide (CO) based on the hourly average for the 24 hour period in the home was 0 $\mu\text{g}/\text{m}^3$ (IQR 0 – 24.4 $\mu\text{g}/\text{m}^3$), when measuring against ambient standards, 15% of homes had hourly CO values exceeding these. The distribution of nitrogen dioxide concentrations differed significantly between Mbekweni 8.6 $\mu\text{g}/\text{m}^3$ (IQR 3.8 -15.3 $\mu\text{g}/\text{m}^3$) and Newman 7.3 $\mu\text{g}/\text{m}^3$ (IQR 3.6 – 11.4 $\mu\text{g}/\text{m}^3$), $p = 0.004$, however these were substantially below acceptable ambient standards (40 $\mu\text{g}/\text{m}^3$). Of the volatile organic compounds, the median benzene concentration was 5.6 $\mu\text{g}/\text{m}^3$ (IQR 2.6-17.1 $\mu\text{g}/\text{m}^3$) with a significant difference in the distribution of the concentrations between the sites: Mbekweni 6.0 $\mu\text{g}/\text{m}^3$ (IQR 2.9 – 27 $\mu\text{g}/\text{m}^3$) versus Newman 5.6 $\mu\text{g}/\text{m}^3$ (IQR 2.3 – 11.3 $\mu\text{g}/\text{m}^3$), $p = 0.010$, both were above the acceptable ambient standard of 5 $\mu\text{g}/\text{m}^3$ (Table 3)

Benzene: In the unadjusted model, the use of fossil fuels for cooking [OR 3.4 (95% CI 2.1-5.4)] as well as the use of fossil fuels for heating [OR 3.2 (95% CI 1.9-5.5)] were significantly associated with an increased level of benzene. Conversely, the presence of electricity in the home was significantly associated with a decrease in levels of benzene [OR 0.2 (95% CI 0.1-0.4)]. (Table 4)

Carbon Monoxide: The unadjusted model also showed significant increase in carbon monoxide levels associated with fossil fuel cooking [OR 2.9 (95% CI 1.7 - 5.0)] and heating [OR 4.0 (95% CI 2.3 - 7.1)] and an associated decrease in these levels when electricity was present [OR 0.2 (0.1 - 0.4)]. (Table 4)

Particulate matter: Compared to households that had 2 people or less per sleeping room, households with 3 or more people per sleeping room were more likely to have increased particulate matter (PM10) levels [OR 2.12 (95% CI 1.22 - 3.69)]. (Table 4)

Nitrogen dioxide: Having 2 or less of the dwelling category dimensions was significantly associated with increased nitrogen dioxide levels [OR 4.5 (95% CI 1.2 - 17.6)] in the unadjusted model. There was also a

significant association between the use of fossil fuels for cooking [OR 18.6 (95% CI 3.9 - 88.9) and heating [OR 14.2 (95% CI 3.6 - 56.0)] and increased nitrogen dioxide levels. (Table 4)

Multivariate analysis: In the adjusted model, the presence of electricity in homes was significantly associated with a decrease in benzene [OR 0.2 (95% CI 0.1-0.6)] and CO levels [OR 0.3 (95% CI 0.1-0.7)]. The use of fossil fuels for heating was significantly associated with an increase in benzene [OR 2.0 (95% CI 1.0-4.0)] and CO levels [OR 2.3 (95% CI 1.0-5.4)]. Only the use of fossil fuels for cooking maintained a significant association with increased levels of nitrogen dioxide [OR 8.6 (95% CI 1.1-67.4)] in the adjusted model. There was no significant association between household characteristics and PM10 levels when adjusted. (Table 4)

A significant seasonal association with benzene and carbon monoxide levels measured was found, with benzene [OR 35.9 (95% CI 10.3 - 125.5)] and carbon monoxide [OR 2.7 (95% CI 1.2 - 6.2)] levels significantly higher in winter. There were an approximately equal number of home visits done in autumn, winter and spring, with fewer in the summer months. (Table 5)

Discussion

In this study in a poor peri-urban, South African area, we identified a number of environmental factors which may influence child health. Many homes were lacking in dimensions and basic amenities. Despite having access to electricity, fossil fuels were used as an alternate energy source in up to 20% of homes. There was a seasonal variation in IAP levels measured with higher levels associated with the winter months. The prevalence of maternal smoking was very high as was exposure to tobacco smoke in non-smoking mothers.

