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Determinants of Indoor Carbonaceous Aerosols in Homes in the Northeast United States

Jessica R. Deslauriers[a], **Carrie A. Redlich**[a], **Choong-Min Kang**[b], **Stephanie T. Grady**[c,e], **Martin Slade**[a], **Petros Koutrakis**[b], **Eric Garshick**[d,e]

[a]Yale Occupational and Environmental Medicine Program, Department of Medicine, Yale University School of Medicine

[b]Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, MA, USA

[c]Research and Development Service, VA Boston Health Care System, Boston, MA, USA

[d]Pulmonary, Allergy, Sleep and Critical Care Medicine Section, VA Boston Healthcare System and Harvard Medical School, Boston, MA, USA

[e]Channing Division of Network Medicine, Department of Medicine, Brigham and Women's Hospital, Boston, MA, USA

Abstract

Background—Little is known about sources of residential exposure to carbonaceous aerosols, which include black carbon (BC), the elemental carbon core of combustion particles, and organic compounds from biomass combustion (delta carbon).

Objective—Assess the impact of residential characteristics on indoor BC and delta carbon when known sources of combustion (e.g. smoking) are minimized.

Methods—Between November 2012-December 2014, 125 subjects (129 homes) in Northeast USA were recruited and completed a residential characteristics questionnaire. Every 3-months, participants received an automated sampler to measure fine particulate matter ($PM_{2.5}$) in their

Corresponding Author (current address): Jessica Deslauriers, Orlando VA Medical Center, 13800 Veterans Way, Room 2Q211, Orlando, FL 32827, 239-770-7964, Jessica.deslauriers-snodgrass@va.gov.

Author Contributions:

JRD contributed to data acquisition, analysis and interpretation of the results. JRD drafted the initial manuscript, made revisions and created all tables.

CAR contributed to data interpretation, manuscript writing, and editing

CMK supervised environmental data analyses, and contributed to data interpretation, manuscript writing, and editing. He collected and analyzed the data that was included in the supplement.

STG assisted with study design and primary data acquisition.

MS contributed to data analysis and interpretation of the results.

PK designed and supervised the collection of the in-home and central site environmental data.

EG designed the study protocol, oversaw all aspects of the study design, and contributed to data interpretation, manuscript writing, and editing.

All authors approved the final manuscript

Conflict of Interest:

The authors declare no conflict of interest.

home during a weeklong period (N=371 indoor air samples) and were also questioned about indoor exposures. The samples were analyzed using a transmissometer at 880nm (reflecting BC) and at 370nm. The difference between the two wavelengths estimates delta carbon. Outdoor BC and delta carbon were measured using a central site aethalometer.

Results—Geometric mean indoor concentrations of BC and delta carbon (0.65μg/m³ and 0.19μg/m³, respectively), were greater than central site concentrations (0.53μg/m³ and 0.02μg/m³, respectively). Multivariable analysis showed that greater indoor concentrations of BC were associated with infrequent candle use, multi-family homes, winter season, lack of air conditioning, and central site BC. For delta carbon, greater indoor concentrations were associated with apartments, spring season, and central site concentrations.

Introduction:

Exposure to fine particulate matter (particles ≤ 2.5μm in diameter, $PM_{2.5}$) is a major cause of death worldwide.[1,2] Previous studies have primarily used environmental sampling from centralized monitoring stations to estimate exposure rather than directly measuring indoor exposure. However, given that Americans spend most of their time indoors, it is recognized that home environmental factors can influence indoor exposures and need to be considered in understanding the type and extent of indoor exposures.[3,4]

Carbonaceous aerosols, such as black carbon (BC) and other organic compounds, are specific components of $PM_{2.5}$. BC, produced from the incomplete combustion of fuels and biomass, represents the carbon core of combustion related particulate matter.[5,6] In the United States, transportation related to traffic is the major source of BC. The majority of indoor BC in the absence of significant indoor sources is from outdoor infiltration.[7,8] BC exposures have been linked to increased respiratory and cardiovascular morbidity and mortality associated with fine particulate air pollution exposure.[9–13] In a recent study of patients with chronic airflow obstruction (the COPD Air Pollution Study conducted at the VA Boston Healthcare System), indoor BC was associated with increased inflammatory and oxidative stress biomarkers[14,15] as well as reduced pulmonary function.[16]

In addition to BC, the combustion of biomass, such as wood burning, also produces carbonaceous compounds associated with $PM_{2.5}$ particles.[9,17,18] An extensive literature has documented the adverse health effects of biomass burning in developing countries, primarily related to household cooking and heating, including asthma, COPD and cardiovascular outcomes.[19,20] With the shift towards renewable sources of energy, biomass burning has been reported to be an increasing source of $PM_{2.5}$ exposures in developed countries, from sources such as wood-burning stoves. However, knowledge about biomass combustion exposures in developed countries and associated health effects is limited.

Studies assessing $PM_{2.5}$ associated health effects in developed countries have mainly focused on outdoor exposures, primarily traffic-associated BC. Indoor exposures, including biomass burning, may be more reflective of individual health risk,[3,4] but are challenging to assess. Indoor exposure to $PM_{2.5}$ reflects the indoor infiltration of outdoor sources of $PM_{2.5}$ as well as indoor sources and building characteristics.[21,22,4] As Americans typically spend most of their time indoors (approximately 90%), it is important to assess how the home

environment influences indoor exposures and if indoor measurements reflect outdoor central monitoring sources.[23]

BC and other carbonaceous compounds in $PM_{2.5}$ filter samples can be measured by taking advantage of differences in light absorption. The absorption of light by $PM_{2.5}$ filter samples at 880 nm reflects BC.[24] The absorption of $PM_{2.5}$ filter samples towards the ultra-violet (UV) wavelength at 370 nm reflects UV-absorbing compounds (UVC).[9,17,18] Carbonaceous compounds from burning biomass can be estimated by measuring the difference of the optical measurements at 880 nm and 370 nm, which is referred to as delta carbon.[5,18,24,25] Data on indoor exposures to delta carbon, a surrogate measurement of the carbonaceous compounds attributable to biomass burning, is limited.[5] The aim of this study is to identify residential characteristics associated with exposure to BC and delta carbon in the homes of study participants. Such source-specific information could be used to improve the quality of indoor air in the home environment.

Materials and Methods:

We used indoor $PM_{2.5}$ filter samples collected from the COPD Air Pollution study cohort described in Garshick et al., 2018, Grady et al., 2018, and Hart et al., 2018. The protocol was approved by the Institutional Review Boards of VA Boston (#2615) and Harvard Medical School (#21672), and all participants provided informed consent. Between November 2012 and December 2014, 125 patients with chronic airflow obstruction were recruited at the VA Boston Healthcare System that mainly serves Eastern Massachusetts, located in Northeast, USA, as part of a study examining associations between indoor air quality and health. All patients were at least 40 years old, had a post-bronchodilator $FEV_1/FVC < 0.70$ or emphysema by CT scan, and were receiving care for obstructive airway disease. Since the purpose of this health study was to assess the effects of exposure to indoor particulate matter of primarily outdoor origin, efforts were made to exclude patients with major known sources of indoor air pollution. This included current smokers, home secondhand smoke exposure, wood stove or fireplace use, or regular burning of incense or candles.

Participants at study entry completed a residential characteristics questionnaire that included questions about type of home, home age, type of heating and fuel source, and estimates of home proximity to sources of dust (construction site, large parking lot or cab/bus idle area). At roughly three-month intervals, up to a total of four times, each participant received a Micro-environmental Automated Particle Sampler which measured indoor air pollutants over a mean of 7.6 days (range 4–10 days). Participants were advised to place the sampler in the living room, family room or another room where they spent the most of their time, but not the kitchen. Participants were advised to place the sample on a table, at least 6 inches away from any wall, with the nozzle facing outwards. Participants were further instructed to not place the sampler on the floor, in a corner, or in front of an open window. $PM_{2.5}$ was collected on Teflon filters with the pump set to a flow rate of 1.8 LPM, using a size-selective impactor to collect particles with a 2.5 μm cut-off. After sampling, participants were questioned regarding indoor exposures during the sampling period, including exposures to biomass, such as indoor smoking, fireplace, open stove heating or candle use. During each

sampling period, air conditioning or heat use, having windows open, use of ventilation in the kitchen, and use of a humidifier or an air purifier were also assessed.