Measuring IAP is difficult and most studies rely on reported exposure or extrapolation following sampling of selected homes (1, 13) with few studies from LMICs and Africa in particular. (27) However, we successfully measured IAP and by-products of combustion in the vast majority of homes (over 600) providing important data on household IAP in a peri-urban, LMIC setting. Surprisingly there was relatively little exposure to IAP with only benzene, a volatile organic compound, having a median concentration above acceptable ambient standards. (24) However, ambient standards serve as a guide to acceptable levels of pollutants with levels continually being lowered. It is therefore difficult to ascertain a clear level at which health effects are associated. (1, 2, 28) The long term effects of exposure to IAP and association with childhood respiratory disease will be longitudinally studied in the DCHS.

In categorising dwellings, we found almost two-thirds of participants lived in homes that were of an inadequate structure. Despite such poor housing and living conditions, IAP measurements were made in most homes, including measures that required devices to be left in situ for 2 weeks. The type of dwelling and home environment may impact on sources of pollutants and levels measured within the home. Factors such as a non-separate kitchen, with poor ventilation, the informal construct of the dwelling and crowding may also contribute to a higher exposure level to pollutants; as evidence of this higher exposure to PM was associated with more household members per sleeping room. (1, 29)

Despite having access to electricity, fossil fuels were used for cooking or heating in almost a third of homes of black African mothers. The relatively high cost of electricity in South Africa (30) and that it is purchased on a pre-paid basis may influence supply and use. The predominant fossil fuels used included paraffin, wood, gas and coal, while other biomass fuels such as animal manure or crop residues were not commonly used. (31) Fossil fuel usage was significantly associated with measured benzene, carbon monoxide and nitrogen dioxide levels, contributing to household IAP. The higher use of fossil fuels amongst black African households compared to mixed race populations may be explained by the relatively lower socio-economic status of the former.

Although we did not show any significant associations between tobacco smoke and measured IAP levels, environmental tobacco smoke remains an important contributor to IAP and a recognised source of benzene. The very high levels of maternal smoking and smoke exposure are of much concern, with potential for several adverse health effects in mothers and children. (32) Other sources of benzene include paraffin and outdoor traffic, (28) both potentially contributing to the significantly higher levels measured in the Mbekweni community.

A limitation of this study was the duration of sampling which ranged between 24 hours to 2 weeks depending on the measure and the device used. Devices were also placed in one room and this might not fully account for IAP occurring in other areas of the home. The devices used to measure IAP (except for carbon monoxide) all gave an average concentration and therefore periods of peak exposure may have been underestimated.

The sub-optimal housing, tobacco smoking and exposure, reliance on fossil fuels for energy and the associated pollutants as a result of their use are all important public health issues that need to be addressed on a policy level. IAP is often overlooked as a significant risk factor for a number of health problems(1); recognising and quantifying these environmental risks are instrumental to effect change.

To our knowledge, this is the first African study to comprehensively measure several possible pollutants and environmental exposures during pregnancy. This study has shown that measurement of IAP in a resource limited setting is feasible; combining this with a dwelling categorisation may provide a novel measure for a household-exposure index.

Funding

This study was funded by: Bill & Melinda Gates Foundation (OPP1017641), Discovery Foundation, South African Thoracic Society AstraZeneca Respiratory Fellowship, Thrasher Foundation, National Research Fund, South Africa Grant 2014, CIDRI Clinical Fellowship, Medical Research Council, South Africa, Clinician Scholarship, SGS Environmental Services.

Acknowledgements

We thank the study and clinical staff at Paarl hospital and Mbekweni and Newman clinics and in particular the fieldworker teams led by Mr Masande Mbovu. Thank you to SGS Environmental Services^R for supporting this project under the guidance of Mr Grant Ravenscroft and Ms Helen Hill. We thank the participants and their families.

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Table 1 Measurements of IAP

Pollutant/Measure	Device	Duration in home	Methodology
Particulate Matter (PM10)	Personal Air Sampling Pump (SKC AirChek 52 ^R)	24 hours	Gravimetrically pre-weighed filter. Weighed post sampling and concentration calculated.(33)
Carbon Monoxide (CO)	Altair ^R Carbon Monoxide single gas detection unit	24 hours	Electrochemical sensor detection of gas at 10 min intervals. Data downloaded from device.
Sulphur dioxide/Nitrogen dioxide (SO2/NO2)	Radiello ^R adsorbent filters in polyethylene diffusive body	2 weeks	Chemisorbed on to filter. Quantified by visible spectrophotometry or ion chromatography.(34)
Volatile Organic Compounds: Benzene, Toluene, Ethyl Benzene, m,p-Xylene, o-Xylene	Markes ^R thermal desorption tubes	2 weeks	Analysed for BTEX using the NIOSH 2549 method.(33)