The SootScan OT21 Transmissometer (Magee Scientific, Berkeley, CA, USA) is a cost-effective, non-destructive method that quantifies filter particles using optical measurements at two different wavelengths (370 nm and 880 nm).[6,17] In previous studies, the OT21 Transmissometer has evaluated biomass burning derived from outdoor air pollutants, where the absorption measurements at different wavelengths can be used to determine the concentration of BC and biomass burning compounds.[24] BC and delta carbon (an estimate of biomass burning, UV signal minus IR signal) were determined by measuring the IR (infra-red) and UV (ultra-violet) light attenuation at 880 nm and 370 nm of each filter sample. We excluded samples collected in two mobile homes. In total, 371 filter measurements were assessed from 129 home addresses.

Central site outdoor BC and delta carbon averages that corresponded to each home sampling period were also calculated using concentrations determined at a Harvard Supersite (located on the roof of Francis A. Countway Library, Boston, MA, 5 stories above ground level) using an aethalometer at 880 nm and 370 nm (AE-33, Magee Scientific, Berkeley, CA, USA).[26] Hourly measurements of BC and delta carbon were obtained from the central site and averaged corresponding to the indoor sampling dates. The performance of the OT21 Transmissometer and central site aethalometer are highly comparable. In a comparison of hourly central site BC (Figure S1) and UVC (Figure S2) values averaged over 24 hours and central site 24-hour $PM_{2.5}$ filters assessed retrospectively (details in supplement) using the OT21 Transmissometer, the coefficient of determination (R^2) for BC values was 0.87 and the R^2 for UVC values was 0.83. Details on quality control and assurance are also available in the supplement.

Statistical Analyses:

Indoor exposure sources and factors such as air conditioning were considered positive if there was any use reported throughout the week of sampling. Associations between each home characteristic with BC and delta carbon were estimated for each address using repeated measures regression with a random intercept for each participant to account for the repeated measures at each residence (SAS version 9.4, SAS Institute, Inc., Cary, NC, USA). BC and delta carbon were natural log-transformed to meet model assumptions. Initially, bivariate linear mixed (fixed and random) effects models were conducted separately to determine the association of BC with delta carbon as well as each of the other study variables. Correlations between each of the independent variables were calculated to assess collinearity between any of the independent predictors. Next, multivariable linear mixed effect modeling was utilized, along with a backward elimination strategy incorporating a significance level of $p=0.05$, to generate specific parsimonious models. To control for multiple comparisons among exposure characteristics with more than 2 categories, the Tukey-Kramer method was utilized. Statistical significance was defined as $p<0.05$ and covariate p-values were from model results.

Results:

Residential characteristics are summarized in Table 1. The most common type of residence was a single-family home (48.8%). The home ages averaged 65.6 years and ranged from 8 to 205 years. One residence was located in Rhode Island (contiguous with Eastern Massachusetts). The majority of residences had radiators (69.0%) for heat and window unit air conditioning (55.8%), with 26.4% having central AC only. Gas was the most common fuel source (50.8%). Residences were located a mean (SD) of 28.0 ± 20.5 km from the central station.

Analysis of collected air samples (N=371) demonstrated that the geometric mean indoor levels of BC and delta carbon (0.65 μg/m³ and 0.19 μg/m³) were higher than the geometric mean central site levels of BC and delta carbon (0.53 μg/m³ and 0.02 μg/m³) (Table 2), and that indoor and central site BC and delta carbon levels were significantly but not strongly correlated (Spearman's r = 0.24 and 0.28, respectively, $p<0.001$). Indoor measurements of BC and delta carbon were only weakly correlated (Spearman's r = 0.18, $p<0.001$). The mean indoor measurements of BC were approximately 20% higher than the mean outdoor central site measurements, with indoor and central site measurements shown in Figure 1. There was a much greater difference between indoor and outdoor site levels for delta carbon with little overlap (Table 2). These findings suggest that the contribution to indoor BC and delta carbon varied depending on source, and also suggested that there were more local and/or indoor sources of delta carbon than for BC.