Table 2 Demographics and Home Environment

	Mbekweni (n, %)	Newman (n, %)	Total (n,%)	p value
<i>Number of mothers</i>	314	319	633	
SES quartiles				
Lowest SES	115 (37)	62 (19)	177 (28)	*p<0.001
Low-mod SES	82 (26)	73 (23)	155 (24)	
Mod-high SES	71 (23)	87 (27)	158 (25)	
High SES	46 (15)	97 (30)	143 (23)	
Household Density (median, IQR)				
Household size	4 (3-6)	5 (4-7)	5 (3-6)	*p<0.001
Persons per room	2 (1-3)	1 (1-2)	2 (1-3)	*p<0.001
Persons per sleeping room	3 (2-4)	3 (2-5)	3 (2-4)	*p<0.001
Dwelling Category (Six Category variant)				
Lacking 6 dimensions†	35 (11)	8 (3)	43 (7)	*p<0.001
Lacking 5 dimensions†	34 (11)	43 (13)	77 (12)	
Lacking 4 dimensions†	63 (20)	34 (11)	97 (15)	
Lacking 3 dimensions†	8 (3)	20 (6)	28 (4)	
Lacking 2 dimensions†	102 (32)	68 (21)	170 (27)	
Lacking 1 dimensions†	55 (18)	146 (46)	201 (32)	
Lacking 0 dimensions†	17 (5)	0 (0)	17 (3)	
Dwelling Category (Two Category variant)				
Has ≤2 dimensions†	132 (42)	85 (27)	217 (34)	*p<0.001
Has > 2 dimensions†	182 (58)	234 (73)	416 (66)	
Electricity Access	277 (88)	308 (97)	585 (92)	*p<0.001
Fossil Fuel (coal, wood, paraffin, gas) Used				
Cooking	88 (28)	32 (10)	120 (19)	*p<0.001
Heating	87 (28)	7 (2)	94 (15)	*p<0.001
Type of Stove				
Electric	265 (84)	286 (90)	551 (87)	p=0.049
Paraffin	79 (25)	3 (1)	82 (13)	*p<0.001
Gas	13 (4)	28 (9)	41 (6)	*p=0.018
Wood	2 (1)	1 (0)	3 (0)	p=0.554
Coal	2 (1)	0 (0)	2 (0)	p=0.153
Smoking Exposure				
Non smoker	107 (38)	30 (11)	137 (25)	*p<0.001
Passive Smoker	143 (51)	102 (37)	245 (44)	
Active Smoker	31 (11)	143 (52)	174 (31)	
Distance of homes from continuously passing trucks				
Less than 50 meters	200 (64)	24 (8)	224 (36)	*p<0.001
50 - 100meters	67 (21)	27 (8)	94 (15)	
100 - 200 meters	42 (13)	34 (11)	76 (12)	
200 - 500 meters	3 (1)	92 (29)	95 (15)	
More than 500 meters	0 (0)	141 (44)	141 (22)	

*Statistically significant results

†Dimensions comprise: type of home; building material; water supply; toilet facilities; kitchen type; ventilation in kitchen areas

Table 3 Pollutants Measured

	Mbekweni median (IQR)	Newman median (IQR)	Total median (IQR)	N	p value
Pollutant					
Particulate Matter (PM10) ug/m3	32.9 (15.1-60.6)	33.2 (11.9-62.8)	33.1 (13.0-62.2)	592	p=0.678
Sulphur Dioxide ug/m3	0.0 (0.0-0.2)	0.0 (0.0-0.2)	0.0 (0.0-0.2)	600	p=0.345
Nitrogen Dioxide ug/m3	8.6 (3.8-15.3)	7.3 (3.6-11.4)	7.9 (3.8-13.3)	598	*p=0.004
Carbon Monoxide mg/m3 §	0.0 (0.0-29.8)	0.0 (0.0-16.1)	0.0 (0.0-24.4)	505	p=0.659
Volatile Organic Compounds					
Benzene ug/m3	6.0 (2.9-27.0)	5.3 (2.3-11.3)	5.6 (2.6-17.1)	579	*p=0.010
Toluene ug/m3	19.8 (9.0-48.5)	19.8 (9.8-54.4)	19.8 (9.3-53.2)	579	p=0.544
Ethyl-benzene ug/m3	2.4 (1.0-8.7)	1.8 (0.8-6.0)	2.1 (0.9-7.2)	579	p=0.085
m,p -Xylene ug/m3	6.1 (2.5-20.5)	5.2 (2.3-14.4)	5.8 (2.4-16.2)	579	p=0.110
o-Xylene ug/m3	2.8 (1.2-9.6)	2.1 (1.0-5.4)	2.4 (1.1-7.0)	579	*p=0.005
	Mbekweni n(%)	Newman n(%)	Total n (%)	N	p value
Carbon Monoxide exceeding ambient standard					
Above Expected Frequency	37 (14)	40 (17)	77 (15)	505	p=0.399