Bivariate regression results and mean indoor levels of delta carbon and BC are listed in Table 3 for each residential characteristic. As this study was designed to minimize indoor sources of combustion particles, smoking, fireplace use, and candle/incense burning were very infrequent during sampling periods. Fireplace use was reported during 1.1% of the sampling periods (mean use was 4 hours for 3 days), candle or incense burning was reported during 6.2% of the sampling periods (mean use was 3.3 hours for 2.6 days) and indoor smoking was reported during 2.2% of the sampling periods (mean smoking was 10.3 minutes total throughout the duration of the sampling period).

For the bivariate analysis, BC concentrations were significantly greater for homes with reported candle or incense burning, a source of dust near the home, and during the winter and fall seasons (vs spring). For delta carbon, levels were significantly greater during the winter and spring seasons (vs summer and fall), for multi-family vs single-family homes, and with the use of oil or gas heat without forced air delivery.

Spearman correlations revealed that none of the independent variables were highly correlated with any of the others, as all of the correlation coefficients were less than 0.6. However, 75% of apartment dwellers utilized electricity as their source of heat, thus the type of heat source was also removed from multivariable analyses.

We adjusted for concurrent central site values in multivariable models. In these models, indoor candle or incense use, home type, season, air conditioning use, and central site BC levels were significantly associated with indoor BC (Table 4). Specifically, multi-family homes had significantly higher indoor BC concentrations as compared to single-family

homes, and was non-significantly higher in apartments. Indoor BC concentrations were higher in the winter and fall (vs spring) and if candles or incense were used, and lower with air conditioning use. Changes in outdoor BC were significantly associated with changes in indoor BC.

In contrast to BC, home type, season, and central site levels were the only factors that were significantly associated with indoor delta carbon levels in the multivariable analyses (Table 4). Indoor delta carbon levels were significantly lower in the fall compared to the other seasons and significantly higher in apartments than other home types. Although central site delta carbon concentrations were low, they were significantly associated with indoor delta carbon concentrations in the multivariable model.

Discussion:

Although Americans spend most of their time indoors, studies to date have primarily focused on more accurately characterizing ambient fine particulate exposures. In this study of 129 homes, we evaluated indoor levels of BC, a measure of particulate matter representing the elemental carbon core of combustion particles, and delta carbon, a measure of organic carbon in particulate matter attributable to biomass burning. For both BC and delta carbon, indoor concentrations were significantly higher than corresponding central site concentrations. For BC, any indoor candle or incense use, lack of air conditioning use, a multi-family home, and winter season were associated with higher indoor levels of BC. For delta carbon, only apartment type housing and spring season were associated with higher indoor levels.

This is the largest study we are aware of that has used OT21 Transmissometer analysis of indoor $PM_{2.5}$ Teflon filter samples to measure delta carbon, a surrogate measure of incomplete biomass combustion, in the home setting. Biomass combustion-related exposures, such as from wood burning (wild fires or the use of wood stoves for cooking/heating), can be challenging to measure using centralized monitoring sites, as exposures tend to occur locally and variably. There is also much less published data characterizing such exposures, as compared to BC. Our finding of noticeably higher home levels of delta carbon compared to central monitoring levels suggests that, even when intentionally minimized, local sources of biomass combustion, not detected by the central site monitor, may be important unrecognized contributors to home indoor particulate air pollution.

As this study was intentionally designed to minimize indoor sources of particulates such as smoking and candle use, it is noteworthy that candle or incense use, even though reported very infrequently (6.2% of sampling periods; mean use of 3.3 hours for 2.6 days), was associated with significantly higher indoor BC concentrations, consistent with published literature showing that indoor exposures such as smoking, candle burning or fireplace use can substantially increase levels of particulate air pollution.[4,7,27] Higher BC levels were also found in multi-family homes and apartments compared to single-family homes (although apartments not significantly so). It is also notable that higher indoor delta carbon was found in apartment housing compared with single and multi-family homes. These findings could in part reflect cooking-related exposures given the central location of kitchens in many

apartments.[28,29] These findings could also reflect incursions of delta carbon and BC from a nearby residence or apartment with indoor combustion sources, or from outdoor local sources[30], such as from an apartment building or multi-family home boiler or furnace.

The finding that the use of air conditioning was associated with lower BC levels is also consistent with studies that have shown that air conditioning (especially central air conditioning), air cleaning (such as with a HEPA filter) or opening windows can decrease indoor levels of particulates.[3,31,32] In this study, air purifier use was reported during only 1.9% of the sampling periods.

Seasonal variation in indoor levels of BC and delta carbon was also found, with home BC levels highest in the winter and delta carbon levels highest in the spring, again suggesting different exposure sources. Variable seasonal associations with indoor air pollution have been noted in other studies; higher indoor particulates have been found in the winter during heating season, suggesting an effect of combustion-based heating in the winter.[33] Higher delta carbon levels in the spring could reflect greater entry into the home from local sources of biomass combustion compared to other seasons.

This study design had several strengths. Air sampling was performed up to 4 times in the same home seasonally, and for approximately a week each time. This study is also the largest indoor air study to date, utilizing a newer, cost-effective method to evaluate individual air pollutant levels at each home site. Concurrent levels of indoor BC and delta carbon, as well as ambient levels were estimated to affect indoor exposure. Each subject completed an extensive residential characteristics questionnaire, as well as additional questions during each sampling period regarding exposures and modifiable home characteristics such as use of ventilation, heating, and air conditioning.

There are also limitations. Residential characteristics were based on self-report. While the questionnaire was quite extensive, it did not ask about home cooking (a source of combustion particles), the number of residential units, or location (floor) of the residence in a multi-family home or apartment building. Furthermore, delta carbon estimates from biomass burning when sources of black carbon are present may vary. Although delta carbon has been shown to increase when particulate matter has a contribution from biomass, the impacts of other sources (such as fossil fuel combustion) are not as well characterized. We note that in the study of Olson et al., 2015, there was an impact of fossil fuel combustion on brown carbon and delta carbon.[34]

It is also possible there was some overlap in the reporting of apartments and multi-family homes, as these terms were not precisely defined on the home questionnaire. However, we expect that apartment homes refer to larger buildings with multiple apartments, whereas a multi-family home in Eastern Massachusetts typically refers to two and three story buildings with one family per floor. Despite these limitations, the findings highlight the importance of incorporating home exposure assessments into future air pollution health effect studies rather than relying solely on outdoor centralized monitoring stations, as has been common. In resource-rich countries where indoor sources of particulate air pollution

are generally minimized, unrecognized local sources of particulate air pollution especially biomass-combustion related exposures, may influence indoor exposures.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Significance

In addition to outdoor central site concentrations, factors related to the type of housing, season, and home exposures are associated with indoor exposure to carbonaceous aerosols. Recognition of these characteristics should enable greater understanding of indoor exposures and their sources.