* Statistically significant results

§Hourly average based on entire duration in house

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Table 4 Associations between home environment variables and specific pollutants

	Benzene		Carbon Monoxide		Particulate matter (PM10)		Nitrogen Dioxide	
	(>5ug/m ³)		(1% exceedence >30ug/m ³)		(>40ug/m ³)		(>40ug/m ³)	
Variable	Unadjusted OR (95%CI)	Adjusted OR (95%CI)	Unadjusted OR (95%CI)	Adjusted OR (95%CI)	Unadjusted OR (95%CI)	Adjusted OR (95%CI)	Crude OR (95%CI)	Adjusted OR (95%CI)
SES quartile: High SES	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Low-mod SES	1.2 (0.7-1.9)	1.2 (0.7-2.0)	0.9 (0.4-1.8)	0.7 (0.3-1.4)	1.6 (0.8-3.1)	1.6 (0.8-3.4)	0.9 (0.1-14.7)	0.52 (0.0-9.6)
Moderate SES	1.0 (0.6-1.6)	1.1 (0.7-1.9)	0.6 (0.3-1.3)	0.5 (0.2-1.1)	1.6 (0.8-3.1)	1.8 (0.8-3.6)	1.8 (0.2-19.5)	2.5 (0.2-32.3)
Lowest SES	1.6 (1.0 - 2.6)	1.4 (0.8-2.3)	1.4 (0.7-2.6)	0.9 (0.4-2.0)	1.4 (0.7-2.8)	1.3 (0.6-2.9)	5.1 (0.6-42.8)	1.8 (0.2-20.2)
Smoking category: Not exposed	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Exposed	0.9 (0.6 - 1.4)	0.9 (0.6 - 1.4)	1.3 (0.7 - 2.4)	1.4 (0.7 - 2.6)	1.5 (0.8 - 2.6)	1.4 (0.8 - 2.5)	3.0 (0.4 - 23.5)	3.5 (0.4 - 29.6)
No Electricity	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Electricity	0.2 (0.1 -0.4)	0.2 (0.1 -0.6)	0.2 (0.1 -0.4)	0.3 (0.1 -0.7)	0.7 (0.3 -1.4)	0.4 (0.2 -1.2)	0.1 (0.0 - 0.4)	1.3 (0.2 - 7.5)
Dwelling Category: Have more than 2	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Have 2 or less	1.0 (0.7 -1.4)	0.6 (0.4 -0.9)	1.3 (0.8 -2.2)	0.7 (0.4 -1.4)	0.7 (0.5 -1.2)	0.6 (0.3 -1.0)	4.5 (1.2 - 17.6)	2.4 (0.4 - 13.8)
No fossil stove	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Fossil Stove	3.4 (2.1 -5.4)	1.5 (0.8 -3.0)	2.9 (1.7 -5.0)	1.1 (0.5 -2.6)	1.2 (0.7 -2.0)	1.1 (0.5 -2.5)	18.6 (3.9 - 88.9)	8.6 (1.1 - 67.4)
No fossil heating	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Fossil Heating	3.2 (1.9 -5.5)	2.0 (1.0 -4.0)	4.0 (2.3 -7.1)	2.3 (1.0 -5.4)	1.3 (0.7 -2.2)	1.3 (0.6 3.0)	14.2 (3.6 - 56.0)	3.2 (0.6 - 16.9)
Room density: 1-2 per room	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
More than 2 per room	1.1 (0.8 -1.5)	1.2 (0.8 -1.8)	1.1 (0.6 -1.8)	1.2 (0.7 -2.2)	2.1 (1.2 -3.7)	1.7 (1.0 -3.0)	0.5 (0.1 - 1.9)	0.5 (0.1 - 1.8)

Table 5 Seasonal association with pollutants measured

	Benzene (>5ug/m³)	Carbon Monoxide (1% exceedence >30ug/m³)	Particulate Matter (PM10) (>40ug/m³)
	Crude OR (95%CI)	Crude OR (95%CI)	Crude OR (95%CI)
Season			
Summer (n=103,16%)	Reference	Reference	Reference
Autumn (n=189,30%)	23.1 (6.6 - 80.9)	0.8 (0.3 - 2.0)	0.7 (0.4 - 1.5)
Winter (n=172,27%)	35.9 (10.3 - 125.5)	2.6 (1.1 - 6.0)	1.3(0.7 - 2.4)
Spring (n=169 27%)	8.3 (2.4 - 28.4)	2.7(1.2 - 6.2)	1 (0.5 – 2.0)

Graphical Abstract