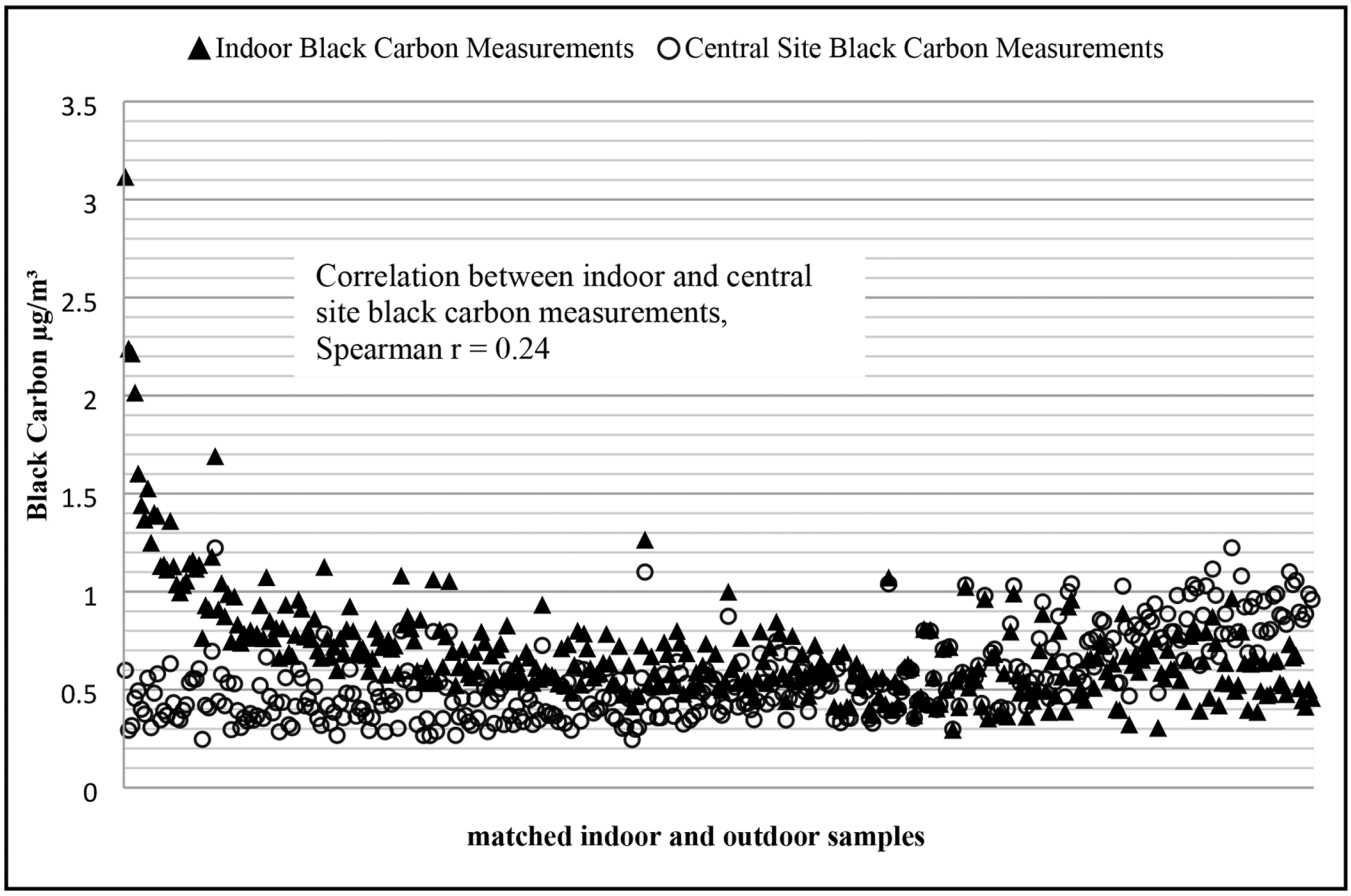

Figure 1:

Comparison of indoor (home) and corresponding central site black carbon concentration. The y-axis is the black carbon concentration for each home and for the corresponding central site concentration for each observation. The x-axis represents each paired home and central site.

Table 1:

Home Characteristics (N=129 Homes)

Characteristic	Level	Mean ± SD (Range) or n (%)
Home Type	Single family home	63 (48.8)
	Multi-family home	25 (19.4)
	Apartment building	41 (31.8)
Home Age	Years	65.6 ± 35.3 (8–205)
Distance from Central Site	Kilometers	28.0 ± 20.5 (1.1–88.2)
Main Type of Heating Fuel	Gas	63 (50.8)
	Electric	27 (21.8)
	Oil	34 (27.4)
Heat Source	Radiator	89 (69.0)
	Forced air	39 (30.2)
	Electric space heater	31 (24.0)
	Open stove/Fireplace/Wood stove	10 (7.8)
Air Conditioning (AC)	No AC	22 (17.0)
	Window units only	72 (55.8)
	Central AC	34 (26.4)
	Window units and central AC	1 (0.8)

Numbers may not sum to total (N=129) due to missing data or more than 1 characteristic in each home. Percentages may not sum to 100% due to rounding.

Table 2:

Distribution of Indoor and Ambient Central Site Black Carbon and Delta Carbon Exposures (N=371 Air Samples)

Sample Site	Agent (μg/m^3)	Range	Geometric Mean			Geometric Coefficient of Variation
			Estimate	L95%	U95%	
Indoor	Black Carbon	0.29 – 3.11	0.65	0.63	0.67	0.34
	Delta Carbon	0.00 – 1.81	0.19	0.17	0.23	2.11
Ambient Central Site	Black Carbon	0.25 – 1.53	0.53	0.18	1.51	2.05
	Delta Carbon	0.00 – 0.22	0.02	0.01	0.09	2.29

Table 3:

Home Characteristics and Mean Indoor Levels of Air Pollutants (N=371 Air Samples)

Variable	Level	n†	%†	Black Carbon		Delta Carbon	
				Estimate (ug/m3)	p-value	Estimate (ug/m3)	p-value
Season	Winter (Dec, Jan, Feb)	80	21.6	0.751	0.001*	0.493	<.0001+
	Spring (Mar, Apr, May)	94	25.3	0.609		0.447	
	Summer (Jun, Jul, Aug)	97	26.1	0.664		0.288	
	Fall (Sep, Oct, Nov)	100	27.0	0.737		0.204	
Home Type	Single family	183	49.3	0.656	0.008**	0.327	0.014++
	Multi-family	68	18.3	0.766		0.311	
	Apartment	120	32.3	0.694		0.407	
Home Age (years)	≤40	85	23.3	0.728	0.511	0.379	0.690
	41–90	195	53.4	0.675		0.368	
	>90	85	23.3	0.680		0.287	
Location of home from outside dust source	≤ 100 yards from residence	182	49.1	0.719	0.008	0.361	0.698
	> 100 yards from residence	189	50.9	0.659		0.339	
Main Type of Heating	Electric	76	20.9	0.689	0.198	0.423	<.001+++
	Oil or Gas (radiator, etc.)	232	63.9	0.698		0.294	
	Oil or Gas with forced Air	55	15.2	0.638		0.491	
Electric Space Heater Used	Yes	45	12.1	0.708	0.591	0.437	0.070
	No	326	87.9	0.686		0.338	
Fireplace/Open Stove Used	Yes	4	1.1	0.722	0.564	0.559	0.128
	No	367	98.9	0.688		0.348	
Windows Open	Yes	174	46.9	0.686	0.848	0.330	0.370
	No	197	53.1	0.691		0.368	
AC Units On (Central or Window)	Yes	102	27.5	0.648	0.173	0.252	0.001
	No	269	72.5	0.704		0.387	
Smoking in Home	Yes	8	2.2	0.783	0.362	0.614	0.609
	No	363	97.8	0.686		0.344	
Pilot Light for Stove/Oven	Yes	64	17.3	0.721	0.447	0.285	0.065
	No	307	82.7	0.682		0.363	
Vented Fan in Kitchen	Yes	198	53.4	0.702	0.121	0.359	0.843
	No	173	46.6	0.673		0.340	
Humidifier Used at Home	Yes	24	6.5	0.727	0.702	0.471	0.100
	No	347	93.5	0.686		0.341	
Air Purifier Used at Home	Yes	7	1.9	0.536	0.093	0.445	0.326

Variable	Level	n†	%†	Black Carbon		Delta Carbon	
				Estimate (ug/m3)	p-value	Estimate (ug/m3)	p-value
	No	364	98.1	0.691		0.348	
Candle or Incense Burned	Yes	23	6.2	1.076	<.0001	0.454	0.562
	No	348	93.8	0.663		0.343	

†Numbers may not sum to total (N=371) due to missing data, and percentages may not sum to 100% due to rounding. Mean BC and delta carbon obtained by exponentiating estimates from unadjusted regression analyses.

*For black carbon, the difference between spring and fall is significant (p=0.001) as well as between winter and spring (p=0.004).

**For black carbon, the difference between single and multi-family home is significant (p=0.009).

+For delta carbon, the difference between spring and summer is significant (p=0.040), winter and summer (p=0.011), winter and fall (p<0.001) and spring and fall (p<0.001).

++For delta carbon, the difference between single family home and apartment is significant (p=0.013).

+++For delta carbon, the difference between electric heat and oil or gas (radiator) is significant (p=0.002) as well as between oil and gas (radiator) and forced heat with oil or gas (p=0.014).

Table 4:

Multivariate Model for Indoor Black Carbon and Indoor Delta Carbon (N=371 Air Samples)

Black Carbon (μg/m^3)					
Variable	**Level**	**Black Carbon (μg/m^3)**			**Pr > F**
		Estimate	**L95%**	**U95%**	
Home Type	**Single family**	0.736	0.680	0.798	0.0101*
	Multi-family	0.852	0.767	0.947	
	Apartment	0.800	0.734	0.873	
AC Units On	**Yes**	0.757	0.688	0.833	0.0294
	No	0.835	0.777	0.897	
Candle	**Yes**	1.001	0.881	1.138	<.0001
	No	0.631	0.603	0.661	
Season	**Winter (Dec, Jan, Feb)**	0.840	0.761	0.926	0.0023**
	Spring (Mar, Apr, May)	0.724	0.658	0.797	
	Summer (Jun, Jul, Aug)	0.796	0.732	0.866	
	Fall (Sep, Oct, Nov)	0.825	0.758	0.897	
Central Site Black Carbon	**Over IQR central site black carbon**	1.126	1.070	1.184	<.0001***
* For Home Type, the difference between Single family and Multi-family is significant (p=0.0045).					
** For Season, the difference between Spring and Winter is significant (p=0.0004) and the difference between Spring and Fall is significant (p=0.0026).					
*** Central Site Black Carbon IQR calculated as difference between 75th percentile of the $\log_e$ transformed central site black carbon value (−0.368) and the 25th percentile of the $\log_e$ transformed central site black carbon value (−0.933). Estimate depicted in table has been exponentiated.					

Delta Carbon (μg/m^3)					
Variable	**Level**	**Delta Carbon (μg/m^3)**			**Pr > F**
		Estimate	**L95%**	**U95%**	
Home Type	**Single family**	0.167	0.135	0.205	0.0050$^+$
	Multi-family	0.177	0.127	0.246	
	Apartment	0.284	0.220	0.365	
Season	**Winter (Dec, Jan, Feb)**	0.221	0.156	0.312	<.0001^{++}
	Spring (Mar, Apr, May)	0.305	0.234	0.396	
	Summer (Jun, Jul, Aug)	0.201	0.151	0.268	
	Fall (Sep, Oct, Nov)	0.125	0.098	0.160	
Central Site Delta Carbon	**Over IQR central site delta carbon**	1.706	1.222	2.381	0.0019^{+++}
+ For Home Type, the difference between Apartment and Single family is significant (0.0016) and the difference between Apartment and Multi-family is significant (p=0.0273).					

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Delta Carbon (μg/m^3)					
Variable	Level	Delta Carbon (μg/m^3)			Pr > F
		Estimate	L95%	U95%	
++ For Season, the difference between Fall and Winter is significant (p=0.0062), the difference between Fall and Spring is significant (p<0.0001), the difference between Fall and Summer is significant (p=0.0081) and the difference between Summer and Spring is significant (p=0.0164).					
+++ Central Site Delta Carbon IQR calculated as difference between 75th percentile of the $\log_e$ transformed central site delta carbon value (−3.240).					